2

The Telecommunications Network: An Overview

This chapter describes the basic operation of a telecommunications network with the help of a conventional telephone. The operation of a conventional telephone, which is easy to understand, is used to clarify how telephone connections are built up in the network. We look at subscriber signaling over the subscriber loop of the telephone network. The same kind of signaling is needed in modern telecommunications networks, such as ISDN and cellular networks. We start with this simple service to lay a foundation for understanding more complicated types of service in later chapters.

In this chapter we divide the network into layers and briefly describe different network technologies that are needed to provide various kinds of service. Some of these, such as mobile and data networks, are discussed in more detail later in this book. The last topic of this chapter is an introduction to the theory of traffic engineering; that is, how much capacity we should build into the network in order to provide a sufficient grade of service for the customers.

2.1 Basic Telecommunications Network

The basic purpose of a telecommunications network is to transmit user information in any form to another user of the network. These users of public networks, for example, a telephone network, are called subscribers. User information may take many forms, such as voice or data, and subscribers may use different access network technologies to access the network, for example, fixed or cellular telephones. We will see that the telecommunications network consists of many different networks providing different services, such as data, fixed, or cellular telephony service. These different networks are discussed in later chapters. In the following section we introduce the basic functions that are needed in all networks no matter what services they provide.

The three technologies needed for communication through the network are (1) transmission, (2), switching, and (3) signaling. Each of these technologies requires specialists for their engineering, operation, and maintenance.

2.1.1 Transmission

Transmission is the process of transporting information between end points of a system or a network. Transmission systems use four basic media for information transfer from one point to another:

1. Copper cables, such as those used in LANs and telephone subscriber lines;
2. Optical fiber cables, such as high-data-rate transmission in telecommunications networks;
3. Radio waves, such as cellular telephones and satellite transmission;
4. Free-space optics, such as infrared remote controllers.

In a telecommunications network, the transmission systems interconnect exchanges and, taken together, these transmission systems are called the transmission or transport network. Note that the number of speech channels (which is one measure of transmission capacity) needed between exchanges is much smaller than the number of subscribers because only a small fraction of them have calls connected at the same time. We discuss transmission in more detail in Chapter 4.

2.1.2 Switching

In principle, all telephones could still be connected to each other by cables as they were in the very beginning of the history of telephony. However, as the number of telephones grew, operators soon noticed that it was necessary to switch signals from one wire to another. Then only a few cable connections were needed between exchanges because the number of simultaneously ongoing calls is much smaller than the number of telephones (Figure 2.1). The

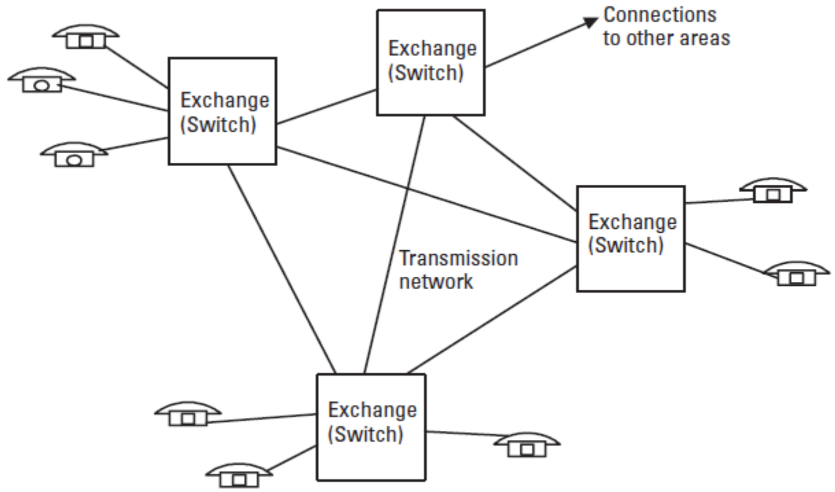

Figure 2.1 A basic telecommunications network.

first switches were not automatic so switching was done manually using a switchboard.

Strowger developed the first automatic switch (exchange) in 1887. At that time, switching had to be controlled by the telephone user with the help of pulses generated by a dial. For many decades exchanges were a complex series of electromechanical selectors, but during the last few decades they have developed into software-controlled digital exchanges. Modern exchanges usually have quite a large capacity—tens of thousands subscribers—and thousands of them may have calls ongoing at the same time.

2.1.3 Signaling

Signaling is the mechanism that allows network entities (customer premises or network switches) to establish, maintain, and terminate sessions in a network. Signaling is carried out with the help of specific signals or messages that indicate to the other end what is requested of it by this connection. Some examples of signaling examples on subscriber lines are as follows:

- *Off-hook condition:* The exchange notices that the subscriber has raised the telephone hook (dc loop is connected) and gives a dial tone to the subscriber.
- *Dial:* The subscriber dials digits and they are received by the exchange.
- *On-hook condition:* The exchange notices that the subscriber has finished the call (subscriber loop is disconnected), clears the connection, and stops billing.

Signaling is naturally needed between exchanges as well because most calls have to be connected via more than just one exchange. Many different signaling systems are used for the interconnection of different exchanges. Signaling is an extremely complex matter in a telecommunications network. Imagine, for example, a foreign GSM subscriber switching his telephone on in Hong Kong. In approximately 10 seconds he is able to receive calls directed to him. Information transferred for this function is carried in hundreds of signaling messages between exchanges in international and national networks. Signaling in a subscriber loop is discussed in Section 2.3 and signaling between exchanges in Section 2.6.

2.2 Operation of a Conventional Telephone

The ordinary home telephone receives the electrical power that it needs for operation from the local exchange via two copper wires. This subscriber line, which carries speech signals as well, is a twisted pair called a local loop. The principle of the power supply coming from the exchange site makes basic telephone service independent of the local electric power network. Local exchanges have a large-capacity battery that keeps the exchange and subscriber sets operational for a few hours if the supply of electricity is cut off. This is essential because the operation of the telephone network is especially important in emergency situations when the electric power supply may be down.

Figure 2.2 shows a simplified illustration of the telephone connection. Elements of the figure and operation of the subscriber loop are explained later in this chapter. Minor operational differences, particularly in the provision of *private branch exchange/automatic branch exchange* (PBX/PABX) systems, exist around the world, but the principles discussed in this chapter apply to the overwhelming majority of PSTN systems.

2.2.1 Microphone

When we raise the hook of a telephone, the on/off hook switch is closed and current starts flowing on the subscriber loop through the microphone that is connected to the subscriber loop. The microphone converts acoustic energy

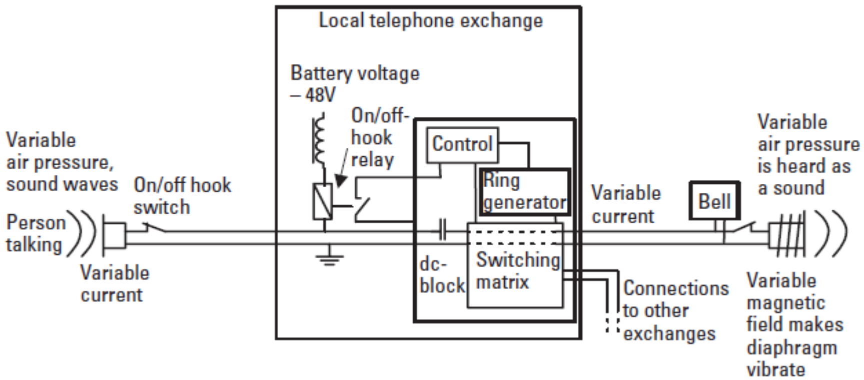

Figure 2.2 Operation principle of a conventional telephone.

to electrical energy. Originally telephone microphones were so-called carbon microphones that had diaphragms with small containers of carbon grains and they operated as variable resistors supplied with battery voltage from an exchange site (see the subscriber loop on the left-hand side of Figure 2.2). When sound waves pressed the carbon grains more tightly, loop resistance decreased and current slightly increased. The variable air pressure generated a variable, alternating current to the subscriber loop. This variable current contained voice information. The basic operating principle of the subscriber loop is still the same today, although modern telephones include more sophisticated and better quality microphones.

2.2.2 Earphone

Alternating current, generated by the microphone, is converted back into voice at the other end of the connection. The earphone has a diaphragm with a piece of magnet inside a coil. The coil is supplied by alternating current produced by the microphone at the remote end of the connection. The current generates a variable magnetic field that moves the diaphragm that produces sound waves close to the original sound at the transmitting end (see the subscriber loop on the right-hand side of Figure 2.2).

2.2.3 Signaling Functions

The microphone generates the electrical current that carries voice information, and the earphone produces the voice at the receiving end of the speech circuit. The telephone network provides a dialed-up or circuit-switched service that enables the subscriber to initiate and terminate calls. The subscriber dials the number to which she wants to be connected. This requires additional information transfer over the subscriber loop and from the exchange to other exchanges on the connection, and this transfer of additional information is called signaling. The basic subscriber signaling phases are described in the following section.

2.3 Signaling to the Exchange from the Telephone

Telephone exchanges supply dc voltage to subscriber loops, and telephone sets use this supplied voltage for operation. The conventional telephone does not include any electronics, and the supplied voltage and current are directly used for speech transmission in addition to signaling functions that include the detection of on/off-hook condition and dialing. Modern electronic telephones would not necessarily need this if they could take their power from a power socket at home. However, getting the power supply from the exchange is still an important feature because it ensures that the telephone network operates even in emergency situations when the power network may be down.

2.3.1 Setup and Release of a Call

Each telephone has a switch that indicates an on- or off-hook condition. When the hook is raised, the switch is closed and an approximately 50 mA of current starts flowing. This is detected by a relay giving information to the control unit in the exchange (Figure 2.2). The control unit is an efficient and reliable computer (or a set of computers) in the telephone exchange. It activates signaling circuits, which then receive dialed digits from subscriber A. (We call a subscriber who initiates a call subscriber A and a subscriber who receives a call subscriber B.) The control unit in the telephone exchange controls the switching matrix that connects the speech circuit through to the called subscriber B. Connection is made according to the numbers dialed by subscriber A.

When the call is being routed to subscriber B, the telephone exchange supplies to the subscriber loop a ringing voltage and the bell of subscriber B's telephone starts ringing. The ringing voltage is often about 70V ac with a 25-Hz frequency, which is high enough to activate the bell on any telephone. The ringing voltage is switched off immediately when an off-hook condition is detected on the loop of subscriber B, and then an end-to-end speech circuit is connected and the conversation may start.

Figure 2.3 shows the signaling phases on a subscriber loop. When the exchange detects the off-hook condition of a subscriber loop, it informs us with a dial tone that we hear when we raise the hook that it is ready to receive digits. After dialing it keeps us informed about whether the circuit establishment is successful by sending us a ringing tone when the telephone at the other end rings. When subscriber B answers, the exchange switches off both the ringing signal and the ringing tone and connects the circuit. At the end of the conversation, an on-hook condition is detected by the exchange and the speech circuit is released.

In next sections we explain in more detail one of the subscriber signaling phases, the transmission of dialed digits from a subscriber's telephone to the local exchange.

2.3.2 Rotary Dialing

The telephone set has a switch that is open in the on-hook condition and closed when the hook is off. This indicates to the telephone exchange when a call is to be initiated and when it has to prepare to receive dialed digits. In old telephones, which exchanges still have to support, this method of local-loop connection/disconnection is used to transmit dialed digits as well (Figure 2.4). We call this principle rotary or pulse dialing.

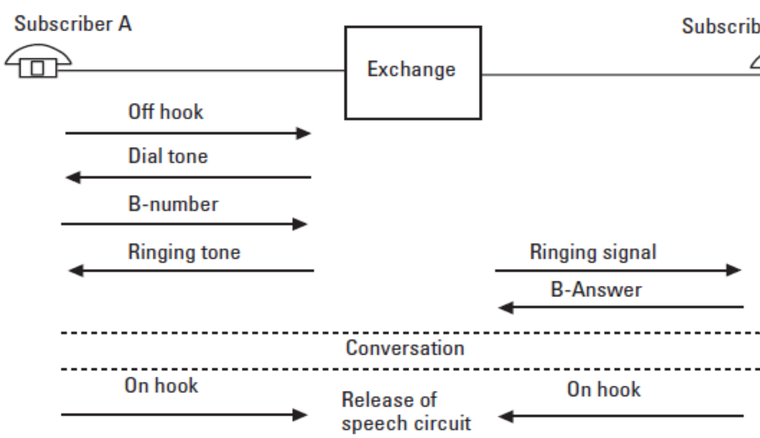

Figure 2.3 Subscriber signaling.

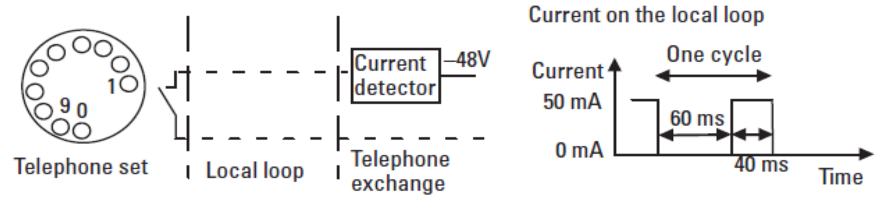

Figure 2.4 Rotary, or pulse, dialing.

In rotary dialing a local loop is closed and opened according to the dialed digits, and the number of current pulses is detected by the exchange. This signaling method is also known as loop disconnect signaling. The main disadvantages of this method are that it is slow and expensive due to high-resolution mechanics and it does not support supplementary services such as call forwarding. The local-loop interfaces in telephone exchanges have to support this old technology though it has been gradually replaced by tone dialing.

When a digit is to be dialed, the dialing plate with finger holes is rotated clockwise to the end and released. While homing, the switch is breaking the line current periodically and the number of these periods indicates the dialed digit. For example, digit 1 has one period, 2 has two periods, and 0 has 10 periods or cycles. Mechanics make the homing speed approximately constant and each period is about 100 ms long with a 60-ms break (Figure 2.4). This method for the transmission of digits has also been used for signaling between exchanges and then it is known as loop disconnect signaling.

The value of the loop current differs slightly from country to country and it is also dependent on line length and supply voltage, for example. Typically it is from 20 to 50 mA, high enough to control old generation electromechanical switches that used pulses to control directly the rotating switches of the switching matrix of an exchange.

2.3.3 Tone Dialing

Currently telephones include electronic circuits that make possible the implementation of better means for signaling. Digital exchanges do not require high-power pulses to drive the selectors as old electromechanical switches did. However, subscriber lines are still, and will be, supplied by a –48- or –60-V battery so that telephones continue to operate independent of the electric power supply. Electronic telephones use 50- to 500-μA current all the time to supply power to their electronic circuitry, which is needed for number repetition, abbreviated dialing, and other additional features of modern telephone sets.

Modern telephones usually have 12 push buttons (keys A to D of Figure 2.5 are not included in an ordinary subscriber set) for dialing, each generating a tone with two frequencies. One of the frequencies is from the upper frequency band and the other from the lower band. All frequencies are inside the voice frequency band (300–3,400 Hz) and can thus be transmitted through the network from end to end, when the speech connection is established. This signaling principle is known as *dual-tone multifrequency* (DTMF) signaling.

Tones are detected at the subscriber interface of the telephone exchange and, if necessary, signaled further to the other exchanges through which the connection is to be established. All digital local exchanges have a capability to use either pulse or tone dialing on a subscriber loop. The subscriber is able to select with a switch on his telephone which type of dialing is to be used. Tone dialing should always be selected if the local exchange is a modern digital one.

Advantages of tone dialing are as follows:

- It is quicker and dialing of all digits takes the same time.
- Fewer dialing errors result.
- End-to-end signaling is possible.
- Additional push buttons are available (*, #, A, B, C, D) for activation of supplementary services.

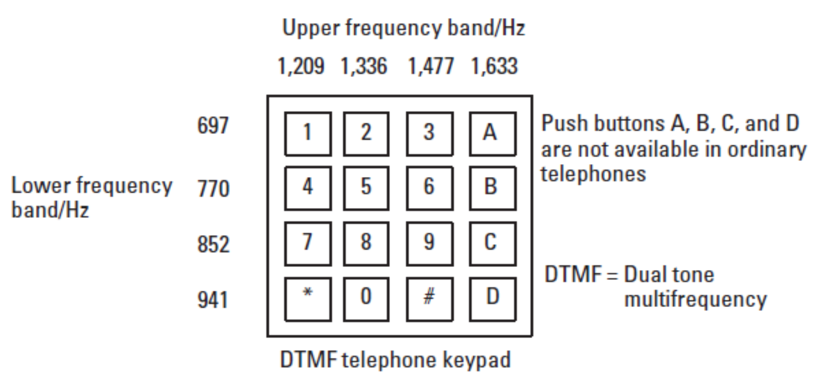

Figure 2.5 Tone dialing.

Supplementary services enable subscribers to influence the routing of their telephone calls. These services, for example, call transfer, are not available with telephones that use pulse dialing. To control these services we need control buttons * and #, which are available only in push-button telephones that use tone dialing.

We use tone dialing also to control *value-added services*. Value-added services are services that we can use via the telephone network but that are usually provided by another service provider, not the telecommunications network operator. One example of value added services is telebanking. Tones are transmitted on the same frequency band as voice, and during a call we are able to dial digits to transmit, for example, our discount number and security codes to the telebanking machine.

The worst disadvantage of a fixed subscriber telephone is still the poor man–machine interface that makes new services difficult to use. Some telephones that have displays are more user friendly, but subscribers still have to memorize command sequences to use the new services offered by a modern telephone network.

2.3.4 Local Loop and 2W/4W Circuits

Any use of telephone channels involves two unidirectional paths, one for transmission and one for reception. The local loop, which connects a telephone to a local exchange is a *two-wire* (2W) circuit that carries the signals in both transmission directions (Figure 2.6). Even ISDN and *asymmetrical digital subscriber lines* (ADSLs) (described in Chapter 6) use this same 2W local

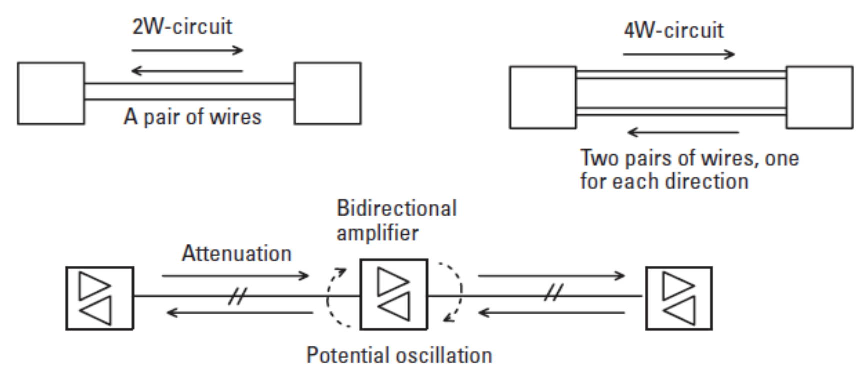

Figure 2.6 2W/4W circuits.

loop. Subscriber loops are and will remain two-wire circuits, because they are one of the biggest investments of the fixed telephone network.

Early telephone connections through the network were two-wire circuits. Longer connections attenuate the speech signal and amplifiers are needed on the line. In two-wire circuits, amplification of a signal may cause oscillation or ringing if the output signal of an amplifier loops back to the input circuit of another transmission direction (Figure 2.6).

The operating principle of electronics in the network is unidirectional and inside the network we use two wires for each direction, or *four-wire* (4W) connections. Four-wire connections are also much easier to maintain than 2W connections because transmission directions are independent from each other and potential oscillation, as shown in Figure 2.6, is avoided. To connect a 2W local loop to a 4W network a circuit called a *2W/4W hybrid* is needed.

We explain the operating principle of the 2W/4W hybrid with the help of transformers. A transformer consists of coils of wires wrapped around an iron object. When an alternating current flows through one coil, it produces a magnetic field in the iron core. This magnetic field generates current to the wires of other coils around the same iron core.

Figure 2.7 shows the 2W/4W hybrid in a subscriber interface of the telephone exchange. Two separate transformers are needed in the hybrid and both of them consist of three similar, tightly coupled windings. In each transformer an alternating current in one coil generates alternating current to all other coils of the same transformer. Spots of coils indicate the direction of the current flow (polarity of the coil). In Figure 2.7 we see that the current of the receive pair generates two currents with opposite polarity through the two coils of transformer T2. These currents have opposite directions in transformer T1; they, or actually their magnetic fields in the iron core, cancel each other, and the signal from the receive pair is not connected to the transmit pair, or at least it is much attenuated. In practice, the balance is not ideal and attenuated signal is connected back, which is heard as an echo from the far end of the telephone circuit if two-way propagation delay of the circuit is long enough. Dashed lines in Figure 2.7 show the main signal paths for received and transmitted speech.

Satellite connections have long propagation delays because of the long propagation distances. Also speech from the digital cellular network to the fixed telephone network suffers long delays because of speech coding (A/D and D/A conversion). The round-trip delays of these connections are longer than 50 to 100 ms, causing a disturbing echo. Hence, in the case of these connections, we have to use special equipment known as *echo cancellers* in the network to eliminate the echo.

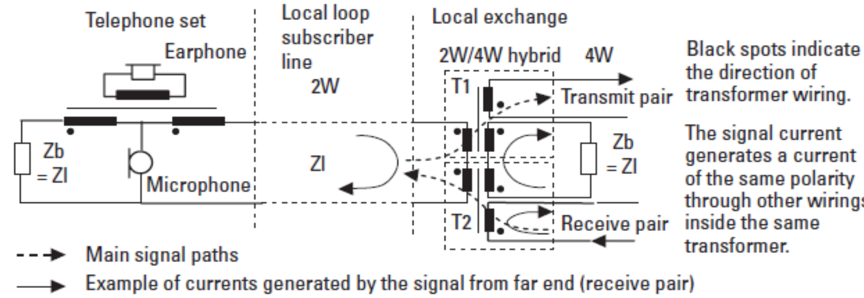

Figure 2.7 Local loop and 2W/4W hybrid.

The 2W/4W hybrid performs the following operations:

- Separates the transmitting and receiving signals.
- Matches the impedance of the 2W local loop to the network circuit.
- Provides a loss to signals arriving on the receiving path, preventing them from entering the transmitting path, which would cause echo.

The ISDN basic rate interface uses bidirectional 160-Kbps data transmission on a 2W circuit (ordinary subscriber loop). There the transmission directions are separated with the help of digital signal processing technology. Many applications use the transformer circuit described earlier together with digital signal processing technology to improve performance.

In every subscriber set quite the same principle as the 2W/4W hybrid is used to attenuate the subscriber's own voice from the microphone to the earphone (Figure 2.7). The reader can imagine what happens when the microphone generates an alternating current in the telephone set of the figure.

2.5 Telephone Numbering

An international telephone connection from any telephone to any other telephone is made possible by unique identification of each subscriber socket in the world. In mobile telephone networks, each telephone set (or subscriber card) has a unique identification number.

The numbering is hierarchical, and it has an internationally standardized country code at the highest level. This makes national numbering schemes independent from each other. E.164 specifies the structure of international telephone numbers and it is presented in Figure 2.8. In the following sections, we explain the fields of the telephone number shown in Figure 2.8.

2.5.1 International Prefix

An international prefix or international access number is used for international calls. It tells the network that the connection is to be routed via an international telephone exchange to another country. The international prefix may differ from country to country, but it is gradually becoming harmonized. For example, all of Europe uses 00; elsewhere it may be different. If many operators are providing international telephone service, a subscriber may select from among different operators by using an operator prefix instead of 00, for example, in Finland a user would dial 999 for Oy Finnet International.

2.5.2 Country Code

The country code contains one to four numbers that define the country of subscriber B. Country codes are not needed for national calls because their purpose is to make the subscriber identification unique in the world. A telephone number that includes the country code is called an international number and it has a maximum length of 12 digits.

Because there are a few hundred countries in the world, many country codes have been defined by the ITU and the length of them varies from a single digit to four digits (some small areas have an even longer code). Consider these examples of country codes: 1 for the United States and Canada, 49 for Germany, 44 for the United Kingdom, 52 for Mexico, 358 for Finland, and 1809 for Jamaica.

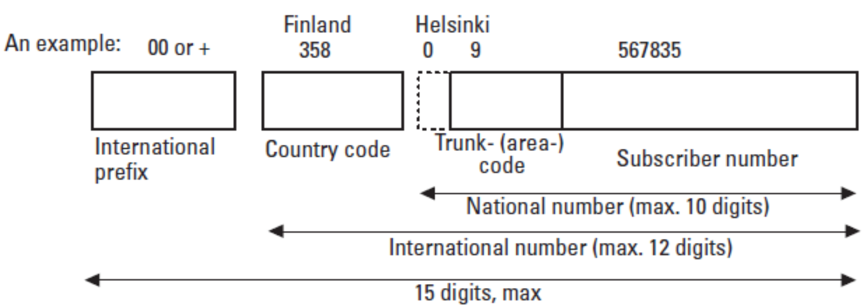

Figure 2.8 The structure of the telephone number hierarchy.

2.5.3 Trunk Code, Trunk Prefix, or Area Code

The trunk code defines the area inside the country where the call is to be routed. The first digit is a long-distance call identification and other numbers identify the area. The first digit is not needed in the case of an international call because that type of call is always routed via the long-distance level of the destination network.

In the case of cellular service, the trunk code is used to identify the home network of the subscriber instead of the location. With the help of this network code, a call is routed to the home network, which then determines the location of the subscriber and routes the call to the destination.

The trunk code and the subscriber number together create a unique identification for a subscriber at the national level. This is called a national number and its maximum length is 10 digits.

Trunk codes start with a 0 in Europe, but the 0 is not used in calls coming from abroad. In countries where multiple operators provide long-distance telephone service, the subscriber may select an operator by dialing an operator prefix in front of the trunk code. In Finland, two examples of the long-distance operator numbers are 109 for Finnet and 1041 for Song Networks.

2.5.4 Subscriber Number

The subscriber number in a fixed telephone network is a unique identification of the subscriber inside a geographical area. To connect to a certain subscriber, the same number is dialed anywhere in the area. Because of the numbering hierarchy, the subscriber part of the telephone number of one subscriber may be the same as that of another subscriber in another area.

If provision of local telephone service is deregulated (as is the goal in Europe), a subscriber is able to choose a network operator for local calls by dialing a local operator prefix in front of the subscriber number.

2.5.5 Operator Numbers

As the telecommunications business is deregulated, new service providers are beginning to enter on the market. Then in addition to the numbers just described, a subscriber will need to dial additional digits to select a service provider (network operator). As explained earlier, a subscriber may choose a service provider for local calls, long-distance calls, and international calls. The national telecommunications authority defines the operator numbers used. The national telecommunications authority also defines how calls dialed without an operator number are charged. If the subscriber does not specify the international and long-distance network operators by operator prefix, the network is chosen randomly or according to other rules specified by the national telecommunications authority. The creation of real competition in fixed telecommunications service provision has been successful in many countries. One problem with this situation is that additional dialing of operator prefixes at all levels is required, and another is that the fees for fixed telephone service are too low to make subscribers interested in taking the time to choose a service provider.

For business users, for which monitoring the costs of telecommunications is essential, competition will certainly reduce those costs. To avoid the problem of additional dialing, a business or residential subscriber may make a service agreement with one of the network operators for local, long-distance, and international calls.

2.6 Switching and Signaling

To build the requested connection from one subscriber to another, the network has switching equipment that selects the required connection. These switching systems are called exchanges. The subscriber identifies the required connection with signaling information (dialing) that is transmitted over the subscriber line. In the network, signaling is needed to transmit the control information of a specific call and circuits from one exchange to another.

2.6.1 Telephone Exchange

The main task of the telephone or ISDN exchange is to build up a physical connection between subscriber A, the one who initiates the call, and subscriber B according to signaling information dialed by subscriber A. The speech channel is connected from the time when the circuit was established to the time when the call is cleared. This principle is called the *circuit switching* concept and is different from *packet switching,* which has been used in data networks.

In the past, the switching matrix was electromechanical and controlled directly by pulses from a telephone. Later, the control functions were integrated into a common control unit. Currently, the common control unit is an efficient and reliable computer or a multiprocessor system, including large amounts of real-time software. This kind of exchange is called a *stored program control* (SPC) exchange (Figure 2.9).

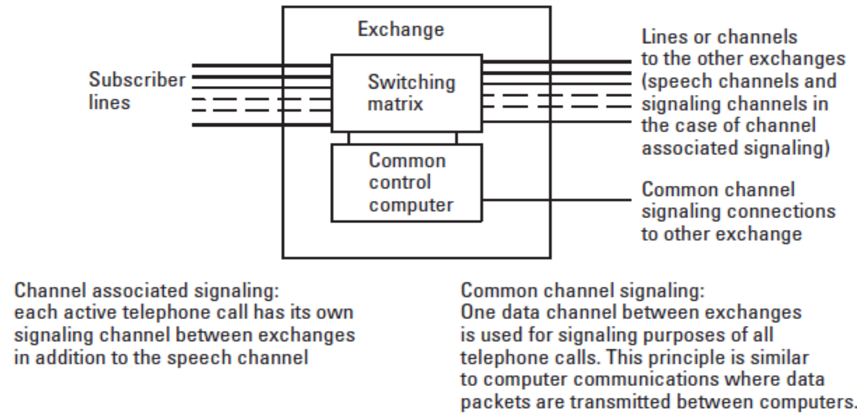

Figure 2.9 SPC exchange and signaling principles used between exchanges.

Every exchange between subscribers A and B connects a speech circuit according to signaling information that is received from a subscriber or from the previous exchange. If the exchange is not the local exchange of subscriber B, it transmits signaling information to the next exchange that connects the circuit further.

2.6.2 Signaling

The control unit of the local exchange receives the subscriber signaling, such as dialed digits, from the subscriber line and makes consequent actions according to its program. Usually the call is routed via many exchanges and the signaling information needs to be transmitted from one exchange to another. This can be done via *channel associated signaling* (CAS) or *common channel signaling* (CCS) methods (Figure 2.9).

2.6.2.1 CAS

When a call is connected from a local exchange to the next exchange, a speech channel is reserved between exchanges for this call. At the same time another channel is reserved only for signaling purposes and each speech path has its own dedicated signaling channel while the call is connected. This channel can be, for example, a signaling channel in time slot 16 of the primary PCM frame as explained later in Chapter 4. The main phases of signaling between exchanges are shown in Figure 2.10. First the speech channel and the related signaling channel are seized from exchange A to exchange B.

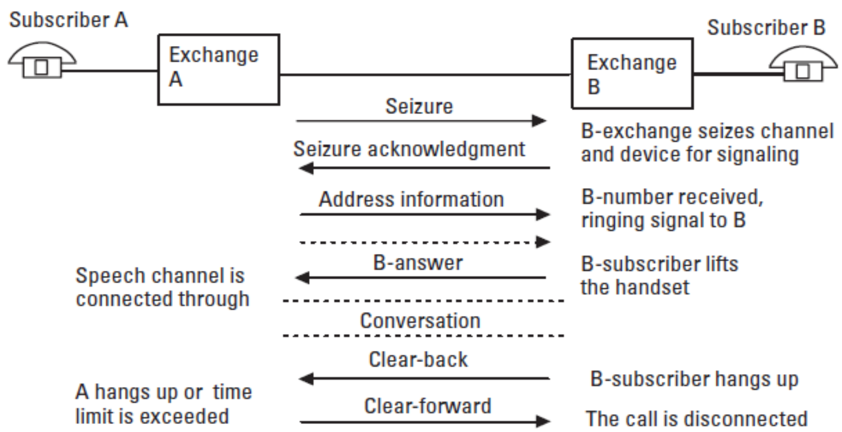

Figure 2.10 CAS between exchanges.

Then the telephone number of subscriber B is transmitted to exchange B, which activates the ringing signal. When subscriber B answers, the speech connection is switched on and the conversation may start.

If subscriber B hangs up first, a *clear-back* (CBK) signal is transmitted from exchange B to A. Exchange A responds with a *clear-forward* (CLF) signal when subscriber A hangs up or when the time constant expires. The call is then disconnected by both exchanges.

Many different signaling systems are used for CAS and some of them include additional signals that are not present in Figure 2.10. Signals that carry signaling information indicated in Figure 2.10 depend on the signaling system in use and they may be, for example, as follows:

- Breaks of the loop between exchanges (loop/disconnect signaling);
- Tones with multiple frequencies, *multifrequency code* (MFC);
- Bit combinations of signaling channel of a PCM frame.

CAS is still used in telephone networks, but it is gradually being replaced with a more efficient standardized method known as CCS.

2.6.2.2 CCS

The modern interexchange signaling system is called CCS. It is based on the principles of computer communications in which data frames containing information are exchanged between computers only when required. Signaling frames contain, for example, information about the connection to which the message belongs, the address of the destination exchange, dialed digits, and information about whether subscriber B has answered. In most cases only one data channel between two exchanges is required to serve all established calls. This is usually one 64-Kbps time slot of a primary 2- or 1.5-Mbps PCM frame, as explained in Chapter 4, and one channel is usually enough for all call-control communication between exchanges.

A widely used international standard of CCS is called CCS7, also known as *signaling system number* 7 (SS7), CCITT#7, or ITU-T 7, and it is used in all modern telecommunications networks such as ISDN and GSM.

Establishing a call requires the same signaling information as indicated in Figure 2.10, but in the case of CCS the signaling information is carried in data frames that are transferred between exchanges via a common data channel.

In Figure 2.11 we see an example in which an ordinary fixed network subscriber, subscriber A, calls subscriber B when CCS is used between exchanges in the network. The dialed digits are transmitted from subscriber A to the local exchange, as explained in Section 2.3. When a set of digits is received by exchange A, it analyzes the dialed digits to determine to which

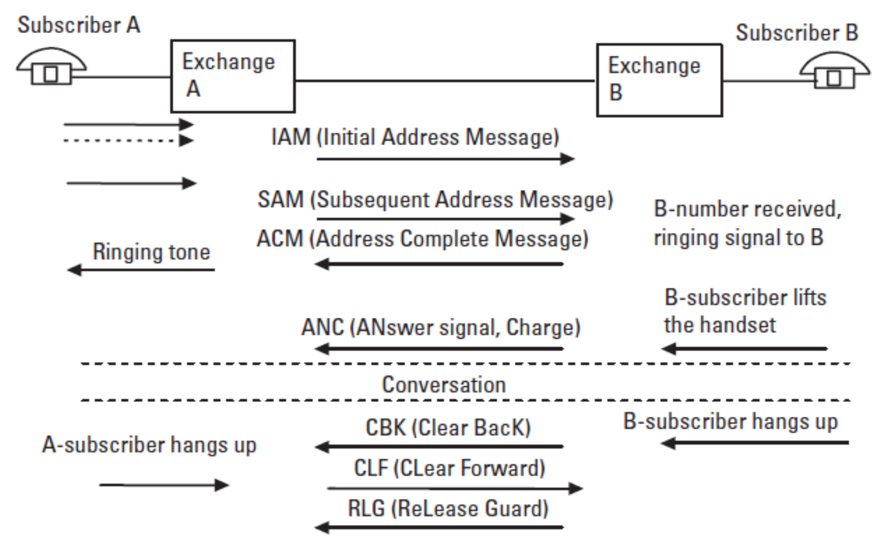

Figure 2.11 CCS between exchanges.

direction it should route the call. From this information it looks up an address of the exchange to which it should send the signaling message for call connection. Then the exchange builds a data packet that contains the address of exchange B. This signaling message, called the *initial address message* (IAM), is then sent to exchange B. The remaining digits that did not fit into the IAM are transmitted in one or more *subsequent address messages* (SAMs).

When all the digits that identify subscriber B are received by exchange B, it acknowledges this with an *address complete message* (ACM), to confirm that all digits have been successfully received. This message also contains information about whether the call is to be charged or not and if the subscriber is free or not. Exchange B transmits the ringing tone to subscriber A and the ringing signal to subscriber B, and telephone B rings.

When subscriber B lifts the handset, an *answer signal charge* (ANC) is sent in order to activate charging. Exchange B switches off the ringing signal and ringing tone. Then both exchanges connect the speech channel through so the conversation can start. When subscriber B hangs up, exchange B detects an on-hook condition and sends a CBK to exchange B. Exchange A responses with CLF signal. All exchanges on the line transmit the CLF message to the next one, and each receiving exchange acknowledges it with a *release guard* (RLG) signal. The RLG message indicates to the receiving exchange that the connection has been cleared and the channel released by the other exchange. It also ensures that both exchanges have cleared the circuit to make it available for a new call.

2.6.3 Switching Hierarchy

During the early years of the telephone, the switching office or exchange was located at a central point in a service area and it provided switched connections for all subscribers in that area. Hence, switching offices are still often referred to as central offices.

As telephone density grew and subscribers desired longer distance connections, it became necessary to interconnect the individual service areas with trunks between the central offices. With further traffic growth, new switches were needed to interconnect central offices and a second level of switching, trunk or transit exchanges, evolved. Currently national networks have several switching levels.

The actual implementation of the hierarchy and the number and names of switching levels differ from country to country. Figure 2.12 shows an example of a possible network hierarchy [1].

The hierarchical structure of the network helps operators manage the network and it makes the basic principle of telephone call routing

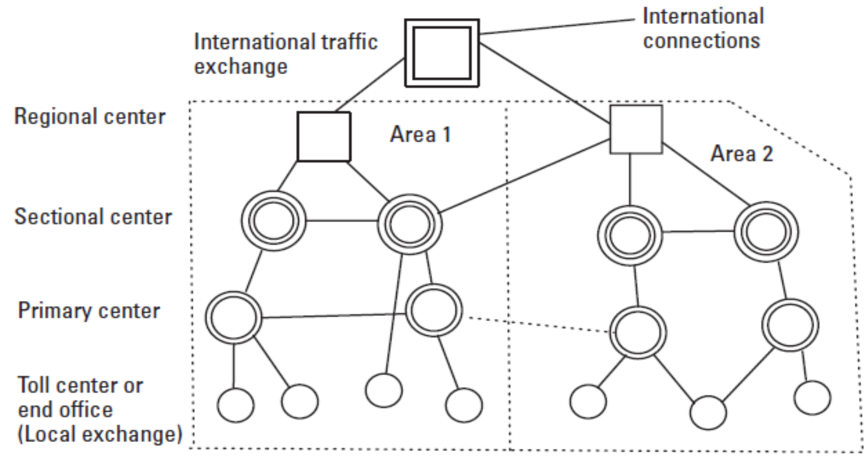

Figure 2.12 An example of switching hierarchy.

straightforward; the call is routed up in the hierarchy by each exchange if the destination subscriber is not located below this exchange. The structure of the telephone number, explained in Section 2.5, supports this simple basic principle of routing up and down in the switching hierarchy.

2.6.4 Telephone Call Routing

Calls that are carried by the network are routed according to a plan, a set of rules. The routing plan includes the numbering plan and network configuration.

2.6.4.1 Numbering Plan

The global rules for the highest-level numbering, country codes, and overall numbering (maximum length and so on) are given by ITU-T. The national telecommunications authority coordinates the national numbering plan. It defines, for example, trunk or area codes and operator prefixes used inside the country. It also defines nationwide service numbers (e.g., emergency numbers). These service numbers are defined to be the same wherever the call is originated and they require additional intelligence from switching systems. Their routing principle is explained later in Section 2.10.4.

At the regional level, the numbering plan includes digits allocated to certain switching offices, exchanges, and the subscriber numbers for subscribers connected to a certain switch.

2.6.4.2 Switching Functionality for Routing

From the received signaling information (dialed digits), a switching system must be able to interpret the address information, determine the route to or toward the destination, and manipulate the codes in order to advance the call properly. This includes the deletion of certain digits and automatic alternate routing. Number conversion may also be needed when, for example, the emergency call dialed with a nationwide short emergency number has to be routed to a regional center that has a different physical telephone number. Some of this intelligence for routing may be stored in a centralized control system from which the exchanges request routing information. This modern network structure is called an *intelligent network* (IN) and is described in Section 2.10.

2.6.4.3 Route Selection Guidelines

The basic routing principle is hierarchical: If the destination does not belong to the subscribers of the switch or of the switches under it, the call is routed upward; otherwise, it is routed to the port toward that destination (Figure 2.13).

In the example of Figure 2.13, a Finnish subscriber makes a call to Stockholm, Sweden, and dials the international prefix "00," country code "46" for Sweden, area code "(0)8" (leaves out zero) for Stockholm, and subscriber number "*xxxxx*." The international prefix is actually all that the lower-level exchanges in Finland need to know. When exchanges in the switching hierarchy detect it, they route this call up toward the international exchange. The international exchange then analyzes the country code and selects an outgoing route to Sweden.

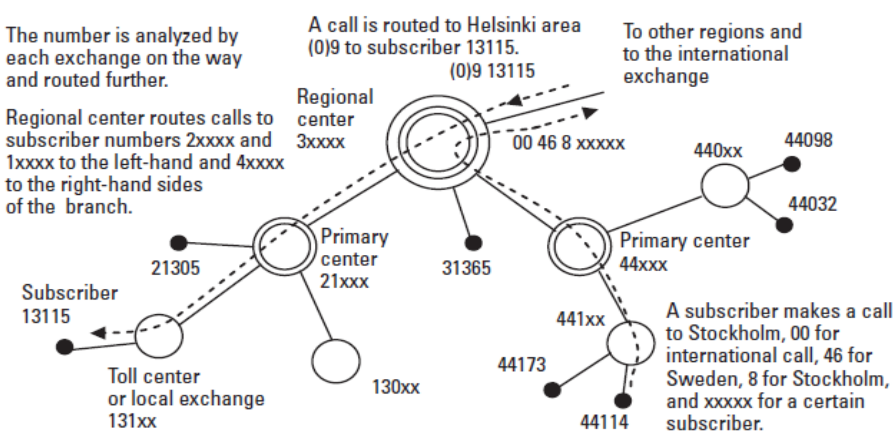

Figure 2.13 Telephone call routing.

Another example in Figure 2.13 illustrates routing of a long-distance call from a subscriber in another region. A subscriber in another region dialed "09 13115" for a long-distance call to Helsinki. The first digit "0" tells the exchanges that this is a long-distance call and is to be routed to the regional exchange. The regional center is connected to other regional centers and then routes this call, with the help of other regional centers, to Helsinki according to the next digit, "9." The regional center of Helsinki analyzes the next two numbers, "13," and selects the route down to the primary center where these subscribers are located. (Operator has defined in his numbering plan that the subscriber numbers 2*xxxx* and 1*xxxx* are placed on the left-hand branch from the regional center.) The primary center then checks the following numbers, "131," and notices that this is not "my subscriber" but the destination subscriber is located "below me" and routes the call to the corresponding lower-level exchange, in this example, the local exchange. The local exchange selects the subscriber loop of the telephone number 13115 and connects a ringing signal to the subscriber.

However, modern exchanges can do more than the simple strictly hierarchical routing just introduced. If there is a sufficient volume of traffic, calls may pass by a hierarchy level or may be connected directly to another low-level switch, as illustrated in Figure 2.12. This may be reasonable, for example, if the local exchanges of subscribers A and B are on the opposite sides of the regional border. The telecommunications operator is free to define the detailed actual routing to optimize the usage of the network.

In this section we have described the switching hierarchy of the telephone network and the telephone call routing principle through the exchanges in this hierarchy. In modern networks the actual implementation may be different from this strictly hierarchical routing principle we described. Local telephone exchanges may analyze the whole telephone number, bypass the switching hierarchy, and route the call directly if the destination is a subscriber of a neighbor local exchange. Also, some sets of the telephone numbers have no fixed connection to the physical location of a subscriber loop. The IN technology, which we discuss later in this chapter, connects a dialed logical number and a certain physical telephone number (i.e., subscriber loop).

Deregulation of the fixed telephone business has created another need for increased intelligence in the network. Local network operators have to be able to connect calls to other parallel networks belonging to competing network operators when subscriber A requires that. The need for this is indicated by the operator prefix dialed by the subscriber as discussed in Section 2.5.

In the next section, we divide the global telecommunications network into three simplified layers in order to clarify their structure and the technologies that are used to implement their required functions.

2.7 Local-Access Network

The local-access network provides the connection between the customer's telephone and the local exchange. Ordinary telephone and ISDN subscribers use two wires, a pair, as a subscriber loop, but for business customers a higher capacity optical fiber or microwave radio link may be required. Many different technologies are used in a local-access network to connect subscribers to the public telecommunications network. Figure 2.14 illustrates the structure of the local-access network and shows the most important technologies in use.

Most subscriber connections use twisted pairs of copper wires. Subscriber cables contain many pairs that are shielded with common aluminum foil and plastic shield. In urban areas cables are dug into the ground and may be very large, having hundreds of pairs. Distribution points that are installed in outdoor or indoor cabinets are needed to divide large cables into smaller

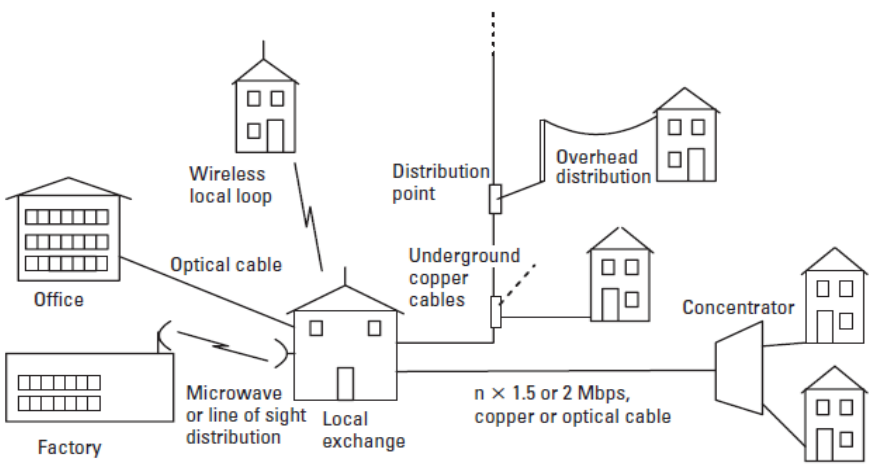

Figure 2.14 An example of a local-access network.

ones and distribute subscriber pairs to houses as shown in Figure 2.14. In suburban or country areas, overhead cables are often a more economical solution than underground cables.

An optical connection is used when a high transmission capacity (more than 2 Mbps) or very good transmission quality is required. A microwave radio relay is often a more economical solution than optical fiber when there is a need to increase data capacity beyond the capacity of an existing cable network. Installation of optical or copper cables takes more time because permissions from landowners and city authorities are required. Installation of cables is also very expensive when they must be sunk into the ground.

One technology for implementation of ordinary subscriber loops for fixed telephone service is known as *wireless local loop* (WLL). WLL uses radio waves and does not require installation of subscriber cables; it is a quick and low-cost way to connect a new subscriber to the public network. With the help of this technology, new operators can provide services in an area where another old operator owns the cables. WLL is also used for replacement of old fixed overhead subscriber telephone lines in rural areas.

When cable network capacity for subscriber connections needs to be increased, it may be more economical to install concentrators, remote subscriber units, or subscriber multiplexers so as to utilize existing cables more efficiently. We use one of these terms to describe the switching capability of the remote unit. Concentrators may be capable to independently switch local calls among the subscribers connected to them. A remote subscriber unit is basically the subscriber interface part of the exchange that is moved away close to the subscribers. Subscriber multiplexers may only connect each subscriber to a time slot (channel) in the PCM frame. The detailed functionality of these systems depends on the manufacturer, but we can say that only those subscribers who have picked up their handsets reserve a channel to the local exchange. Digital transmission between an exchange and a concentrator further improves cable utilization so that two cable pairs serve tens of subscribers.

We have explained the access alternatives shown in Figure 2.14 mainly from a fixed telephone service point of view, but they can also be used to provide access to the Internet. Technologies used for Internet access are explained in Chapter 6.

2.7.1 Local Exchange

Local or subscriber loops connect subscribers to local exchanges, which are the lowest-level exchanges in the switching hierarchy. These are the main tasks of the digital local exchange:

- Detect off-hook condition, analyze the dialed number, and determine if a route is available.
- Connect the subscriber to a trunk exchange for longer distance calls.
- Connect the subscriber to another in the same local area.
- Determine if the called subscriber is free and connect ringing signal to her.
- Provide metering and collect charging data for its own subscribers.
- Convert 2W local access to 4W circuit of the network.
- Convert analog speech into a digital signal (PCM).

The size of local exchanges varies from hundreds of subscribers up to tens of thousand subscribers or even more. A small local exchange is sometimes known as a *remote switching unit* (RSU) and it performs the switching and concentration functions just as all local exchanges do. A local exchange reduces the required transmission capacity (number of speech channels) typically by a factor of 10 or more; that is, the number of subscribers of the local exchange is 10 times higher than the number of trunk channels from the exchange for external calls. The number of required trunk circuits is analyzed in Section 2.12. Figure 2.15 shows some different subscriber connections to a local exchange and the way they are physically installed.

2.8 Trunk Network

As we saw in Section 2.6, the national switching hierarchy includes multiple levels of switches above local exchanges. Figure 2.16 shows a simplified structure for a network where higher levels than local exchanges are shown as a single level of trunk exchanges. The local exchanges are connected to these trunk exchanges, which are linked to provide a network of connections from any customer to any other subscriber in the country.

High-capacity transmission paths, usually optical line systems, with capacities up to 10 Gbps, interconnect trunk exchanges. Note that a transport network has alternative routes. If one of these transmission systems fails, switches are able to route new calls via other transmission systems and trunk exchanges to bypass the failed system (Figure 2.16). Connections between local and trunk exchanges are usually not fault protected because their faults affect on a smaller number of subscribers.

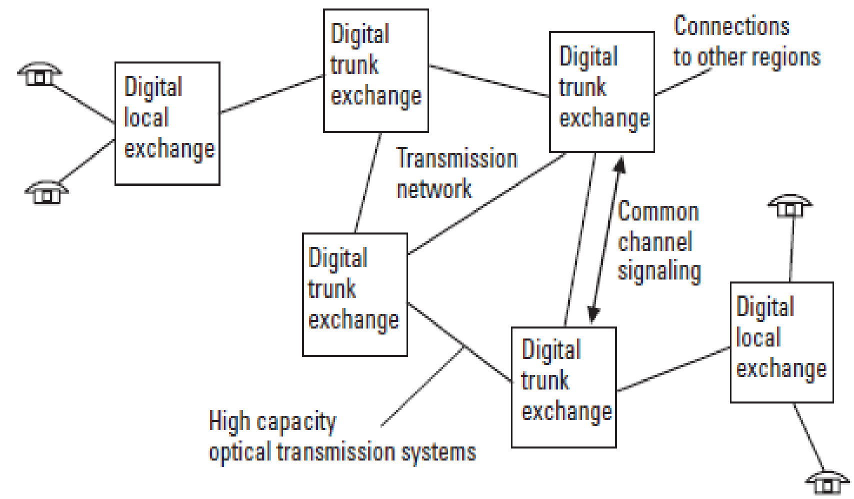

Figure 2.16 Two-layer network and links between trunk and local exchanges.

The transmission systems that interconnect trunk exchanges make up a transmission or transport network. Its basic purpose is simply to provide a required number of channels (or data transmission capacity) from one exchange site to another. Exchanges use these channels of the transport network for calls that they route from one exchange to another on subscriber demand.

The trunk exchanges are usually located in major cities. They are digital and use the international common channel signaling standard SS7 to exchange routing and other signaling information between exchanges. The transmission lines between exchanges have conventionally carried TDM telephone channels, as explained in Chapter 4. Currently the use of IP networks for connections among exchanges is increasing and it requires *media gateways* (MGWs) between the exchange and IP network to take care of signaling and real-time transmission through the IP network.

2.9 International Network

Each country has at least one international switching center to which trunk exchanges are connected, as shown in Figure 2.17. Via this highest switching hierarchy level, international calls are connected from one country to another and any subscriber is able to access any of the other more than 2 billion subscribers around the world.

High-capacity optical systems interconnect international exchanges or switching centers of national networks. Submarine cables (coaxial cable or optical cable systems), microwave radio systems, and satellites connect continental networks to make up the worldwide telecommunications network.

The first submarine cable telephone system across the north Atlantic Ocean was installed in 1956, and it had the capacity of 36 speech channels. Modern optical submarine systems have a capacity of several hundred thousand speech channels and new high capacity submarine systems are put into use every year. In addition to speech, submarine systems carry intercontinental Internet traffic, which is estimated to take most of the capacity of the new systems under installation. Submarine systems are the main paths for intercontinental telephone calls and Internet communication. Satellite systems are sometimes used as backup systems in the case of congestion.

We described the common structure of the global telecommunications network without separating the different network technologies. We need different network technologies to provide different types of services, and the telecommunications network is actually a set of networks, each of them having characteristics suitable for the service it provides. In the next section we describe briefly the most important network technologies, some of which are discussed in more detail in later chapters.

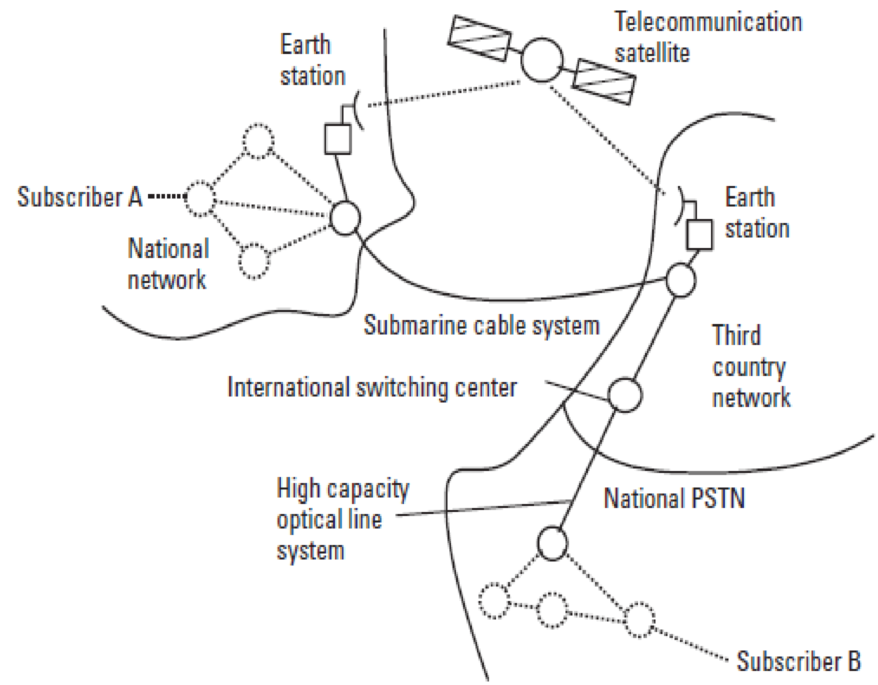

Figure 2.17 The international network.

2.13 Problems and Review Questions

Problem 2.1

Describe how dialed digits are transferred from a subscriber's telephone to the local exchange.

Problem 2.2

Explain how the telephone attenuates the speaker's voice from the microphone to the earphone. (*Hint:* Draw the current coming from the microphone in Figure 2.7 and imagine what happens to the magnetic field in the iron core of the transformer.)

Problem 2.3

What is a 2W/4W hybrid and why is it needed at the end of the subscriber line?

Problem 2.4

Explain how a 2W/4W hybrid prevents the signal from the network (receiving pair) from looping back to the transmitting pair.

Problem 2.5

Explain the basic principle of telephone call routing through the switching hierarchy to another region of the country.

Problem 2.6

A network has N subscribers. Each subscriber is connected directly to all other subscribers.

(a) What is the total number of lines L in the network?

(b) What is the value of L for $N = 2$, 10, 100, and 1,000?

(c) How many lines must be built to each subscriber?

(d) Is this kind of network structure suitable for a public telecommunications network? Explain.

Problem 2.7

What are the basic differences between the public and private telecommunications networks? List a few examples of both public and private networks.

Problem 2.8

What is ISDN? How does the service and structure of the subscriber interface differ from the conventional analog telephone service?

Problem 2.9

How does an IN differ from conventional fixed telephone network? List some examples of IN services.

Problem 2.10

A PBX/PABX has seven telephone channels to a public exchange. During the busy hour, on average, 3.4 lines are occupied. (a) What is the traffic intensity during the busy hour? (b) Estimate, with the help of the Table 2.1, the GoS (blocking probability).

Problem 2.11

What is the total offered traffic intensity from a PBX/PABX to PSTN if 10 calls are made, each with a duration of 6 minutes during 1 hour?

Problem 2.12

A subscriber makes one 6-minute call in one day between 10:00 and 10:06. What is the average traffic intensity of her subscriber line during (a) 10:00–10:06, (b) 10:00–10:15, (c) 10:00–11:00, and (d) 00:00–24:00 of that day?

Problem 2.13

Use the Poisson (or "Molina lost calls held") trunking formula to calculate the blocking probability (GoS) when the total offered traffic is 2 Erl and the number of available transmission channels in the network is 5.

Problem 2.14

Draw two curves for GoS levels of 1% and 10%. Use the vertical axis as a ratio A/n from 1% to 100% and the horizontal axis as a number of circuits n from 1 to 20. Use traffic engineering Table 2.1. What can you say about network utilization when the number of circuits n is small? How does the utilization of the circuits depend on the allowed probability of blocking?

Problem 2.15

What will the approximate capacity of a network be (i.e., how many channels should be available) if there are 100 subscribers and each of them generates offered traffic of 40 mErl? The probability of blocking is (a) 20% and (b) 1%. Use traffic engineering Table 2.1.

Problem 2.16

There are 20 users of a keyphone system that has two lines to a public network. What is the blocking probability when each user generates a 100-mErl offered traffic?