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Wireless Telecommunications Systems and Networks

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For more information contact Thomson Delmar Learning
Executive Woods
5 Maxwell Drive, PO Box 8007,
Clifton Park, NY 12065-8007
Or find us on the World Wide Web at
www.delmarlearning.com

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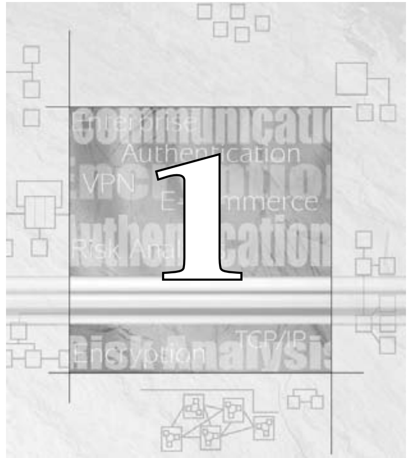
Introduction to Wireless Telecommunication Systems and Networks



Objectives Upon completion of this chapter, the student should be able to:

- Discuss the general history and evolution of wireless technology from a North American viewpoint and explain the cellular radio concept.
- Discuss the evolution of modern telecommunications infrastructure.
- Discuss the structure and operation of the Public Switched Telephone Network, the Public Data Network, and the SS7 Network.
- Explain the basic structure of broadband cable TV systems.
- Explain the basic concept and structure of the Internet.
- Discuss the usage of the various telecommunications networks and their relationship to one another.
- Discuss the OSI model and how it relates to network communications.
- Discuss wireless network applications and the future of this technology.

Outline

1.1 The History and Evolution of Wireless Radio Systems
1.2 The Development of Modern Telecommunications Infrastructure
1.3 Overview of Existing Network Infrastructure
1.4 Review of the Seven-Layer OSI Model
1.5 Wireless Network Applications: Wireless Markets
1.6 Future Wireless Networks

Key Terms and Acronyms

cellular
cellular digital packet data
circuit-switched
code division multiple access
connectionless
connection-oriented
digital radio
DOCSIS
EDGE
frequency reuse

general packet radio service
GSM
HiperLAN/2
internetwork
interoffice
intraoffice
local area network
local exchange
metropolitan area network
private data networks
protocol
service control points
service switching points
signal transfer points
SS7
trunk
tunneling protocol
U-NII bands
virtual private data networks
wide area network

Practical electrical communications began in the United States over 150 years ago with the invention of the telegraph by Morse. The invention of the telephone by Bell in 1876 brought with it the first manually switched wireline network. Radio or wireless was invented at the turn of the twentieth century, adding the convenience of mobile or untethered operation to electronic communications. For many years, wireless communications primarily provided entertainment and news to the masses through radio broadcasting services. Wireless mobility took the form of a car radio with simplex (one-way) operation. Two-way mobile wireless communications were limited to use by various public service departments, government agencies and the military, and for fleet communications of various industries. As technology decreased the size of the mobile unit, it became a handheld device known as a "walkie-talkie."

Further advances in integrated circuit technology or microelectronics gave us cordless telephones during the late 1970s that foreshadowed the next wireless advance. Starting in 1983, the public had the opportunity to subscribe to cellular telephone systems. These wireless systems, which provide mobile access to the public switched telephone network infrastructure, have become immensely popular and in many cases have even replaced subscribers' traditional fixed landlines. Technology advances and network build-outs have increased wireless system capacity and functionality.

Today's cellular networks provide access to the public telephone network from almost anywhere and provide access to the public data network or Internet. In two decades, cell phones have become indispensable communications devices and Internet appliances. During the same time period, wireless local area network (LAN) technology has come of age and is gaining in acceptance by both the *Enterprise* (for profit and not-for profit business ventures) and the general public. Today, many homes and apartments have their own wireless LANs. This chapter will present a short history of wireless technology, a brief summary of the evolution and operation of the fixed public networks, a general idea of how these networks fit together, and an overview of how wireless systems connect to this modern infrastructure. Additional topics covered by the chapter are a review of the OSI model, an overview of wireless network applications, and a brief look at the future of wireless.

1.1 The History and Evolution of Wireless Radio Systems

One can trace the evolution of wireless radio systems back to the late 1800s. In 1887, Heinrich Hertz performed laboratory experiments that proved the existence of electromagnetic waves, just as Maxwell predicted back in 1865. An obscure inventor by the name of Mahlon Loomis was in fact issued a U.S. patent for a crude type of aerial wireless telegraph in 1872. Although several prominent inventors of the day (Lodge, Popoff, and Tesla) experimented with the transmission of wireless signals, Marconi seems to have received most of the credit for the invention of radio because he was first to use it in a commercial application. From 1895 to 1901 Marconi experimented with a wireless telegraph system. He initially started his experiments at his family's villa in Bologna, Italy. He then moved to England in 1896 to continue his work. He built several radio telegraph stations there and started commercial service between England and France during 1899. However, the defining moment for wireless is usually considered to have taken place on December 12, 1901, when Marconi sent a message (the signal was a repetitive letter "s" in Morse code) from Cornwall, England to Signal Hill, St. John's, Newfoundland—the first transmission across the Atlantic Ocean. This was accomplished without the aid of any modern "electronic devices"—vacuum tubes and transistors did not exist at the time.

Historical Note: For another view of what actually happened during those early days, read Dr. Jack Belrose's account of the development of wireless radio at www.radiocom.net/Fessenden/Belrose.pdf.

Early AM Wireless Systems

A typical early wireless transmitter is shown in Figure 1–1. Note the inductance and capacitance used to tune the output frequency of the spark-gap. The resonant frequency of these two components tended to maximize output power at that particular frequency.

Due to the nature of the spark-gap emission, maximum power output typically occurred at a very low frequency with its corresponding long wavelength. Although little was known about antenna theory at the time, it was discovered early on that for a conductor to effectively radiate long wavelength signals the antenna had to be oriented vertical to the earth's surface and physically had to be some appreciable fraction of a wavelength. It was common for early wireless experiments to use

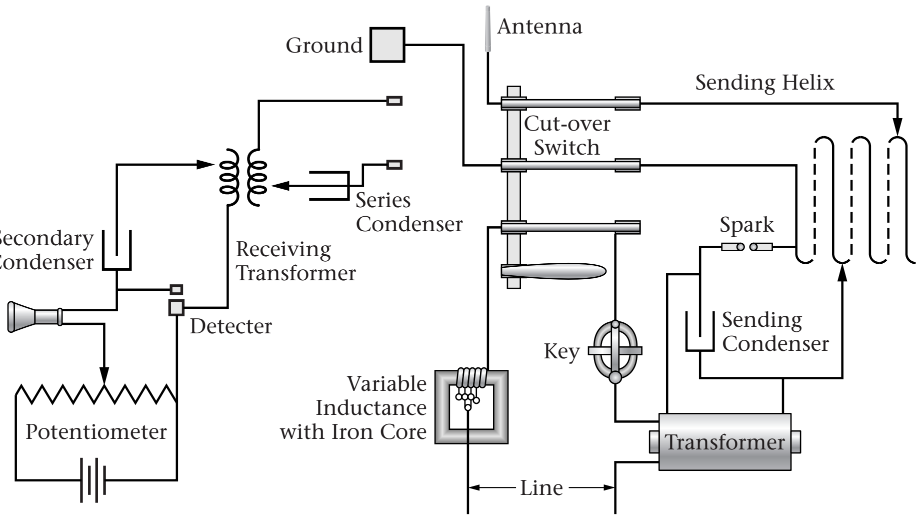


FIGURE 1–1 Typical early wireless transmitter.

balloons and kites to support long lengths of wire that served as the antennas. Also at that time it was thought that transmitting distance would be limited by the curvature of the earth. This belief became an additional rationale for tall antennas.

The wireless transmitter shown in Figure 1–1 would emit a signal of either long or short duration depending on the length of time the telegraph key was closed. The transmitted signal was the electromagnetic noise produced by the spark-gap discharge. This signal propagated through the air to a receiver located at some distance from the transmitter. At the receiver, the detected signal was interpreted by an operator as either a dot or a dash depending upon its duration. Using Morse code, combinations of dots and dashes stood for various alphanumeric characters. This early wireless transmission form is now known as amplitude modulation (AM) and in particular, on-off keying (OOK).

The next generation of wireless transmitters used more stable radio-frequency (RF) alternators or high-powered Poulsen spark-gap transmitters for their signal sources. These RF alternator-based transmitters were used to transmit another form of AM that is sometimes referred to as binary amplitude-shift keying (BASK), which is essentially the same as OOK. The Poulsen transmitters used a form of frequency-shift keying (FSK) to transmit a signal that was received and interpreted as a BASK signal by the detector of the radio receiver.

The First Broadcast

Beginning in 1905, Reginald Fessenden conducted experiments with continuous wave (CW) wireless transmissions at Brant Rock, Massachusetts, using 50-kHz high-frequency alternators built by General Electric. The output of this type of generator was much more stable than that of a spark-gap or Poulsen transmitter, allowing him to experiment with a continuous form of amplitude modulation. His experiments culminated on Christmas Eve of 1906, when he is credited with transmitting the first ever radio broadcast. This broadcast was repeated on New Year's Eve the following week. Prior to this time, it is reported that Fessenden, while experimenting with a wireless spark-gap transmitter at an experimental station on Cobb Island on the Maryland side of the Potomac River, had successfully broadcast a voice message over a distance of 1600 meters on December 23, 1900.

During the 1910s, the U.S. Navy led a major effort to develop wireless radio for ship-to-ship and ship-to-shore communications. Historical accounts of the sinking of the *Titanic* on the night of April 14, 1912, tell of the transmission of futile "SOS" distress messages by the ship's wireless operator. The start of World War I during the last part of the decade was also a major driver of the development of radio technology by the U.S. military.

The 1920s might well be characterized as the decade of high-frequency or short-wave radio development. During this era, Marconi's research on radio wave propagation revealed that transatlantic radio transmission was feasible at frequencies much higher than had previously been though possible. At the same time, vacuum-tube technology had improved to such an extent as to increase the upper-frequency limit of their operation. Radio wave propagation studies had demonstrated that ionospheric layers could be used to reflect high-frequency waves back and forth between the earth's surface and the ionosphere, hence allowing for the propagation of radio waves around the earth. Other technological advances in antennas and their application helped make transatlantic communications a practical reality. By 1926, transoceanic telephone calls were available via high-frequency radio transmission. The 1930s and 1940s saw more advancement in radio technology with the invention of television, radar, and vacuum tubes with the ability to generate "microwaves."

Modern AM

Amplitude modulation is now used for low-frequency legacy radio broadcasting, which had its corporate beginnings after World War I; shortwave broadcasting; low-definition (NTSC) television video-signal transmission; amateur and CB radio; and various other low-profile services. Newer uses of AM include quadrature amplitude modulation (QAM or n-QAM, where n is a power of 2). QAM is a hybrid form of amplitude and phase modulation (PM) used for high-speed data transmission at RF frequencies. QAM is considered a digital modulation technique. Today, QAM is used extensively by broadband cable and wireless systems to achieve bandwidth efficiency.

The Development of FM

Major Edwin Armstrong, a radio pioneer who invented first the regenerative and then the superheterodyne receiver in the 1910s, worked on the principles of frequency and phase modulation starting in the 1920s. It was not until the 1930s, however, that he finally completed work on a practical technique for wideband frequency modulation (FM) broadcasting. FM broadcasting became popular during the late 1960s and early 1970s when technological advances reduced the cost of consumer equipment and improved the quality of service. Many public safety departments were early adopters of FM for their fleet communications. AMPS cellular telephone service, an FM-based system, was introduced in the United States in 1983. Today FM is used for transmissions in the legacy FM broadcast band, standard over-the-air TV-broadcasting sound transmission, direct-satellite TV service, cordless telephones, and just about every type of business band and mobile radio service. FM is capable of much more noise immunity than AM, and is now the most popular form of analog modulation.

The Evolution of Digital Radio

AT&T built its original long-distance network from copper wires strung on poles. The first experimental broadband coaxial cable was tested in 1936, and the first operational L1 system that could handle 480 telephone calls was installed in 1941. Microwave radio relay systems developed in tandem with broadband coaxial cable systems. The first microwave relay system was installed between Boston and New York in 1947. AT&T's coast-to-coast microwave radio relay system was in place by 1951. Microwave relay systems had lower construction and maintenance costs than coaxial cable (especially in difficult terrain). By the 1970s, AT&T's microwave relay system carried 70% of its voice traffic and 95% of its broadband television traffic.

At the time, most of these systems used analog forms of modulation, although simple digital modulation forms like binary frequency shift keying (BFSK) existed. Advances in microwave digital radio technology and digital modulation techniques that provide increased data rates over the same radio channel caused these systems to gain in popularity during the 1970s and 1980s. However, fiber-optic cables and geosynchronous satellites proved to be disruptive technologies as far as the use of microwave digital radio by the Bell system was concerned. Many of the analog and digital microwave relay systems in use became backup systems to newly installed fiber-optic cables or they were removed from service entirely.

Today, microwave **digital radio** systems are enjoying a resurgence of sorts. Many service providers of point-to-point connectivity are employing microwave and millimeter-wave radio transmission systems that use the most modern digital modulation techniques to obtain high data rate links. Cellular operators are using economical point-to-point microwave radio systems to backhaul aggregated bandwidth signals to a common network interface point from both remote and not-so-remote cell sites. Wireless Internet service providers (WISPs) are using digital radio equipment designed for the Unlicensed National Information Infrastructure **(U-NII) bands** for point-to-point and point-to-multipoint systems that provide high bit-rate Internet connections to their customers. Cordless telephones adopted digital radio technology years ago and all the newest wireless systems and network technologies use modern digital modulation techniques to achieve higher data rates and better noise immunity. Today, the television broadcasting industry is in the process of transitioning to a high-definition television (HDTV) standard for over-the-air broadcast that uses a digital transmission system. It is not too radical a concept to conjecture that FM broadcasting might follow suit in the not-too-distant future. All but the oldest analog cellular systems (these systems are in the process of being phased out) are digital, and all of the newest wireless LAN, MAN, and PAN technologies use complex digital modulation schemes. It may be that analog modulation schemes, with their inefficient use of radio spectrum, might disappear entirely for over-the-air applications in the not-too-distant future!

The Cellular Telephone Concept

The cellular telephone concept evolved from earlier mobile radio networks. The first mobile radios were used primarily by police departments or other law enforcement agencies. The Detroit Police Department is cited for its early use of mobile radios (beginning in 1921) by numerous references. These one-way mobile radio systems, operating at about 2 MHz, were basically used to page the police cars. They did not become operational two-way (duplex) systems until much later in 1933. There was no thought at the time for these systems to be connected to the public telephone system. It was not until after World War II that the Federal Communications Commission (FCC), at the request of AT&T, allocated a small number of frequencies for mobile telephone service. AT&T made a request for many mobile frequencies on behalf of the Bell telephone companies in 1947, but the FCC deferred any action on this request until 1949. At that time, the FCC only provided a limited number of frequencies that were to be split between the Bell companies and other non-Bell service providers. The FCC apparently felt that since these frequencies were used by the police and fire (public service) departments that the public interest would be best served by limiting the number of frequencies released to this new service. It should be observed that the state of the art of wireless technology at the time restricted the given spectrum available for any new wireless service that might be desired.

The mobile phone service that grew out of these new frequency allocations was very primitive by today's standards. It usually consisted of a single, tall, centrally located tower with a high-power transmitter that could only service one user at a time per channel over a particular metropolitan area. This also precluded the reuse of the same frequency within approximately a seventy-five-mile radius. Due to the limited number of frequency allocations, only several dozen simultaneous users were possible. The capacity of these systems was quickly exhausted in the major cities by the mid-1950s. Customers of the service paid extremely high monthly or yearly rates and it was perceived to be a service that only a business or the wealthy could afford. At the time, the available wireless transceiver technology (which usually had to be located in the car trunk due to its bulk) offered no way of reusing the frequencies within the same general area or any other way of increasing the capacity of the system.

The FCC in 1968, in response to the congestion of the presently deployed system, asked for technical proposals for a high-capacity, efficient mobile phone system. AT&T proposed a **cellular** system. In this cellular system there would be many towers, each low in height, and each with a relatively low-power transmitter. Each tower would cover a "cell" or small circular area several miles in diameter. Collectively, the towers would cover the entire metropolitan area. Each tower or cell site would use only a few of the total number of frequencies available to the entire system. Due to the small cell sizes, these same frequencies could then be reused (hence the term frequency reuse) by other cells at a much shorter spacing than previously possible thus increasing the total potential number of simultaneous users within the entire system. Additionally, as a mobile user (car) moved within the metropolitan area it would be "handed off" from cell to cell and to different frequencies as assigned to the different cells. All the cells would be connected to a central switch that would in turn connect them to the wireline telephone network. As more users signed up for the service and cells became too congested, the cells could be split into several smaller cells to increase their capacity. In theory, this process could be repeated many times yielding an almost infinite number of potential simultaneous users for a limited number of available frequencies. In 1970, the FCC released 75 MHz of additional spectrum for use by the current system and authorized AT&T's Bell Laboratories to test the cellular concept under urban traffic conditions. In 1971, Bell Labs reported that the test had been successful. The cellular concept worked! In 1974 the FCC released 40 MHz more of spectrum for the development of cellular systems. In a far-reaching decision, the FCC also determined that both the incumbent Bell Telephone Company and other nonwireline entities would share the newly made available spectrum. By late 1982, the FCC started to award construction permits for cellular systems, and by late 1983 and early 1984 most major metropolitan areas had functioning systems that supported the user's ability to roam between systems. The rest is history. Twenty years later the cell phone has become a ubiquitous information appliance with well over one billion users worldwide.

1.2 The Development of Modern Telecommunications Infrastructure

The wireless networks and systems that have been rapidly evolving over roughly the past two decades have the basic function of connecting users to the public switched telephone network (PSTN) or, more recently, the public data network (PDN). Therefore, it is instructive to examine exactly what these two public networks are and how they have evolved over the course of time.

Over the last four decades, several other telecommunications networks have evolved. The SS7 network is a packet data network used in conjunction with the PSTN to establish, manage, and terminate inter-exchange telephone calls. Broadband cable television networks have been developed for the delivery of video services and more recently high-speed data services (Internet connectivity) and telephony service. The Internet, which is the world's largest computer network, has experienced phenomenal growth over the past two decades and continues to expand both its reach and high-speed data capacity. Finally, in the United States, cellular telephone networks have become nationwide providing subscribers access to both the PSTN and the PDN.

The Early Days

Morse invented the telegraph in 1837 and formed a telegraph company based on his new technology in the mid-1840s. The Western Union Telegraph Company was established in 1856 and within a decade bought out most of its competitors. Early long-distance telegraph systems required many relay points because signals had a limited maximum range. In 1867, an improved telegraph relay was invented by Elisha Gray. Gray's company was bought out by another company that in 1872 became the Western Electric Manufacturing Company. Alexander Graham Bell received a patent for the telephone in 1876 and formed the Bell Telephone Company in 1877. In 1882, Bell bought the Western Electric Company and in 1885 formed what was to become the American Telephone and Telegraph Company (AT&T).

By 1900, the Bell system served approximately 60% of telephone subscribers in the United States. During the next decade, AT&T bought out most of its competitors and in essence formed a telecommunications monopoly. Starting in the late 1940s the U.S. Department of Justice (DOJ) sued AT&T for violations of the Sherman Antitrust Act. This event signaled the start of deregulation of the existing telecommunications industry. Eventually, other FCC decisions and U.S. government lawsuits resulted in what is known as the “Modified Final Judgment,” which took effect on January 1, 1984. In simple terms, AT&T was required to divest itself of all the Bell Operating Companies (BOCs) and the long-distance telecommunications market became deregulated, therefore allowing competition. These events, coupled with the more recent Telecommunications Reform Act of 1996, have helped shape our present-day telecommunications infrastructure.

The Public Switched Telephone Network

In the United States and most other industrialized nations, the present-day PSTN has evolved over time to become an almost entirely digital network. Deregulation has allowed other competitors to sell telephone service but they all essentially use the same technology. In an effort to explain the physical infrastructure of the PSTN, it is instructive to consider the various pathways of communication available through the system.

Within a **local exchange** or company office (CO) a subscriber may be connected to the exchange in several different ways as shown in Figure 1–2. For plain-old telephone service (POTS) the subscriber may be connected through a local loop connection consisting of a pair of copper wires. In this case, dialing information (via dual-tone multifrequency [DTMF] or traditional rotary dialing [pulsing]) signals are interpreted by the local exchange switch to set up the correct pathway or connection through the switch to the desired called party. Call signaling information (dial tone, ringing, call-waiting tones, etc.) is sent to the called party and also sent back to the caller.

For an **intraoffice** call between two subscribers connected to the same switch, the analog voice signal from the subscriber’s telephone propagates through the copper wire pair to a line card located at the switch. The line card converts the analog signal to a digital pulse code modulated (PCM) DS0 signal, which gets timed through the switch in such a way as to be connected to the corresponding line card of the called party. This counterpart line card performs the complementary conversion of the digital PCM signal from the switch into an analog signal that is sent to the called party over another pair of copper wires. A separate return path or connection is also created from the called party’s line card through the switch to the calling party’s line card. The line cards also provide the necessary opposite signal conversion functions for this return path and together the two paths through the switch provide for duplex operation for the duration of the telephone call. Since the call appears to be

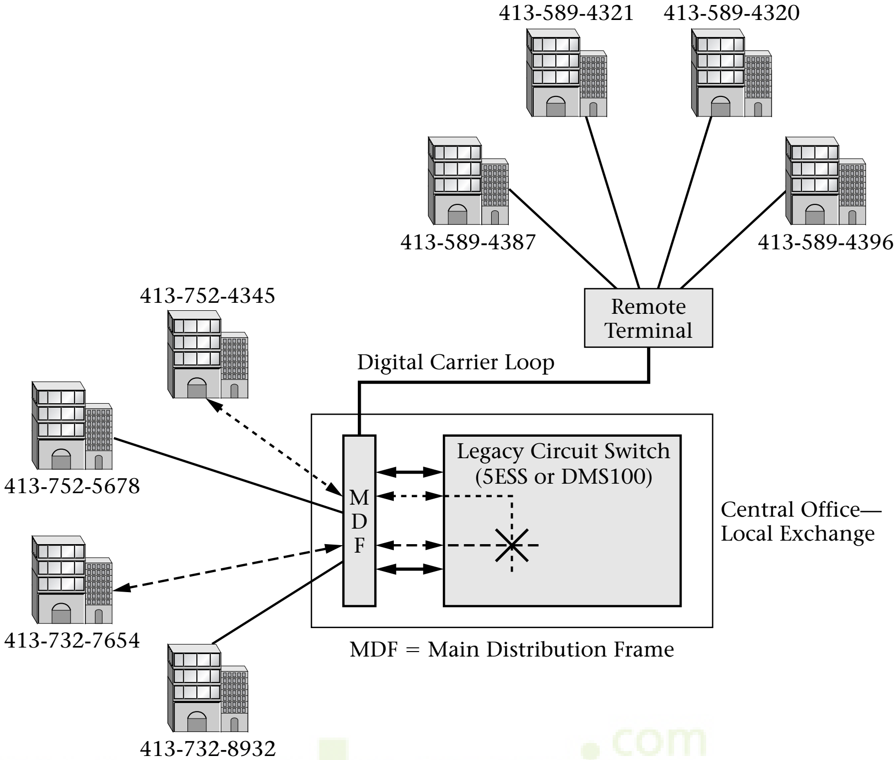
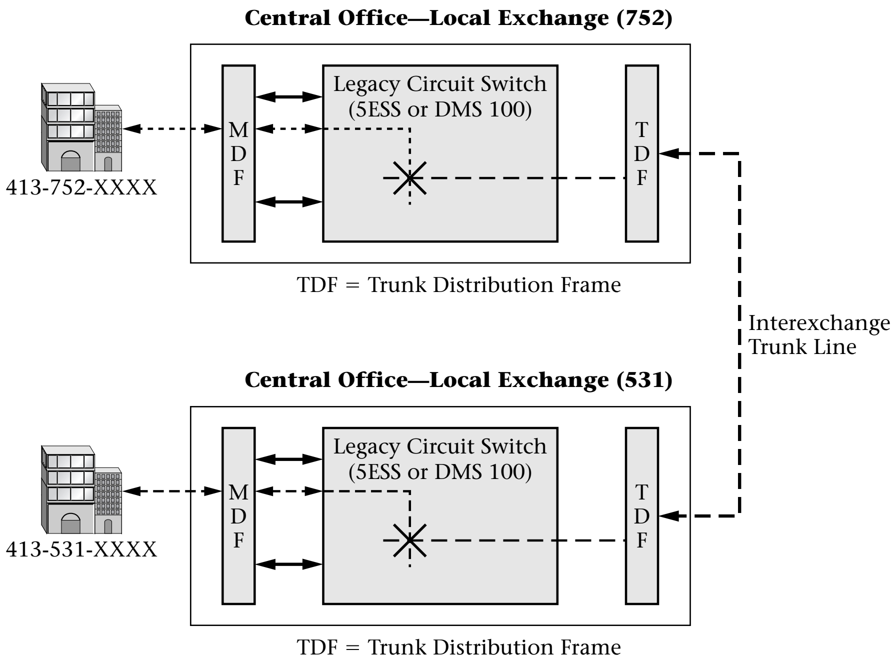


FIGURE 1–2 A PSTN intraoffice call through a local exchange.

physically connected by a circuit and is using the resources of the switch, this type of operation is termed **"connection-oriented"** or in particular a **"circuit-switched"** connection. If the party to be called is connected to a different switch at another exchange within the same calling area (an **interoffice** call), the PCM signal from the calling subscriber's switch is timed through the switch in such a fashion that it is eventually forwarded to a multiplexer and then transmitted over a digital interoffice transmission facility (**trunk** line). Figure 1–3 shows this type of interoffice connection.

This interoffice connection might use some type of T-carrier transport technology (T-1, T-3, etc.) that might be carried over copper wires, but most likely it will be some form of fiber-optic connection that is transporting data at OC-1, OC-3, or OC-12 data rates using SONET transport technology. If the party to be called is in a different calling area (a long-distance call), the local switch will forward the caller's PCM packets to a long-distance carrier's multiplexed facilities using the area code of the called number to direct the call. The long-distance carrier's network will have switching centers located in different parts of the country typically connected by long-haul fiber facilities. Once the caller's signal is

FIGURE 1–3 A PSTN interoffice call over an inter-exchange trunk line.



delivered by the long-distance carrier's network to the correct local end exchange it is demultiplexed back to a DS0 signal, the process that occurs to connect to the called party is the same as before. The signal is timed through the appropriate end switch to connect it to the called party's line card. Again, a completely separate circuit will be set up in the call's return direction.

Subscribers that live a substantial distance from the local exchange are usually connected by copper pairs to a remote terminal that provides an extended service area at some distance out from the local exchange. The remote terminal might use T-carriers or fiber-optic technology to connect to the local exchange, thus extending the digital network farther out from the switch and also providing the descriptive term "carrier service area" to describe the area served by the remote terminal. Refer to Figure 1–2 again.

To recap, the PSTN consists of copper pairs that transmit analog signals from the subscriber to a digital network that digitizes the signal and then processes it through a digital switch, at which point it might be converted back to an analog signal and delivered to another subscriber through another pair of copper wires. Or, after processing by the switch, the signal is forwarded to a number of digital facilities (multiplexers, demultiplexers, and various transmission media) that transmit the signal to other digital switches using any one of a variety of digital transport technologies. The digital switches use stored programs to control their operation and the sequence of operations needed for the appropriate transmission of calls between users connected to the switch or users connected to other switches.

Signaling System #7

The early PSTN used "in-band" signaling to set up and tear down interoffice and long-distance telephone calls. By this, we mean that the same facilities used to transport the call were first used to create an actual physical circuit for the call to be sent over. A big disadvantage of this type of system is that a voice trunk (an interoffice facility) or possibly many trunks had to be "seized" in order to do the signaling necessary to set up the call. If the call is nonchargeable (the called party is unavailable or the line is busy), the charges for the seizure of the trunk circuits must be paid for by the service provider that owns the local exchange. Furthermore, this type of system was very prone to fraud since the signaling was performed by sending easily reproducible audio tones over the trunking circuits. As the PSTN evolved into a digital network, for economic reasons and for both efficiency and security, an entirely separate network was created for the purpose of routing long-distance calls (calls between different exchanges or switches). This system of using a separate facility or channel to perform the call routing function is known as "out-of-band" signaling. AT&T's early out-of-band system was called Common Channel Interoffice Signaling (CCIS). With advances in technology, this common channel signaling system has been adopted by the international telecommunications community for use with both PSTNs and public land mobile networks (PLMNs). Today, it is known as CCIS #7 or simply Signaling System #7 (SS7).

The **SS7** system is a packet network that consists of **signal transfer points** (STP) and transmission facilities linking the signal transfer points as shown in Figure 1–4. The signal transfer points connect to **service switching points** (SSP) at the local exchange and interface with the local exchange switch or mobile switching center in the case of a PLMN. The service switching points convert signaling information from the exchange voice switch into SS7 signaling messages in the form of data packets that are sent over the SS7 network. All SS7 data packets travel from one service switching point to another through signal transfer points that serve the network as routers, directing the packets to their proper destination. There are several different types of redundant links between the signal transfer points to provide the SS7 network with a high degree of reliability.

The SS7 system provides two forms of services: circuit related—the setting up and tearing down of circuits, and non-circuit-related—the access of information from databases maintained by the network (e.g., 8XX number translation, prepaid calling plans, Home Location Register interrogation). **Service control points** act as the interface between the SS7 network and the various databases maintained by the telephone

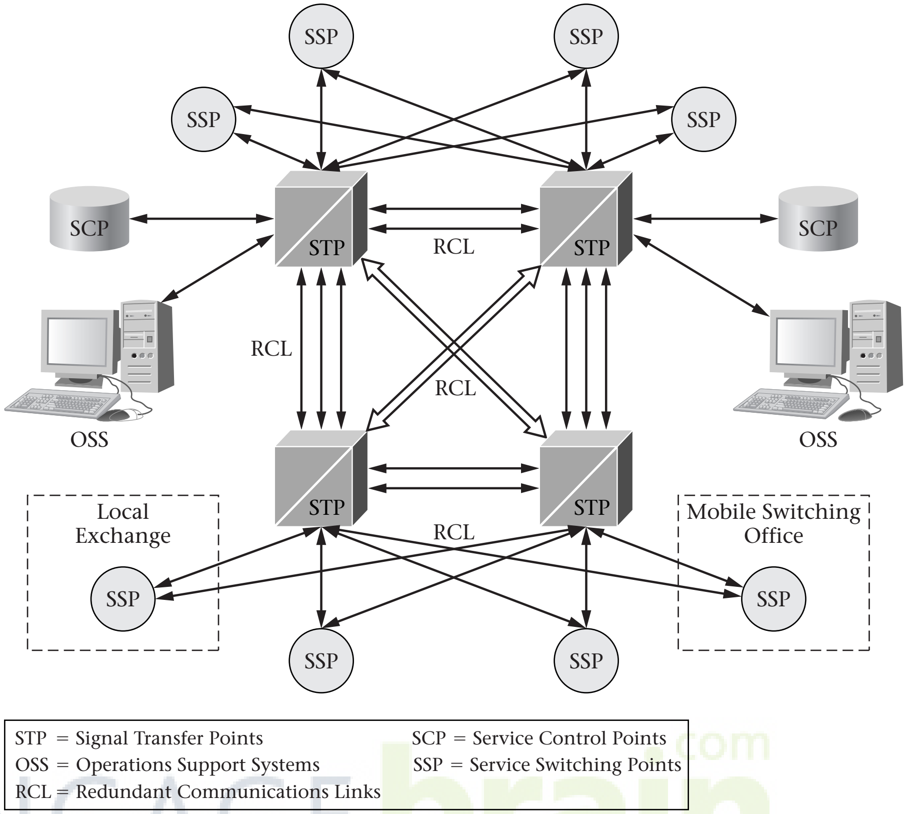


FIGURE 1–4 The network elements of the SS7 system.

companies. The entire network is connected to a remote maintenance center for monitoring and management. This maintenance center is commonly referred to as a network operations center or NOC.

In the cellular telephone system, a service provider's cell sites in a metropolitan area are all connected to switching systems that are all tied to a common switch that is in turn connected to the fixed wireline network. This common gateway mobile switching center (GMSC) uses SS7 to signal between itself and the other switches and between itself and the fixed network. All PSTNs and PLMNs use SS7 for signaling operations within the network and between the network and other networks.

The Public Data Network

In the early days of data transmission, the PSTN was used to carry data and it is still used today for this purpose. This was accomplished both then and now through the use of modems. After performing handshaking functions to set up a circuit connection to another modem at a remote location, the modems perform the function of converting data from the host computers into digital signals (audio tones) that can be transmitted across the PSTN. Modem technology has gradually increased data rates close to the theoretical maximum possible through the PSTN switch or the digital network that extends outside the local exchange (recall the remote terminals used by the telephone companies to extend their service area to the suburbs).

The physical limitation to these modem data rates is in turn driving new technologies such as adaptive digital subscriber line (ADSL) and cable modems to provide high-speed data to the home or business. However, even though data can be sent through the circuit-switched voice network this does not mean that it serves the same purpose or is as efficient as the public data network.

The public data network (PDN) has been evolving for many years in response to the connectivity needs of business, industry, and government for the transport of data over wide area networks (WANs). The PDN is often depicted as a fuzzy "cloud" on diagrams that only show how the end users are connected to it. The reason for the use of a cloud is that the network uses many different types of transport technologies (T-carrier, xDSL, Ethernet, frame relay, ISDN, ATM, SONET, etc.) and physical media to transmit data within it and therefore from end point to end point. The connections to it might be through leased lines (copper pairs), fiber facilities, or wireless radio links using any one of the transport technologies mentioned earlier. Furthermore, the data network transports packets of data that, depending upon the type of transport protocol, can be configured in many different ways (size, overhead, etc.) and can take many different routes or paths through the network. See Figure 1–5 for one possible view of the PDN.

Additionally, the PDN can support many different types of service structures, including permanent virtual circuits, switched virtual circuits, and semipermanent virtual circuits. These different so-called connection-oriented service structures provide different levels of quality of service (QoS) to the customer. The PDN also consists of **"connectionless"** systems that use connectionless protocols to forward data packets through the network. This type of data transmission tends to reduce overhead requirements and therefore be faster. Finally, many modern networks use a combination of both connection-oriented and connectionless protocols to obtain the benefits of both technologies.

Private data networks use all the same technologies previously mentioned and may be constructed, owned, and maintained by the user or leased from some service provider. **Virtual private data networks** use the public data network, maintaining privacy through the use of a **tunneling protocol** that effectively conceals the private network data and protocol information by encapsulating it within the public network transmission packets. Typically, further security is provided through the use of data encryption and decryption procedures.

Modern cellular telephone systems are currently in an evolutionary upgrade phase in an effort to provide mobile subscribers with high-speed

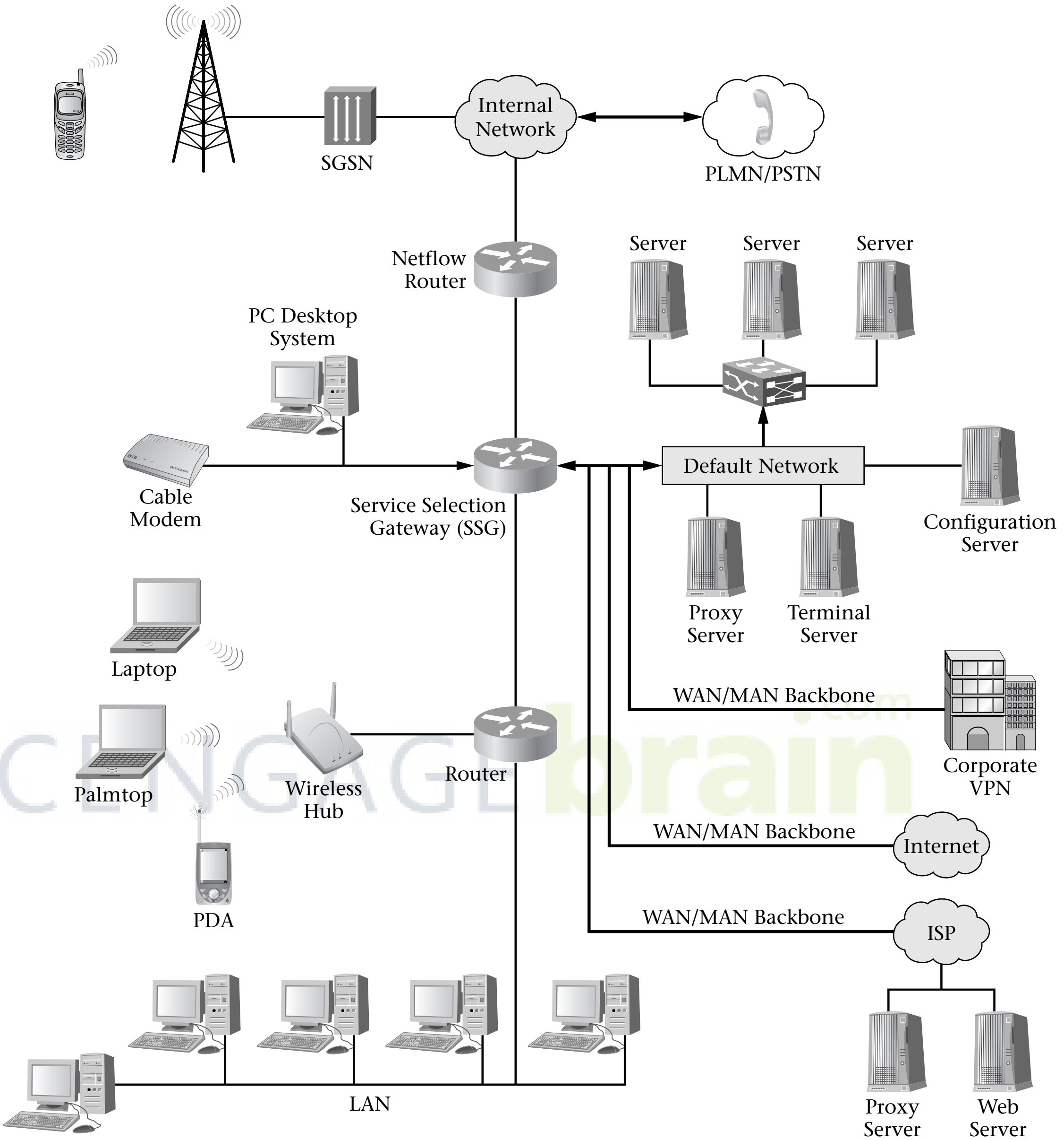


FIGURE 1–5 A depiction of the public data network.

connectivity to the PDN. Rapidly advancing technology for the implementation of wireless LANs and MANs is also providing this type of untethered connectivity at steadily increasing data rates and at an ever increasing number of geographical locations.

Broadband Cable Systems

Broadband cable systems have evolved from their early beginnings to become sophisticated and complex wideband networks designed to deliver analog and digital video signals (including HDTV), data, and plain-old telephone service to the subscriber. The video content can come from local off-air television stations, satellite feeds of network or distant-station program content, and local access facilities. The data service typically connects to an Internet service provider (ISP) and telephone service connects to the PSTN. The most important change in the legacy cable-TV plant is the migration to the two-way hybrid fiber-coaxial cable system shown in Figure 1–6. The bandwidth of cable systems has been expanded to 870 MHz, and the use of the frequency

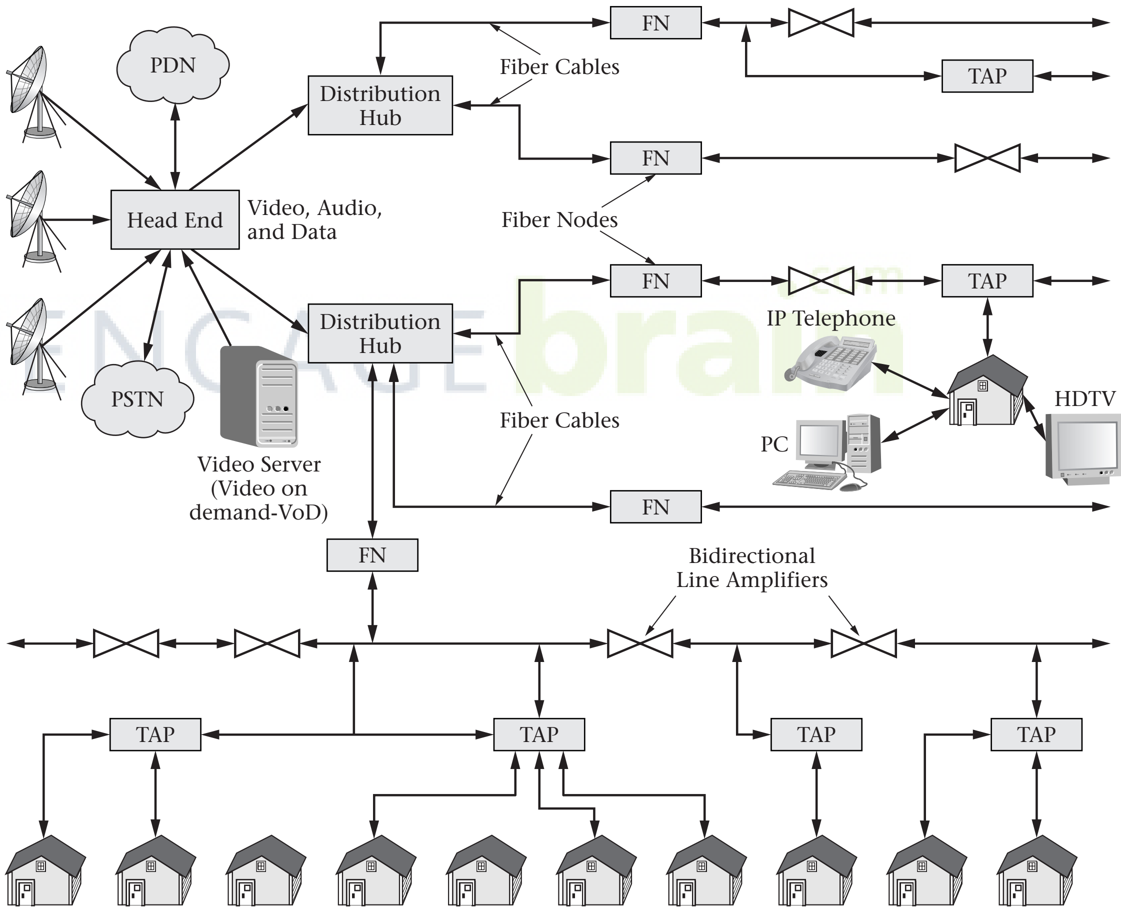


FIGURE 1–6 Modern two-way hybrid fiber-coaxial cable-TV system with fiber nodes.

spectrum between 5 and 42 MHz now allows for upstream data transmission over the network. Another important aspect to the evolution of the cable system is the development and standardization of the cable modem (CM). The data-over-cable-service interface specification (**DOCSIS**) project has led to multiple-vendor interoperability of cable modems located at the subscriber premise and cable modem termination systems (CMTS) located at the cable service providers' network centers or "head ends." These systems allow for a shared high-speed data connection over the cable network to the Internet (access to the Internet is provided at the CMTS) that passes Ethernet packets to and from the subscriber's cable modem to the subscriber's PC. The modern broadband cable network has become just one more connection to the public data network.

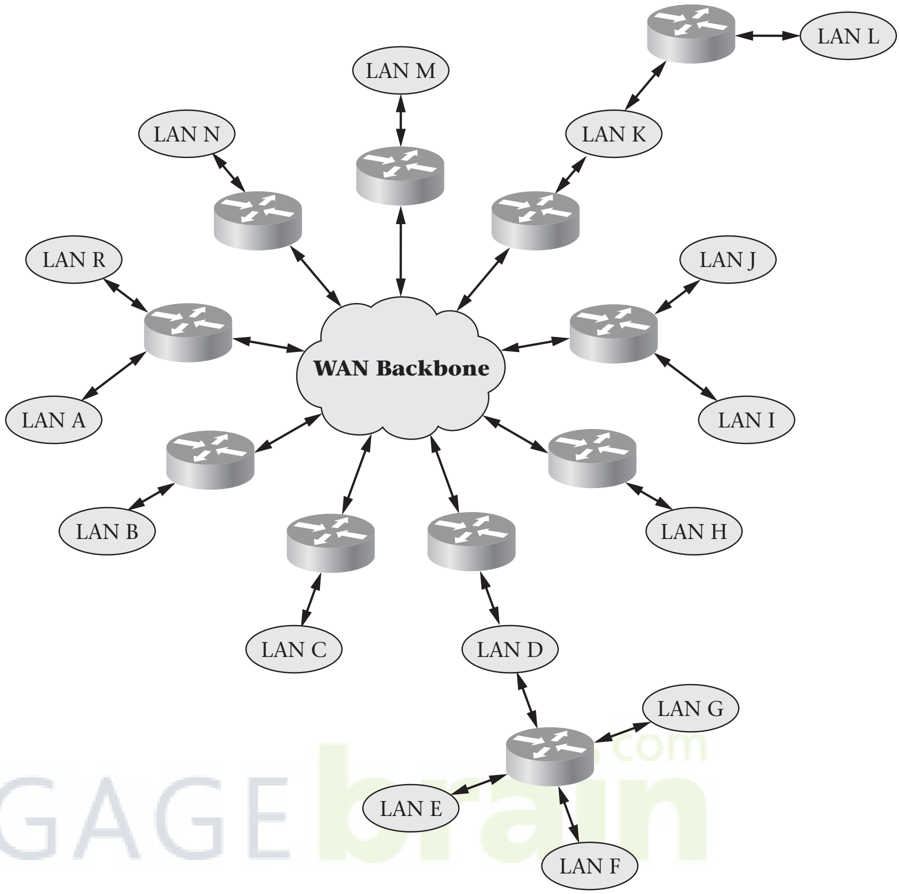
The Internet

The Internet is the world's largest computer network. Over the Internet any computer or computer network may access any other computer or computer network. The structure of the Internet is shown conceptually in Figure 1–7. It consists of thousands of computer networks interconnected by dedicated special-purpose switches called routers. The routers are interconnected by a **wide area network** (WAN) backbone. This WAN backbone actually consists of several networks operated by national service providers (SprintLink, UUNet Technologies, internet MCI, etc.) These networks consist mainly of high-speed, fiber-optic, long-haul transport systems that are interconnected at a limited number of hubs that also allow for the connection of regional ISPs.

These national service provider (NSP) networks are interconnected to each other at switching centers known as network access points (NAPs). Regional ISPs may tap into the backbone at either the NSP hubs or the NAPs. If an individual wants to connect to the Internet, he or she must usually go through an ISP. The user might connect to the ISP through the PSTN over a low-speed dial-up connection using a modem that communicates with a "modem pool" at the ISP, or through high-speed cable-modem or ADSL (adaptive digital subscriber line) service. These services are usually connected through the PDN to the ISP. A **local area network** (LAN) at an Enterprise location will usually be connected to the ISP through some type of high-speed connection to the PDN (usually leased from a service provider) and then through the ISP's high-speed connection to the PDN. The ISP will in turn be connected to the Internet through another high-speed network connection.

Today, one may be connected to the Internet by a wireless device while roaming or while connected to a LAN. Cellular telephones and personal digital assistants (PDAs) allow one to connect through the packet

FIGURE 1–7 Conceptual structure of the Internet.



data network. The Web "browser" experience is not the same as with a desktop computer, but it is an Internet connection nevertheless.

Cellular Telephone Systems

Since their first deployment some two decades ago, cellular telephone systems have grown at a phenomenal rate. The public has been quick to adopt cellular technology, and the operator's networks have expanded to become national in scope. The technology used to implement cellular systems has also quickly evolved from analog (first generation or 1G), to digital (second generation or 2G), to systems with medium-speed data access (called 2.5G). High-speed data-access third-generation or 3G systems are already being deployed worldwide. Cellular operators have expanded coverage and capacity by using new frequency allocations, new air interface technologies, and cell splitting, and they have increased the functionality of their systems by expanding their scope to include access to the PDN, as well as the PSTN.

1.3 Overview of Existing Network Infrastructure

Figure 1–8 shows an overview of the existing network infrastructure in place today. As mentioned previously, wireless telecommunication systems and networks perform the function of connecting to the existing

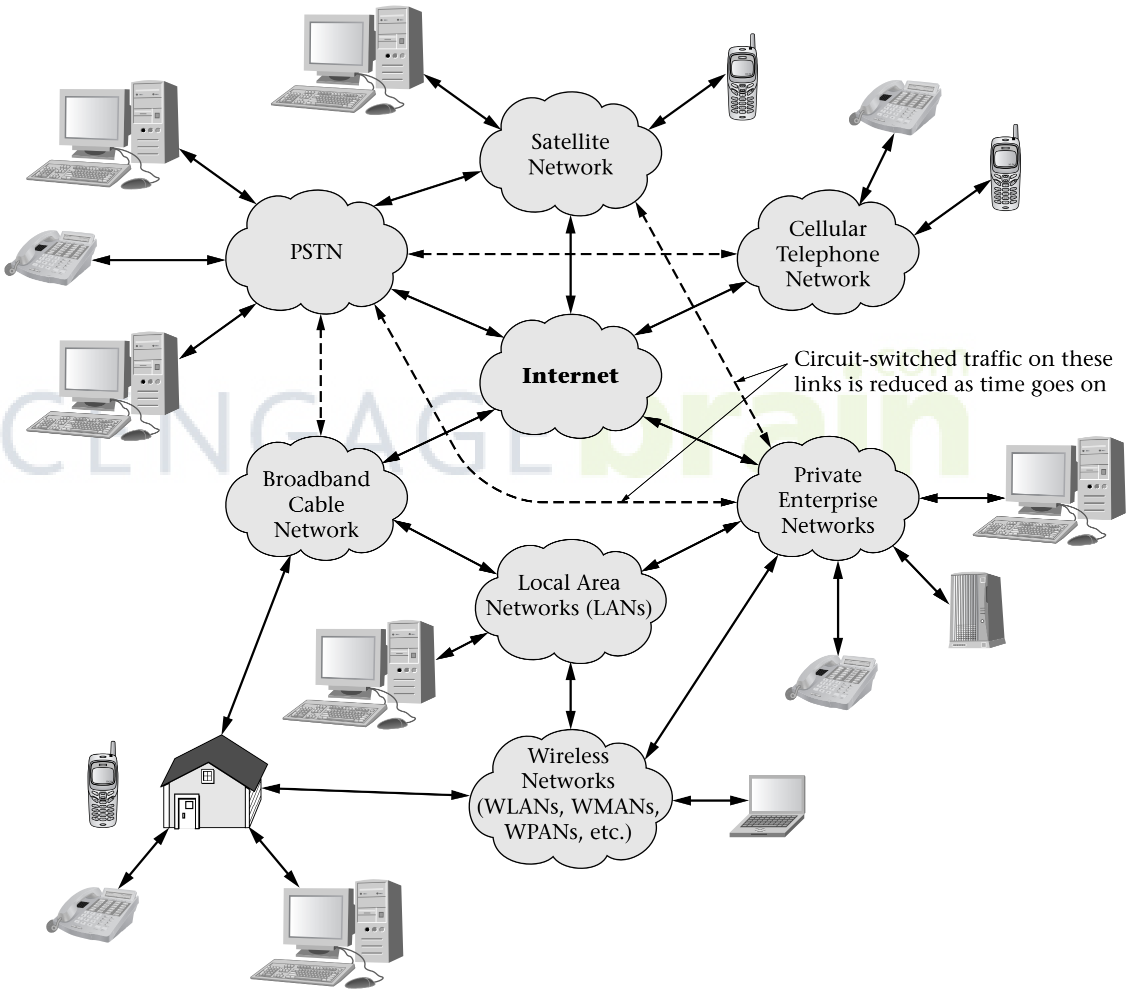


FIGURE 1–8 Today's existing network infrastructure.

network infrastructure. The three major types of traffic carried by the telecommunications network infrastructure are voice, video, and data (often known collectively as multimedia).

The PSTN was originally designed for voice transmission. To provide this function, the PSTN was structured in such a way as to provide a circuit-switched path for the conversation, which occurs in real time and therefore requires a certain Quality of Service (QoS). This physical path would be set up during the dialing of the call and torn down at the completion of the call. Supervisory, alerting, and progress tones and signals are generated by the system to facilitate creation of the connection and perform call handshaking functions. The network would take care of authentication and billing functions. Today the PSTN is an almost entirely digital system except for the analog signals that propagate over the copper wire pairs that provide a subscriber access to the network. The cellular telephone system gives a subscriber access to the PSTN.

The fixed network infrastructure developed to transport broadband analog video or television signals to the public is the hybrid fiber-coaxial cable (HFC) broadband cable television network. This system broadcasts the same video signals to all the subscribers connected to the network. A cable modem or set-top box allows the system to provide different levels of access to the entire suite of video signals transmitted over the system. If a subscriber has paid for premium services, these services are allowed to be passed to the subscriber's television tuner or are decrypted if they had previously been encrypted or "scrambled."

Through system upgrades and rebuilds and use of the DOCSIS standard, the modern cable television network has become bidirectional, allowing both downstream and upstream data transmission. Most cable operators now offer shared high-speed Internet access over their systems. Presently, cellular systems do not provide access to this network infrastructure. However, one may easily set up a wireless LAN to connect to this infrastructure in one's own home or apartment.

The data network was originally developed to carry bursty data traffic for business and industry. As technology has evolved the Enterprise data network has also evolved. Today's Enterprise data networks tend to have a wide area network (WAN) or **metropolitan area network** (MAN) high-speed backbone with a collection of local area networks (LANs) connected to it. This backbone network may be dedicated or switched and might use several different types of data transport technologies. Voice, data, and video can share these transport facilities. Usually, the Enterprise private branch exchange (PBX) is also connected to the high-speed backbone as well as the PSTN. The Internet and the PDN are also interconnected. Some would argue that they are one and the same! As Voice over IP (VoIP) becomes more popular that line will blur even more. Wireless data networks tie into this infrastructure at the Enterprise level through wireless LANs and through cellular systems connected to the PDN.

1.4 Review of the Seven-Layer OSI Model

As we move toward a totally digital telecommunications infrastructure it is important to have some knowledge of the Open System Interconnection (OSI) reference model. This model describes how information moves from a software application in one computer to a software application in another computer either over a simple network or through a complex connection of networks or **internetwork.** An internetwork is usually defined as a collection of individual networks that are connected together by intermediate networking devices. To the user, an internetwork functions as a single large network.

Since one of the major functions of today's wireless systems and networks is to link the user to the installed wireline, wireless, coaxial cable and fiber-optic telecommunications infrastructure (i.e., PSTN and PDN), it is very often instructive to examine that particular interconnection and other wireless system interconnections through the OSI model. Therefore, this section will give a brief overview of the OSI model with emphasis on the lower layers of the model.

The OSI Model

The OSI reference model is a conceptual model that consists of seven layers. Each layer of the model specifies particular network functions. The model was developed by the International Organization for Standardization (ISO) in the 1980s, and it is now considered the major architectural model for network and internetwork data communications. The OSI model divides the tasks that are involved with moving information between networked computers into seven groups or layers of smaller, more manageable tasks. The tasks assigned to each layer are relatively autonomous and therefore can be implemented independently of tasks in other layers. This allows for changes or updates to be made to the functions of one layer without affecting the other layers. Figure 1–9 shows the seven layers of the OSI model.

Usually, the seven-layer model can also be divided into two categories: upper layers and lower layers. The upper layers are usually associated with application issues and are implemented in software. The lower layers handle data transport issues. The lowest two layers, data link and physical, are implemented in hardware and software. The lowest layer, the physical layer, is a description (electrical and physical specifications) of the actual hardware link between networks. Figure 1–10 shows the two sets of layers that make up the OSI model. In this text, emphasis generally will be on the data transport layers and on the physical layer when discussing particular air interfaces.

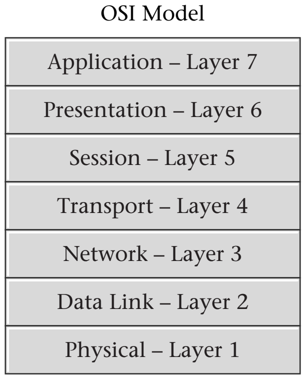


FIGURE 1–9 The seven-layer OSI model.

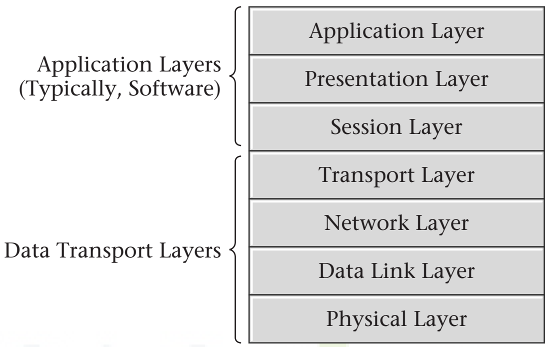
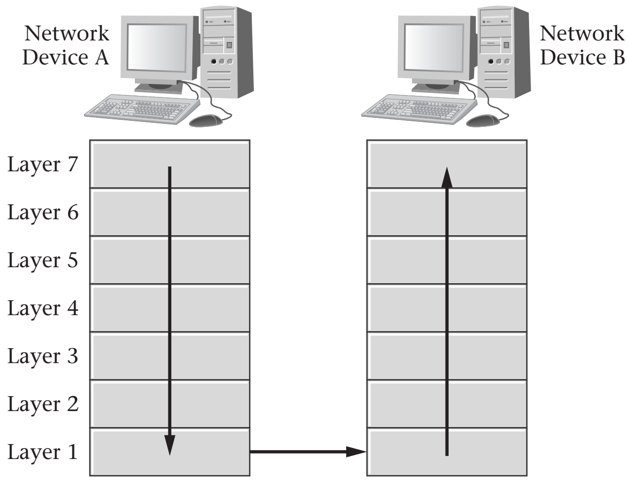


FIGURE 1–10 The two sets of layers that make up the OSI model.

Protocols

Although the OSI model provides one with a conceptual structure for the communication of information between computers, it itself is not a means of communication. The actual transmission of data is made possible through the use of communications **protocols.** A protocol is a formal set of rules and conventions that allows computers to exchange information over a particular network. A protocol is used to implement the tasks and operations of one or more of the OSI layers. There are many different communications protocols that are used today for different types of networks. LAN protocols define the transport of data for various different LAN media (CAT-n, fiber, wireless, etc.) and work at the physical and data link level. WAN protocols define the transport of data for various different wide area media and work at the network, data link, and physical level. Routing protocols work at the network layer level. These protocols are responsible for exchanging the required data between routers so that they can select the correct path for network traffic. Network protocols are the various upper-layer protocols that exist in any particular protocol suite. An example of a network protocol is AppleTalk Address Resolution Protocol (AARP).

FIGURE 1–11 Information transfer between network devices as depicted by the OSI model.



Relation of OSI Model to Communications between Systems

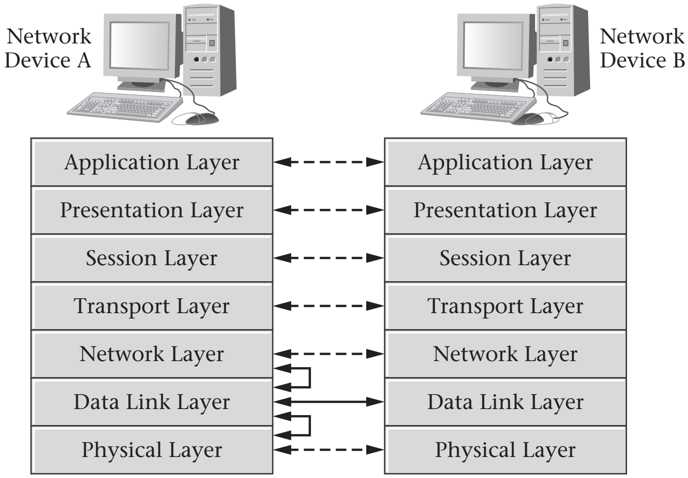
Information that is being transferred from a software application in one computer through a computer network to a software application in another computer must pass through the OSI layers. Figure 1–11 depicts this process.

Referring to Figure 1–11, data from an application in Device A is passed down through the OSI model layers, across the network media to the other OSI model, and up through the OSI layers to the application running on Device B. A closer look at this process might be instructive. The application program running on Device A will pass its information to the application layer (Layer 7) of Network Device A. The application layer of Device A will pass the information to the presentation layer (Layer 6) of Device A. The presentation layer then passes the information down to the session layer (Layer 5) of Device A and so on until the information is finally at the physical layer (Layer 1) of Device A. At the physical layer level, the information is placed on the physical network medium and transmitted (sent) to Device B. The process is reversed in Device B with the information being passed from layer to layer upward until it finally reaches the application layer (Layer 7) of Device B. At this point, the application layer of Device B passes the information on to the application program running on Network Device B.

More OSI Model Detail

In general, each OSI layer can communicate with three other layers: the layer directly below it, the layer directly above it, and the layer directly equivalent to it (its peer layer) in the other networked computer system (See Figure 1–12). The OSI layers communicate with their adjacent layers

FIGURE 1–12 OSI model layers communicating with other layers.



to make use of the services provided by these layers. The services provided by the adjacent layers in the OSI model are designed to allow a given OSI layer to communicate with its equivalent or peer layer in another computer system connected to the network.

The seven OSI layers use different forms of control information to communicate with their peer layers in other computer systems or system elements connected to a network. This control information (protocol specific) usually consists of header and trailer information that has been added to data passed down from upper layers, and it represents various requests and instructions that are sent to peer OSI layers. As the information is passed down from one layer to the next, the added control information from the prior layer is now considered by the next layer to also be data. This process, which may be repeated several times, is referred to as encapsulation. Figure 1–13 depicts this encapsulation process as information is passed downward through the seven-layer OSI model. Note how each new header is added to any previously added headers and the original data. Eventually, the entire assembled data unit is transmitted via the physical network connection.

Information Exchange

At this point it would be instructive to give an example of the entire process of information exchange between two computer systems that are both connected to a network. Computer System A has information from a software application to send to Computer System B. The information (data packet) is forwarded to the application layer. The System A application layer adds any control information to the data packet that will be needed by the application layer in Computer System B. The resulting information packet (control information and data) is forwarded to the

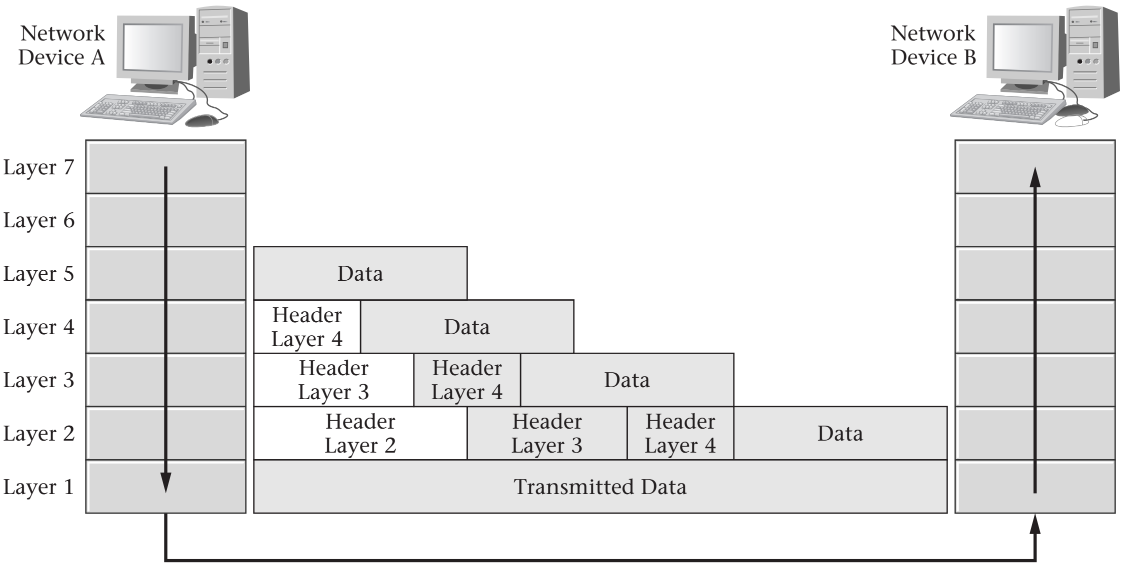


FIGURE 1–13 The process of data and header encapsulation during information exchange over a network.

presentation layer. The presentation layer now adds any required control information for the presentation layer of Computer System B. This process is repeated several more times as the information packet is forwarded to each succeeding lower layer. At each layer the information packet grows in size as the required control information is added to the packet. Finally, at the physical layer the entire data packet is placed onto the network medium. Refer to Figure 1–13 again. The physical layer of Computer System B receives the data packet and forwards it to the data link layer of System B. The data link layer of System B reads the control information contained in the data packet, strips this information from the packet, and forwards the remaining data packet to the network layer. The network layer performs the same type of process, reading the control information meant for it, stripping this information from the data packet, and forwarding it upward to the next layer. This process is repeated by each layer until finally the application layer forwards the exact same data packet sent by Computer System A to the software application running on Computer System B.

Overview of the OSI Model Layers

As a final wrap-up to coverage of this topic, this section will present an overview of each OSI model layer. Where possible, examples of typical layer implementations will be presented.

Layer 7—Application Layer The application layer is closest to the end user. By that, we mean that the OSI application layer and the end user both interact with the software application that is running on the computer. Some examples of application layer implementations include File Transfer Protocol (FTP) for file transfer services, Simple Mail Transfer Protocol (SMTP) for electronic mail, Domain Name System (DNS) for name server operations, and Telnet for terminal services.

Layer 6—Presentation Layer The presentation layer provides a variety of conversion and coding functions that are applied to application layer information/data. This is done to assure that information sent from the application layer of one machine is compatible with the application layer of another machine (possibly a different type of computer system). Some of the types of coding and conversion that are performed are common data representation formats (standard multimedia formats), conversion of character representation formats (e.g., EBCDIC and ASCII converted to a syntax acceptable to both machines), common data compression schemes (e.g., GIF, JPEG, and TIFF), and common data encryption schemes. In each case, the use of these presentation layer coding and conversion functions allows data from the source system to be properly interpreted at the destination system.

Layer 5—Session Layer The session layer has the task of establishing, managing, and terminating communications sessions over the network. An example of a session layer implementation is the AppleTalk Session Protocol (ASP) from the AppleTalk protocol suite.

Layer 4—Transport Layer The transport layer accepts data from the session layer and then segments the data in the proper manner for transport across the network. Since the transport layer is tasked with delivering the data in proper sequence and in an error-free fashion, flow control is implemented at the transport layer. Flow control manages the data transmission between devices. Virtual circuits are set up and torn down by this layer, error checking and correction is executed, and multiplexing may be performed. Familiar transfer protocols are Transfer Control Protocol (TCP) and User Datagram Protocol (UDP).

Layer 3—Network Layer The network layer isolates the upper OSI layers from routing and switching functions in the network. The functions within the network layer create, maintain, and release connections between the nodes in the network and also manage addressing and routing of messages. A typical network layer implementation is Internet Protocol (IP). With IP, network addresses may be defined in such a way that route selection can be determined systematically by comparing the source network address and the destination address and applying the subnet mask.

Layer 2—Data Link Layer The data link layer provides for the reliable transmission of data across a physical network connection or link. Different data link layer specifications define different network and protocol characteristics. Some of these characteristics include physical addressing, error notification, network topology, sequencing of frames, and flow control. The Institute of Electrical and Electronics Engineers (IEEE) has subdivided the data link layer into two sublayers: Logical Link Control (LLC) and Media Access Control (MAC). The LLC sublayer of the data link layer manages communications over a single link of a network. The MAC sublayer of the data link layer manages protocol access to the physical network medium. The IEEE MAC specification defines MAC addresses. This specification allows multiple devices to be uniquely identifiable at the data link layer.

Layer 1—Physical Layer The physical layer defines the electrical and mechanical specifications for the physical network link. Characteristics such as voltage levels, timing, physical data rates, maximum distance of transmission, and physical connectors are all part of this specification for wireline media. For fiber-optic media similar specifications exist for the type of network transport technology employed (FDDI, ATM, SONET, etc.). Usually, physical layer implementations can be categorized as LAN, MAN, or WAN specifications. For cellular wireless networks, characteristics such as frequency of operation, channel format, modulation type, timing, hopping sequences, coding, and other technical specifications are grouped under the term "air interface" and depend upon the particular cellular system being discussed. Today the most prominent players in the development and publication of cellular specifications are the European Telecommunications Standards Institute (ETSI), the Telecommunications Industry Association (TIA), and the two Third-Generation Partnership Projects: 3GPP and 3GPP2.

For wireless LANs (local area networks), PANs (personal area networks), and MANs (metropolitan area networks) the IEEE produced the IEEE 802.11x, 802.15x, and 802.16x specifications (respectively) to cover the particular technology implementation.

The physical layer also defines the procedural and functional specifications for activating, maintaining, and deactivating the physical link between the devices communicating over the network systems.

During the discussion of various wireless systems and networks in other parts of this book, the operation of these systems will at times be illustrated through the relationship of the particular operations with the layers in the OSI model. For most of these illustrations, the lower transport layers will be of most importance and the physical layer will usually receive the most attention since it contains the details of the air interface that differentiate these various systems.

1.5 Wireless Network Applications: Wireless Markets

The markets for wireless services have evolved into two basic categories: the traditional voice-oriented market and the newer data-oriented market. The first market has enjoyed an amazing acceptance by the general public with an extremely fast take-up rate for the service offered—a connection to the PSTN via cellular telephone. With newer personal communications services (PCS) systems being built out on a different frequency band, there is the potential for a new generation of digital phones that offer voice, data, and fax services to the subscriber. However, there is actually little to differentiate between cellular and PCS service, and most network operators are offering both (subscribers have dual- and tri-mode phones) in an effort to achieve better coverage. Most operators are offering nationwide plans with an ever increasing number of minutes of system connection time per dollar. The newer data-oriented market has evolved around the Internet and computer LAN technology. More recently the cellular telephone data-oriented market has been driven by short messaging service (SMS), instant messaging (IM), and multimedia messaging service (MMS) applications and other novel entertainment-type applications. This shift has been noted by both service providers and content developers and is focusing applications development on entertainment- or "infotainment"-based uses of the cell phone. Wireless LANs have been steadily gaining in popularity and acceptance for both Enterprise and home use. The adoption of new standards that provide for the use of new unlicensed frequency bands and higher data rates have led to many predictions of a fast uptake rate for this technology and a potential threat to the cellular operators as they evolve their networks to offer faster data rates. In addition, wireless MANs and PANs are starting to be seen in the marketplace.

Voice Network Evolution

The development of voice-oriented wireless networks began in earnest during the early 1970s at AT&T's Bell Labs. The technology for frequency division multiple access (FDMA) analog cellular systems was developed but not deployed in the United States until much later in 1983 as the Advanced Mobile Phone System (AMPS). Similar systems were deployed in the Nordic countries a year earlier in 1982 as the Nordic Mobile

Telephony (NMT) system. At about the same time, digital cellular networks were starting to be developed under the Groupe Spécial Mobile standardization group that eventually became the Global System for Mobile Communications or GSM. The **GSM** group was formed in an attempt to deal with international roaming, which was a serious problem for the European Union countries. This led to a new digital time division multiple access (TDMA) second-generation technology (i.e., GSM) that was deployed in many parts of the world beginning in late 1992. At present approximately 72% of cellular telephone users are serviced by GSM systems. In the United States, in an effort to increase capacity, a digital North American version of TDMA was introduced in the early 1990s. This new digital system was a hybrid air interface that used both first- and second-generation technology. At this time, its successor standard, TDMA IS-136, has a worldwide subscriber base of over 100 million users or approximately 9% of all cellular telephone users. The most recent entry into the cellular mix has been a **code division multiple access** (CDMA) technology-based system. First deployed in the United States in 1995, this standard now has a worldwide subscriber base of over 170 million users. An additional standard, personal digital cellular (PDC), is a Japanese TDMA-based standard. It also has a subscriber base of approximately 60 million users; however, some Japanese operators have already announced plans to phase out their PDC systems and shift to CDMA systems.

Although not as high profile as cellular technology, cordless telephones belong to the wireless voice network class of products also. First introduced in the late 1970s, these devices, which provided a wireless connection from the telephone handset to a fixed “base station,” became an instant commercial success. Second-generation digital cordless telephones appeared in the early 1980s and the concept of the PCS device evolved in the early 1990s.

A PCS service was considered the next generation of residential cordless telephone. Although there have been some deployments of PCS systems worldwide, none of the PCS standards have become a major commercial success or a competitor to the cellular telephone systems. In the United States the PCS bands have been put into use, but the PCS standards were not adopted for use in these bands. As mentioned before, most operators are using the PCS bands for cellular service and to fill gaps in their coverage area.

Data Network Evolution

The concept of data-oriented wireless networks started in the 1970s, but development did not start in earnest until the early 1980s. Amateur radio operators had built and operated simple wireless packet radio networks earlier, but commercial development of radio-based LANs did not begin until 1985 when the FCC opened up the industrial, scientific, and medical (ISM) bands located between 920 MHz and 5.85 GHz to the public. During the early 1990s the Institute of Electrical Engineers (IEEE) formed a "working group" to set standards for wireless LANs. The IEEE finalized the initial 802.11 standard in 1997 for operation at 2.4 GHz with data rates of 1 and 2 mbps.

Advances in wireless LAN technology have been occurring at a rapid pace. The IEEE 802.11x family of standards has been expanded to include operation in the 5-GHz U-NII bands with data rates of up to 54 mbps through the use of complex digital modulation schemes.

The IEEE has adopted two other families of standards, IEEE 802.15x for operation of wireless personal area networks (wireless PANs), also known as Bluetooth, and IEEE 802.16x for the operation of wireless metropolitan area networks (wireless MANs), also known as broadband wireless access. A great deal of promise lies in these new standards and the technologies that will be used to implement them, but only time will tell if they will enjoy widescale adoption.

There are parallel development activities occurring in Europe under the European Telecommunications Standards Institute (ETSI) for high-speed wireless LANs that appear to have characteristics similar to IEEE 802.11x-based products. The ETSI **HiperLAN/2** standard specifies operation in the 5-GHz band and also has the same maximum data rate of 54 mbps. More detailed coverage of these topics is given in Chapters 9 through 11.

Mobile data services were first introduced in North America with the ARDIS project sponsored by Motorola and IBM in 1983. Mobitex (an open version of ARDIS) was introduced in 1986 and then in 1993 **cellular digital packet data** (CDPD) service was introduced in the United States. Both ARDIS and Mobitex are based on proprietary packet-switched data networks. Mobitex service is still available from Cingular Wireless in the United States with data rates of about 8 kbps. CDPD service allows cellular systems to deliver packet data to subscriber phones albeit at low data rates (generally below 19.2 kbps). Currently there exist several data-only wireless operators. Data speeds over these networks range from less than 2.4 kbps for two-way paging applications to 19.2 kbps for the fastest systems. Note however that these peak data rates do not translate into real throughput rates. These values are typically 50% of the peak rate.

General packet radio service (GPRS) with its slightly higher user data rates of 20 to 50 kbps has been available over GSM systems since the early 2000s. GSM systems are implementing EDGE technology (2.5G to 3G) worldwide to achieve enhanced data rates. **EDGE** stands for Enhanced Data Rate for Global Evolution. The first operational CDMA systems offered data throughput rates to 14.4 kbps. The second phase of CDMA systems (IS-95-B) offer higher data rates (up to 56 kbps). The evolutionary pathway to third-generation (3G) CDMA systems includes a phasing in of greater packet data transfer rates. The first implementation phase (offered in 2002) of 3G is known as cdma2000 1xRTT and offers packet data rates of up to 144 kbps with real throughput rates of from 60 to 80 kbps.

Cellular service providers are spending a great deal of money to upgrade their systems to offer higher-speed data throughput rates to and from the PDN, as well as continued traditional access to the PSTN voice network. Future plans for all cellular technologies include upgrades to 3G technologies with even higher standard data rates and increased mobility. Will the public desire these digital services and subscribe to them? Only time will tell.

1.6 Future Wireless Networks

Present-day research efforts in the wireless field are geared toward the concept of seamless connectivity. It is conceived that in the not-too-distant future, an individual will be able to be connected to the installed telecommunication infrastructure in a seamless fashion. That is, the individual can be roaming throughout different service providers' networks that possibly use different delivery technologies and still be connected to the Internet without losing connectivity. Mobile IP will allow for both universal mobility and high data rate access either in a fixed location or while in motion. The user will not notice any loss of connectivity or change in service regardless of the conditions or the type of wireless network. Even before the installation of 3G cellular systems has become commonplace, 4G systems with ATM access speeds (over 100 mbps) are being discussed by the wireless research community. Many, including this author, believe that almost all access to the Internet will become wireless in the future. The future of wireless telecommunications technology appears to be unlimited!

Summary

To summarize, the general public worldwide has embraced the notion of mobility. Wireless technology in the form of cellular telephones, wireless LANs, MANs, or PANs, or yet-to-be-developed products have won us over. Our access to the public telephone or data network and the Internet will become faster and more ubiquitous with time. Wireless networks with multimedia capabilities will provide us the ability to see the other person or persons that we our conversing with and make available unique applications that are unheard of today but will become tomorrow's standard. For wireless technology, the best is yet to come!

Questions and Problems

Section 1.1

1. Do an Internet search for information about Mahlon Loomis. Write a short description of the theoretical operation of his patented aerial wireless telegraph system.
2. Do an Internet search for information about Marconi's first wireless experiments. What frequencies did Marconi first use for his wireless experiments?
3. Determine the length of a half-wave antenna for Fessenden's 50-kHz transmitter that he used at Brant Rock. What was the actual length of the antenna he used? Hint: Do an Internet search for information about Fessenden's early experiments. Hint: $\lambda = c/f$ where c is the speed of light and f is the frequency.
4. Use the Internet to research the deployment of over-the-air HDTV. By what date is HDTV broadcasting expected to be totally deployed?

Section 1.2

5. What is the data rate of a DS0 signal?
6. In theory, how many DS0 calls can be transported by an OC-3 fiber-optic facility? After multiplexing to higher DSn rates, what is the practical capacity of DS0 calls that can be handled by an OC-3 facility?
7. What is the typical data transfer rate (in bps) over a SS7 transfer link?
8. Describe how a high-speed cable modem, xDSL service, or cellular telephone service extends the PDN.

Section 1.3

9. In your own words, define the extent of a local area network (LAN).
10. In your own words, define the extent of a metropolitan area network (MAN).
11. In your own words, define the extent of a wide area network (WAN).

Section 1.4

12. Describe the encapsulation process in the context of the OSI model.
13. At what OSI layer does flow control occur?
14. What is the function of the MAC sublayer?
15. Which OSI layer provides the specifications for the wireless air interface?

Section 1.5

16. Go to an Internet Web site devoted to the GSM industry and determine the present total number of worldwide GSM subscribers.
17. Go to an Internet Web site devoted to the cellular telephone industry and determine the percentage of subscribers for the different major cellular telephone technologies (GSM, NA-TDMA, CDMA, PDC, etc.).
18. Go to the IEEE Wireless Standards Web site. Check the status of the IEEE 802.11 wireless LAN standard. Write a short one-paragraph report on the state of one of the IEEE 802.11 working group's amendments to 802.11.
19. Describe a cellular telephone use that would be considered an infotainment use.

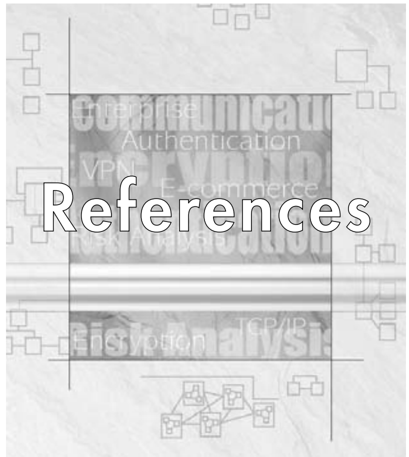
Section 1.6

20. Compare 3G cellular telephone data transfer rates with those available over wireless LANs. Comment on the difference. Is it important?

Advanced Questions and Problems

These advanced questions and problems will typically require students to first research the particular question area in further detail and then draw upon other supplementary materials to complete their answer. In many cases, team projects or presentations could be assigned from this group of questions.

1. Research the MPEG-n data compression techniques and comment on their use in telecommunications systems.
2. Describe the concept of video on demand and explain how it is accomplished via a cable TV system. Hint: research this topic on the Internet.
3. Research the operation of Voice over IP (VoIP) and take a position on what effect it will have on the incumbent telephone companies.
4. Go to the FCC Web site (www.fcc.gov) and write a short report on one of the hot technical topics presently receiving a large share of the FCC's attention.
5. Research 4G cellular and write a short report on its status.



Chapter 1

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