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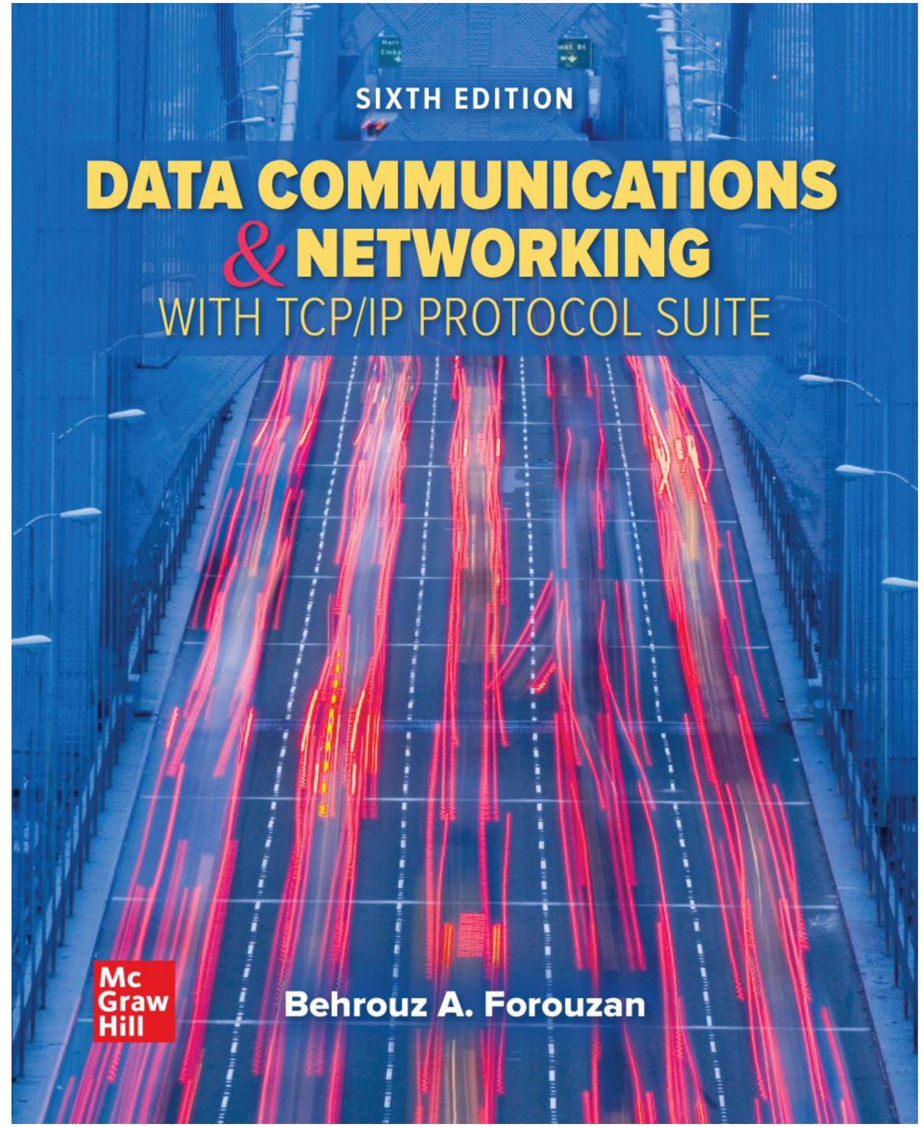
Chapter 05

Wide Area Network: WANs

Data Communications and Networking, With TCP/IP protocol suite
Sixth Edition
Behrouz A. Forouzan



Chapter 5: Outline

5.1 Telephone Network

5.2 Cable Network

5.3 Cellular Telephone

5.4 Satellite Network

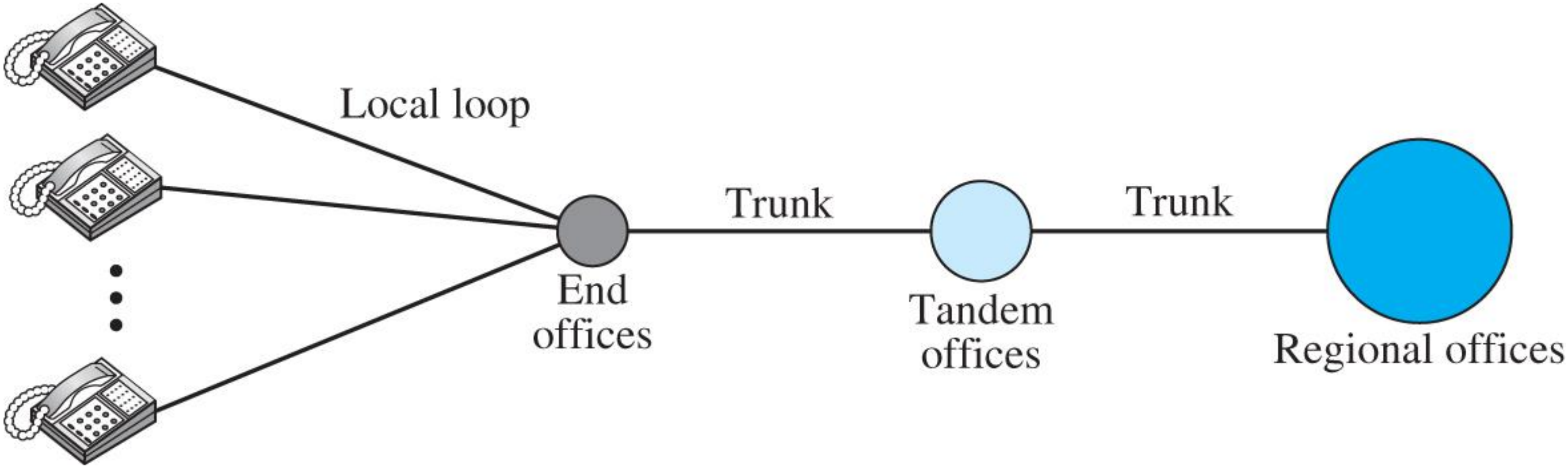
5-1 TELEPHONE NETWORK

The telephone network had its beginnings in the late 1800s. The entire network was originally an analog system using analog signals to transmit voice. During the last decade, the telephone network has undergone many technical changes. The network is now digital as well as analog.

5.1.1 Major Components

The telephone network is made of three major components: local loops, trunks, and switching offices. The telephone network has several levels of switching offices such as end offices, tandem offices, and regional offices.

Figure 5.1 A telephone system



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Local Loop

One component of the telephone network is the local loop, *a twisted-pair cable that connects the subscriber telephone to the nearest end office or local central office.*

Trunks

Trunks are transmission media that handle the communication between offices. A trunk normally handles hundreds or thousands of connections through multiplexing. Transmission is usually through optical fibers or satellite links.

Switching Office

To avoid having a permanent physical link between any two subscribers, the telephone company has switches located in a switching office. A switch connects several local loops or trunks and allows a connection between different subscribers.

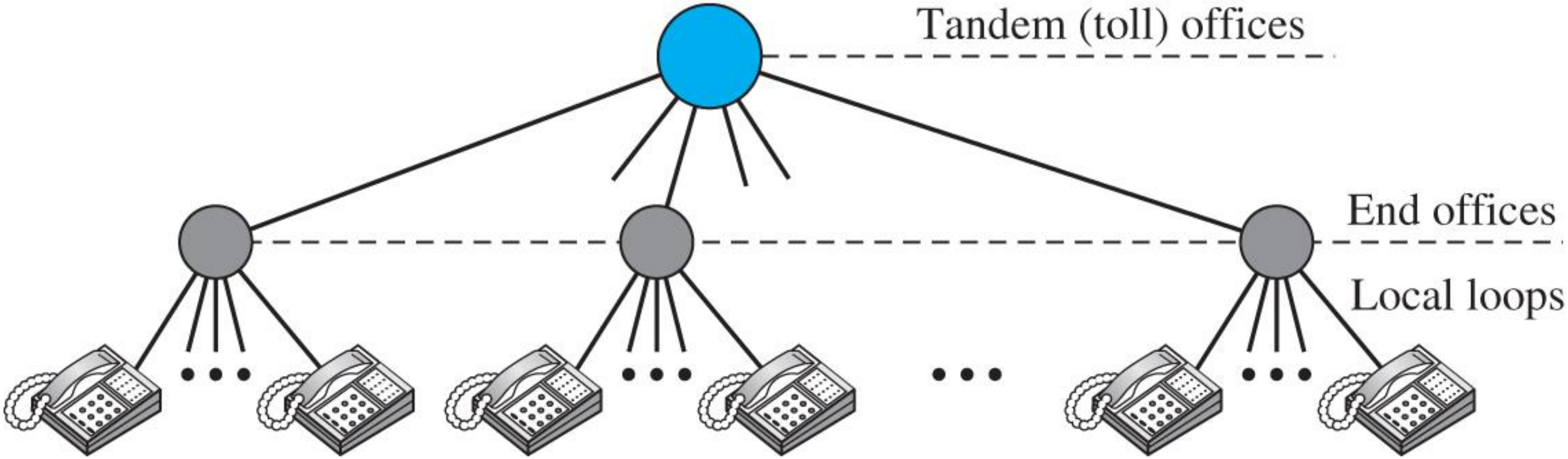
5.1.2 LATAs

After the divestiture of 1984, the United States was divided into more than 200 local-access transport areas (LATAs). The number of LATAs has increased since then. A LATA can be a small or large metropolitan area. A small state may have one single LATA; a large state may have several LATAs. A LATA boundary may overlap the boundary of a state; part of a LATA can be in one state, part in another state.

Intra-LATA Service

The services offered by the common carriers (telephone companies) inside a LATA are called intra-LATA services. The carrier that handles these services is called a local exchange carrier *(LEC).*

Figure 5.2 Switching offices in a LATA



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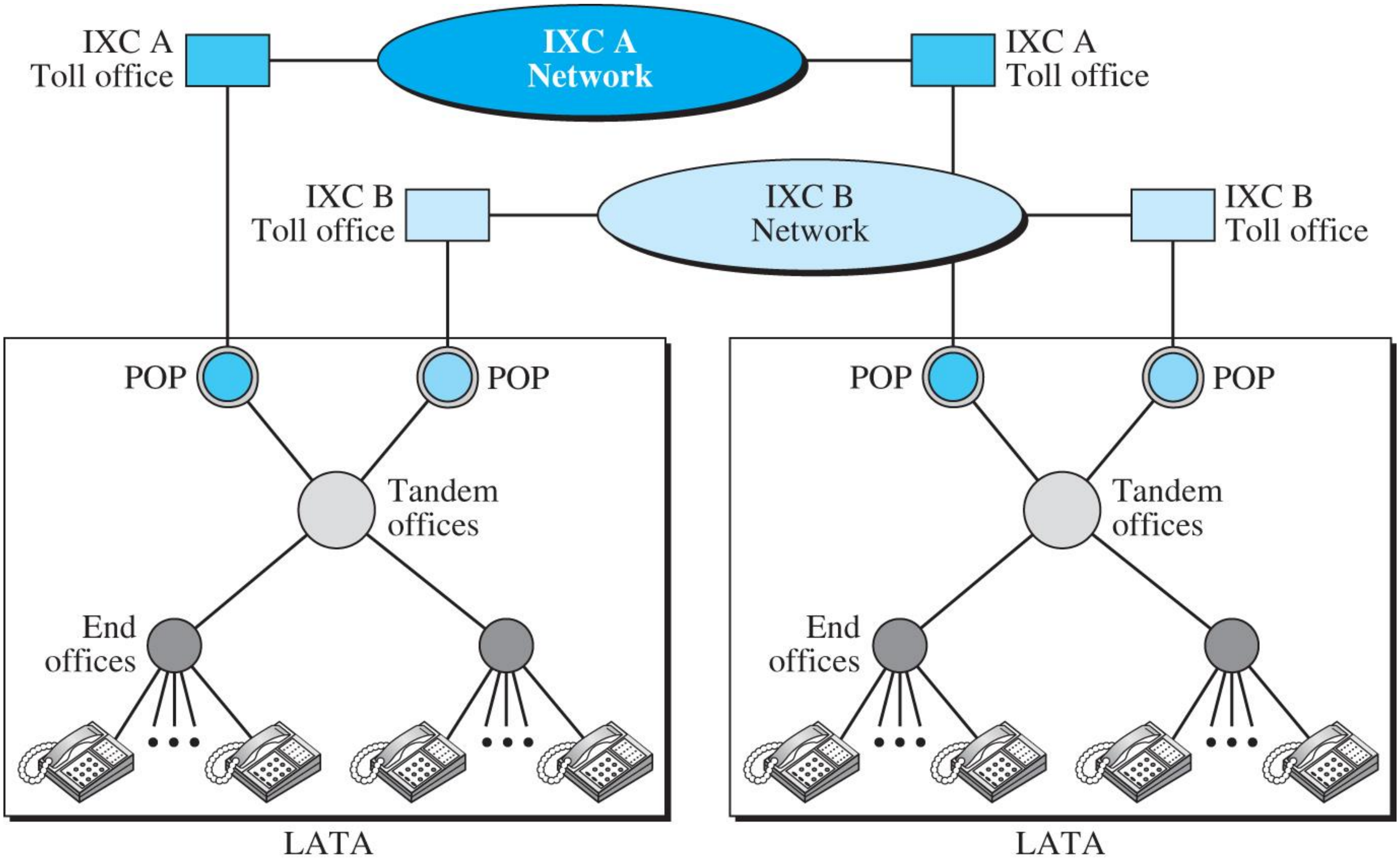
Inter-LATA Service

The services between LATAs are handled by interexchange carriers (IXCs). These carriers, sometimes called long-distance companies, provide communication services between two customers in different LATAs. After the act of 1996, these services can be provided by any carrier, including those involved in intra-LATA services. The field is wide open.

Points of Presence

Intra-LATA services can be provided by several LECs. Inter-LATA services can be provided by several IXCs. How do these carriers interact with one another? The answer is, via a switching office called a point of presence (POP).

Figure 5.3 Point of presence (POP)



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5.1.3 Signaling

The telephone network, at its beginning, used a circuit-switched network with dedicated links. In the beginning, this task was performed by human operators. Later, the signaling system became automatic. Rotary telephones were invented that sent a digital signal defining each digit in a multidigit telephone number. The switches in the telephone companies used the digital signals to create a connection between the caller and the called parties. Both in-band and out-of-band signaling were used.

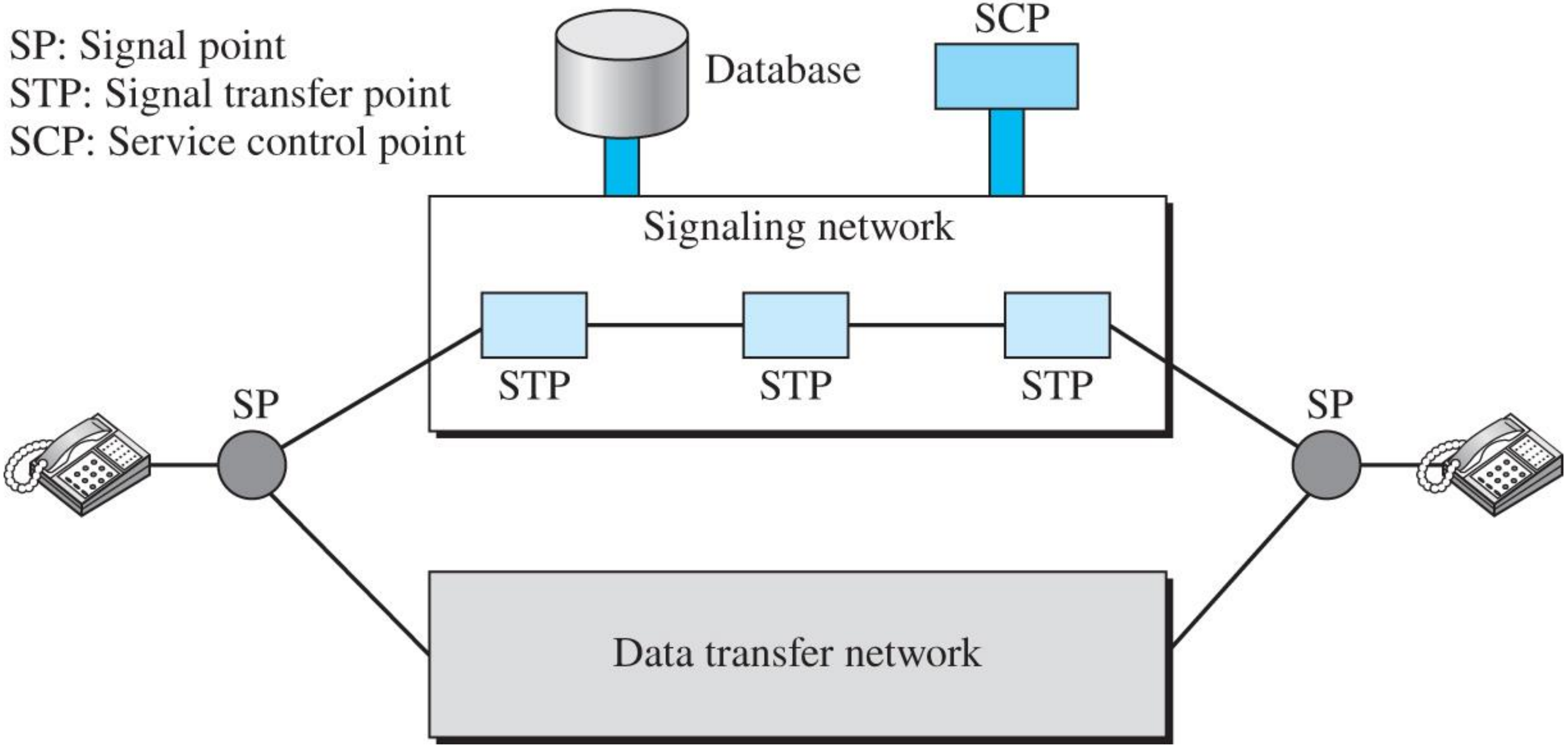
Data Transfer Network

The data transfer network that can carry multimedia information today is, for the most part, a circuit-switched network, although it can also be a packet-switched network. This network follows the same type of protocols and model as other networks discussed in this book.

Signaling Network

The signaling network, which is our main concern in this section, is a packet-switched network involving the layers alike to those in the OSI model or Internet model. The nature of signaling makes it more suited to a packet-switching network with different layers.

Figure 5.4 Data transfer and signaling networks



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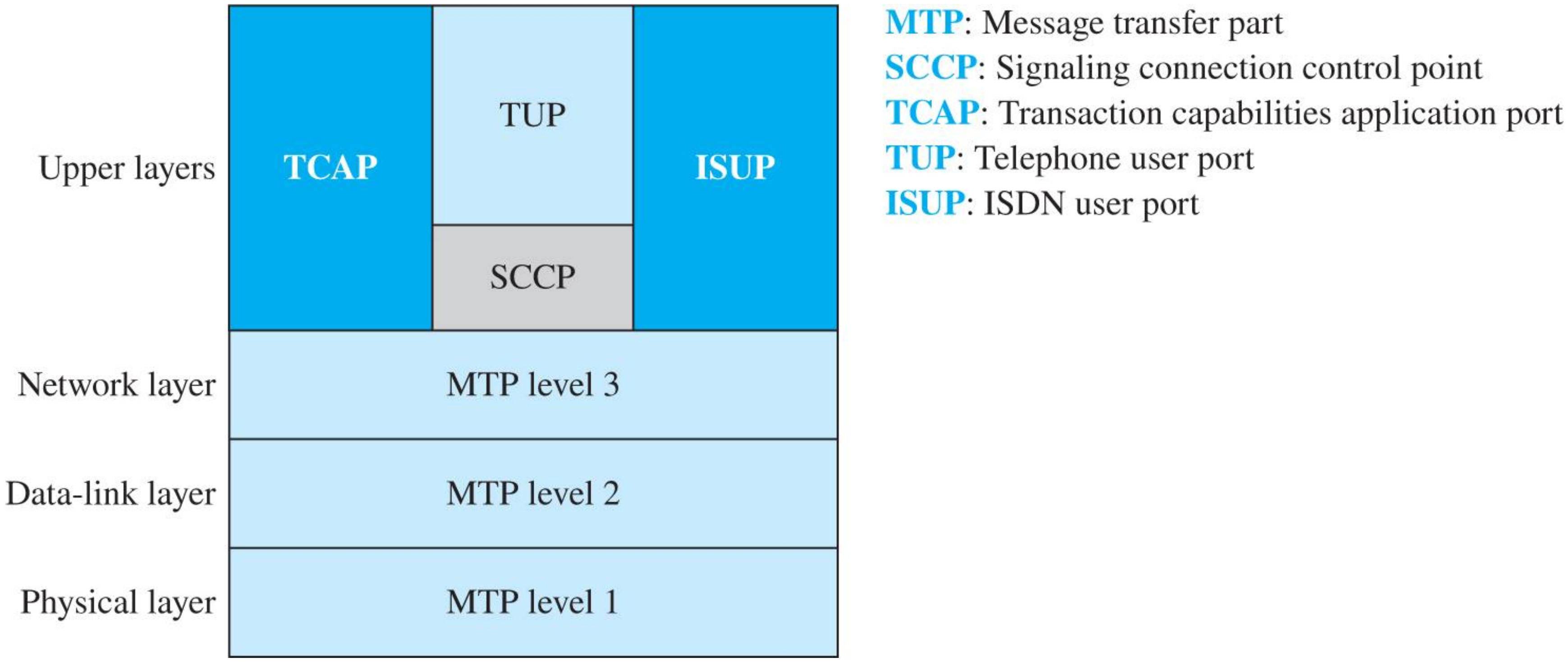
Signaling System Seven (SS7)

The protocol that is used in the signaling network is called Signaling System Seven (SS7). It is very similar to the five-layer Internet model we saw before, but the layers have different names.

Figure 5.5 Layers in SS7



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5.1.4 Services Provide by Telephone

Telephone companies provide two types of services: analog and digital.

Analog Services

In the beginning, telephone companies provided their subscribers with analog services. These services still continue today. We can categorize these services as either analog switched services or analog leased services.

Digital Services

Later telephone companies began offering digital services to their subscribers. Digital services are less sensitive than analog services to noise and other forms of interference. The two most common digital services are switched/56 service and digital data service (DDS).

5.1.5 Dial-Up Service

Traditional telephone lines can carry frequencies between 300 and 3300 Hz, giving them a bandwidth of 3000 Hz. All this range is used for transmitting voice, where a great deal of interference and distortion can be accepted without loss of intelligibility. As we have seen, however, data signals require a higher degree of accuracy to ensure integrity.

Figure 5.6 Telephone line bandwidth

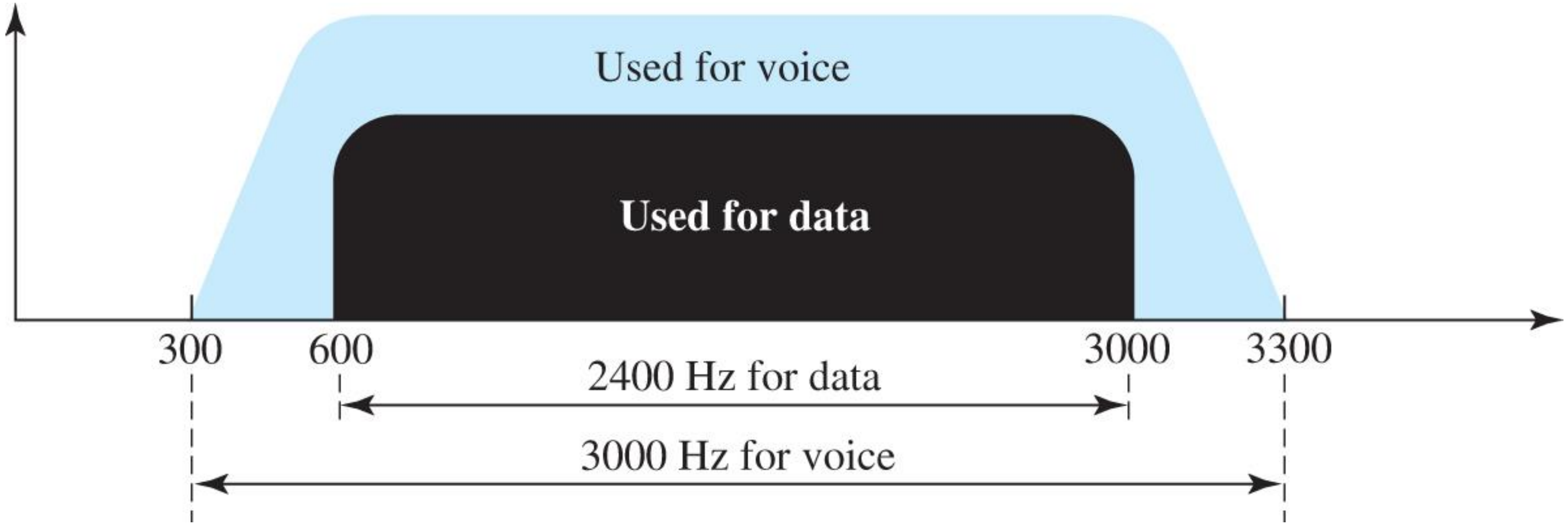

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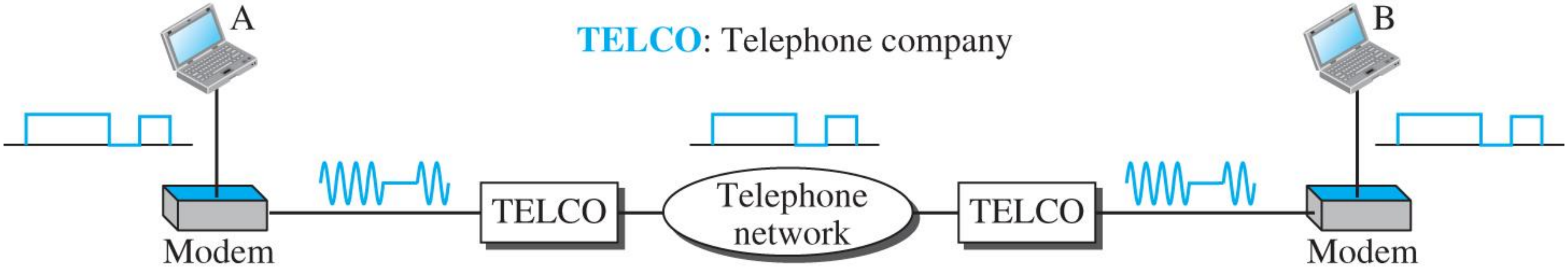
Figure 5.7 Modulation/demodulation



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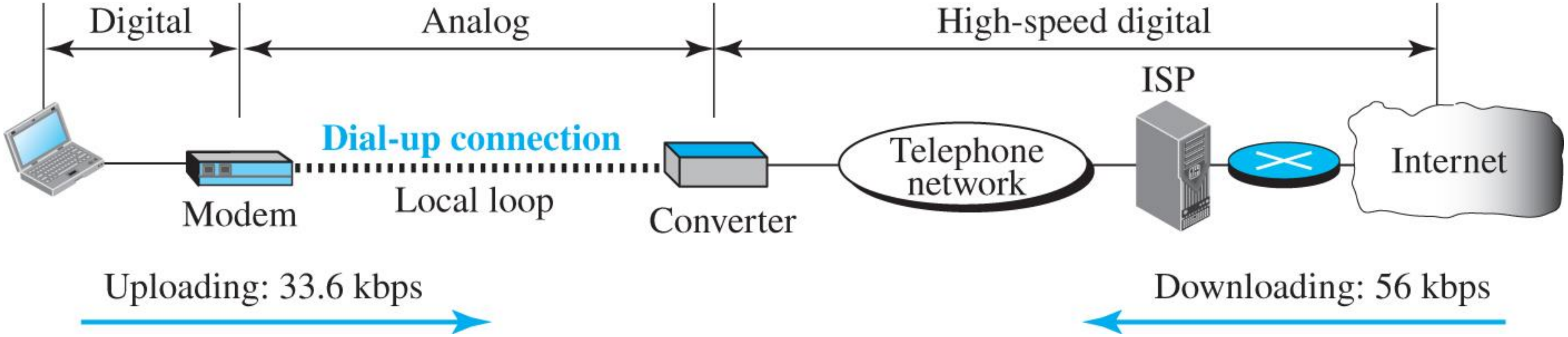
56K Modems

Traditional modems have a data rate limitation of 33.6 kbps, as determined by the Shannon capacity. However, modern modems with a bit rate of 56,000 bps are available; these are called 56K modems. These modems may be used only if one party is using digital signaling.

Figure 5.8 Dial-up network to provide Internet services



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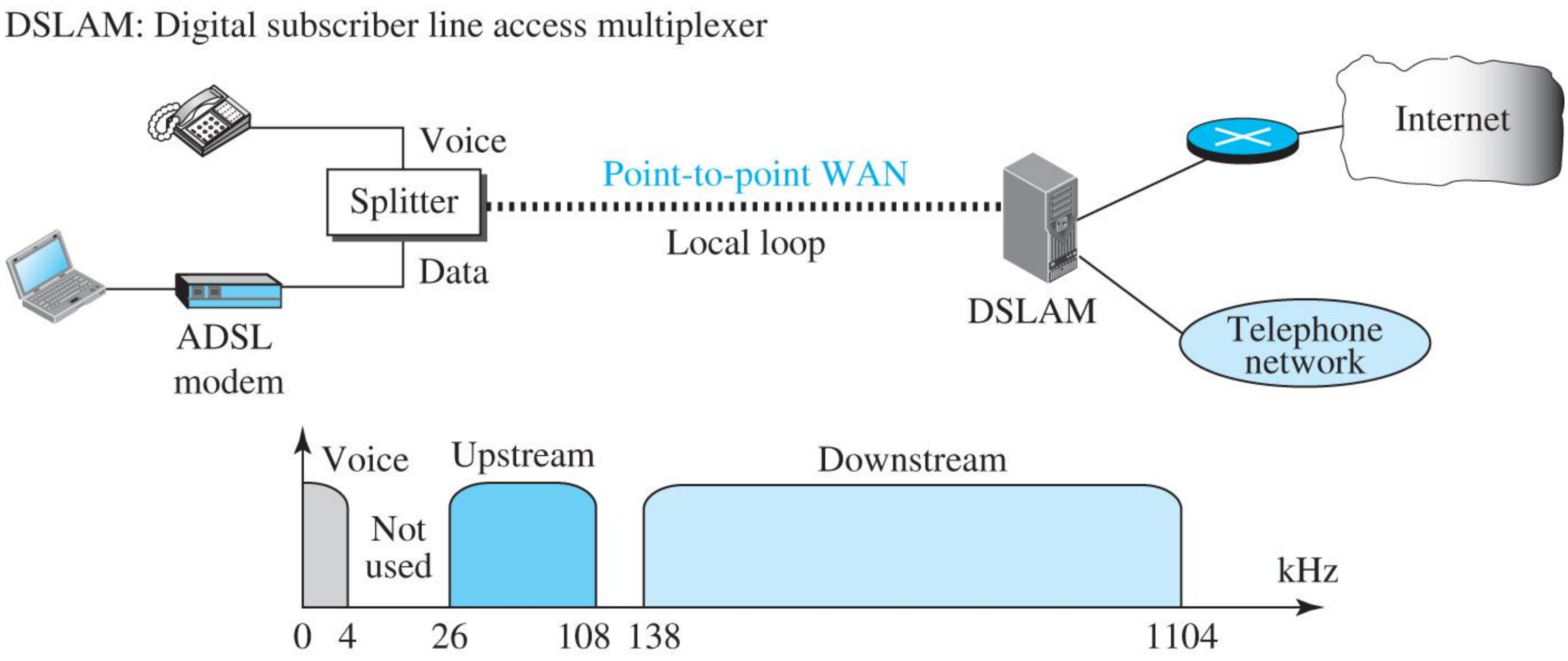
5.1.6 Digital Subscriber Line

After traditional modems reached their peak data rate, telephone companies developed another technology, DSL, to provide higher-speed access to the Internet. Digital subscriber line (DSL) technology is one of the most promising for supporting high-speed digital communication over the existing telephone. DSL technology is a set of technologies, each differing in the first letter (ADSL, VDSL, HDSL, and SDSL

Using Existing Local Loop

One interesting point is that ADSL uses the existing telephone lines (local loop). But how does ADSL reach a data rate that was never achieved with traditional modems?

Figure 5.9 ADSL point-to-point network



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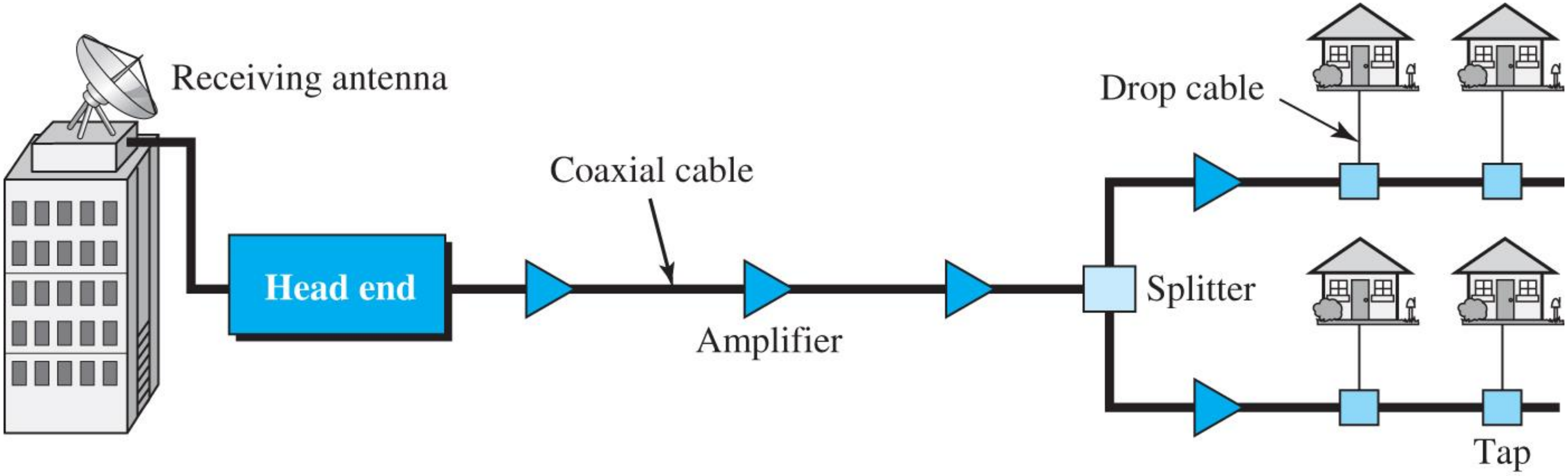
5-2 CABLE NETWORK

Cable networks were originally created to provide access to TV programs for those subscribers who had no reception because of natural obstructions such as mountains. Later the cable networks became popular with people who just wanted a better signal. In addition, cable networks enabled access to remote broadcasting stations via microwave connections.

5.2.1 Traditional Cable Network

Cable TV started to distribute broadcast video signals to locations with poor or no reception in the late 1940s. It was called community antenna TV (CATV) because an antenna at the top of a tall hill or building received the signals from the TV stations and distributed them, via coaxial cables, to the community. Figure 5.10 shows a schematic diagram of a traditional cable TV network.

Figure 5.10 Traditional cable TV network



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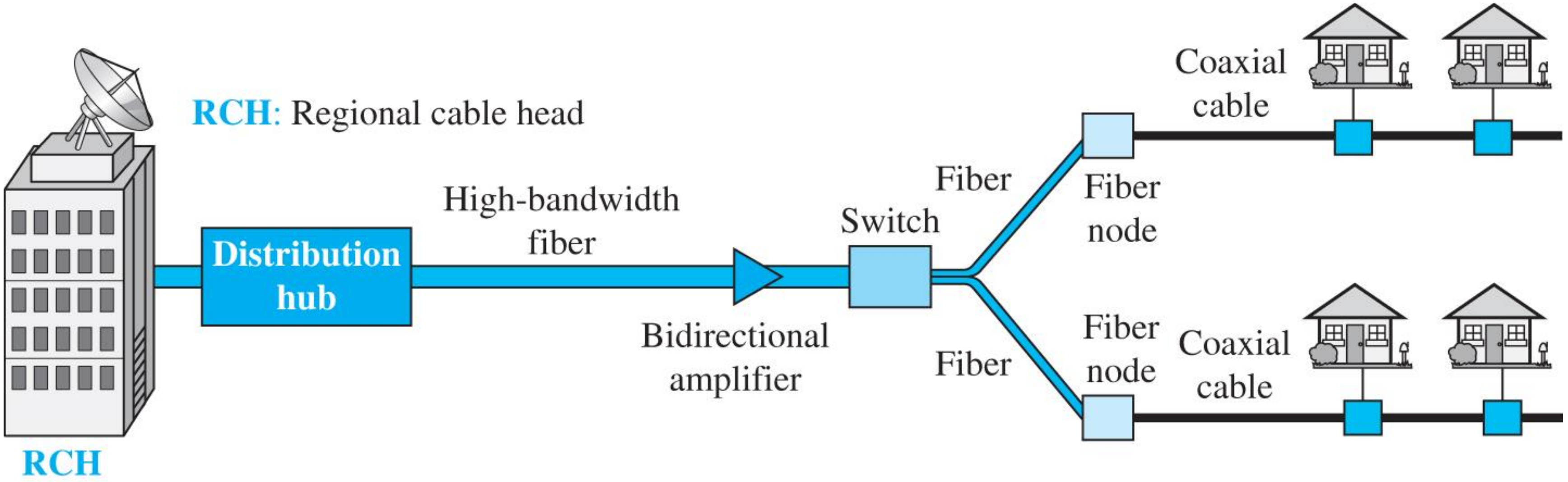
5.2.2 Hybrid Fiber-Coaxial Network

The second generation of cable networks is called a hybrid fiber-coaxial (HFC) network. The network uses a combination of fiber-optic and coaxial cable. The transmission medium from the cable TV office to a box, called the fiber node, is optical fiber; from the fiber node through the neighborhood and into the house is still coaxial cable. Figure 5.11 shows a schematic diagram of an HFC network.

Figure 5.11 Hybrid fiber-coaxial (HFC) network



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5.2.3 Cable TV for Data Transfer

Cable companies are now competing with telephone companies for the residential customer who wants high-speed data transfer. DSL technology provides high-data-rate connections for residential subscribers over the local loop. However, DSL uses the existing unshielded twisted-pair cable, which is very susceptible to interference.

Figure 5.12 Division of coaxial cable band by CATV

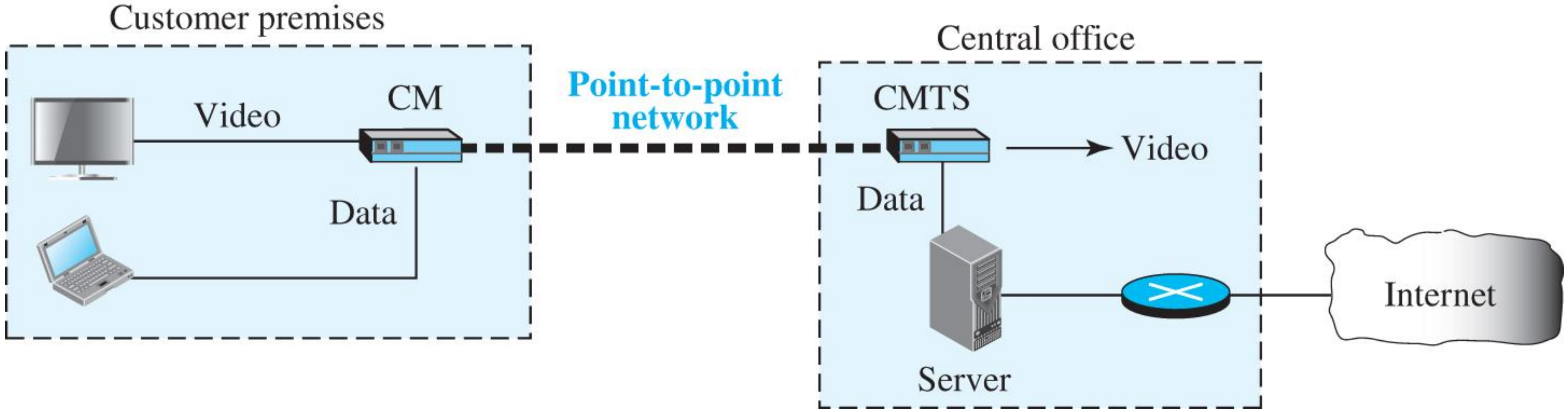
Sharing

Both upstream and downstream bands are shared by the subscribers. The upstream data bandwidth is 37 MHz's. This means that there are only six 6-MHz channels available in the upstream direction. A subscriber needs to use one channel to send data in the upstream direction. The question is, "How can six channels be shared in an area with 1000, 2000, or even 100,000 subscribers?" The solution is time-sharing. The band is divided into channels; these channels must be shared between subscribers in the same neighborhood.

CM and CMTS

To use a cable network for data transmission, we need two key devices: a cable modem (CM) and a cable modem transmission system (CMTS). The cable modem is installed on the subscriber premises. The cable modem transmission system is installed inside the cable company. It receives data from the Internet and sends them to the subscriber. The CMTS also receives data from the subscriber and passes them to the Internet.

Figure 5.13 Cable modem transmission system (CMTS)



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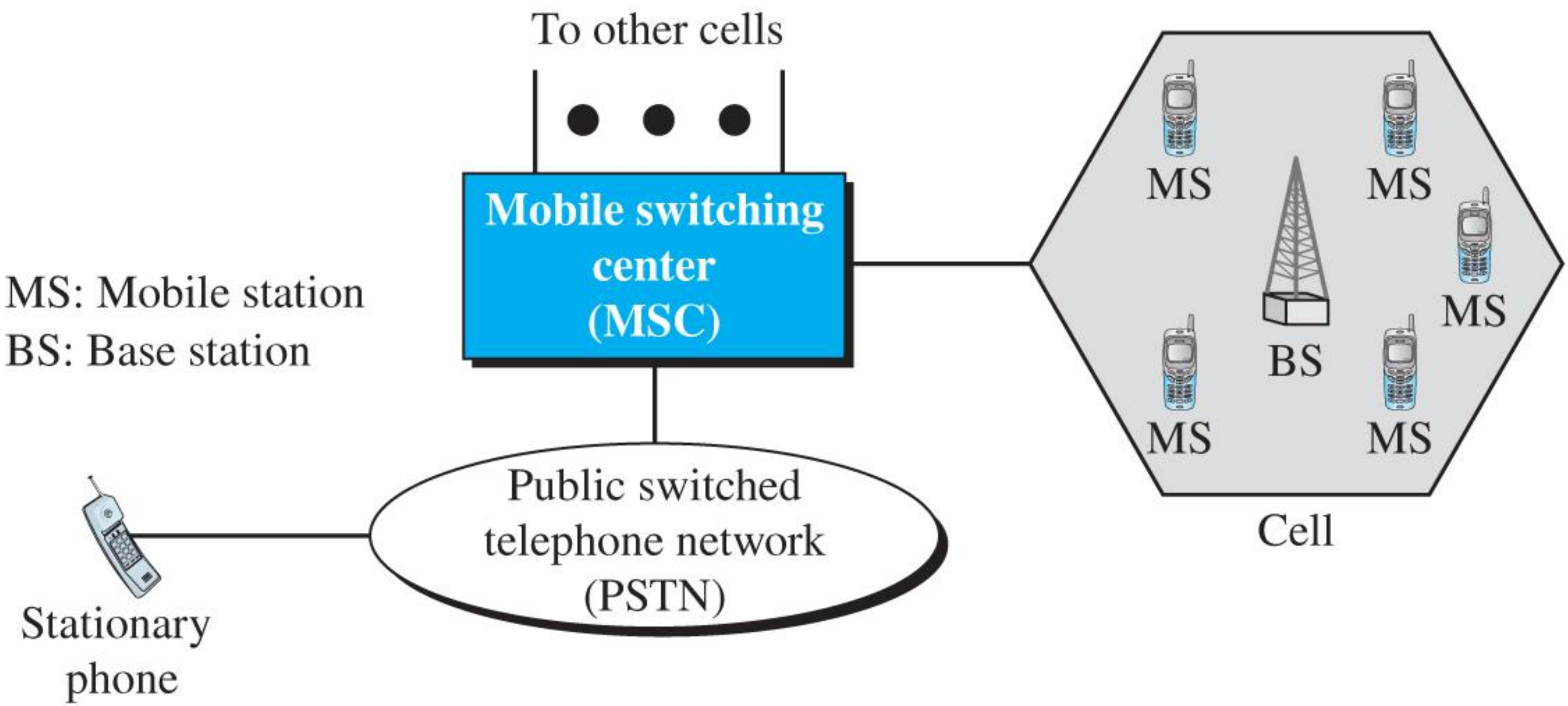
5-3 CELLULAR TELEPHONY

Cellular telephony is designed to provide communications between two moving units, called mobile stations (MSs), or between one mobile unit and one stationary unit, often called a land unit. A service provider must be able to locate and track a caller, assign a channel to the call, and transfer the channel from base station to base station as the caller moves out of range.

Figure 5.14 Cellular system



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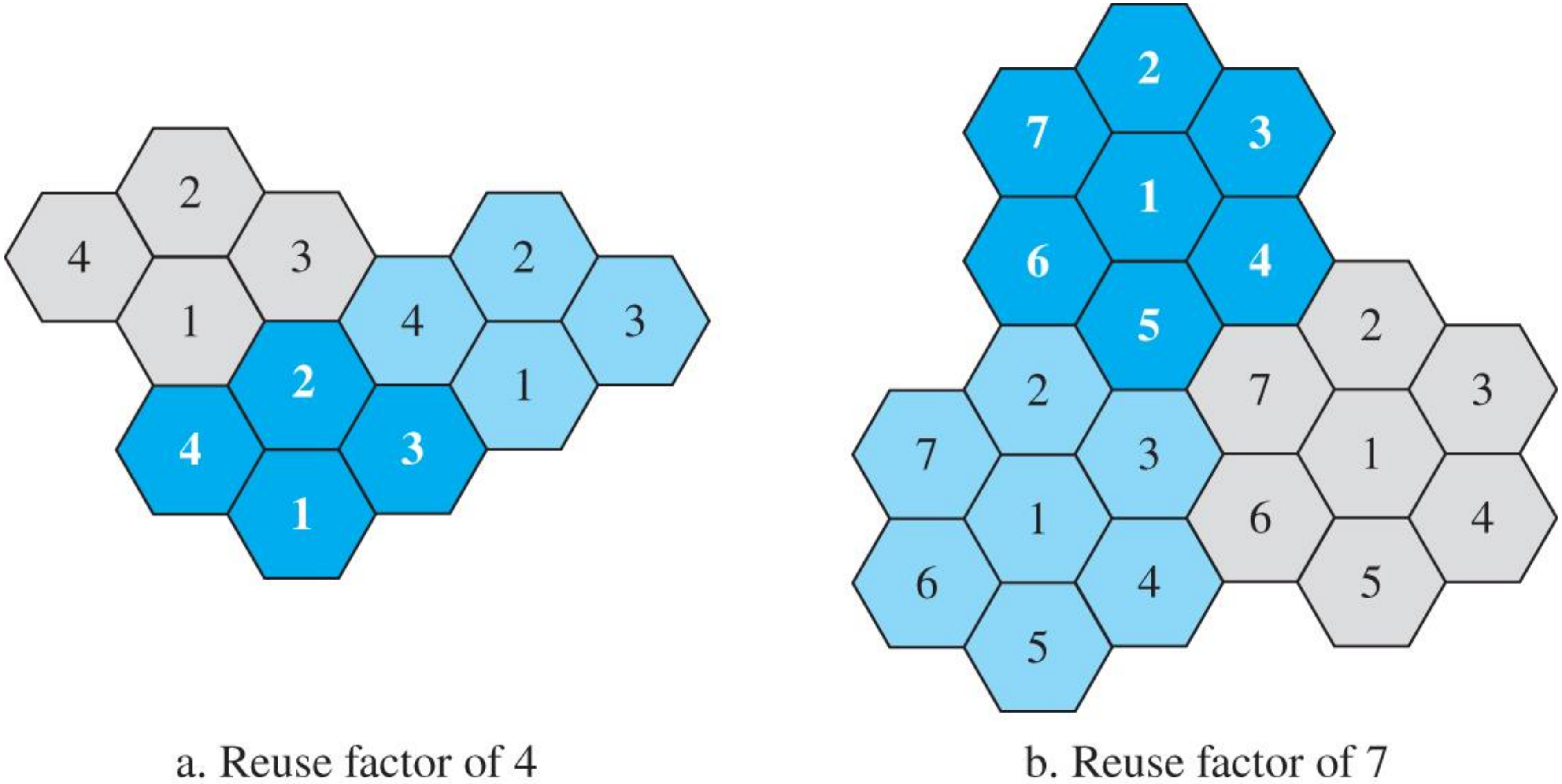
5.3.1 Operation

Let us first briefly discuss the operation of the cellular telephony.

Frequency-Reuse Principle

In general, neighboring cells cannot use the same set of frequencies for communication because it may create interference for the users located near the cell boundaries. However, the set of frequencies available is limited, and frequencies need to be reused. A frequency reuse pattern is a configuration of N cells, N being the reuse factor, in which each cell uses a unique set of frequencies. When the pattern is repeated, the frequencies can be reused. There are several different patterns. Figure 5.15 shows two of them.

Figure 5.15 Frequency reuse pattern



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Transmitting

To place a call from a mobile station, the caller enters a code of 7 or 10 digits (a phone number) and presses the send button. The mobile station then scans the band, seeking a setup channel with a strong signal, and sends the data (phone number) to the closest base station using that channel. The base station relays the data to the MSC. The MSC sends the data on to the telephone central office.

Receiving

When a mobile phone is called, the telephone central office sends the number to the MSC. The MSC searches for the location of the mobile station by sending query signals to each cell in a process called paging. Once the mobile station is found, the MSC transmits a ringing signal and, when the mobile station answers, assigns a voice channel to the call, allowing voice communication to begin.

Handoff

It may happen that, during a conversation, the mobile station moves from one cell to another. When it does, the signal may become weak. To solve this problem, the MSC monitors the level of the signal every few seconds. If the strength of the signal diminishes, the MSC seeks a new cell that can better accommodate the communication. The MSC then changes the channel carrying the call (hands the signal off from the old channel to a new one).

Roaming

One feature of cellular telephony is called roaming. Roaming means, in principle, that a user can have access to communication or can be reached where there is coverage. A service provider usually has limited coverage. Neighboring service providers can provide extended coverage through a roaming contract. The situation is similar to snail mail between countries. The charge for delivery of a letter between two countries can be divided upon agreement by the two countries.

5.3.2 First Generation (1G)

Cellular telephony is now in its fourth generation. The first generation was designed for voice communication using analog signals. We discuss one first-generation mobile system used in North America, AMPS.

AMPS

Advanced Mobile Phone System (AMPS) is one of the leading analog cellular systems in North America. It uses FDMA to separate channels in a link.

Figure 5.16 Cellular bands for AMPs

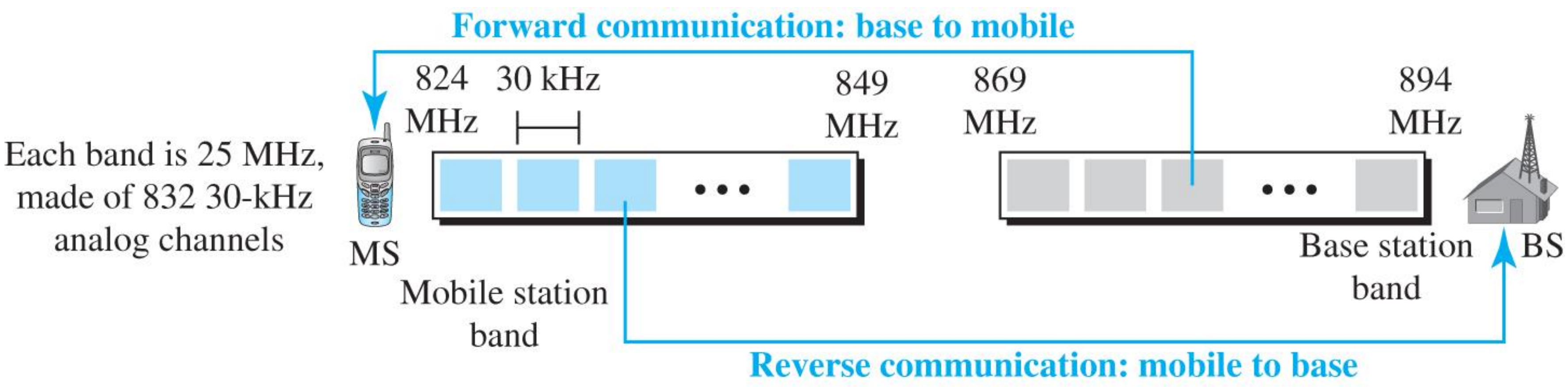

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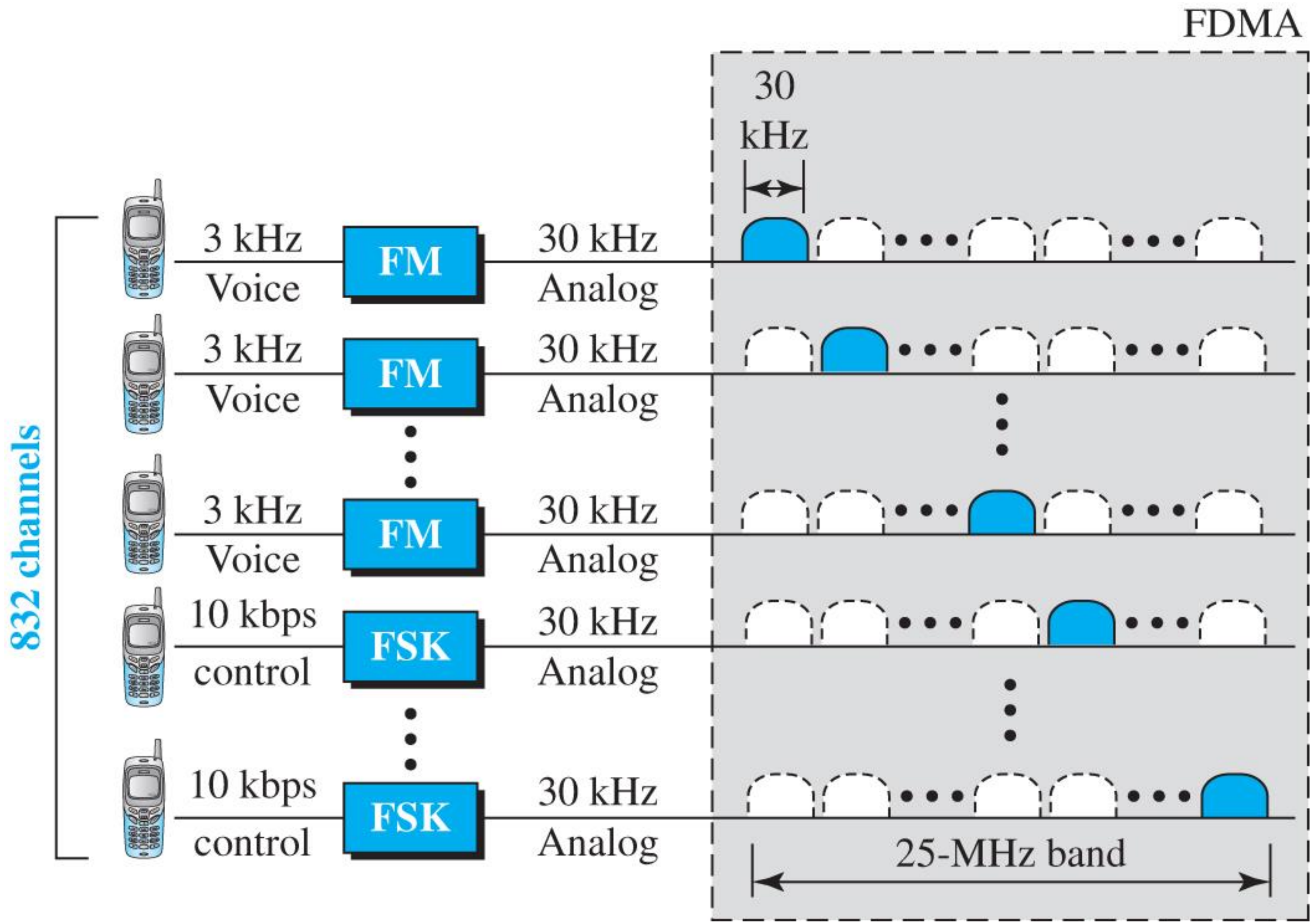
Figure 5.17 AMPS reverse communication band



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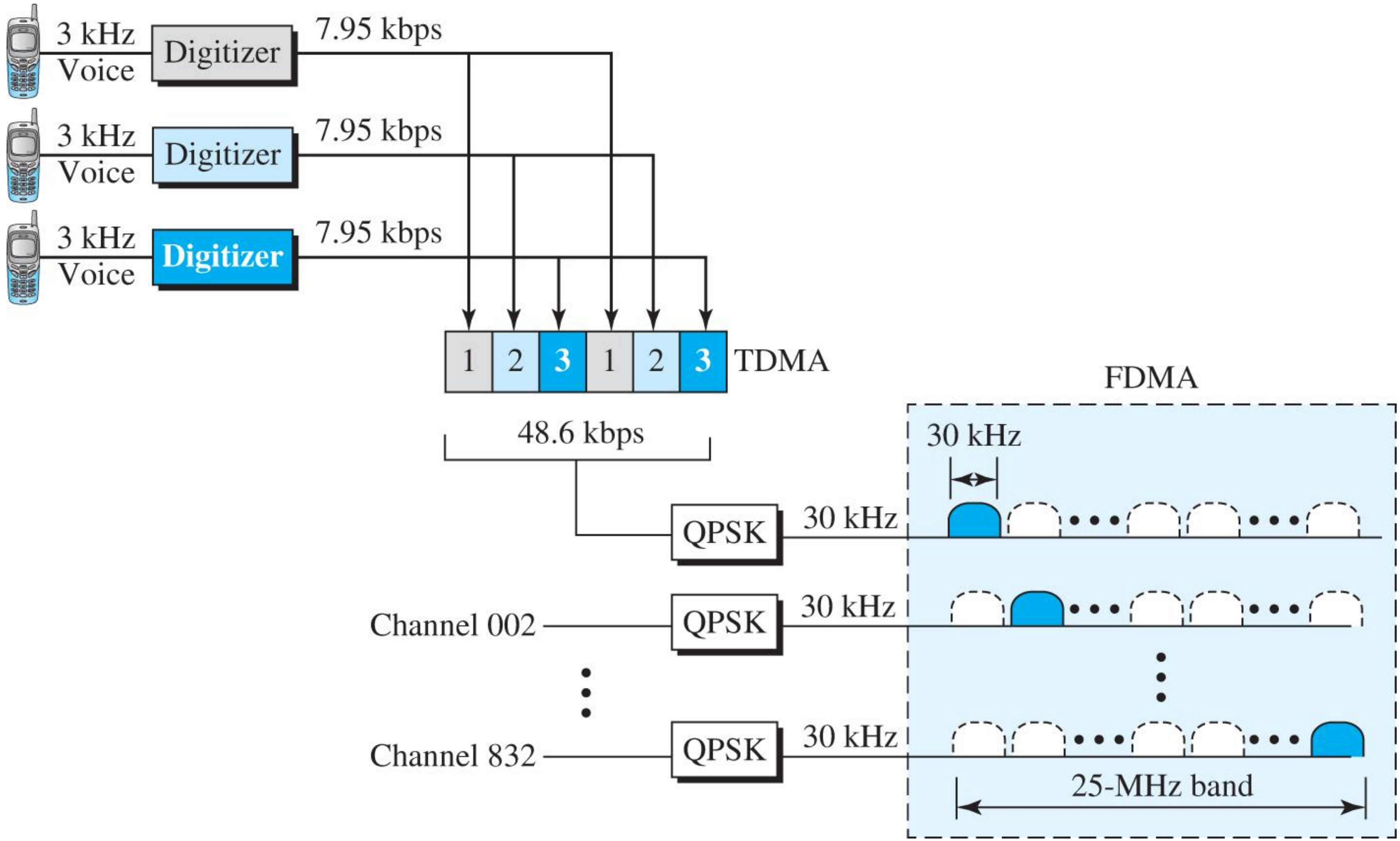
5.3.3 Second Generation (2G)

To provide higher-quality (less noise-prone) mobile voice communications, the second generation of the cellular phone network was developed. While the first generation was designed for analog voice communication, the second generation was mainly designed for digitized voice. Three major systems evolved in the second generation: D-AMPS, GSM, and CDMA.

D-AMPS

The product of the evolution of the analog AMPS into a digital system is digital AMPS (D-AMPS). D-AMPS was designed to be backward-compatible with AMPS. This means that in a cell, one telephone can use AMPS and another D-AMPS. D-AMPS was first defined by IS-54 (Interim Standard 54) and later revised by IS-136.

Figure 5.18 D-AMPS



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GMS

The Global System for Mobile Communication (GSM) is a European standard that was developed to provide a common second-generation technology for all Europe. The aim was to replace a number of incompatible first-generation technologies.

Figure 5.19 GSM bands

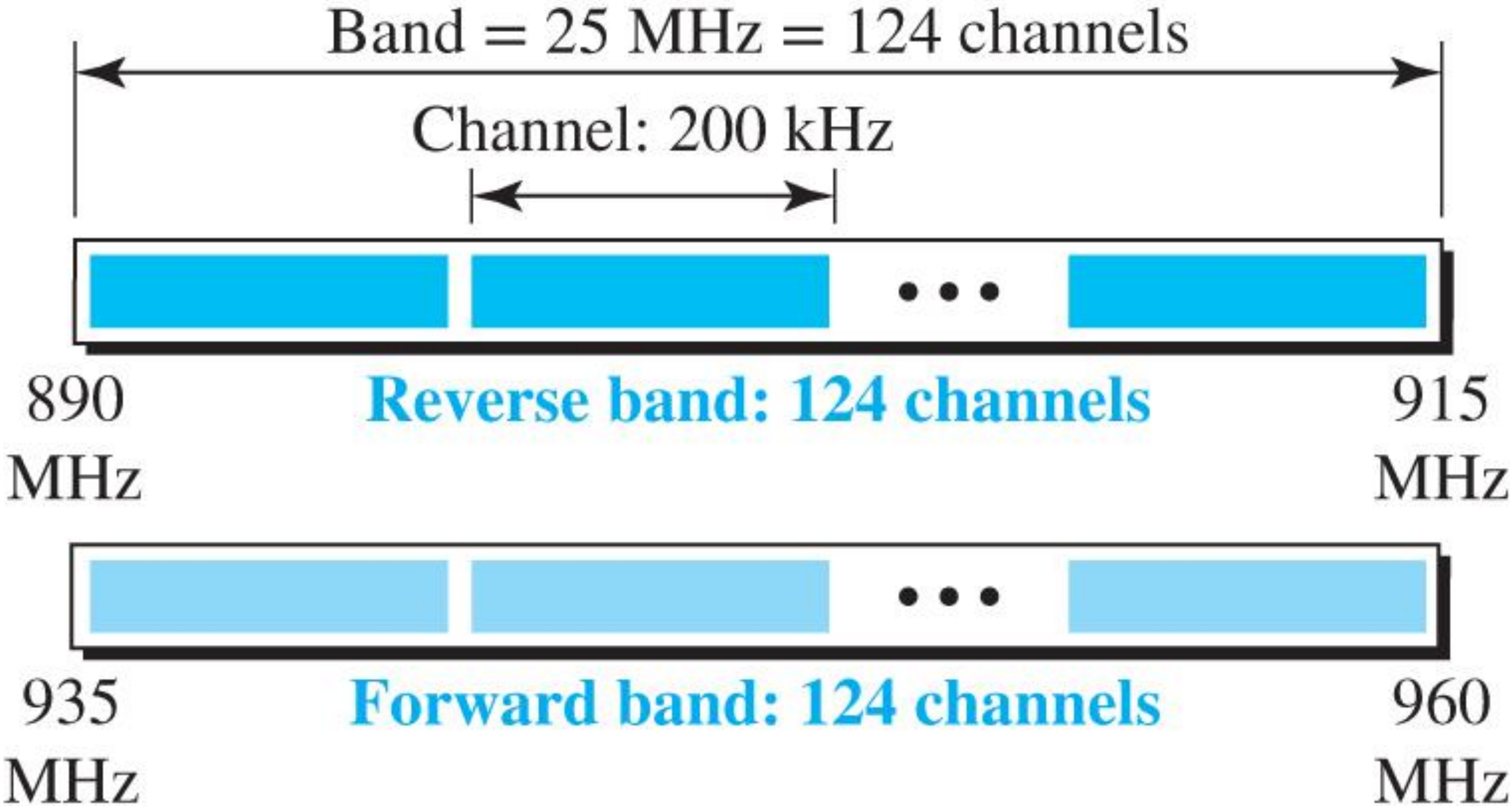

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Figure 5.20 GSM

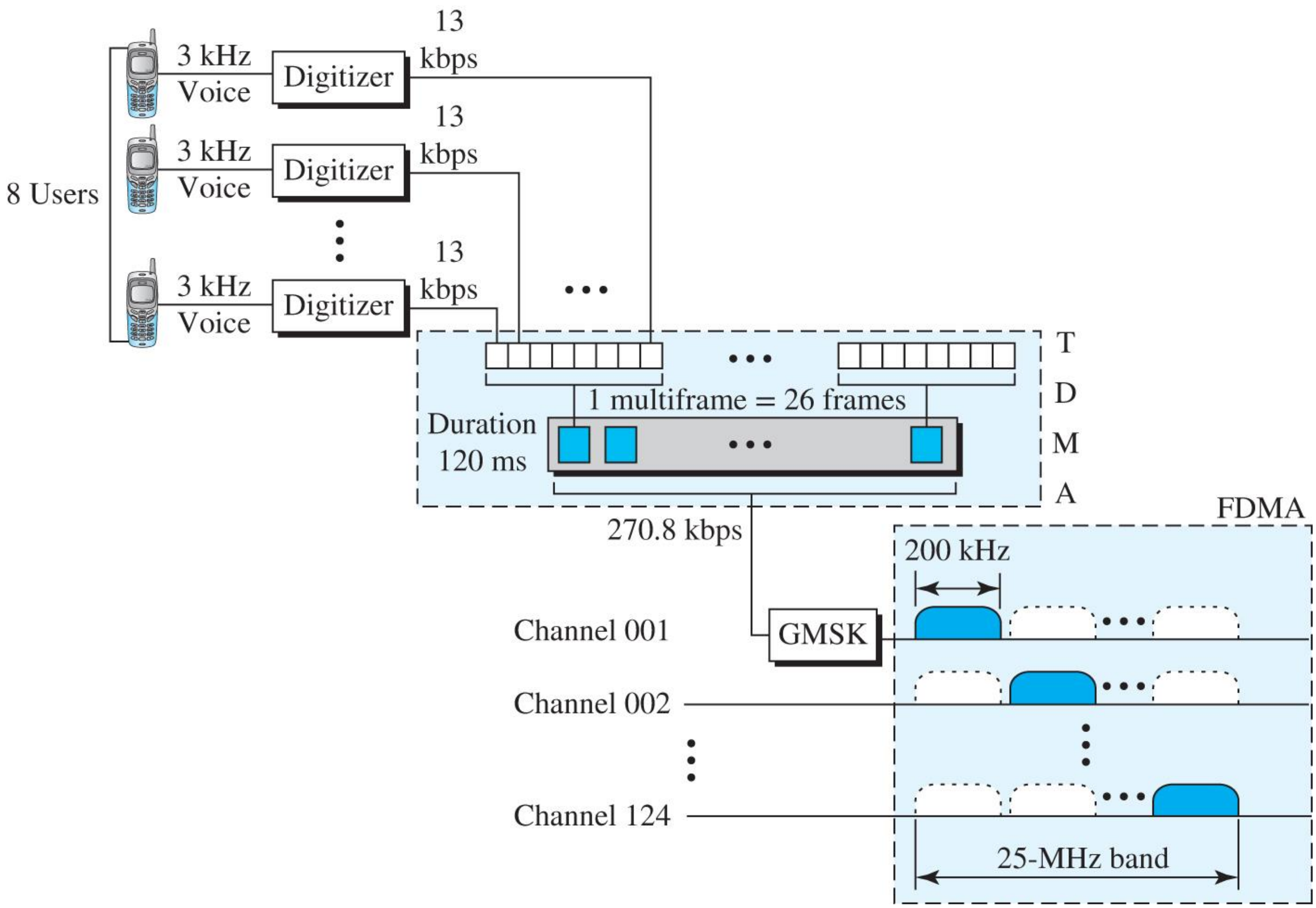

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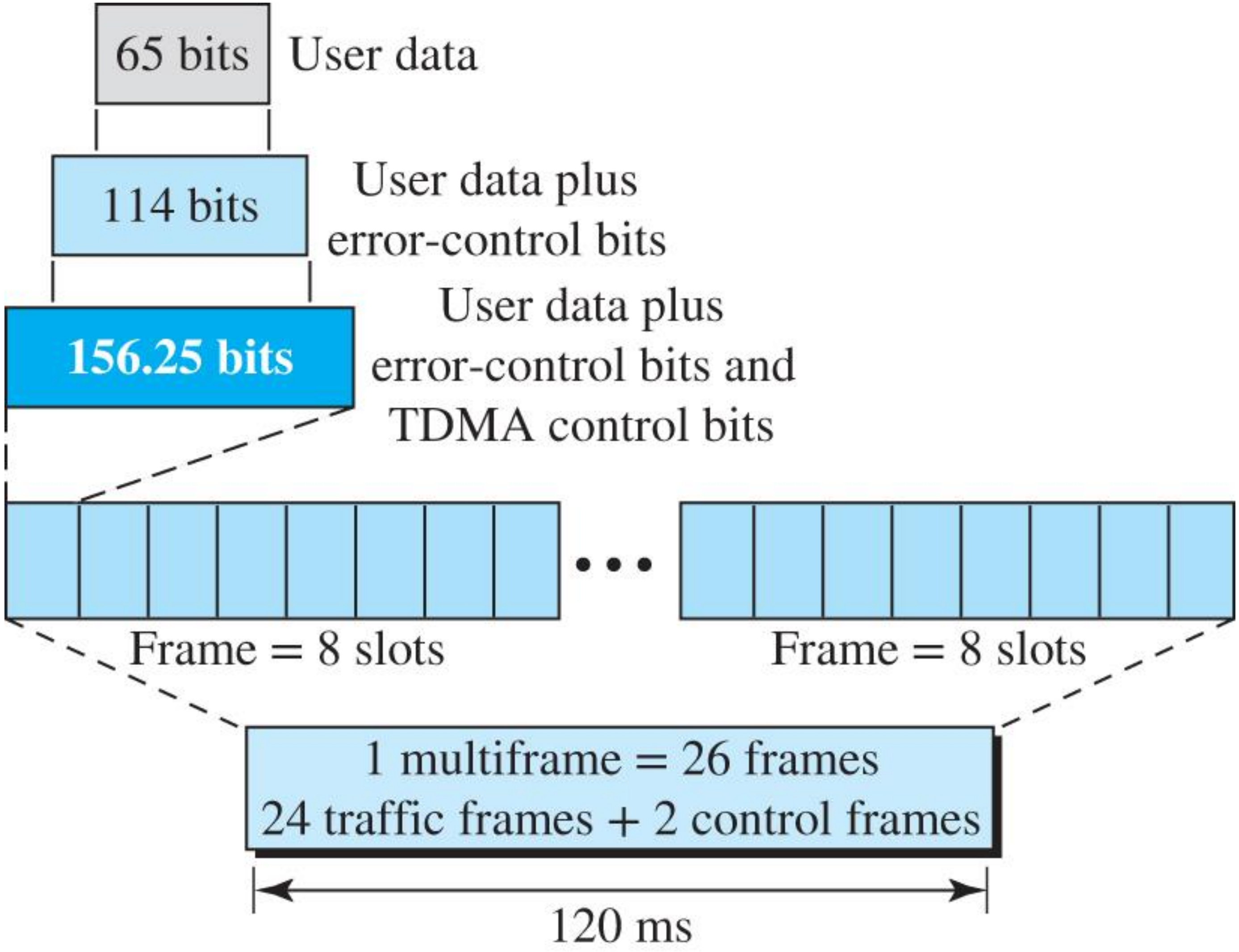
Figure 5.21 Multiframe components



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IS-95

One of the dominant second-generation standards in North America is Interim-Standard 95 (IS-95). It is based on CDMA and DSSS.

Figure 5.22 IS-95 forward transmission

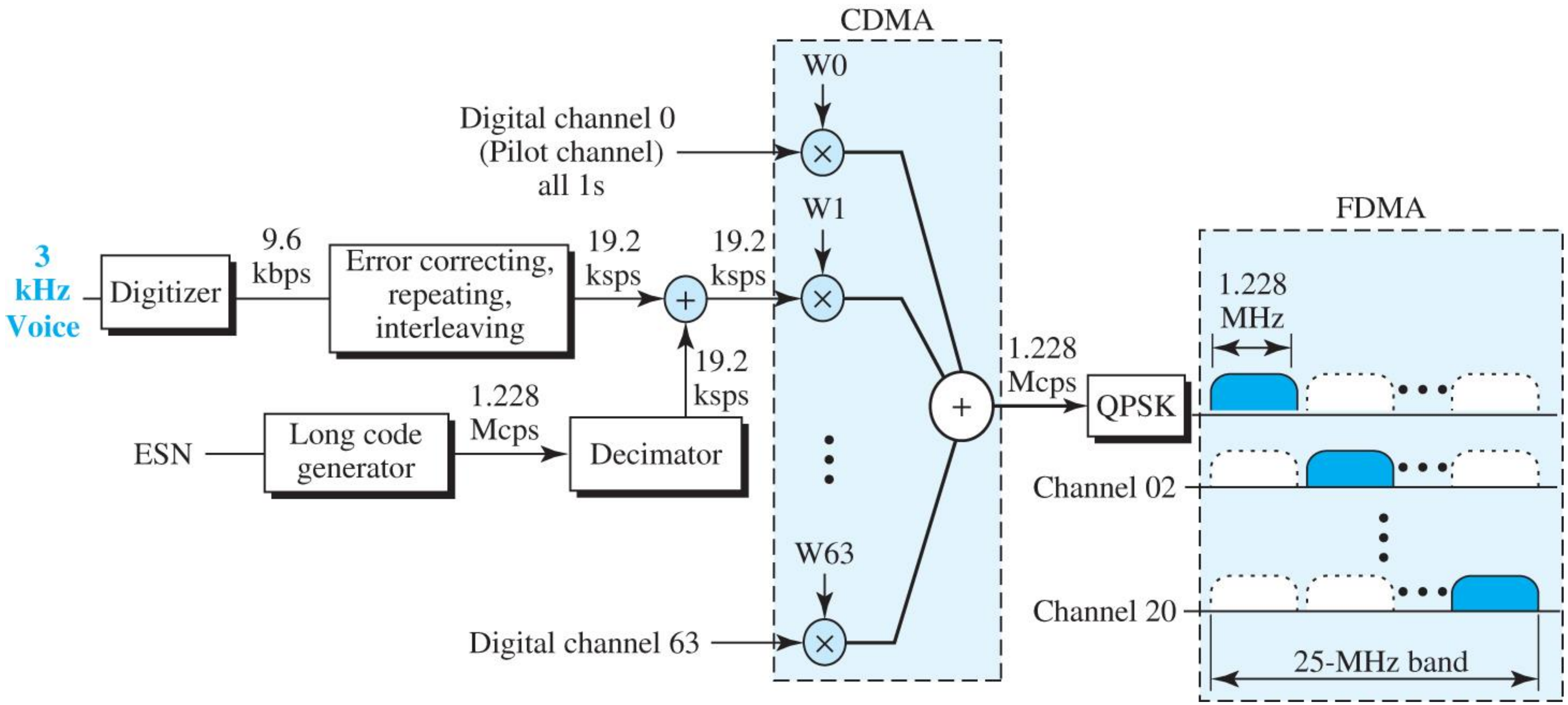

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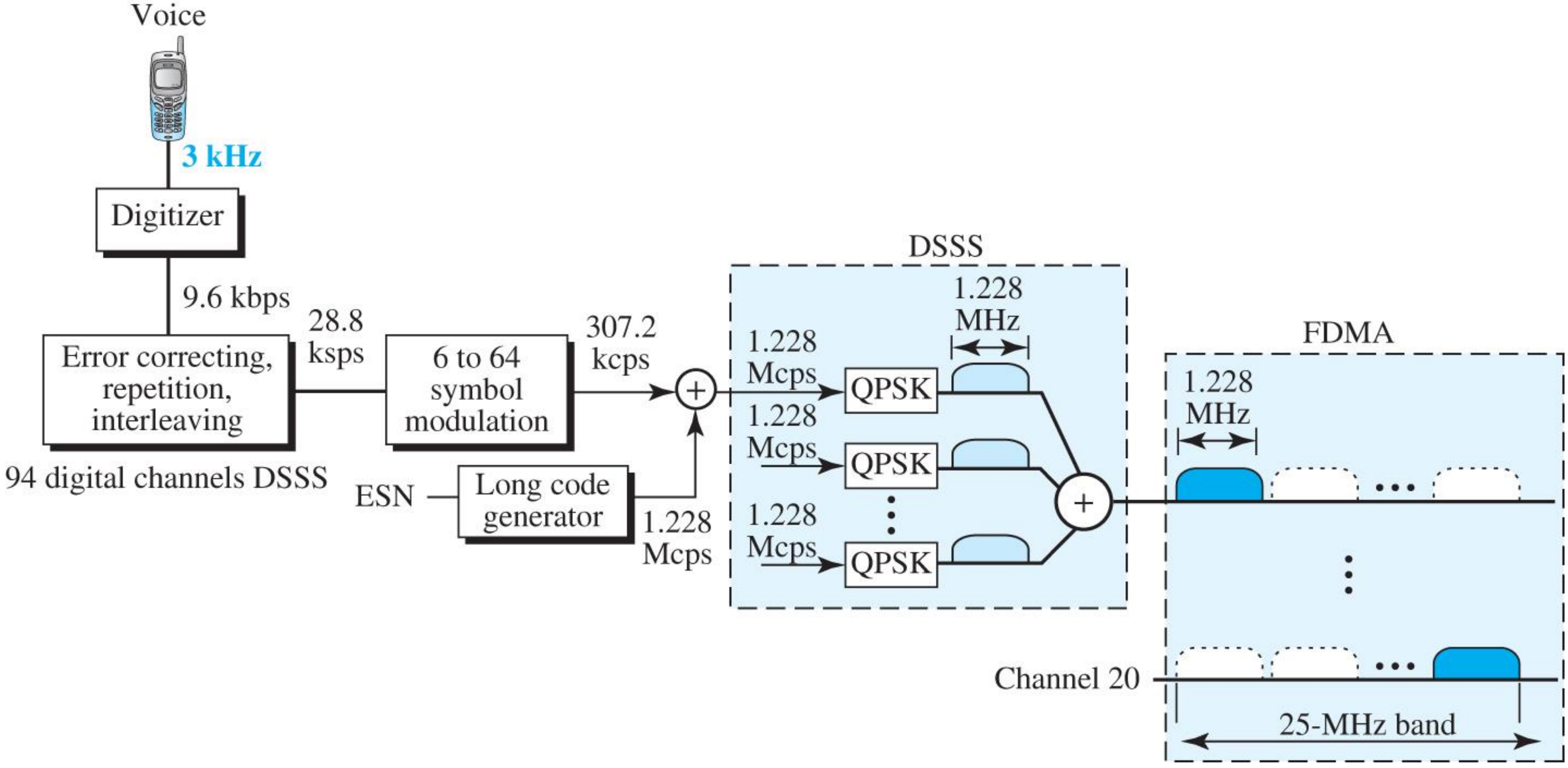
Figure 5.23 IS95 reverse transmission



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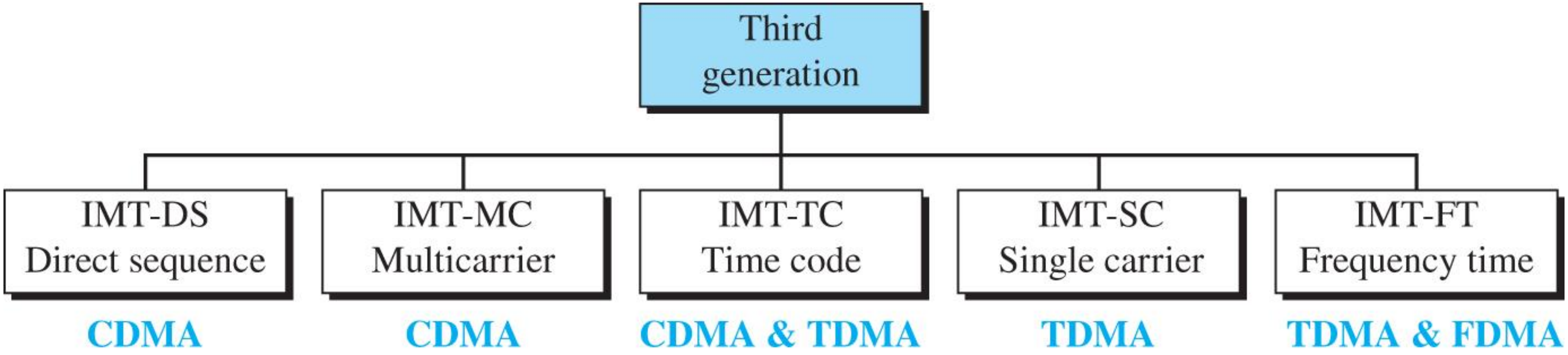
5.3.4 Third Generation

The third generation of cellular telephony refers to a combination of technologies that provide both digital data and voice communication. Using a small portable device, a person is able to talk to anyone else in the world with a voice quality similar to that of the existing fixed telephone network.

Figure 5.24 IMT-2000 radio interface



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5.3.5 Fourth Generation

The fourth generation of cellular telephony is expected to be a complete evolution in wireless communications. Some of the objectives defined by the 4G working group are discussed later.

Access Scheme

To increase efficiency, capacity, and scalability, new access techniques are being considered for 4G. For example, orthogonal FDMA (OFDMA) and interleaved FDMA (IFDMA) are being considered respectively for the downlink and uplink of the next generation Universal Mobile Telecommunications System (UMTS). Similarly, multi-carrier code division multiple access (MC-CDMA) is proposed for the IEEE 802.20 standard.

Modulation

More efficient quadrature amplitude modulation (64-QAM) is being proposed for use with the Long-Term Evolution (LTE) standards.

Radio System

The fourth generation uses a Software Defined Radio (SDR) system. Unlike a common radio that uses hardware, the components of an SDR are pieces of software and thus flexible. The SDR can change its program to shift its frequencies to mitigate frequency interference.

Antenna

The multiple-input multiple-output (MIMO) and multi-user MIMO (MU-MIMO) antenna system, a branch of intelligent antenna, is proposed for 4G. Using this antenna system together with special multiplexing, 4G allows independent streams to be transmitted simultaneously from all the antennas to increase the data rate into multiple folds. MIMO also allows the transmitter and receiver coordinates to move to an open frequency when interference occurs.

Application

A satellite network is a combination of nodes, some of which are satellites, that provides communication from one point on the Earth to another. A node in the network can be a satellite, an Earth station, or an end-user terminal or telephone.

5-4 SATELITE NETWORK

A satellite network is a combination of nodes, some of which are satellites, that provides communication from one point on the Earth to another. A node in the network can be a satellite, an Earth station, or an end-user terminal or telephone.

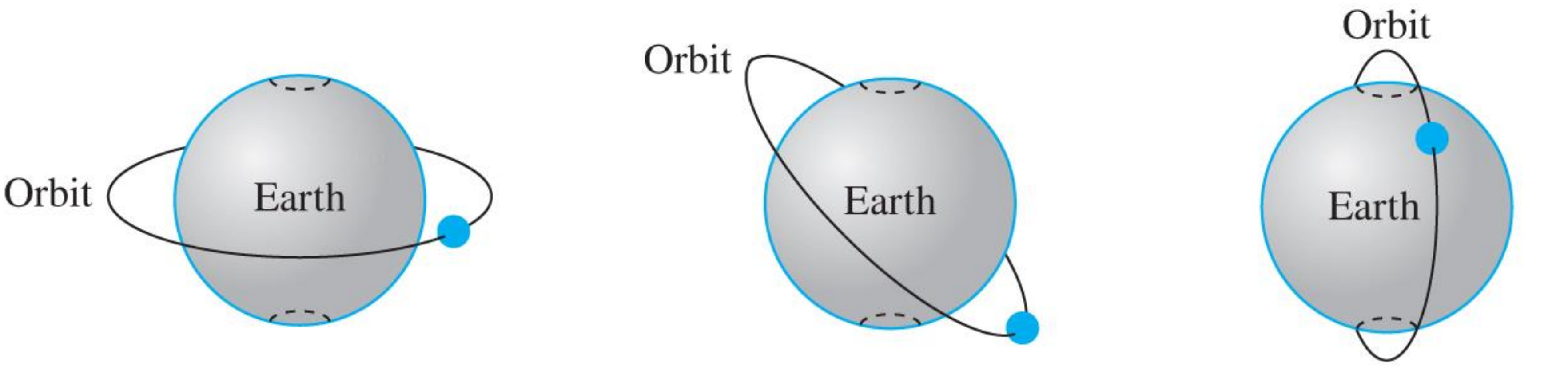
5.4.1 Operation

Let us first discuss some general issue related to the operation of satellites.

Orbits

An artificial satellite needs to have an orbit, the path in which it travels around the Earth. The orbit can be equatorial, inclined, or polar, as shown in Figure 5.25.

Figure 5.25 Satellite orbits



a. Equatorial-orbit satellite b. Inclined-orbit satellite c. Polar-orbit satellite

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Example 5.1

What is the period of the moon, according to Kepler's law?

$$\text{Period} = C * \text{distance}^{1.5}$$

Here C is a constant approximately equal to 1/100. The period is in seconds and the distance in kilometers.

Solution

Applying the formula, we get the following.

$$\text{Period} = (1/100) * (384,000 + 6378)^{1.5} = 2,439,090 \text{ s} = 1 \text{ month}$$

Example 5.2

What is the period of a satellite that is located at an orbit approximately 37865 Km above the Earth?

Solution

Applying the formula, we get the following.

$$\text{Period} = (1/100) * (35,786 + 6378)^{1.5} = 86,579 \text{ s} = 24 \text{ h}$$

This means that a satellite located at 35,786 km has a period of 24 hours.

Footprint

Satellites process microwaves with bidirectional antennas (line-of-sight). Therefore, the signal from a satellite is normally aimed at a specific area called the footprint. The signal power at the center of the footprint is maximum. The power decreases as we move out from the footprint center. The boundary of the footprint is the location where the power level is at a predefined threshold.

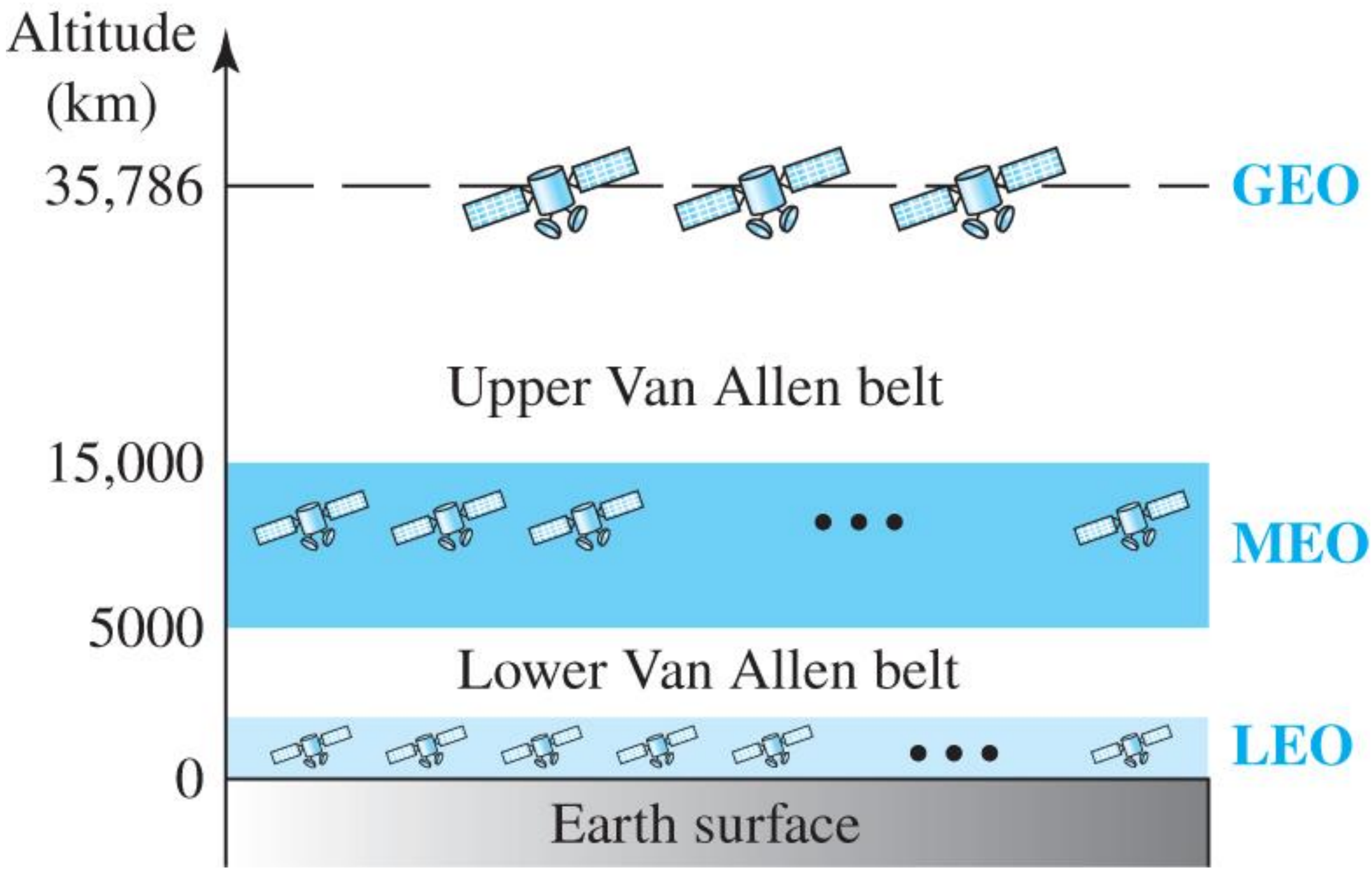
Frequency Band for Satellite Communication

The frequencies reserved for satellite microwave communication are in the gigahertz (GHz) range. Each satellite sends and receives over two different bands. Transmission from the Earth to the satellite is called the uplink. Transmission from the satellite to the Earth is called the downlink.

Three Categories of Satellites

Based on the location of the orbit, satellites can be divided into three categories: geostationary Earth orbit (GEO), low-Earth-orbit (LEO), and medium-Earth-orbit (MEO).

Figure 5.26 Satellite orbit altitudes



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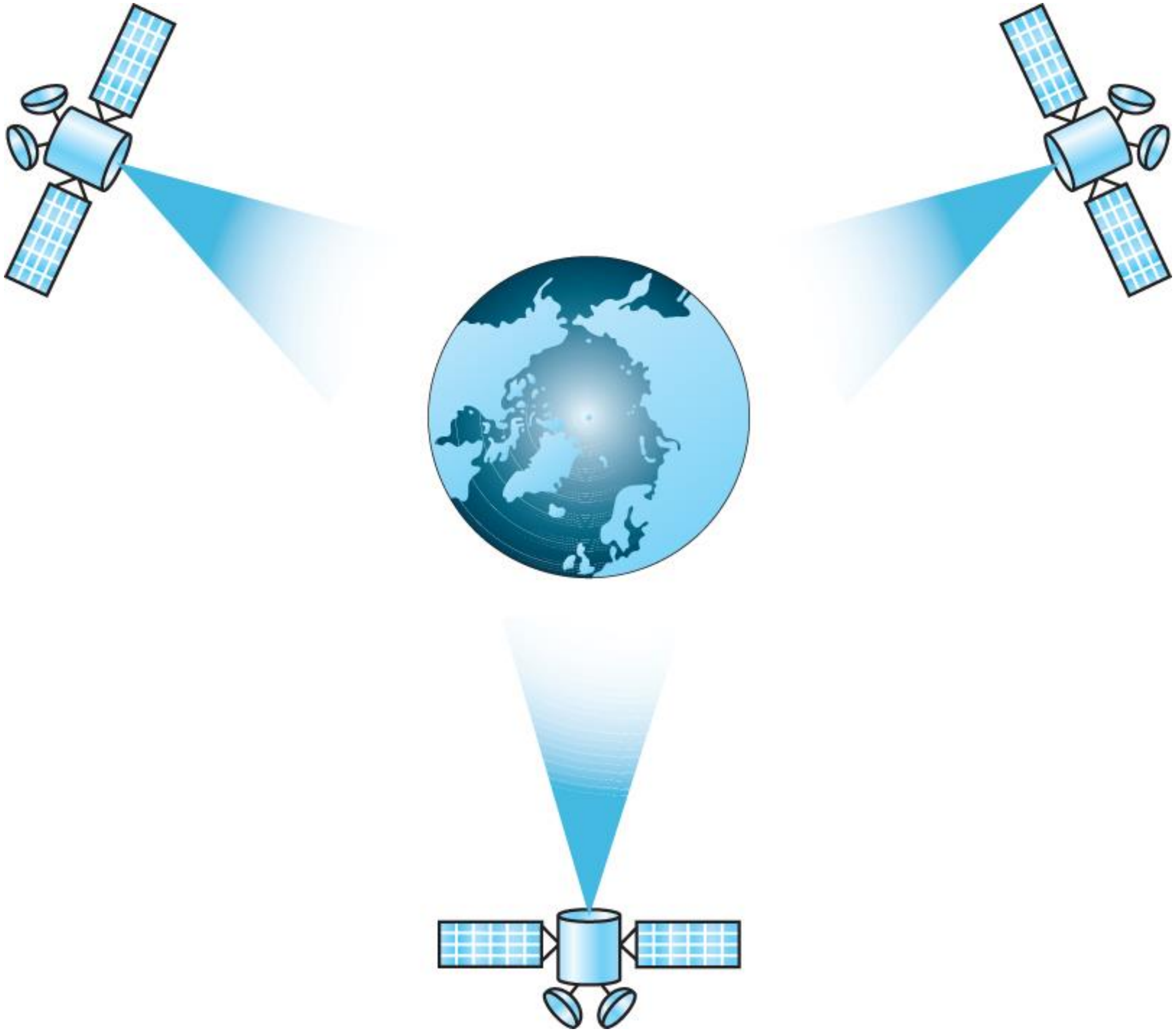
5.4.2 GEO Satellite

Line-of-sight propagation requires that the sending and receiving antennas be locked onto each other's location at all times. For this reason, a satellite that moves faster or slower than the Earth's rotation is useful only for short periods. To ensure constant communication, the satellite must move at the same speed as the Earth so that it seems to remain fixed above a certain spot. Such satellites are called geostationary.

Figure 5.27 Satellites in geostationary orbit



5.4.3 MEO Satellite

Medium-Earth-orbit (MEO) satellites are positioned between the two Van Allen belts. A satellite at this orbit takes approximately 6 to 8 hours to circle the Earth.

Global Positioning System

One example of a MEO satellite system is the Global Positioning System (GPS), contracted and operated by the U.S. Department of Defense, orbiting at an altitude about 18,000 km (11,000 mi) above the Earth.

Figure 5.28 Orbits for global positioning system

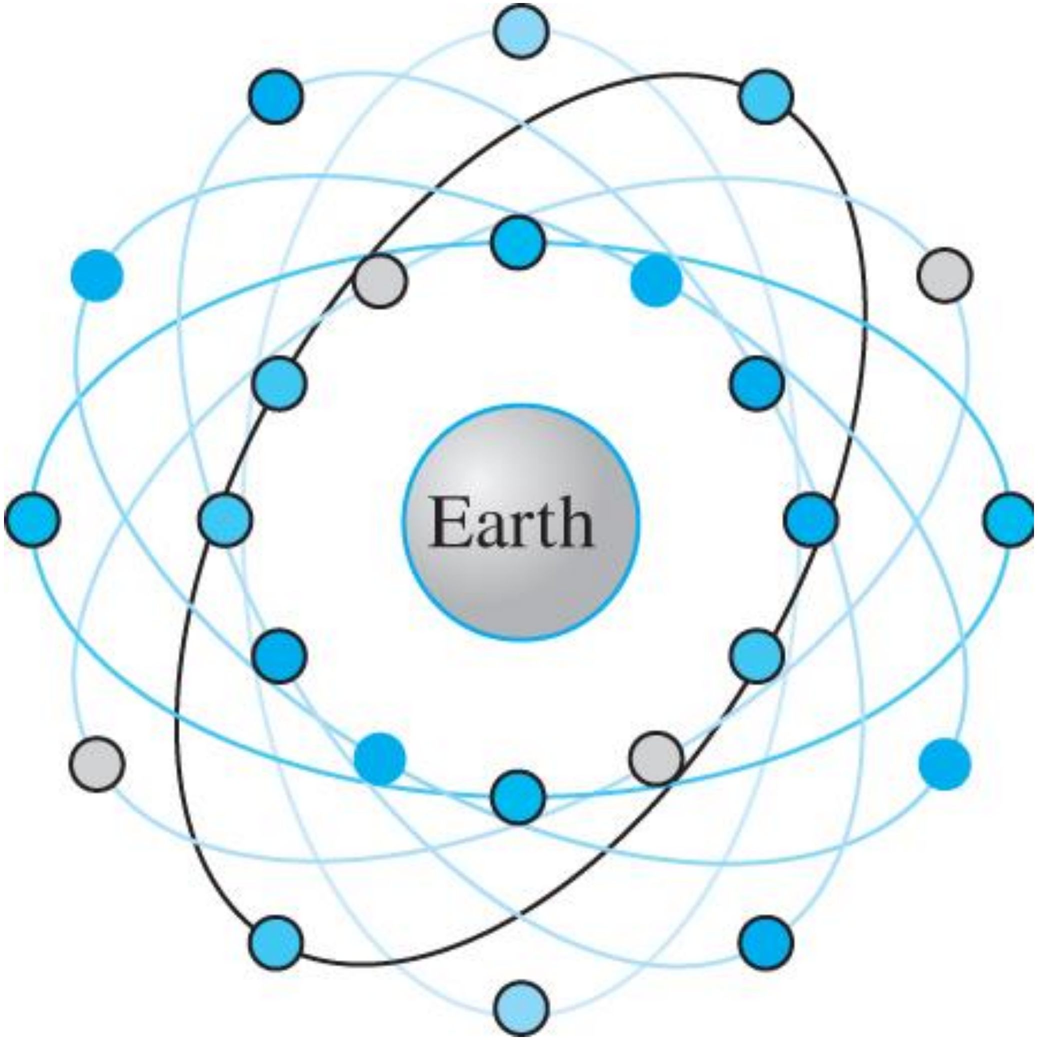
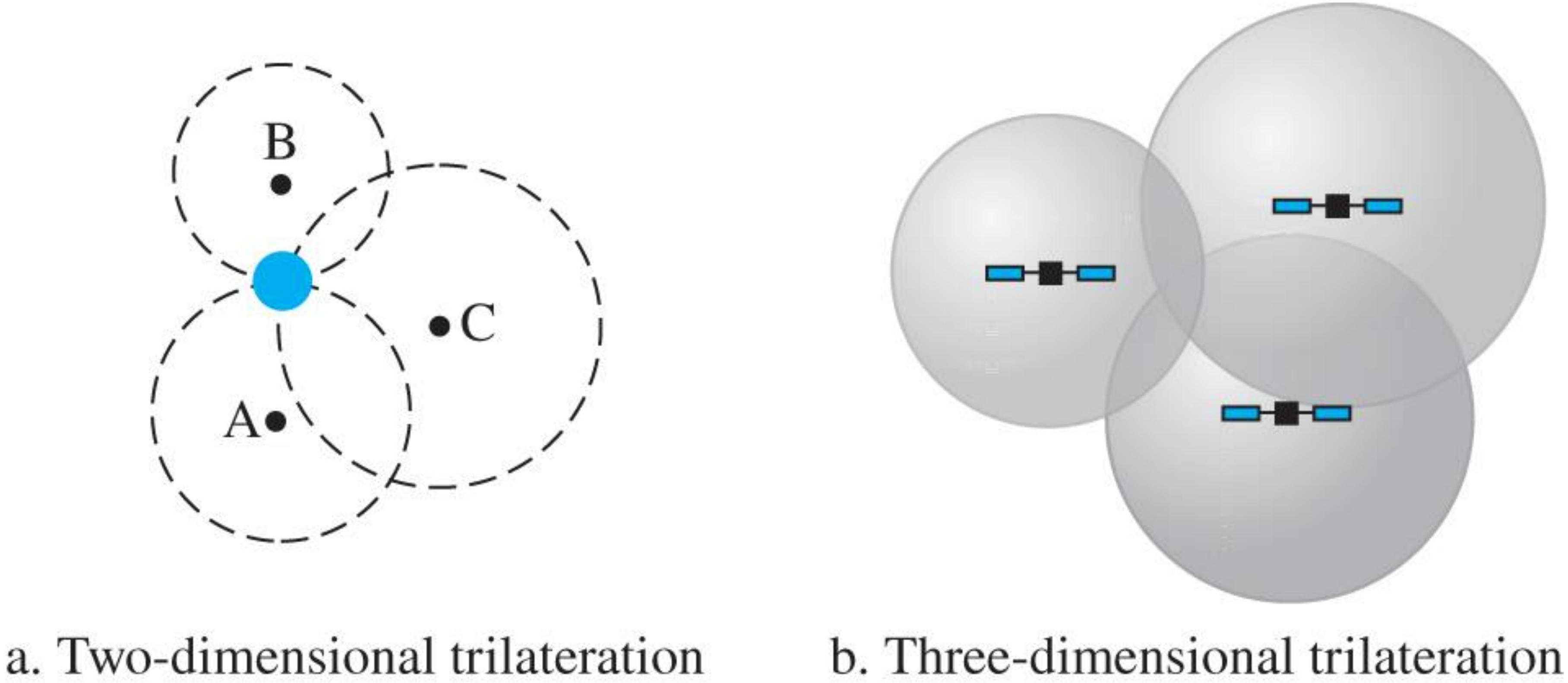


Figure 5.29 Trilateration on a plane



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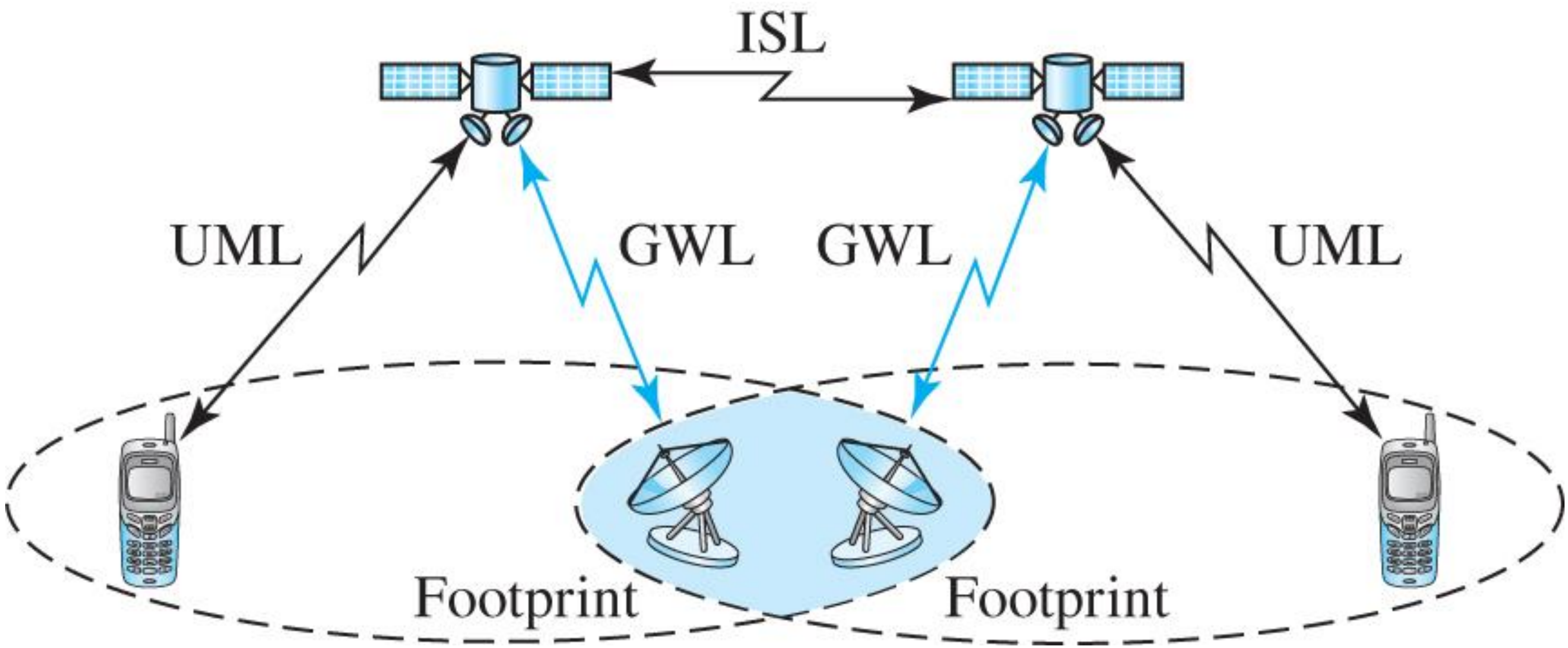
5.4.4 LEO Satellite

Low-Earth-orbit (LEO) satellites have polar orbits. The altitude is between 500 and 2000 km, with a rotation period of 90 to 120 min. The satellite has a speed of 20,000 to 25,000 km/h. A LEO system usually has a cellular type of access, similar to the cellular telephone system. The footprint normally has a diameter of 8000 km.

Figure 5.30 Leo Satellite



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