2

The Telephone Network

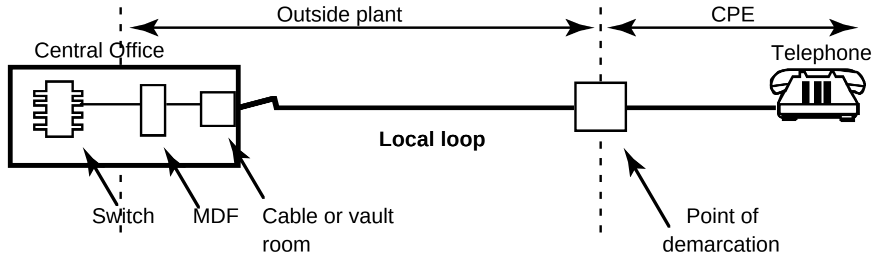
INTRODUCTION

This chapter provides an introduction to the telephone network, known in telephony circles, as “The Network.” Some people use the term network to describe the Internet, and often shorten the term to “The Net.”

We begin with a discussion of the outside telephone plant, the link between our telephones and computers to the telephone system. Next the “inside” of the telephone network is explained, with a discussion of switching offices and trunks. The remainder (and the bulk) of the chapter describes the basic signaling (call processing) procedures employed in making a telephone call.

GOALS OF A TELEPHONE SYSTEM

In building the telephone system, the telephone companies established three goals. First, there had to be sufficient direct current flow to operate the customer’s station sets. It was decided that all power requirements would be the responsibility of the service provider, and not the



Where:
CPE Customer premise equipment
MDF Main distribution frame

Figure 2–1 The Telephone Plant

customer—a decision that millions of customers take for granted, but provides an very valuable service.[1]

The second goal was to support dc/low-frequency call process signaling (dialing, ringing) and to keep the signaling simple at the customer's terminal.

The third goal was to limit signal loss to acceptable levels such that the voice conversation between the customers would appear as "natural" as possible.

THE TELEPHONE PLANT

Figure 2–1 shows the basic telephone company (telco) set up with a customer's telephone. The line connecting the customer premises equipment (CPE) to the telephone central office (CO) consists of two wires and is called the local loop. The connecting point between the CPE and CO is called the point of demarcation and is usually found in a box (the protection block or station block) on the outside of a house. The outside plant facilities include the wires and supporting hardware to the CO.

At the CO, the lines enter through a cable room (aerial lines) or a cable vault (buried lines). The lines are then spliced to tip cables and di-

[1]A native mode IP telephony network (that is, eliminating the telco local loop) will not provide electrical power unless special arrangements are made between a service provider and the customer. And they would have to be very special. One can envision the ISP building a plant to the subscriber that provides UPS!

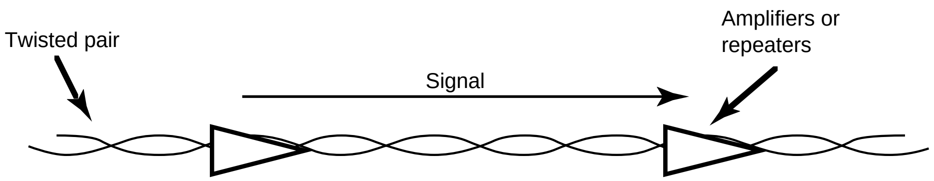


Figure 2–2 Twisted Pair Cable

rected to the main distribution frame (MDF); each wire is attached to a connector at the MDF.[2] From the MDF, the wires are directed to other equipment such as a switch.

THE MEDIA TO THE CUSTOMER

The telephone plant uses copper wires for the sending of the voice traffic between the subscriber and the central office. Call processing signals are also sent on these wires. The systems use wire pairs. The twisting of each pair (in a multipair cable) is staggered, as shown in Figure 2–2. Radiated energy from the current flowing in one wire of the pair is largely canceled by the radiated energy of the current flowing back in the return wire of the same pair. This approach greatly reduces the effect of crosstalk (interference on the pair). Moreover, each pair in the cable is less acceptable to external noise; the pair cancels out much of the noise because noise is coupled almost equally in each wire of the pair.

These characteristics describe a balanced line. Both wires carry current; the current in one wire is 180° out-of-phase with the current in the other wire. Both wires are above ground potential. In contrast, an unbalanced line carries the current on one wire and the other wire is at ground potential.

The two wires on the twisted pair are referred to as tip and ring. As Figure 2–3 shows, the terms originated during the days of the manual telephone switchboards when the conventional telephone plug was used to make the connections through the switchboard. A third wire (if present) is sometimes called a sleeve, once again after the switchboard plug. In a 4-wire system the four leads are called T, R, T1, and R1.

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[2]Even though the MDF is at the CO, it is usually considered part of the outside plant and CO performance is usually measured between the MDFs.

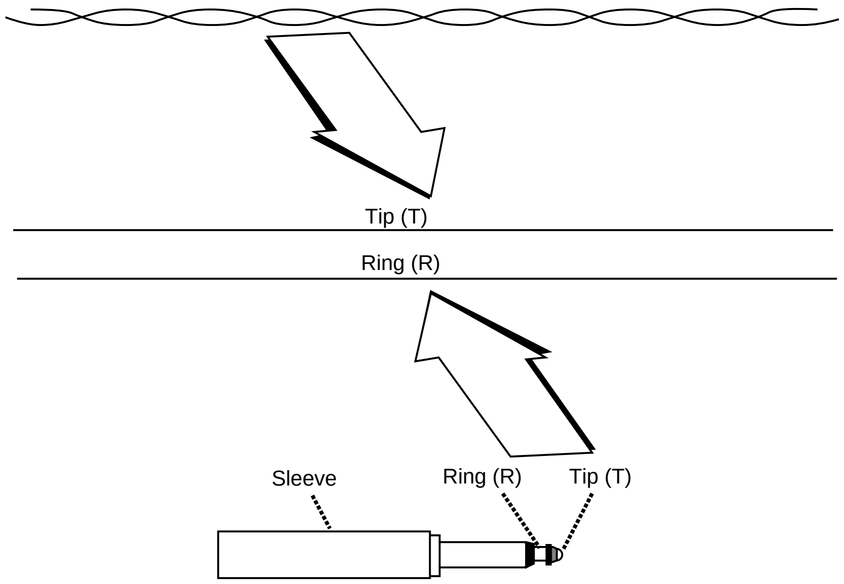


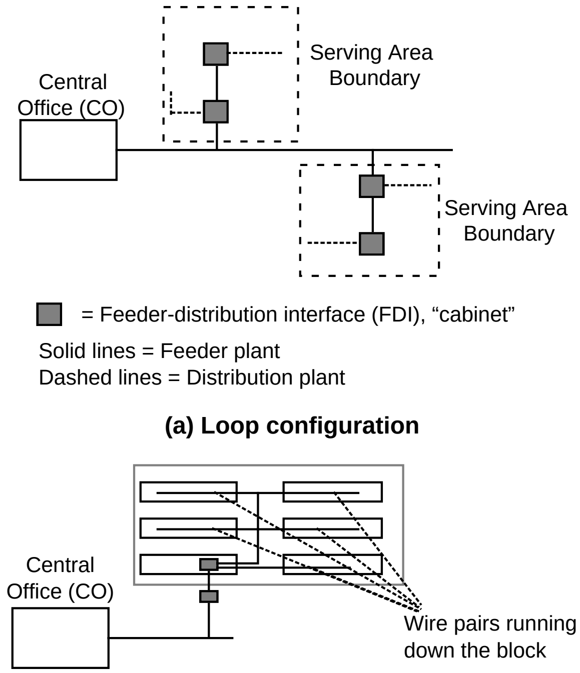
Figure 2–3 Tip and Ring

A MORE DETAILED LOOK AT THE OUTSIDE PLANT

Figure 2–4 depicts several aspects of the local (subscriber) loop. As shown in Figure 2–4(a), the system consists of feeder plant, distribution plant, and the feeder-distribution interface (FDI). The feeder plant consists of the large number of physical wires and signal repeaters. Usually, they are located based on geographical constraints and the customer locations. They often run parallel to roads and highways. The distribution plant consists of a smaller number of cables and connects to the customer's network interface (NI), which is usually located in a "box" attached to the customer's building. The serving area interface (interface plant) is the term used to describe the manual cross-connections between the feeder and distribution plants. This interface is designed to allow any feeder unit to be connected to any distribution pair.

The subscriber loop consists of sections of copper pairs (usually about 500 feet long). The sections are joined together with electrical joints, called splices, at the telephone poles for aerial cables and at a manhole for underground cables. The cable pairs are bundled together in a cable binder group.

Figure 2–4(b) shows the serving area boundary in more detail. This term describes the geographical division of the outside plant into discrete



(a) Loop configuration

(b) Serving area in more detail (serving boundary)

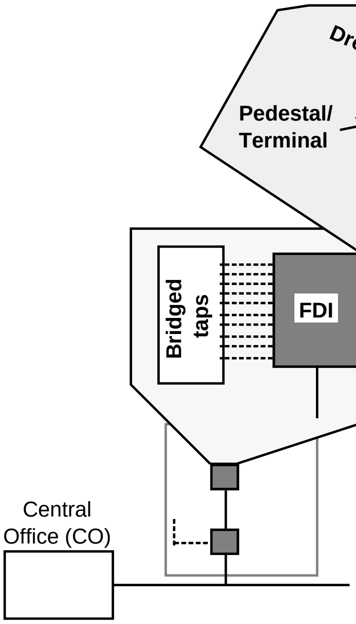
Figure 2–4 The Outside Plant

parts. All wires in a serving area are connected to a single serving area interface to the feeder plant, which simplifies ongoing maintenance and record keeping.

Connecting the Business or Residence

As shown in Figure 2–5, the feeder cables provide the links from the central office to the local subscriber area, and then the distribution cables carry on from there to the customer sites (a residence or business). Since the subscriber loop system is usually installed before all the customers are connected, there will be unused distribution cables. The common practice is to connect a twisted pair from a feeder cable to more than one distribution cable, and these unused distribution cables are called bridged taps. These bridged taps must be set up within the loop plant rules to minimize adverse effects on the system, such as signal loss, radiation, and spectrum distortions.

The connection points in the distribution cables are in pedestals for underground cables, and terminals for aerial cables. The connection into the



Where:
FDI Feeder distribution interface

Figure 2–5 Connecting to the Customer

customer site is called the drop wire. It is short, and can (potentially) pick up other frequency radiations. It might also radiate signals to other devices.

OFFICES AND TRUNKS

Figure 2–6 depicts several lines and types of equipment and types of “offices” found in the public network. Most of the terms in this figure are self-explanatory, but it should prove useful to amplify some of them:

- Trunk: A communication channel between two switching systems.
- Tandem office: A broad category of office that represents systems that connect trunks to trunks. Local tandem offices connect trunks within a metropolitan area. Toll offices connect trunks in the toll part of the network. With some exceptions, the end customer is not connected to a tandem.
- Toll connecting trunk: A trunk between an end office (local office) and a toll office.

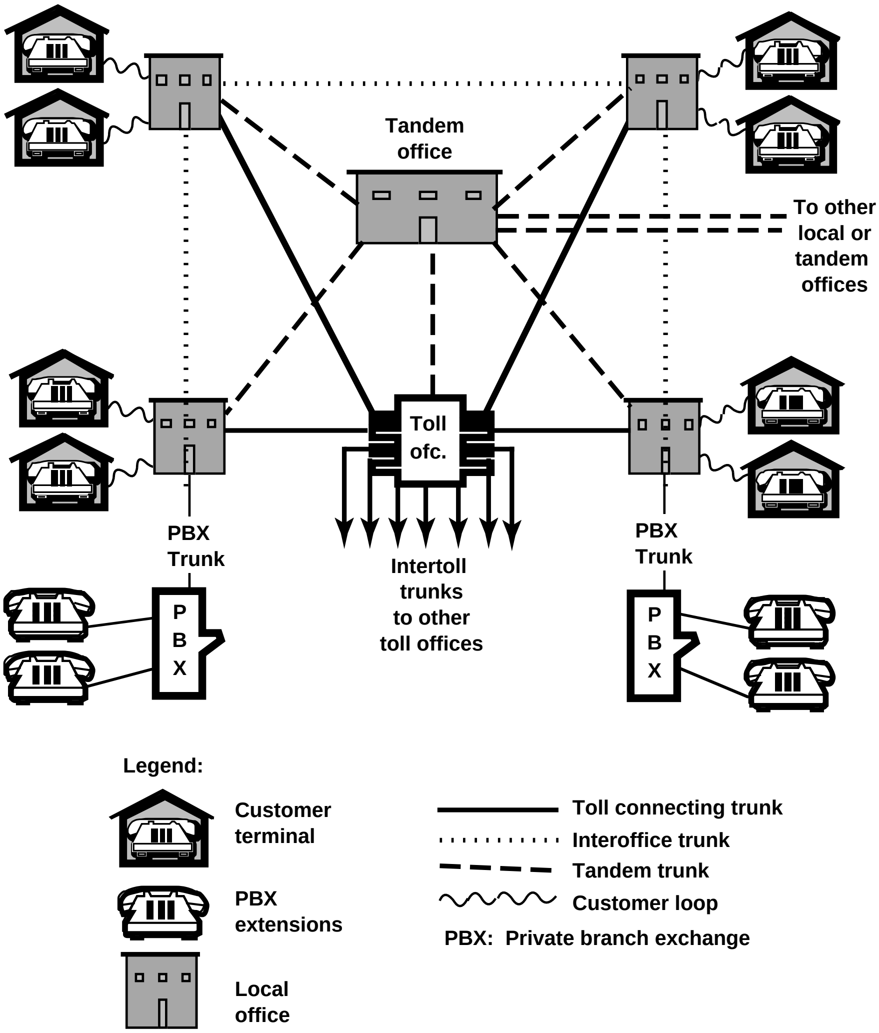


Figure 2–6 Offices and Trunks

THE TELEPHONE DIALING PLAN

The current dialing plan in North America is a seven-digit address to identify each network station (telephone). The address takes the form:

NXX-XXXX

where N can be any digit 2 through 9 and X can be 0 through 9. The arbitrarily assigned NXX portion of the address identifies the customer location where the station is homed. It cannot be the same as the NXX digits assigned to the same switch for public network use. The XXXX digits are the numbers of the individual station at the customer location.

This address is preceded with a three-digit area code, and for dialing since the 1984 divestiture, the full dialing address is:

10XXX (to be expanded to 101XXXX) carrier access code

where XXX identifies the specific carrier. The dialing sequence is 10XXX + (0/1) + 7/10 digits (D), where X can be any digit from 0 to 9. The 7/10 digits dialed must conform to the North American Numbering Plan (NANP).

In the local exchange carrier (LEC) network, the complete convention for "Dial 0" services is as follows:

• Intra-exchange:	0	or	0 + /10D
• Interexchange (inside world zone 1):	10 xxx +0 +7/10D	or	0 + 7/10D*
• Outside world zone 1:	10 xxx + 01 + CC + NN	or	01 + CC + NN*
• No call address	10 xxx + 0	or	00*

where CC = country code and NN = network number; * represents presubscribed numbers.

BASICS OF TELEPHONY CALL PROCESSING

This part of the chapter provides an introduction to the basics of telephony call processing. To begin this analysis, a few definitions are needed.

Access line signaling defines the operations to connect the customer to the switching system. The signaling can take place across a two-wire or four-wire interface, and signaling is transmitted in various modes, depending on the specific implementation by the network provider. Regardless of the mode of operation, these classes of signals are used during access line operations. These terms and definitions are derived from various Bellcore/ANSI manuals and vendor specifications.

- *Supervisory:* These signals are used to initiate or terminate connections. From the sending customer, the initiator requests a service. From the standpoint of the receiver, they represent the initiation of a connection.

- *Address:* These signals provide information to the network about the destination user. In so many words, they are the called party (and maybe the calling party) numbers.
- *Alerting:* These signals are provided by the network to the receiving customer that an incoming call is taking place, or to alert that some need is being signaled (flashing, recall, etc.).
- *Call progress:* These signals inform the user about the progress or lack-of-progress of a call that has been initiated by this user.
- *Control:* These signals are used for functions that usually remain transparent to the end customer. They are usually associated with network connections to the point-of-termination (POT) or the demarcation point. One example of a control signal is the requirement for party identification.
- *Test signals:* These signals are used for a wide array of circuit validation and quality checks.

Supervisory Signals

The supervisory signals convey the following service conditions.

- *Idle circuit:* Indicated by the combination of an on-hook signal and the absence of any connection in the switching system between loops.
- *Seizure (request for service):* Indicated by an off-hook signal and the absence of any connection to another loop or trunk.
- *Disconnect:* Indicated by an on-hook signal in the presence of a connection to a trunk or another loop.
- *Wink start:* Indicated by an off-hook signal from the called end after a connect signal is sent from the calling end. The signal duration is about 320± ms.
- *Delay start:* Indicated by an off-hook signal sent to the originating end after the terminating end has received a connect signal. It is maintained until the terminating end is ready to receive digits. The signal duration is typically 256± ms.
- *Immediate start:* Refers to outpulsing where the originating end outpulses 120 ms after having sent the connect signal.
- *Answer signal:* Indicated by a sustained off-hook signal toward the originating end.

- *Start dialing:* Indicated by an off-hook signal sent by the terminating end to indicate it can now receive digits. This signal is also called start pulsing. The originating end must delay 70 ms after receiving the start dialing before it can outpulse.
- *Stop/go:* Indicated by an off-hook signal sent by the terminating end within the interdigit interval to halt the outpulsing of digits. The go signal is an on-hook sent by the terminating end, with a duration of about 330 ms.

Off-hook and On-hook

To keep matters simple, the telephone system was designed to perform many of its signaling operations by on-hook and off-hook operations. The on-hook operation means the telephone is not being used, a term derived in the old days when the telephone handset was placed on a hook (later a cradle) when it was not being used. The off-hook is just the opposite; the handset is being used—it is lifted from the telephone.

Name	Type	Direction Originating Terminating	Meaning
Connect	Off-hook	→	Request service and hold connection
Disconnect	On-hook	→	Release connection
Answer	Off-hook	→	Terminating end has answered
Hangup	On-hook	←	Message complete
Delay start	Off-hook	←	Terminating end not ready for digits
Wink start	Off-hook	←	Terminating end ready to receive digits
Start dialing	On-hook	←	Terminating end ready for digits
Stop	Off-hook	←	Terminating end not ready for further digits
Go	On-hook	←	Terminating end ready for further digits
Idle trunk	On-hook	↔	
Busy trunk	Off-hook	↔	

Figure 2–7 On-hook and Off-hook Operations

The off-hook and on-hook operations change the electrical state of the line between the terminal and the CO (or PBX). The signals shown in Figure 2–7 are on-hook or off-hook signals of various durations to convey different meanings, as summarized in the far right-hand column of the figure.

EXAMPLE OF A CALL

Figure 2–8 builds on the information just explained and shows the typical operations involved in setting up a call. The operations are self-explanatory, based on the previous information provided in this book.

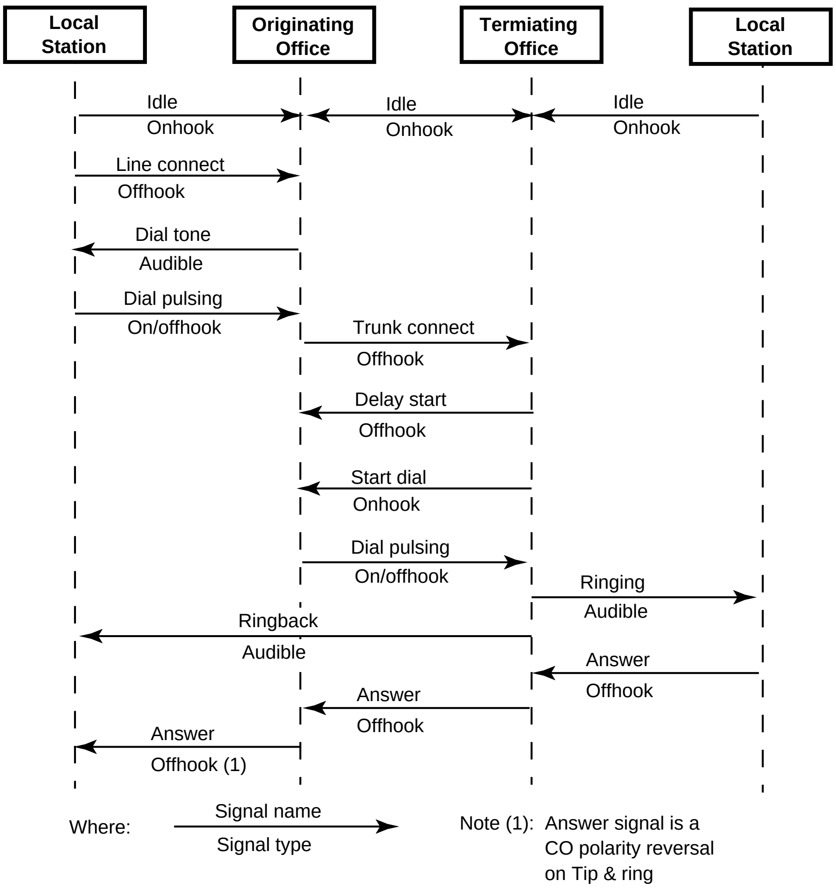


Figure 2–8 Using On-hook and Off-hook End-to-End (Off-hook and On-hook Signals Within Network Are Rare Today)

One point should be made regarding the signaling between the originating office (CO) and the terminating office (CO). The example shows conventional on-hook and off-hook signaling, which has been the method used in the past. Newer systems replace this type of signaling with message-based operations. The same type of information is carried between the offices, but it is conveyed in a signaling protocol, that contains digital codes (fields) in the message. This “new” type of signaling is an example of Signaling System Number 7 (SS7), introduced later in this chapter, and explained in more detail in Appendix B.

MULTIFREQUENCY (MF) SIGNALS

To this point in the discussion, we have discussed several types of signals and tests that are used in telephony systems. Most of these signals are represented with the off-hook/on-hook operations or the measurement of a voltage level on the circuit.

In addition to these simple arrangements, analog telephone systems use multifrequency (MF) pulsing. This type of signaling consists of com-

Table 2–1 Multifrequency (MF) Codes

Frequencies (in Hz)	Digit and Control
700 + 900	1
700 + 1100	2
700 + 1300	4
700 + 1500	7
700 + 1700	
900 + 1100	3
900 + 1300	5
900 + 1500	8
900 + 1700	
1100 + 1300	6
1100 + 1500	9
1100 + 1700	Key pulse (KPP)
1300 + 1500	0
1300 + 1700	
1500 + 1700	Start (ST)

binations of frequencies to send other kinds of information over trunks. The combinations of two frequencies represents a signal and as depicted in Table 2–1, each combination represents a digit. These signals fall within the speech bandwidth, so they can be sent over regular voice channels. MF pulses are used to transfer information to the control equipment that sets up the connections through the switches.

MF pulsing is also used to send information on the call in a BOC Centralized Automatic Message Accounting-Automatic Number Identification (CAMA-ANI) procedure. The calling number is transmitted from the originating end office to the CAMA office after the sending of the called number. For equal access arrangements to an IC, the calling number is sent first, followed by the called number.

A key pulse (KP) signal is a multifrequency tone of 1100 + 1700 Hz ranging form 90 to 120 ms. Its function is to indicate the beginning (the start) of pulsing, that is the dialed number follows the KP signal. The start (ST) signal does not mean the start of the signal. It indicates the end of the pulsing: that is, the end of the dialed telephone number. From the perspective of the telephone exchange, it represents the beginning of the processing of the signal.

DTMF SIGNALING

For customer stations, the signaling arrangement is used called dual-tone multifrequency (DTMF) signaling. DTMF is provided for the push buttons on the telephone set. This form of signaling provides 16 distinct signals, and each signal uses two frequencies selected from two sets of four groups. Table 2–2 shows the arrangement for the DTMF pairs.

Table 2–2 Dual-tone Multifrequency (DTMF) Pairs

		High Group (Hz)			
		1209	1336	1477	1633
Low Group *(Hz)*	697	1	2	3	A
	770	4	5	6	B
	852	7	8	9	C
	941	*	0	#	D

OTHER TONES AND EVENTS ON THE SUBSCRIBER LINE

In addition to the off-hook/on-hook signals, the tones to represent dialed digits, and some additional events, the ITU-T (Recommendation E.182) defines other tones and events that can appear on a subscriber line. The tones explained below are tones that may be heard by the calling party [SCHU99].[3]

- Busy tone: The called line is busy.
- Call waiting tone: Indicates another party wishes to communicate with the subscriber.
- Caller waiting tone: Indicates the called terminal is busy, but has call waiting available.
- Calling card service tone: Used for calling card operations.
- Comfort tone: Indicates the call is being processed. May be used in situations where there is a long delay in dialing the callee, such as an international call.
- Congestion tone: The telco facilities are busy.
- CPE alerting signal (CAS): Used to alert a device of an arriving in-band frequency shift key (FSK) data transmission.
- Dial tone: This tone is placed on the line after the calling party goes off-hook. It indicates the telephone exchange is ready to receive address information (dialed digits).
- Hold tone: Indicates the caller has been placed on hold.
- Intrusion tone: Indicates call is being monitored by an operator.
- Negative indication tone: A supplementary service could not be activated.
- Off-hook warning tone: Indicates a phone as been left off-hook for an extended time.
- PABX internal dial tone: Indicates that a PABX is ready to receive address information.
- Pay tone: Indicates the payphone user is to deposit additional coins to continue the service.
- Positive indication tone: A supplementary service has been activated.

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[3][SCHU99]. Schulzrinne, Henning and Petrack, Scott. "RTP Payload DTMF Digits, Telephony Tones, and Telephony Signals." Ietf-avt-tones-o1.ps, August, 1999.

- Record tone: Indicates the caller is connected to an automatic answering device, and is being requested to start speaking.
- Ringing tone: Indicates that a called has been placed to the callee, and a ringing signal has been transmitted to this party.
- Second dial tone: The telco network has accepted the address information but is requesting additional information.
- Special dial tone: Serves the same function as a dial tone, except it indicates the caller's line has a special condition associated with it, such as an indication that voice mail is available.
- Special information tone: The callee cannot be reached, but not because of the callee being busy, nor because of network congestion. Used on automatic equipment.
- Special ringing tone: A special service is active at the called number, such as call forwarding or call wailing.
- Warning tone: Indicates the call is being recorded.

EXAMPLES OF CALL PROCESSING OPERATIONS

Signaling systems must support (interwork with) the older analog signaling systems because analog is still the pervasive technology used in the local loop. The next part of this chapter shows two common operations.

These examples are not all-inclusive, but they represent common implementations. For the reader who needs information on each service option offered by the U.S. BOCs, I refer you to Bellcore Document SR-TSV-002275, Issue 2, April 1994.

Feature Group B (FGB)

The BOCs classify several of their access arrangements with the title "Feature Group." The example in Figure 2–9 is feature group B, which specifies an access agreement between an LEC end office (EO) and an interexchange carrier (IC). With this arrangement, the calls to the IC must use the initial address of: (I) + 950 + WXXX Where: W = 0/1.

Figure 2–9 is largely self-descriptive, but some rules for the signaling sequences shown in the figure should be helpful. For calls from EOs or an access tandem: (a) the carrier returns a wink signal with 4 seconds of trunk seizure, and (b) the carrier returns an off-hook signal within 5 seconds of completion of the address outpulsing. For calls from a carrier to an EO or access tandem: (a) the end office or access tandem returns

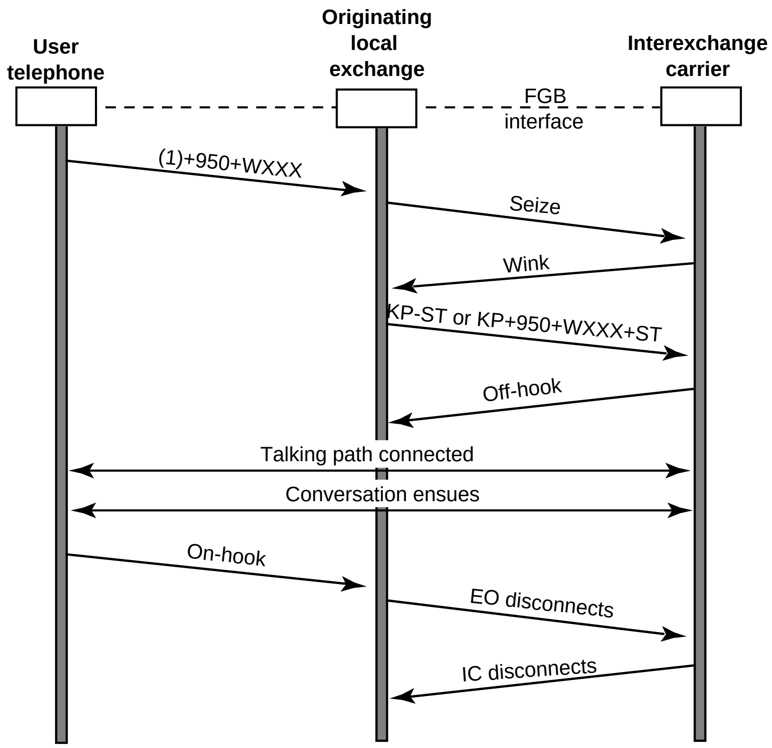

Figure 2–9 Example of Trunk-side Access Arrangement

the wink start signal within 8 seconds of trunk seizure; (b) the carrier starts outpulsing the address with 3.5 seconds of the wink; and (c) the carrier completes sending the address sequence within 20 seconds.

Operator Service Signaling (OSS)

OSS signaling is similar to one of the feature groups, but it has some characteristics that may be more familiar to the reader. Figure 2–10 shows these operations, with six events.

In event 1, the customer dials 10XXX + (1) + 7 or 10, or 10XXX + 0 + 7 or 10. Upon receiving these signals, the EO (event 2) seizes an outgoing trunk. In event 3, the OS facility responds with a wink. Upon receiving the wink signal the EO outpulses in event 4 the called number after a delay of 40 to 200 ms. The outpulsing is KP + 7/10 digits + ST (STP, ST2P, ST3P), or KP + STP(ST3P). In event 5, the OS facility will go off-hook (any time after the start of the ST pulse). Off-hook indicates its ability to receive ANI.

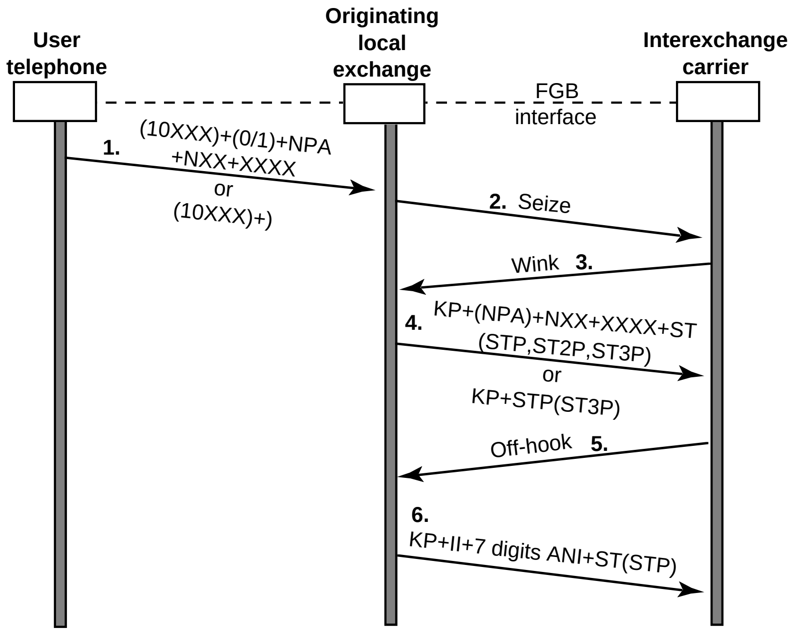

Figure 2–10 Operator Service Signaling (OSS)

In event 6, the EO sends the ANI (after a delay of 40–200 ms). The signals are KP + 02 + ST (STP).

ISDN

In the 1960s and 1970s, as digital technology began to find its way into the telephone providers' networks, and as the costs of digital technology declined, the telephone industry began to look for ways to move this technology into the local loop. The telephone service providers' view was that the superior characteristics of digital technology (over analog) would make it attractive to the customer.

Additionally, the use of analog signaling over the local loop was quite limited with regard to data rates (in bit/s). In fact, when ISDN was first introduced in 1984, the V.22 bis modem was just introduced, operating at 2400 bit/s. So, a 64 kbit/s rate sounded very attractive to the data user.

There was also the recognition that the T1 technology was proving to be effective within the telephone carriers' backbone network—so why not use some version of T1 at the local loop? This "version" is ISDN.

IP Call Processing Protocols must be able to interwork with ISDN, and these interworking examples are shown later in this book. If you are not familiar with ISDN, take a look at Appendix B.

SS7

SS7 is the prevalent signaling system for telephone networks for setting up and clearing calls and furnishing services such as 800 operations. It is designed also to operate with the ISDN technology.

Common channel signaling (CCS) systems were designed in the 1950s and 1960s for analog networks and later adapted for digital telephone switches. In 1976, AT&T implemented the Common Channel Interoffice Signaling (CCIS) into its toll network. This system is referred to as CCS6 and was based on the CCITT Signaling System No. 6 Recommendation.

SS6 and CCS6 were slow and designed to work on low-bit rate channels. Moreover, these architectures were not layered which made changing the code a complex and expensive task. And they were designed for analog networks, which was not the "technology of the future."

Consequently, the CCITT (now the ITU-T) began work in the mid-1970s on a new generation signaling system. These efforts resulted in the publication of SS7 in 1980 with extensive improvements published in 1984 and again in 1988. Today, SS7 and variations are implemented throughout the world. Indeed, SS7 has found its way into other communications architectures such as personal communications services (PCS) and global systems for mobile communications (GSM).

Later chapters offer several examples of how IP Call Processing protocols and Gateways interact with SS7 networks. If you are not familiar with SS7, Appendix B has a short tutorial on the subject.

SUMMARY

The telephone network provides a wide variety of call processing signals and operations which deal with: supervision, addressing, alerting, call progress, and testing. In order to interface with the telephone network and/or a user legacy telephone, the IP Call Processing Protocols must understand the telephony call processing operations.