Cellular Communications

Definition

A cellular mobile communications system uses a large number of low-power wireless transmitters to create cells—the basic geographic service area of a wireless communications system. Variable power levels allow cells to be sized according to the subscriber density and demand within a particular region. As mobile users travel from cell to cell, their conversations are "handed off" between cells in order to maintain seamless service. Channels (frequencies) used in one cell can be reused in another cell some distance away. Cells can be added to accommodate growth, creating new cells in unserved areas or overlaying cells in existing areas.

Overview

This tutorial discusses the basics of radio telephony systems, including both analog and digital systems. Upon completion of this tutorial, you should be able to accomplish the following:

1. describe the basic components of a cellular system
2. identify and describe digital wireless technologies

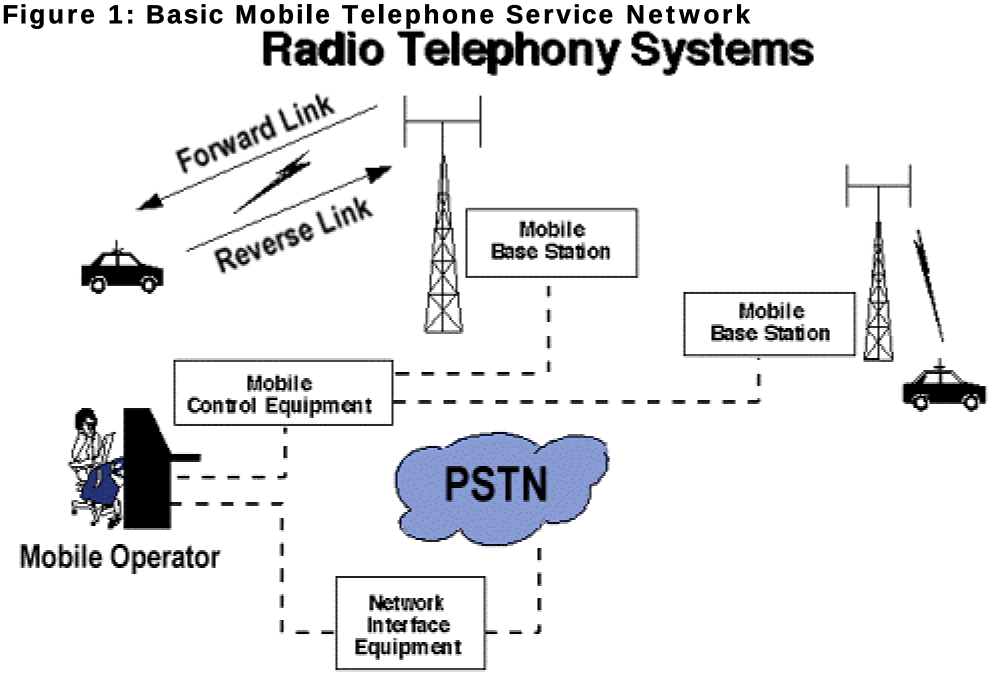
Topics

Acronym Guide

1. Mobile Communications Principles

Each mobile uses a separate, temporary radio channel to talk to the cell site. The cell site talks to many mobiles at once, using one channel per mobile. Channels use a pair of frequencies for communication—one frequency, the forward link, for transmitting from the cell site, and one frequency, the reverse link, for the cell site to receive calls from the users. Radio energy dissipates over distance, so mobiles must stay near the base station to maintain communications. The basic structure of mobile networks include telephone systems and radio services. Where mobile radio service operates in a closed network and has no access to the telephone system, mobile telephone service allows interconnection to the telephone network (see Figure 1).

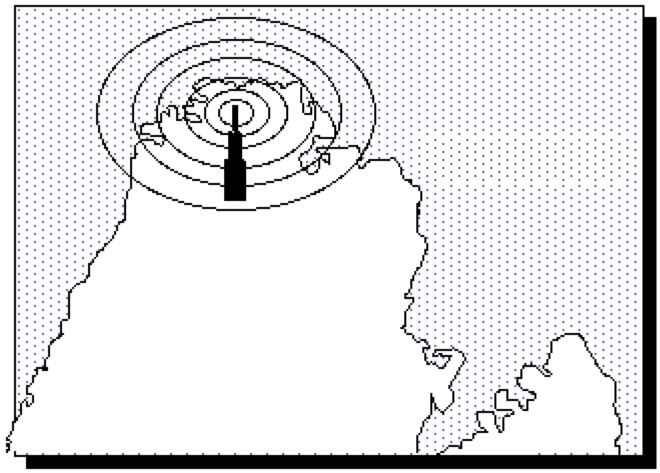
Figure 1: Basic Mobile Telephone Service Network



Early Mobile Telephone System Architecture

Traditional mobile service was structured similar to television broadcasting: One very powerful transmitter located at the highest spot in an area would broadcast in a radius of up to fifty kilometers. The cellular concept" structured the mobile telephone network in a different way. Instead of using one powerful transmitter, many low-power transmitters were placed throughout a coverage area. For example, by dividing a metropolitan region into one hundred different areas (cells) with low-power transmitters using twelve conversations (channels) each, the system capacity theoretically could be increased from twelve conversations—or voice channels using one powerful transmitter—to twelve hundred conversations (channels) using one hundred low-power transmitters. Figure 2 shows a metropolitan area configured as a traditional mobile telephone network with one high-power transmitter.

Figure 2: Early Mobile Telephone System Architecture



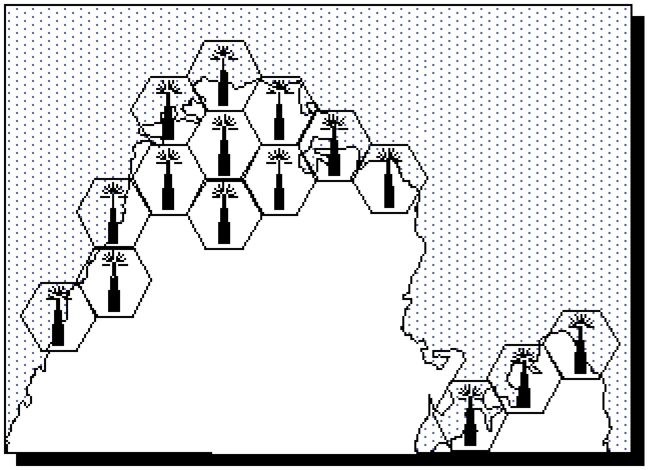
2. Mobile Telephone System Using the Cellular Concept

Interference problems caused by mobile units using the same channel in adjacent areas proved that all channels could not be reused in every cell. Areas had to be skipped before the same channel could be reused. Even though this affected the efficiency of the original concept, frequency reuse was still a viable solution to the problems of mobile telephony systems.

Engineers discovered that the interference effects were not due to the distance between areas, but to the ratio of the distance between areas to the transmitter power (radius) of the areas. By reducing the radius of an area by fifty percent, service providers could increase the number of potential customers in an area fourfold. Systems based on areas with a one-kilometer radius would have one hundred times more channels than systems with areas ten kilometers in radius. Speculation led to the conclusion that by reducing the radius of areas to a few hundred meters, millions of calls could be served.

The cellular concept employs variable low-power levels, which allows cells to be sized according to the subscriber density and demand of a given area. As the population grows, cells can be added to accommodate that growth. Frequencies used in one cell cluster can be reused in other cells. Conversations can be handed off from cell to cell to maintain constant phone service as the user moves between cells (see Figure 3).

Figure 3: Mobile Telephone System Using a Cellular Architecture



The cellular radio equipment (base station) can communicate with mobiles as long as they are within range. Radio energy dissipates over distance, so the mobiles must be within the operating range of the base station. Like the early mobile radio system, the base station communicates with mobiles via a channel. The channel is made of two frequencies, one for transmitting to the base station and one to receive information from the base station.

3. Cellular System Architecture

Increases in demand and the poor quality of existing service led mobile service providers to research ways to improve the quality of service and to support more users in their systems. Because the amount of frequency spectrum available for mobile cellular use was limited, efficient use of the required frequencies was needed for mobile cellular coverage. In modern cellular telephony, rural and urban regions are divided into areas according to specific provisioning guidelines. Deployment parameters, such as amount of cell-splitting and cell sizes, are determined by engineers experienced in cellular system architecture.

Provisioning for each region is planned according to an engineering plan that includes cells, clusters, frequency reuse, and handovers.

Cells

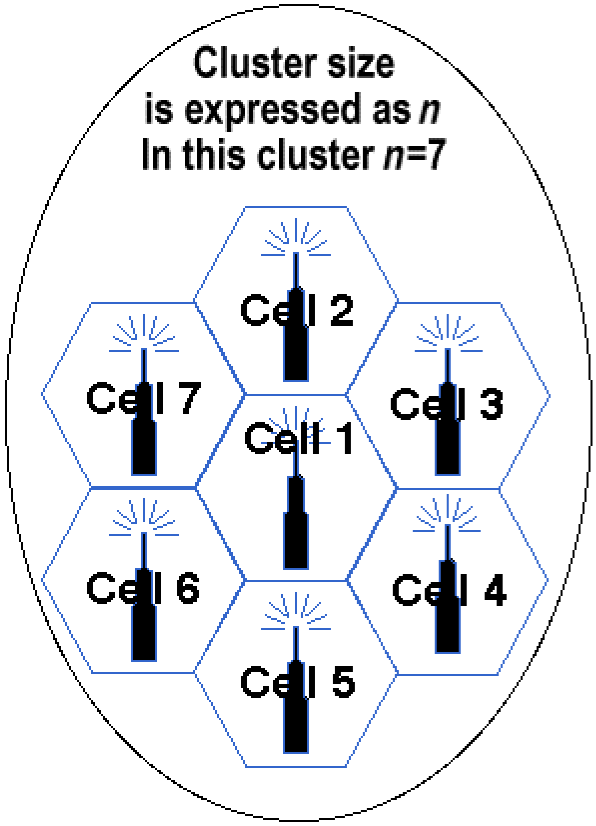
A cell is the basic geographic unit of a cellular system.

The term *cellular* comes from the honeycomb shape of the areas into which a coverage region is divided. Cells are base stations transmitting over small geographic areas that are represented as hexagons. Each cell size varies depending on the landscape. Because of constraints imposed by natural terrain and man-made structures, the true shape of cells is not a perfect hexagon.

Clusters

A cluster is a group of cells. No channels are reused within a cluster. Figure 4 illustrates a seven-cell cluster.

Figure 4: A Seven-Cell Cluster

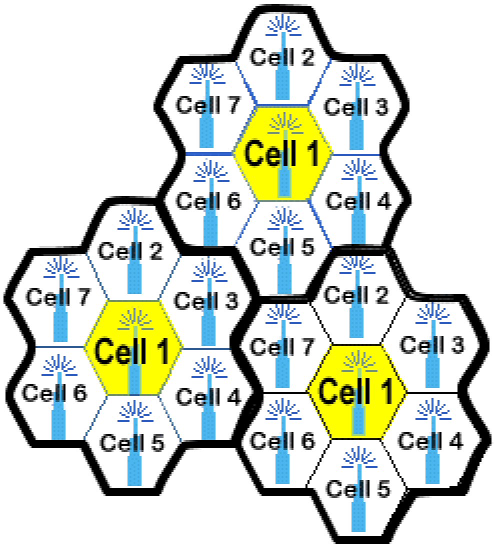


Frequency Reuse

Because only a small number of radio channel frequencies were available for mobile systems, engineers had to find a way to reuse radio channels in order to carry more than one conversation at a time. The solution the industry adopted was called frequency planning or frequency reuse. Frequency reuse was implemented by restructuring the mobile telephone system architecture into the cellular concept.

The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area. Cells are assigned a group of channels that is completely different from neighboring cells. The coverage area of cells are called the footprint. This footprint is limited by a boundary so that the same group of channels can be used in different cells that are far enough away from each other so that their frequencies do not interfere (see Figure 5).

Figure 5: Frequency Reuse

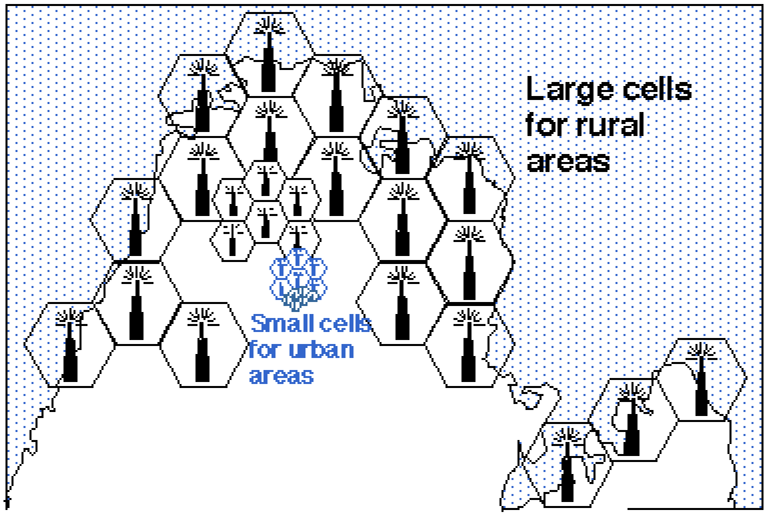


Cells with the same number have the same set of frequencies. Here, because the number of available frequencies is 7, the frequency reuse factor is 1/7. That is, each cell is using 1/7 of available cellular channels.

Cell Splitting

Unfortunately, economic considerations made the concept of creating full systems with many small areas impractical. To overcome this difficulty, system operators developed the idea of cell splitting. As a service area becomes full of users, this approach is used to split a single area into smaller ones. In this way, urban centers can be split into as many areas as necessary in order to provide acceptable service levels in heavy-traffic regions, while larger, less expensive cells can be used to cover remote rural regions (see Figure 6).

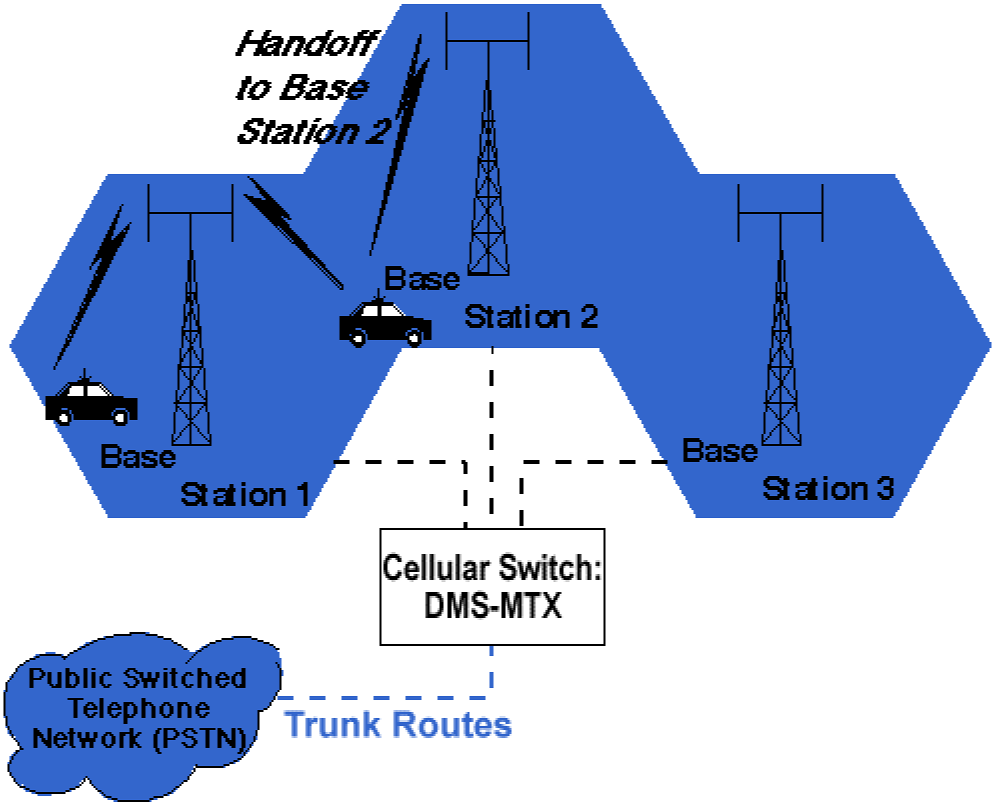
Figure 6: Cell Splitting



Handoff

The final obstacle in the development of the cellular network involved the problem created when a mobile subscriber traveled from one cell to another during a call. As adjacent areas do not use the same radio channels, a call must either be dropped or transferred from one radio channel to another when a user crosses the line between adjacent cells. Because dropping the call is unacceptable, the process of handoff was created. Handoff occurs when the mobile telephone network automatically transfers a call from radio channel to radio channel as a mobile crosses adjacent cells (see Figure 7).

Figure 7: Handoff between Adjacent Cells



During a call, two parties are on one voice channel. When the mobile unit moves out of the coverage area of a given cell site, the reception becomes weak. At this point, the cell site in use requests a handoff. The system switches the call to a stronger-frequency channel in a new site without interrupting the call or alerting the user. The call continues as long as the user is talking, and the user does not notice the handoff at all.

4. North American Analog Cellular Systems

Originally devised in the late 1970s to early 1980s, analog systems have been revised somewhat since that time and operate in the 800-MHz range. A group of government, telco, and equipment manufacturers worked together as a committee to develop a set of rules (protocols) that govern how cellular subscriber units (mobiles) communicate with the "cellular system." System development takes into consideration many different, and often opposing, requirements for the system, and often a compromise between conflicting requirements results. Cellular development involves some basic topics:

1. frequency and channel assignments

2. type of radio modulation
3. maximum power levels
4. modulation parameters
5. messaging protocols
6. call-processing sequences

The Advanced Mobile Phone Service (AMPS)

AMPS was released in 1983 using the 800-MHz to 900-MHz frequency band and the 30 kHz bandwidth for each channel as a fully automated mobile telephone service. It was the first standardized cellular service in the world and is currently the most widely used standard for cellular communications. Designed for use in cities, AMPS later expanded to rural areas. It maximized the cellular concept of frequency reuse by reducing radio power output. The AMPS telephones (or handsets) have the familiar telephone-style user interface and are compatible with any AMPS base station. This makes mobility between service providers (roaming) simpler for subscribers. Limitations associated with AMPS include:

1. low calling capacity
2. limited spectrum
3. no room for spectrum growth
4. poor data communications
5. minimal privacy
6. inadequate fraud protection

AMPS is used throughout the world and is particularly popular in the United States, South America, China, and Australia. AMPS uses frequency modulation (FM) for radio transmission. In the United States, transmissions from mobile to cell site use separate frequencies from the base station to the mobile subscriber.

Narrowband Analog Mobile Phone Service (NAMPS)

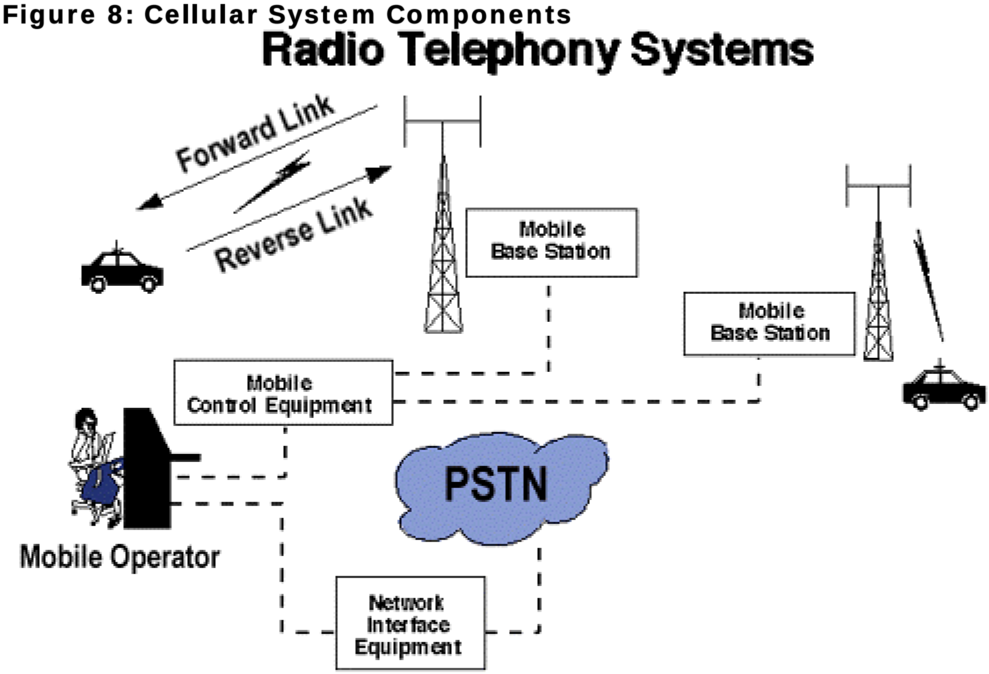
Since analog cellular was developed, systems have been implemented extensively throughout the world as first-generation cellular technology. In the second generation of analog cellular systems, NAMPS was designed to solve the problem of low calling capacity. NAMPS is now operational in 35 U.S. and overseas markets and NAMPS was introduced as an interim solution to capacity problems. NAMPS is a U.S. cellular radio system that combines existing voice processing with digital signaling, tripling the capacity of today's AMPS systems. The NAMPS concept uses frequency division to get three channels in the AMPS 30-kHz single channel bandwidth. NAMPS provides three users in an AMPS channel by dividing the 30-kHz AMPS bandwidth into three 10-kHz channels. This increases the possibility of interference because channel bandwidth is reduced.

5. Cellular System Components

The cellular system offers mobile and portable telephone stations the same service provided fixed stations over conventional wired loops. It has the capacity to serve tens of thousands of subscribers in a major metropolitan area. The cellular communications system consists of the following four major components that work together to provide mobile service to subscribers (see Figure 8):

1. public switched telephone network (PSTN)
2. mobile telephone switching office (MTSO)
3. cell site with antenna system
4. mobile subscriber unit (MSU)

Figure 8: Cellular System Components



PSTN

The PSTN is made up of local networks, the exchange area networks, and the long-haul network that interconnect telephones and other communication devices on a worldwide basis.

Mobile Telephone Switching Office (MTSO)

The MTSO is the central office for mobile switching. It houses the mobile switching center (MSC), field monitoring and relay stations for switching calls from cell sites to wireline central offices (PSTN). In analog cellular networks, the MSC controls the system operation. The MSC controls calls, tracks billing information, and locates cellular subscribers.

The Cell Site

The term *cell site* is used to refer to the physical location of radio equipment that provides coverage within a cell. A list of hardware located at a cell site includes power sources, interface equipment, radio frequency transmitters and receivers, and antenna systems.

Mobile Subscriber Units (MSUs)

The mobile subscriber unit consists of a control unit and a transceiver that transmits and receives radio transmissions to and from a cell site. Three types of MSUs are available:

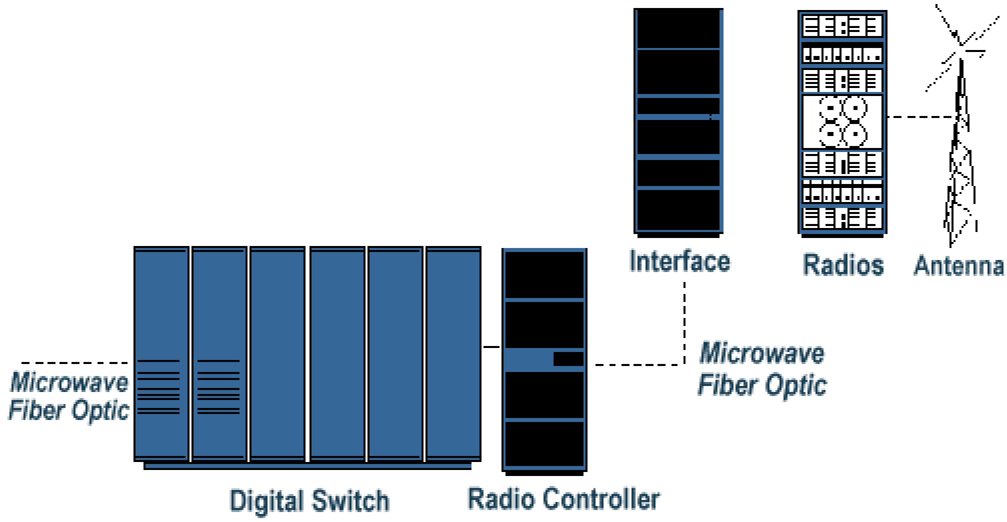
1. the mobile telephone (typical transmit power is 4.0 watts)
2. the portable (typical transmit power is 0.6 watts)
3. the transportable (typical transmit power is 1.6 watts)

The mobile telephone is installed in the trunk of a car, and the handset is installed in a convenient location to the driver. Portable and transportable telephones are hand-held and can be used anywhere. The use of portable and transportable telephones is limited to the charge life of the internal battery.

6. Digital Systems

As demand for mobile telephone service has increased, service providers found that basic engineering assumptions borrowed from wireline (landline) networks did not hold true in mobile systems. While the average landline phone call lasts at least ten minutes, mobile calls usually run ninety seconds. Engineers who expected to assign fifty or more mobile phones to the same radio channel found that by doing so they increased the probability that a user would not get dial tone—this is known as call-blocking probability. As a consequence, the early systems quickly became saturated, and the quality of service decreased rapidly. The critical problem was capacity. The general characteristics of TDMA, GSM, PCS1900, and CDMA promise to significantly increase the efficiency of cellular telephone systems to allow a greater number of simultaneous conversations. Figure 9 shows the components of a typical digital cellular system.

Figure 9: Digital Cellular System



The advantages of digital cellular technologies over analog cellular networks include increased capacity and security. Technology options such as TDMA and CDMA offer more channels in the same analog cellular bandwidth and encrypted voice and data. Because of the enormous amount of money that service providers have invested in AMPS hardware and software, providers look for a migration from AMPS to DAMPS by overlaying their existing networks with TDMA architectures.

Table: AMPS / DAMPS Comparison

	Analog	**Digital**
Standard	EIA–553 (AMPS)	IS–54 (TDMA + AMPS
Spectrum	824 MHz to 891 MHz	824 MHz to 891 MHz
Channel Bandwidth	30 kHz	30 kHz
Channels	21 CC / 395 VC	21 CC / 395 VC
Conversations per Channel	1	3 or 6
Subscriber Capacity	40 to 50 Conversations per cell	125 to 300 Conversations per cell
TX / RCV Type	Continuous	Time shared bursts
Carrier Type	Constant phase Variable frequency	Constant frequency Variable phase
Mobile/Base Relationship	Mobile slaved to base	Authority shared cooperatively
Privacy	Poor	Better—easily scrambled
Noise Immunity	Poor	High
Fraud Detection	ESN plus optional password (PIN)	ESN plus optional password (PIN)

Time Division Multiple Access (TDMA)

North American digital cellular (NADC) is called DAMPS and TDMA. Because AMPS preceded digital cellular systems, DAMPS uses the same setup protocols as analog AMPS. TDMA has the following characteristics:

1. IS–54 standard specifies traffic on digital voice channels
2. Initial implementation triples the calling capacity of AMPS systems
3. Capacity improvements of 6 to 15 times that of AMPS are possible
4. Uses many blocks of spectrum in 800 MHz and 1900 MHz
5. All transmissions are digital
6. TDMA/FDMA application 7. 3 callers per radio carrier (6 callers on half rate later), providing three times the AMPS capacity

TDMA is one of several technologies used in wireless communications. TDMA provides each call with time slots so that several calls can occupy one bandwidth. Each caller is assigned a specific time slot. In some cellular systems, digital packets of information are sent during each time slot and reassembled by the receiving equipment into the original voice components. TDMA uses the same frequency band and channel allocations as AMPS. Like NAMPS, TDMA provides three to six time channels in the same bandwidth as a single AMPS channel. Unlike NAMPS, digital systems have the means to compress the spectrum used to transmit voice information by compressing idle time and redundancy of normal speech. TDMA is the digital standard and has 30-kHz bandwidth. Using digital voice encoders, TDMA is able to use up to six channels in the same bandwidth where AMPS uses one channel.

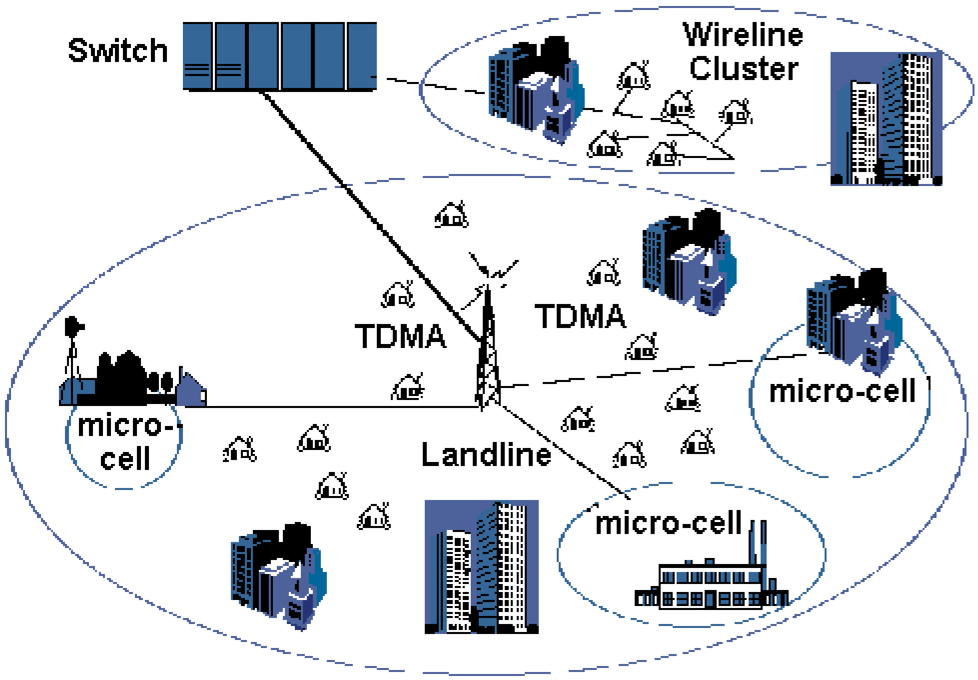
Extended Time Division Multiple Access (E–TDMA)

The extended TDMA (E–TDMA) standard claims a capacity of fifteen times that of analog cellular systems. This capacity is achieved by compressing quiet time during conversations. E–TDMA divides the finite number of cellular frequencies into more time slots than TDMA. This allows the system to support more simultaneous cellular calls.

Fixed Wireless Access (FWA)

Fixed wireless access (FWA) is a radio-based local exchange service in which telephone service is provided by common carriers (see Figure 10). It is primarily a rural application—that is, it reduces the cost of conventional wireline. FWA extends telephone service to rural areas by replacing a wireline local loop with radio communications. Other labels for wireless access include fixed loop, fixed radio access, wireless telephony, radio loop, fixed wireless, radio access, and Ionica. FWA systems employ TDMA or CDMA access technologies.

Figure 10: Fixed Wireless Access



Personal Communications Services (PCS)

The future of telecommunications includes personal communications services. PCS at 1900 MHz (PCS1900) is the North American implementation of DCS1800 (Global System for Mobile communications, or GSM). Trial networks were operational in the United States by 1993, and in 1994 the Federal Communications Commission (FCC) began spectrum auctions. As of 1995, the FCC auctioned commercial licenses. In the PCS frequency spectrum the operator's authorized frequency block contains a definite number of channels. The frequency plan assigns specific channels to specific cells, following a reuse pattern which restarts with each *n*th cell. The uplink and downlink bands are paired mirror images. As with AMPS, a channel number implies one uplink and one downlink frequency: e.g., Channel 512 = 1850.2 MHz uplink paired with 1930.2 MHz downlink.

Code Division Multiple Access (CDMA)

Code division multiple access (CDMA) is a digital air interface standard, claiming eight to fifteen times the capacity of analog. It employs a commercial adaptation of military spread-spectrum single-sideband technology. Based on spread spectrum theory, it is essentially the same as wireline service—the primary difference is that access to the local exchange carrier (LEC) is provided via wireless phone. Because users are isolated by code, they can share the same carrier frequency, eliminating the frequency reuse problem encountered in AMPS and DAMPS. Every CDMA cell site can use the same 1.25 MHz band, so with respect to clusters, n = 1. This greatly simplifies frequency planning in a fully CDMA environment.

CDMA is an interference limited system. Unlike AMPS/TDMA, CDMA has a soft capacity limit; however, each user is a noise source on the shared channel and the noise contributed by users accumulates. This creates a practical limit to how many users a system will sustain. Mobiles that transmit excessive power increase interference to other mobiles. For CDMA, precise power control of mobiles is critical in maximizing the system's capacity and increasing battery life of the mobiles. The goal is to keep each mobile at the absolute minimum power level that is necessary to ensure acceptable service quality. Ideally, the power received at the base station from each mobile should be the same (minimum signal to interference).

Self-Test

1. Interference effects in cellular systems are a result of ____________.

    a. the distance between areas

    b. the power of the transmitters

    c. the ratio of the distance between areas to the transmitter power of the areas

    d. the height of the antennas

2. Larger cells are more useful in ___________________.

    a. densely populated urban areas

    b. rural areas

    c. lightly populated urban areas

    d. mountainous areas

3. The most widely used standard for cellular communications is __________.

    a. the advanced mobile phone service (AMPS)

    b. the mobile subscriber unit (MSU)

    c. the mobile telephone switching office

    d. code division multiple access (CDMA)

4. How many conversations per channel can TDMA digital cellular carry at once?

    a. 1

    b. 2

    c. 3

    d. 10

5. Which of the following is not a limitation of AMPS?

    a. low calling capacity

    b. poor privacy protection

    c. Limited spectrum

    d. wide coverage area

6. Digital cellular technologies offer increased capacity and security.

    a. true

    b. false

7. TDMA, a digital air interface standard, has twice the capacity of analog.

    a. true

    b. false

8. Cells are always hexagonal in shape.

    a. true

    b. false

9. Frequency reuse was maximized by increasing the size of cells.

    a. true

    b. false

10. Fixed wireless access is primarily a rural application.

    a. true

    b. false

Correct Answers

1. Interference effects in cellular systems are a result of _________.

    a. the distance between areas

    b. the power of the transmitters

    c. the ratio of the distance between areas to the transmitter power of the areas

    d. the height of the antennas

    See Topic 2

2. Larger cells are more useful in ______________.

    a. densely populated urban areas

    b. rural areas

    c. lightly populated urban areas

    d. mountainous areas

    See Topic 3

3. The most widely used standard for cellular communications is _______.

    a. the advanced mobile phone service (AMPS)

    b. the mobile subscriber unit (MSU)

    c. the mobile telephone switching office

    d. code division multiple access (CDMA)

See Topic 4

4. How many conversations per channel can TDMA digital cellular carry at once?

    a. 1

    b. 2

    c. 3

    d. 10

    See Topic 6

5. Which of the following is not a limitation of AMPS?

    a. low calling capacity

    b. poor privacy protection

    c. limited spectrum

    d. wide coverage area

    See Topic 4

6. Digital cellular technologies offer increased capacity and security.

    a. true

    b. false

    See Topic 6

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    See Topic 6

8. Cells are always hexagonal in shape.

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See Topic 3

9. Frequency reuse was maximized by increasing the size of cells.

   a. true

   b. false

   See Topic 3

10. Fixed wireless access is primarily a rural application.

    a. true

    b. false

    See Topic 6

Acronym Guide

AMPS
advanced mobile phone service; another acronym for analog cellular radio

BTS
base transceiver station; used to transmit radio frequency over the air interface

CDMA
code division multiple access; a form of digital cellular phone service that is a spread spectrum technology that assigns a code to all speech bits, sends scrambled transmission of the encoded speech over the air, and reassembles the speech to its original format

DAMPS
digital advanced mobile phone service; a term for digital cellular radio in North America

DCS
digital cellular system

ESN
electronic serial number; an identity signal that is sent from the mobile to the MSC during a brief registration transmission

ETDMA
extended TDMA; developed to provide fifteen times the capacity over analog systems by compressing quiet time during conversations

FCC
Federal Communications Commission; the government agency responsible for regulating telecommunications in the United Sates

FCCH
frequency control channel

FDMA
frequency division multiple access; used to separate multiple transmissions over a finite frequency allocation; refers to the method of allocating a discrete amount of frequency bandwidth to each user to permit many simultaneous conversations

FM
frequency modulation; a modulation technique in which the carrier frequency is shifted by an amount proportional to the value of the modulating signal

FRA
fixed radio access

GSM
global system for mobile communications; standard digital cellular phone service in Europe and Japan; to ensure interpretability between countries, standards address much of the network wireless infrastructure, including radio interfaces, switching, signaling, and intelligent networks

Hz
hertz; a measurement of electromagnetic energy, equivalent to one wave or cycle per second

kHz
kilohertz; thousands of hertz.

MHz
megahertz; millions of hertz.

MS or MSU
mobile station unit; handset carried by the subscriber

MSC
mobile services switching center; a switch that provides services and coordination between mobile users in a network and external networks

MTSO
mobile telephone switching office; the central office for the mobile switch, which houses the field monitoring and relay stations for switching calls from cell sites to wireline central offices (PSTN)

MTX
mobile telephone exchange

NADC
North American digital cellular (also called United States digital cellular, or USDC); a time division multiple access (TDMA) system that provides three to six times the capacity of AMPS

NAMPS
narrowband advanced mobile phone service; NAMPS was introduced as an interim solution to capacity problems; NAMPS provides three times the AMPS capacity to extend the usefulness of analog systems

PCS
personal communications service; a lower-powered, higher-frequency competitive technology that incorporates wireline and wireless networks and provides personalized features

PSTN
public switched telephone network; a PSTN is made of local networks, the exchange area networks, and the long-haul network that interconnect telephones and other communication devices on a worldwide basis

RF
radio frequency; electromagnetic waves operating between 10 kHz and 3 MHz propagated without guide (wire or cable) in free space

SIM
subscriber identity module; a smartcard, which is inserted into a mobile phone to get it going

SNSE
supernode size enhanced

TDMA

time division multiple access; used to separate multiple conversation transmissions over a finite frequency allocation of through-the-air bandwidth; used to allocate a discrete amount of frequency bandwidth to each user; to permit many simultaneous conversations, each caller is assigned a specific timeslot for transmission