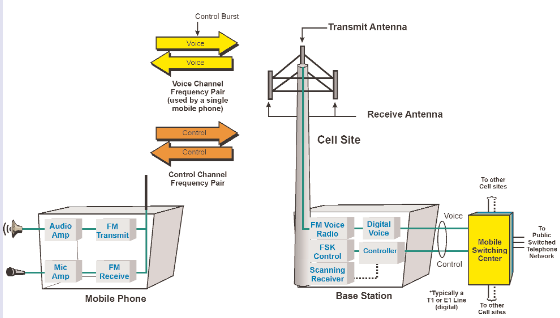
Introduction to Mobile Telephone Systems

1G, 2G, 2.5G, and 3G Wireless Technologies and Services

Lawrence Harte

2nd Edition



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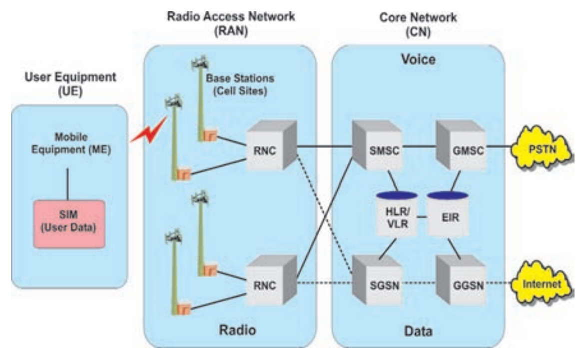
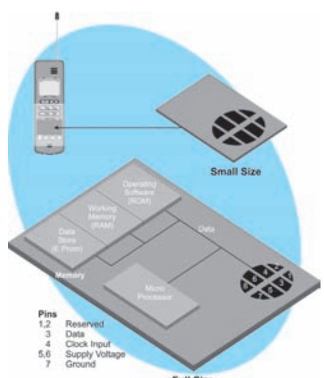
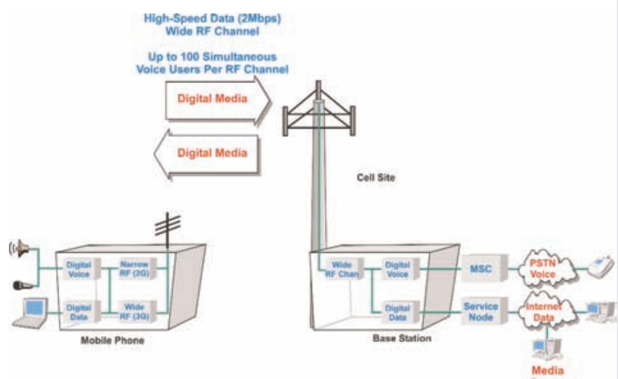


Mobile Telephone System



Subscriber Identity Module
(SIM) Card



3rd Generation (3G)
Broadband Digital

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Table of Contents

MOBILE TECHNOLOGIES 2

Cellular Frequency Reuse 3
Handover 5
Speech Compression 7
Modulation Types 8
Access Multiplexing 9
Frequency Division Multiple Access (FDMA) 10
Time Division Multiple Access (TDMA) 11
Code Division Multiple Access (CDMA) 12
Spatial Division Multiple Access (SDMA) 13
Packet Data 14

MOBILE DEVICES 15

Subscriber Identity Module (SIM) 15
PCMCIA Air Cards 17
Embedded Radio Modules 17
Mobile Telephones 17
External Radio Modems 17

MOBILE SYSTEMS 19

Base Stations 20
Radio Antenna Towers 21
Communication Links 21
Mobile Switching Center (MSC) 22
Authentication, Authorization, and Accounting (AAA) 22
Interworking Function (IWF) 22
Message Center (MC) 23
Serving General Packet Radio Service Support Node (SGSN) 23

Gateway GPRS Support Node (GGSN) 23
Base Station Controller (BSC) 23
Voice Message System (VMS) 24
Public Switched Telephone Network (PSTN) 24
Public Packet Data Network (PPDN) 24
Network Databases 24
Home Location Register (HLR) 25
Visitor Location Register (VLR) 25
Equipment Identity Register (EIR) 25
Billing Center (BC) 26
Authentication Centre (AuC) 26
Number Portability Database (NPDB) 26
IP Backbone Network 27

MOBILE SYSTEM OPERATION 27

Initialization 29
Idle 29
Access Control and Initial Assignment 30
Authentication 31
Paging 32
Connected Mode 32
Packet Data Scheduling Algorithm 33
Registration 34

ANALOG SYSTEMS (1ST GENERATION) 34

Advanced Mobile Phone Service (AMPS) 39
Total Access Communication System (TACS) 40
Nordic Mobile Telephone (NMT) 41
Narrowband AMPS (NAMPS) 43
Japanese Mobile Cellular System (MCS) 44
CNET 45
MATS-E 45

DIGITAL CELLULAR SYSTEMS (2ND GENERATION) 46
Global System for Mobile Communication (GSM) 51
North American TDMA (IS-136 TDMA) 52
Extended TDMA (E-TDMA)TM 54
Integrated Dispatch Enhanced Network (iDEN) 56
Code Division Multiple Access (IS-95 CDMA) 56
Japanese Personal Digital Cellular (PDC) 58

PACKET DIGITAL CELLULAR SYSTEMS (GENERATION 2.5) 59
General Packet Radio Service (GPRS) 60
Enhanced Data Rates for Global Evolution (EDGE) 60
CDMA2000™ 1xRTT 61
Evolution Data Only (1xEVDO) 61
Evolution Data and Voice (1xEVDV) 61

WIDEBAND DIGITAL CELLULAR SYSTEMS (3RD GENERATION) 62
Wideband Code Division Multiple Access (WCDMA) 63
Code Division Multiple Access 2000 (CDMA2000) 64
Time Division Synchronous CDMA (TD-SCDMA) 64

FOURTH GENERATION (4G) NETWORKS 64

MOBILE SERVICES 65
Voice Services 65
Circuit Switched Voice 66
Push to Talk (PTT) 67
Messaging 68
Data Service 68
Circuit Switched Data 69
Packet Switched Data 69
Location Based Services (LBS) 70
Multicast Services 70

Quality of Service (QoS) 70
Conversation Class *71*
Streaming Class *71*
Interactive Class *71*
Background Class *72*

Introduction to Mobile Telephone Systems

Mobile telephone service (MTS) is a type of service where mobile radio telephones connect people to the public switched telephone system (PSTN), to other mobile telephones or to other communication systems (such as to the Internet).

Cellular, personal communication service (PCS), and third generation 3G mobile radio systems are all cellular wireless communication networks that provide for voice and data communication throughout a wide geographic area. Cellular systems divide large geographic areas into small radio areas (cells) that are interconnected with each other. Each cell coverage area has one or several transmitters and receivers that communicate with mobile telephones within its area.

Figure 1.1 shows a basic cellular mobile communications system. The cellular system connects mobile radios (called mobile stations) via radio channels to base stations. Some of the radio channels (or portions of a digital radio channel) are used for control purposes (setup and disconnection of calls) and some are used to transfer voice or customer data signals. Each base station contains transmitters and receivers that convert the radio signals to electrical signals that can be sent to and from the mobile switching center (MSC). The MSC contains communication controllers that adapt signals from base stations into a form that can be connected (switched) between other base stations or to lines that connect to the public telephone network. The switching system is connected to databases that contain active customers (customers active in its system). The switching system in the MSC is coordinated by call processing software that receives requests for service and processes the steps to setup and maintain connections through the MSC to destination communication devices such as to other mobile telephones or to telephones that are connected to the public telephone network.

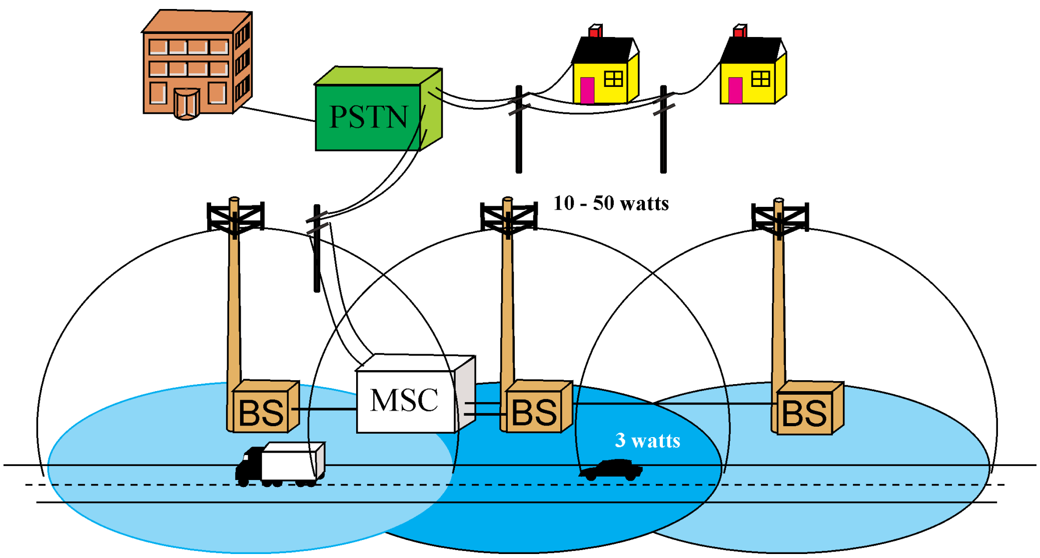

Figure 1.1, Basic Cellular System

Mobile Technologies

The key technologies used in cellular mobile radio include cellular frequency reuse, handover, digital modulation, access technologies and packet data transmission.

Cellular Frequency Reuse

Frequency reuse is the process of using the same radio frequencies on radio transmitter sites within a geographic area that are separated by sufficient distance to cause minimal interference with each other. Frequency reuse allows for a dramatic increase in the number of customers that can be served (capacity) within a geographic area on a limited amount of radio spectrum (limited number of radio channels).

In early mobile radio telephone systems, one high-power transmitter served a large geographic area with a limited number of radio channels. Because each radio channel requires a certain frequency bandwidth (radio spectrum) and there is a very limited amount of radio spectrum available, this dramatically limits the number of radio channels that keeps the low serving capacity of such systems. For example, in 1976, New York City had only 12 radio channels to support 545 customers and a two-year long waiting list of typically 3,700 [1].

To conserve the limited amount of radio spectrum (maximum number of available radio channels), the cellular system concept was developed. Cellular systems allow reuse of the same channel frequencies many times within a geographic coverage area. The technique (called frequency reuse) makes it possible for a system to provide service to more customers (called system capacity) by reusing the channels that are available in a geographic area. In large systems such as the systems operating in New York City and Los Angeles, radio channel frequencies may be reused over 300 times. As systems start to become overloaded with many users, to increase capacity, the system can expand by adding more radio channels to the base station or by adding more cell cites with smaller coverage areas.

To minimize interference in this way, cellular system planners position the cell sites that use the same radio channel farthest away from each other. The distances between sites are initially planned by general RF signal propagation rules. It is difficult to account for enough propagation factors to precisely position the towers, which usually leads the cell site position and power levels to be adjusted later.

Figure 1.2 shows that radio channels (frequencies) in a cellular communication system can be reused in towers that have enough distance between them. This example shows that radio channel signal strength decreases exponentially with distance. As a result, mobile radios that are far enough apart can use the same radio channel frequency with minimal interference.

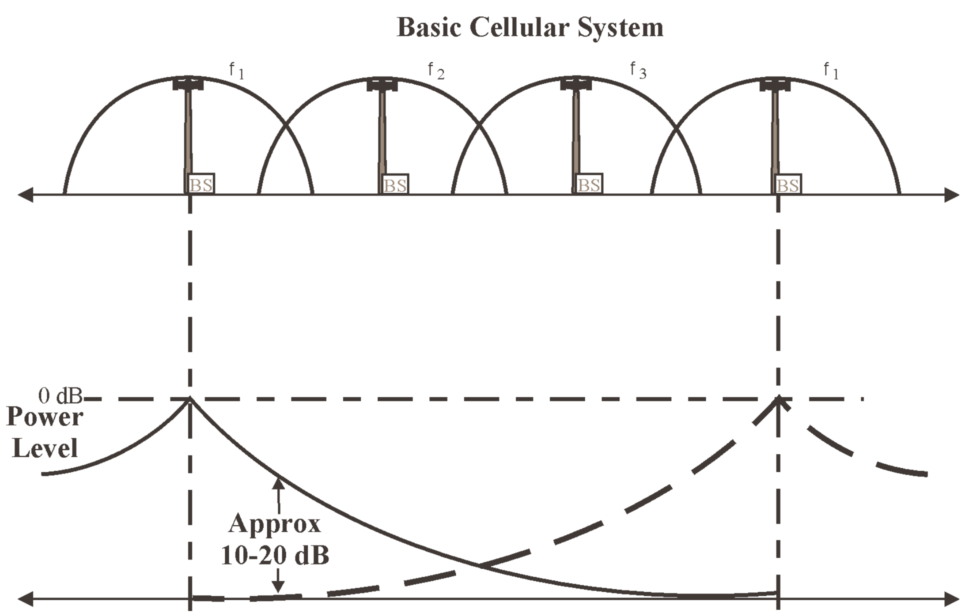

Figure 1.2, Frequency Reuse

The acceptable distance between cells that use the same channels are determined by the distance to radius (D/R) ratio. The D/R ratio is the ratio of the distance (D) between cells using the same radio frequency to the radius (R) of the cells. In today's analog system, a typical D/R ratio is 4.6:1, which means a channel used in a cell with a 1-mile radius would not interfere with the same channel being reused at a cell 4.6 miles away. For some of the digital systems (such as TDMA or GSM), the reuse factor can be lower than 2.0.

Another technique, called cell splitting, helps to expand capacity gradually. Cells are split by adjusting the power level and/or using reduced antenna height to cover a reduced area. Reducing a coverage area by changing the RF boundaries of a cell site has the same effect as placing cells farther apart, and allows new cell sites to be added. However, the boundaries of a cell site vary with the terrain and land conditions, especially with seasonal variations in foliage. Coverage areas can actually increase in fall and winter as the leaves fall from the trees.

When a cellular system is first established, it can effectively serve only a limited number of callers. When that limit is exceeded, callers experience system busy signals (known as blocking) and their calls cannot be completed. More callers can be served by adding more cells with smaller coverage areas - that is, by cell splitting. The increased number of smaller cells provides more available radio channels in a given area because it allows radio channels to be reused at closer geographical distances.

When linked together to cover an entire metro area, the radio coverage areas (called cells) form a cellular structure resembling that of a honeycomb. Cellular systems are designed to overlap each cell border with adjacent cell borders to enable a “handover” from one cell to the next. As a customer (called a subscriber) moves through a cellular system, the mobile switching center (MSC) coordinates and transfers calls from one cell to another and maintains call continuity.

Handover

Handover is a process where a mobile radio operating on a particular channel is reassigned to a new channel. The process is often used to allow subscribers to travel throughout the large radio system coverage area by switching the calls (handover) from cell-to-cell (and different channels) with better coverage for that particular area when poor quality conversation is detected.

Handover (also called handoff) is necessary for two reasons. First, where the mobile unit moves out of range of one cell site and is within range of another cell site. Second, a handover may be required when the mobile has requested the services of a type of cellular channel that different capabilities (e.g. packet data). This might mean assignment from a digital channel to an analog channel or assignment from a wide digital channel to a packet data channel.

Figure 1.3 shows the basic handoff process that occurs in a mobile telephone system. In this example, the system has determined that the radio signal strength of mobile telephone has fallen below a predefined level. When this occurs, the serving base station sends a control message to the system indicating that the signal quality of the mobile's radio signal is declining and a handover may be necessary. The system determines that an adjacent cell site is a candidate for the handoff and it sends command messages to the adjacent cell site to prepare to receive a new connection. Messages are exchanged between the base stations and the mobile device that informs it to change to a new channel and the MSC switches the audio path to the new cell site when necessary.

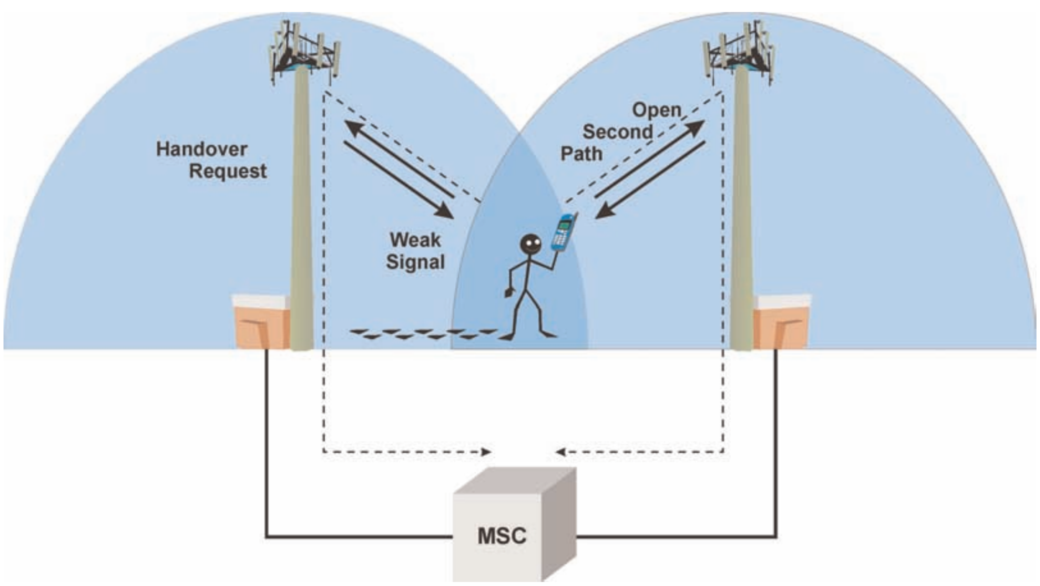

Figure 1.3, Handover Operation

Speech Compression

Speech compression is a technique for converting or encoding audio (sound) information so that a smaller amount of information elements or reduced bandwidth is required to represent, store or transfer audio signals.

Figure 1.4 shows the basic digital speech compression process. The first step is to periodically sample the analog voice signal (5 - 20 msec) into pulse code modulated (PCM) digital form (usually 64 kbps). This digital signal is analyzed and characterized (e.g. volume, pitch) using a speech coder. The speech compression analysis usually removes redundancy in the digital signal (such as silence periods) and attempts to ignore patterns that are not characteristic of the human voice. In this example, these speech compression processes use pre-stored codebook tables that allow the speech coder to transmit abbreviated codes that represent larger (probable) digital speech patterns. The result is a digital signal that represents the voice content, not a waveform. The end result is a compressed digital audio signal that is 8-13 kbps instead of the 64 kbps PCM digitized voice.

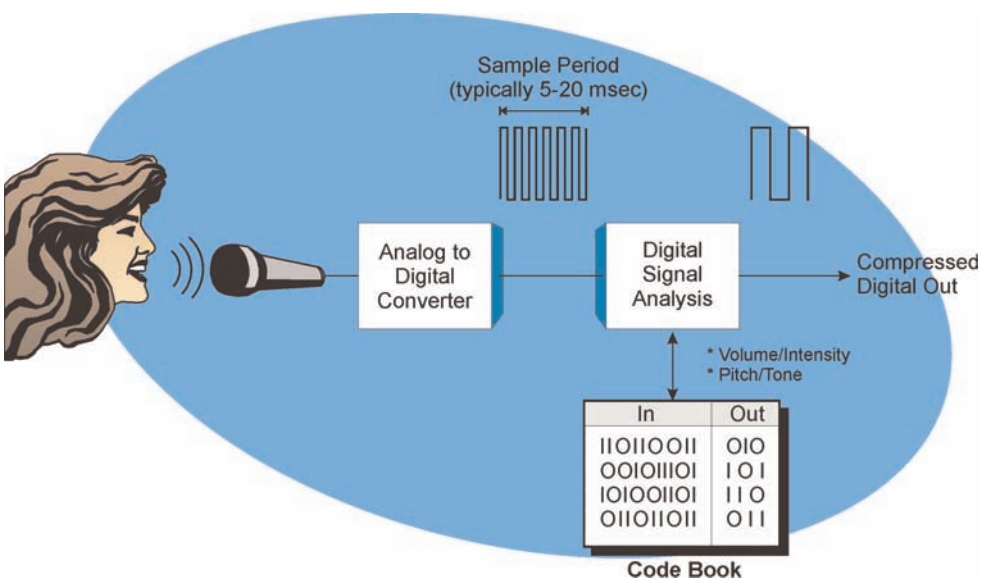

Figure 1.4, Speech Coding

Modulation Types

Modulation is the process of changing the amplitude, frequency, or phase of a radio frequency carrier signal (a carrier) to change with the information signal (such as voice or data). Mobile systems use analog or digital modulation.

Analog modulation is a process where the amplitude, frequency or phase of a carrier signal is varied directly in proportion or in direct relationship to the information signal. Digital modulation is a process where the amplitude, frequency or phase of a carrier signal is varied by the discrete states (on and off) of a digital signal. Mobile telephone systems primarily use digital modulation.

To increase the efficiency of mobile telephone systems, it is desirable to send more information with less frequency bandwidth (more information transported by the carrier signal). Modulation efficiency is a measure of how much information can be transferred onto a carrier signal. In general, more efficient modulation processes require smaller changes in the characteristics of a carrier signal (amplitude, frequency, or phase) to represent the information signal. To increase the amount of information that can be transported on a carrier signal, it is possible to use (combine) multiple forms of modulation on the same carrier wave (e.g. use both amplitude and phase modulation).

Figure 1.5 shows different forms of digital modulation. This diagram shows ASK modulation that turns the carrier signal on and off with the digital signal. FSK modulation shifts the frequency of the carrier signal according to the on and off levels of the digital information signal. The phase shift modulator changes the phase of the carrier signal in accordance with the digital information signal. This diagram also shows that advanced forms of modulation such as QAM can combine amplitude and phase of digital signals.

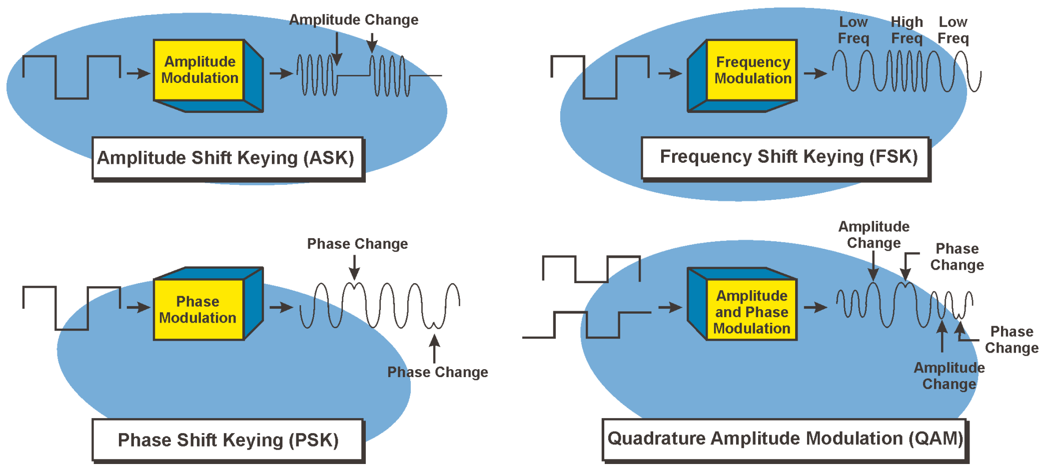

Figure 1.5, Digital Modulation

Access Multiplexing

Access multiplexing is a process used by a communications system to coordinate and allow more than one user to access the communication channels within the system. There are four basic access-multiplexing technologies used in wireless systems: frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA) and space division multiple access (SDMA). Other forms of access multiplexing (such as voice activity multiplexing) use the fundamentals of these access-multiplexing technologies to operate.

Frequency Division Multiple Access (FDMA)

Frequency division multiple access is a process of allowing mobile radios to share radio frequency allocation by dividing up that allocation into separate radio channels where each radio device can communicate on a single radio channel during communication.

Figure 1.6 shows how a frequency band can be divided into several communication channels using frequency division multiplexing (FDM). When a device is communicating on a FDM system using a frequency carrier signal, its carrier channel is completely occupied by the transmission of the device. For some FDM systems, after it has stopped transmitting, other transceivers may be assigned to that carrier channel frequency. When this process of assigning channels is organized, it is called frequency division multiple access (FDMA). Transceivers in an FDM system typically have the ability to tune to several different carrier channel frequencies.

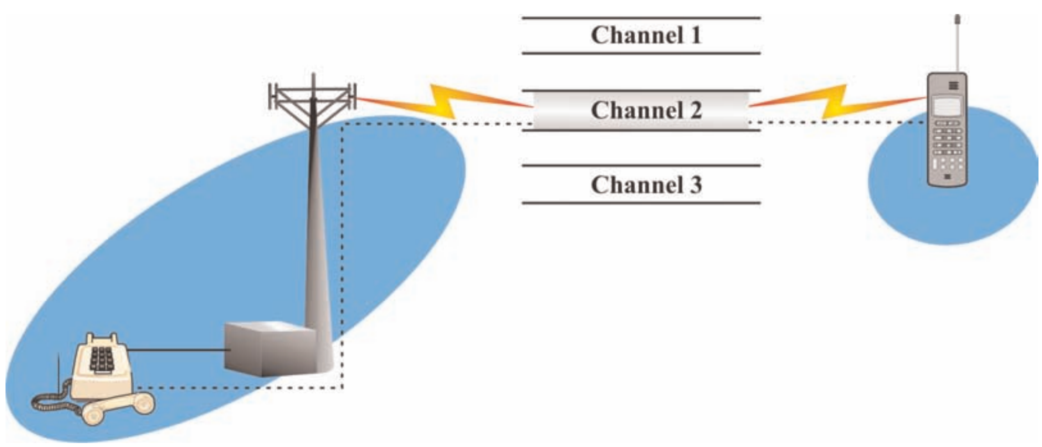

Figure 1.6, Frequency Division Multiple Access

Time Division Multiple Access (TDMA)

Time division multiple access (TDMA) is a process of sharing a single radio channel by dividing the channel into time slots that are shared between simultaneous users of the radio channel. When a mobile radio communicates with a TDMA system, it is assigned a specific time position on the radio channel. By allowing several users to use different time positions (time slots) on a single radio channel, TDMA systems increase their ability to serve multiple users with a limited number of radio channels.

Figure 1.7 shows how a single carrier channel is time-sliced into three communication channels. Transceiver number 1 is communicating on time slot number 1 and mobile radio number 2 is communicating on time slot number 3. Each frame on this communication system has three time slots.

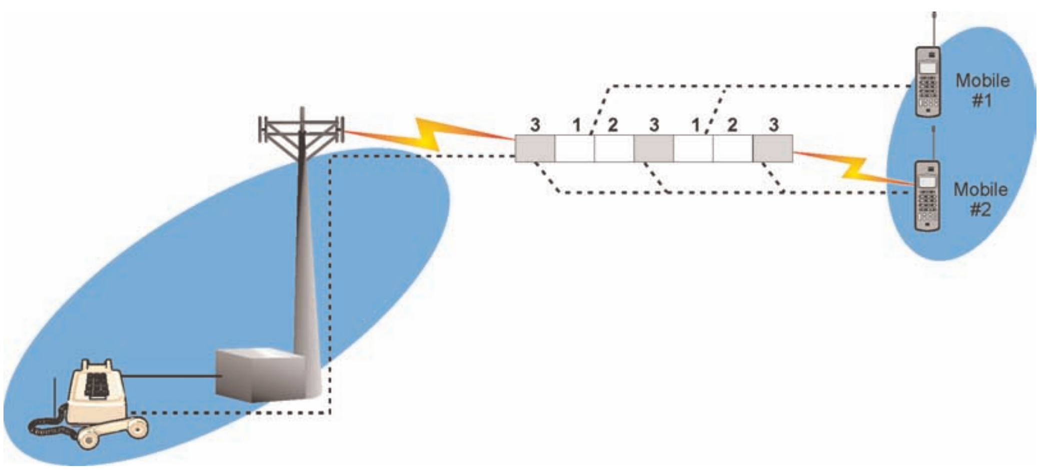

Figure 1.7, Time Division Multiple Access (TDMA)

Code Division Multiple Access (CDMA)

Code division multiple access (CDMA) is the sharing of a radio channel by multiple users by share adding a unique code for each data signal that is being sent to and from each of the radio transceivers. These codes are used to spread the data signal to a bandwidth much wider than is necessary to transmit the data signal without the code.

Figure 1.8 shows how CDMA radio channels can provide multiple communication channels through the use of multiple coded channels. This diagram shows that a code pattern mask is used to decode each communication channel. The channel mask is shifted along the radio channel until the code chips (or a majority of the code chips) match the expected code pattern. When a match occurs, this produces a single bit of information (a logical 1 or 0). This example shows that the use of multiple code patterns (multiple masks in this example) allow multiple users to share the same radio channel.

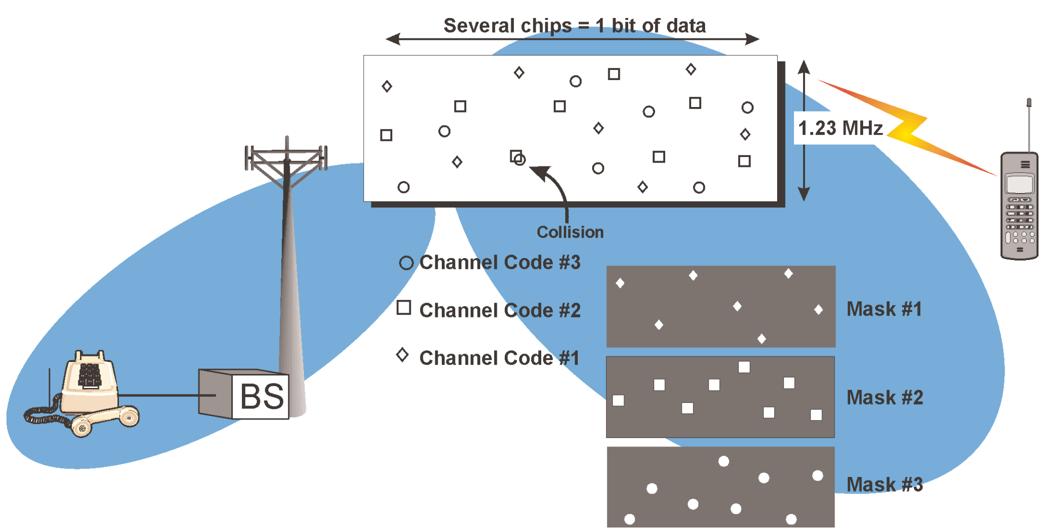

Figure 1.8, Code Division Multiple Access (CDMA)

Spatial Division Multiple Access (SDMA)

Spatial division multiple access (SDMA) is a system access technology that allows a single transmitter location to provide multiple communication channels by dividing the radio coverage into focused radio beams that reuse the same frequency. To allow multiple access, each mobile radio is assigned to a focused radio beam. These radio beams may dynamically change with the location of the mobile radio. SDMA technology has been successfully used in satellite communications for several years.

Figure 1.9 shows an example of an SDMA system. Diagram (a) shows the conventional sectored method for communicating from a cell site to a mobile telephone. This system transmits a specific frequency to a defined (sectored) geographic area. Diagram (b) shows a top view of a cell site that uses SDMA technology that is communicating with multiple mobile telephones operating within the same geographic area on a single frequency. In the SDMA system, multiple directional antennas or a phased array antenna system directs independent radio beams to different directions. As the mobile telephone moves within the sector, the system either switches to an alternate beam (for a multi-beam system) or adjusts the beam to the new direction (in an adaptive system).

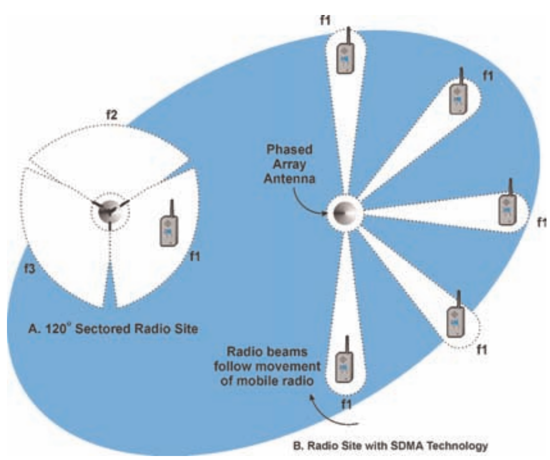

Figure 1.9, Spatial Division Multiple Access (SDMA)

Packet Data

Packet data is the sending of data through a network in small packets (typically under 1000 bytes of information per packet). A packet data system divides large quantities of data into small packets for transmission through a switching network that uses the addresses of the packets to dynamically route these packets through a switching network to their ultimate destination. When a data block is divided, the packets are given sequence numbers so that a packet assembler/disassembler (PAD) device can recombine the packets to the original data block after they have been transmitted through the network.

To send packet data on mobile networks, the system is designed to coordinate the dynamic assignment and reception of radio packets. The wireless system is connected to packet switching nodes. Packet switching nodes in GSM systems are called GPRS Support Nodes (GSNs). GSNs receive and forward data packets toward their destination.

To add packet radio and packet data switching to a mobile system, this system can be separated into two separate parts; a voice part and a packet data part. The voice part connects voice calls to a single location using a circuit switched connection (circuit path). The packet data part dynamically routes packets towards their destination depending on the address that is contained in the data packet.

Figure 1.10 shows a simplified functional diagram of a mobile network that is capable of combining voice and packet data services. This diagram shows that the packet data network is attached to the base station in an addition to the switched voice system and the voice and packet switched data systems that share a common radio access network. The base station (BS) contains a radio transceiver (radio and transmitter) that converts the radio signal into data signals (data and digital voice) that can transfer through the network. The base station separates the radio channel data so the voice data is sent to the voice switching system (the MSC) and the data packets are sent to the packet data system (GSN).

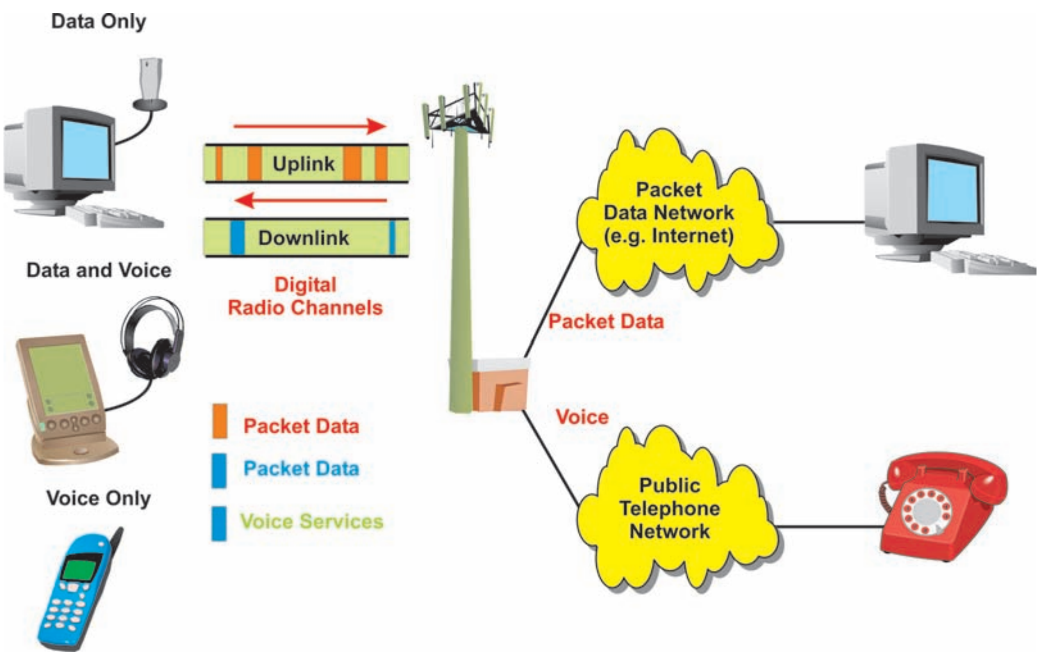

Figure 1.10, Packet Mobile System

Mobile Devices

Mobile devices (also called access terminals) are input and output devices that are used to communicate with a radio site (base stations). Mobile devices may include removable subscriber identity modules (SIMs) that hold service subscription information. The common types of available mobile devices include external radio modems, PCMCIA cards, radio modules, and dual mode mobile telephones.

Subscriber Identity Module (SIM)

The subscriber identity module (SIM) is a small “information” card that contains service subscription identity and personal information. This information includes a phone number, billing identification information and a small amount of user specific data (such as feature preferences and short messages). This information is stored in the card rather than programming this information into the phone itself. This intelligent card, either credit card-sized (ISO format), or the size of a postage-stamp (Plug-In format), can be inserted into any SIM ready wireless telephone.

Figure 1.11 shows a block diagram of a SIM. This diagram shows that SIM cards have 8 electrical contacts. This allows for power to be applied to the electronic circuits inside the card and for data to be sent to and from the card. The card contains a microprocessor that is used to store and retrieve data. Identification information is stored in the cards protected memory that is not accessible by the customer. Additional memory is included to allow features or other information such as short messages to be stored on the card.

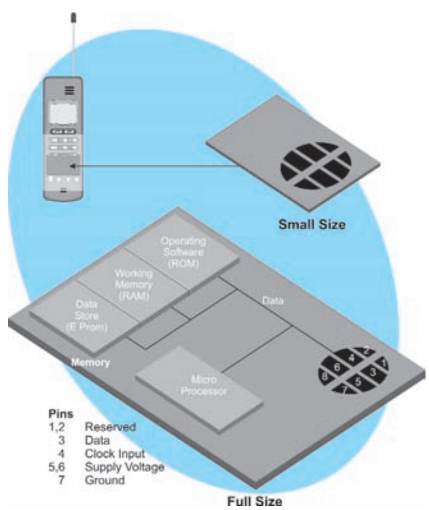

Figure 1.11, Subscriber Identity Module (SIM) Block Diagram

PCMCIA Air Cards

The PCMCIA card uses a standard physical and electrical interface that is used to connect memory and communication devices to computers, typically laptops. The physical card sizes are similar to the size of a credit card 2.126 inches (51.46 mm) by 3.37 inches (69.2 mm) long. There are 4 different card thickness dimensions: 3.3 (type 1), 5.0 (type 2), 10.5 (type 3), and 16 mm (type 4). WCDMA PCMCIA radio cards can be added to most laptop computers to avoid the need of integrating or attaching radio devices.

Embedded Radio Modules

Embedded radio modules are self-contained electronic assemblies that may be inserted or attached to other electronic devices or systems. Embedded radio modules may be installed in computing devices such as personal digital assistants (PDAs), laptop computers, and other types of computing devices that can benefit from wireless data and/or voice connections.

Mobile Telephones

Mobile telephones are radio transceivers (combined transmitter and receive) that convert signals between users (typically people, but not always) and radio signals. Mobile telephones can vary from simple voice units to advanced multimedia personal digital assistants (PDAs).

External Radio Modems

External radio modems are self-contained radios with data modems that allow the customer to simply plug the radio device to their USB or Ethernet data port on their desktop or laptop computer. External modems are commonly connected to computers via standard connections such as universal serial bus (USB) or RJ-45 Ethernet connections.

To allow for the conversion from analog systems to digital systems, some mobile systems allow for the use of dual mode or multi-mode mobile radios. These mobile radios may be capable of operating on an analog or digital radio channel or on multiple types of digital channels, depending on whichever is available. Most dual mode phones prefer to use the most recent version of digital radio channels in the event both are available (e.g. 3G is preferred over 2G). This allows them to take an advantage of the additional capacity and new features such as short messaging and digital voice quality, as well as offering greater capacity.

Figure 1.12 shows the common types of mobile devices available to customers. This diagram shows that the product types available for mobile systems include dual mode and single mode mobile telephones, PCMCIA data cards, integrated (embedded) radio modules and external radio modems. Mobile telephones may be capable of operating on voice and analog radio channels or on the data only channels "dual mode". PCMCIA data cards may allow for both data and voice operations when inserted into portable communications devices such as laptops or personal digital assistants (PDAs). Small radio assemblies may be integrated (embedded) into other devices such as laptop computers or custom communication devices. External modems may be used to provide data services to fixed users (such as desktop computers).

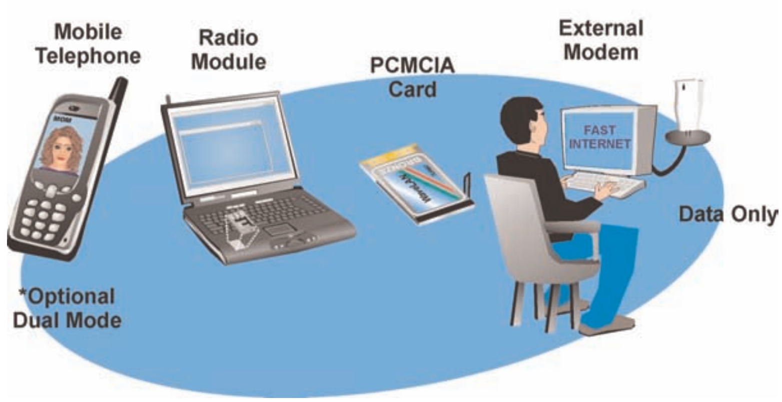

Figure 1.12 Mobile Product Types

Mobile Systems

Mobile systems are composed of include base stations (BS), switching systems and various data processing functions. The radio system portion of mobile networks is called a radio access network (RAN).

Mobile networks inter-connect wireless devices with nearby radio towers that route calls through switching systems to other wireless telephones to other telephones or data networks. Creating and managing a wireless network involves equipment selection and installation, implementation methods, inter-connection to the public switched telephone network (PTSN) and other networks such as the Internet.

The mobile system uses either a mobile switching center (MSC) for voice and medium-speed data or a packet data service node (PDSN) for packet data services. The MSC coordinates the overall allocation and routing of calls throughout the wireless system. The PDSN ensures packets from the mobile devices can reach their destination.

Figure 1.13 shows a simplified functional diagram of a mobile network. This diagram shows that the mobile system is composed of 3 key parts; the user equipment (UE), radio access network (RAN) and a core interconnecting network (CN). The UE is divided into 2 parts, the mobile equipment (ME) and the subscriber identity module (SIM) card. The RAN is composed of base stations and base station controllers (BSCs). This example shows that the BSCs connect voice calls to mobile switching centers (MSCs) and connects data sessions to packet data service nodes (PDSNs). The core network is basically divided into circuit switched (primarily voice) and packet switched (primarily data) parts. The core network circuit switch parts contain the serving MSC (SMSC) and a gateway MSC (GMSC). The serving SMSC connects to the RAN system and the gateway GMSC connects to the public telephone network. The core network packet switched parts contain the serving general packet radio service (GPRS) support node (SGSN) and a gateway GPRS service node (GGSN). The SGSN connects to the RAN system and the GGSN connects to data networks such as the Internet.

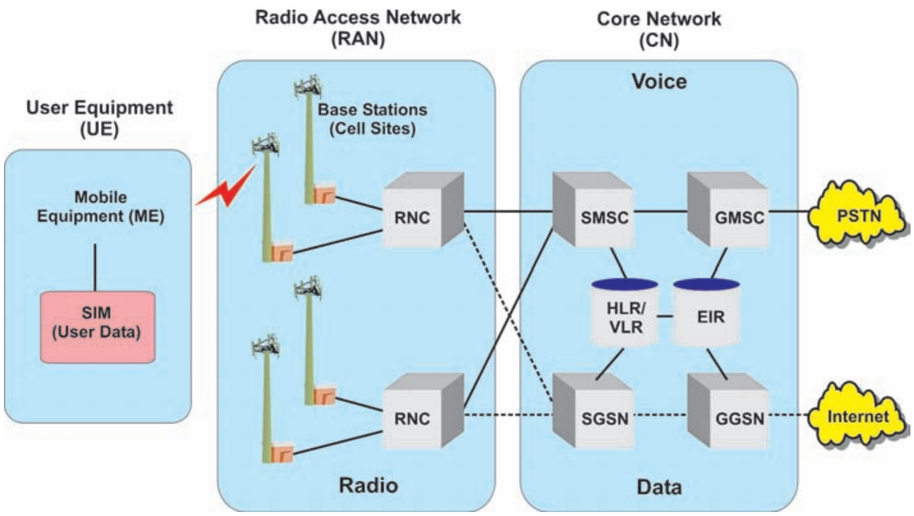

Figure 1.13, Mobile Network

Base Stations

Base stations may be stand alone transmission systems or part of a cell site and is composed of an antenna system (typically a radio tower), building, and base station radio equipment. Base station radio equipment consists of RF equipment (transceivers and antenna interface equipment), controllers, and power supplies. Base station transceivers have many of the same basic parts as a mobile device. However, base station radios are coordinated by the mobile system's BSC and have many additional functions than a mobile device.

The radio transceiver section is divided into transmitter and receiver assemblies. The transmitter section converts a voice or data signal to RF for transmission to wireless devices and the receiver section converts RF from the wireless device to voice or data signals routed to the MSC or packet switching network. The controller section commands insertion and extraction of signaling information.

Unlike end user wireless devices (such as a mobile telephone or laptop computer), the transmitter, receiver, and control sections of an access point may be grouped into equipment racks. For example, a single equipment rack may contain all of the RF amplifiers or voice channel cards. Unlike analog or early-version digital cellular systems that dedicated one transceiver in each base station for a control channel, the mobile system combines control channels and voice channels are mixed on a single physical radio channel.

Radio Antenna Towers

Wireless base station antenna heights can vary from a few feet to more than three hundred feet. Radio towers raise the height of antennas to provide greater area coverage. There may be several different antenna systems mounted on the same radio tower. These other antennas may be used for paging systems, a point to point microwave communication link, or land mobile radio (LMR) dispatch systems. Shared use of towers by different types of radio systems in this way are very common due to the economies realized by sharing the cost of the tower and shelter. However, great care must be taken in the installation and testing to avoid mutual radio interference between the various systems.

Communication Links

Communication links carry both data and digital voice information between the base station and the mobile network. The physical connection options for communication links include copper wire, microwave radio, or fiber optic links. Duplicate and/or alternate communication links are sometimes used to help ensure communication may continue in the event of the failure of a communication line (such as when a cable seeking backhoe cuts a line).

Mobile Switching Center (MSC)

The mobile switching center (MSC) processes requests for service from mobile devices and land line callers, and routes calls between the base stations and the public switched telephone network (PSTN). The MSC receives the dialed digits, creates and interprets call-processing tones, and routes the call paths.

Authentication, Authorization, and Accounting (AAA)

Authentication, Authorization, and Accounting are the processes used in validating the claimed identity of an end user or a device, such as a host, server, switch, or router in a communication network. Authentication is a process of exchanging information between a communications device (typically a user device such as a mobile phone or computing device) and a communications network that allows the carrier or network operator to confirm the true identity of the user (or device). Authorization is the act of granting access rights to a user, groups of users, system, or a process. Accounting is the method to establish who, or what, performed a certain action, such as tracking user connection and logging system users.

Interworking Function (IWF)

Interworking functions are systems and/or processes that attach to a communications network that is used to process and adapt information between dissimilar types of network systems. IWFs in the mobile system may include data gateways that convert circuit switched data from the MSC to the Internet.

Message Center (MC)

The message center is a node or network function within a communications network that accommodates messages sent and received via short messaging service (SMS).

Serving General Packet Radio Service Support Node (SGSN)

A serving general packet radio service support node is a switching node that coordinates the operation of packet radios that are operating within its service coverage range. The SGSN operates in a similar process of a MSC and a VLR, except the SGSN performs packet switching instead of circuit switching. The SGSN registers and maintains a list of active packet data radios in its network and coordinates the packet transfer between the mobile radios.

Gateway GPRS Support Node (GGSN)

A gateway GPRS support node is a packet switching system that is used to connect a GPRS packet data communication network to other packet networks such as the Internet.

Base Station Controller (BSC)

A base station controller is an automatic coordinator (controller) in a mobile system that allows one or more base transceiver stations (BTS) to communicate with a mobile switching center and/or a packet data communication system. A BSC is called a Radio Network Controller (RNC) in the WCDMA system.

Voice Message System (VMS)

The voice mail system is a telecommunications system that allows a subscriber to receive and play back messages from a remote location (such as a PBX telephone or mobile phone). The VMS consists primarily of memory storage (for messages), telephone interfaces (to connect to the communication system), and message recording, playback, and control features (typically via DTMF tones).

Public Switched Telephone Network (PSTN)

Public switched telephone networks are communication systems that are available to the public to allow users to interconnect communication devices. Public telephone networks within countries and regions are standard integrated systems of transmission and switching facilities, signaling processors, and associated operations support systems that allow communication devices to communicate with each other when they operate.

Public Packet Data Network (PPDN)

A packet data network is a network that is generally available for commercial users (the public). An example of a PPDN is the Internet.

Network Databases

Network databases are information storage and retrieval systems that are accessible by a network. There are many network databases in the mobile network. Some of the key network databases include a master subscriber database (home location register), temporary active user subscriber database (visitor location register), an unauthorized or suspect user database (equipment identity register), billing database, and authorization and validation center (authentication).

Home Location Register (HLR)

The home location register (HLR) is a subscriber database containing each customer's international mobile subscriber identity (IMSI) and international mobile equipment identifier (IMEI) to uniquely identify each customer. There is usually only one HLR for each carrier even though each carrier may have many MSCs.

The HLR holds each customer's user profile which includes the selected long distance carrier, calling restrictions, service fee charge rates, and other selected network options. The subscriber can change and store the changes for some feature options in the HLR (such as call forwarding.) The MSC system controller uses this information to authorize system access and process individual call billing.

The HLR is a magnetic storage device for a computer (commonly called a hard disk). Subscriber databases are critical, so they are usually regularly backed up, typically on tape or CDROM, to restore the information if the HLR system fails.

Visitor Location Register (VLR)

The visitor location register (VLR) contains a subset of a subscriber's HLR information for use while a mobile telephone is active on a particular MSC. The VLR holds both visiting and home customer's information. The VLR eliminates the need for the MSC to continually check with the mobile telephone's HLR each time access is attempted. The user's required HLR information is temporarily stored in the VLR memory and then erased either when the wireless telephone registers with another MSC , registers in another system or after a specified period of inactivity.

Equipment Identity Register (EIR)

The equipment identity register is a database that contains the identity of telecommunications devices (such as wireless telephones) and the status of these devices in the network (such as authorized or not-authorized). The EIR is primarily used to identify wireless telephones that may have been stolen or have questionable usage patterns that may indicate fraudulent use. The EIR has three types of lists; white, black and gray. The white list holds known good mobile devices. The black list holds invalid (barred) mobile device. The gray list holds mobile devices that may be suspect for fraud or are being tested for validation.

Billing Center (BC)

A separate database (called the billing center) keeps records on billing. The billing center receives individual call records from MSCs and other network equipment. The switching records (connection and data transfer records) are converted into call detail records (CDRs) that hold the time, type of service, connection points, and other details about the network usage that is associated with a specific user identification code. These billing records are then transferred via tape or data link to a separate computer typically by electronic data interchange (EDI) to a billing system or company that can settle bills between different service providers (a clearinghouse company).

Authentication Centre (AuC)

The Authentication Centre stores and processes information that is required to validate (authenticate) the identity of a wireless device before service is provided. During the authentication procedure, the AuC provides information to the system to allow it to validate the mobile device.

Number Portability Database (NPDB)

Number portability is the ability for a telephone number to be transferred between different service providers. This allows customers to change service providers without having to change telephone numbers. Number portability involves three key elements: local number portability, service portability and geographic portability. To enable number portability, the mobile system maintains a number portability database (NPDB). This database helps to route calls to their destination which may have an assigned telephone number that is different (number has been ported) than the destination phone number.

IP Backbone Network

A backbone network is the core infrastructure of a network that connects several major network components together. A backbone system is usually a high-speed communications network such as ATM or FDDI. The mobile system uses a backbone network that can provide end-to-end IP transmission capability.

Backbone network is a communications network that connects the primary switches or nodes within the network. The backbone network is usually composed of high-speed switches and communication lines.

The focus on using IP communication allows carriers to use off-the-shelf IP network equipment. This typically lowers the equipment cost (due to a large selection of vendors and equipment options), reduces operation and maintenance costs due to one type of system to maintain (less training and processes), and allows for the use of standard software (traffic monitoring and management).

Mobile System Operation

Mobile system operation is the set of tasks performed to complete key operations: initialization of information when the subscriber unit is turned on, monitoring of control information, accessing the system, and maintaining communication sessions.

When a mobile device is first turned on, it gathers its initial information (initializes) by scanning the available radio channels to find control channels. If it finds control channel (or its pilot signal), it determines the type of service capability and it will begin to synchronize (time align) with the channel to obtain system broadcast information.

If it finds more than one control channel, it will usually tune to the radio channel with the strongest or best quality signal level. If the mobile device does not find any control channels, it may begin to scan an alternate channel type if the user has programmed the mobile device to allow access to an alternative system (if the device has multi-mode capability). If it finds a control channels from the other type of system, it will synchronize with the control channel and gather its system broadcast information.

The system broadcast information provides the information needed by the mobile device to monitor for incoming calls (paging messages) and to coordinate how to access the system (power level and maximum number of system access attempts).

After the mobile device has gathered its initial information (initialized), it will typically register with the system. This allows the system to route incoming calls to the cell site(s) that are able to communicate with the mobile device. The mobile device will continually register (sending short messages) to the system as it moves through new radio coverage areas.

When a mobile device desires to obtain service from a mobile system, it sends an access request message. Before attempting to access the system, the mobile device must first listen to the control channel to determine if the system is idle (not currently busy) serving access requests from other mobile devices.

When a call is received by the wireless system for the mobile device, the system sends a call alert (page) message to the radio coverage area(s) where the mobile device has last registered. After the mobile device has initialized with the system, it constantly listens to the paging channels for page messages (its own identification number).

After the mobile device has gained the attention of the system and has been granted access to services, a communication session (connected mode) is established. During the communication session, a voice path and/or data path may be opened (communication sessions). While the mobile device is in connected mode, other processes may simultaneously happen such as channel handover.

Initialization

Initialization is the process of a mobile device initially finding an available radio channel, synchronizing with the system and obtaining system parameters from the pilot channel, synchronization channel (SCH), and broadcast channel (BCH) to determine the information requirements for access and communication.

Initialization phase begins when the mobile device first powers on. It initially looks to the stored information or information contained in its subscriber identity module (SIM) card for a preferred control channel list. If there is no list, the mobile device scans all of the available radio channels to find a control channel.

Idle

During idle mode, the mobile device monitors several different control channels to acquire system access parameters, determine if it has been paged or received an order, initiate a call (if the user is placing a call) or to start a data session (if the user has started a data application).

After obtaining the system parameters, the mobile device continuously monitors the broadcast channel for changes in system parameters, including system identification and access information. If the mobile device has discontinuous reception (sleep mode) capability, and if the system supports it, the mobile device turns off its receiver and other non-essential circuitry for a fixed number of burst periods. The system knows that it has commanded the mobile device to sleep, so it does not send pages designated for that mobile device during the sleep period.

The mobile device then monitors the paging control channel to determine if it has received a page. If a call is to be received, an internal flag is set indicating that the mobile device is entering access mode in response to a page. If the system sends an order such as a registration message, an internal flag is set indicating that the mobile device is attempting access in response to an order. When a user initiates a call, an internal flag is set indicating that the access attempt is a call origination, and dialed digits will follow the access request.

Access Control and Initial Assignment

Access control and initial assignment is the process of gaining the attention of the system, obtaining authorization to use system services and the initial assignment to communication channel to setup a communication session.

Access control and initial assignment occurs when a mobile device responds to a page (incoming connection request), desires to setup a call, or any attempt by the mobile device. Access to the mobile system is a random (at any time) occurrence (not usually preplanned.) To avoid access “collisions” between mobile devices, a seizure collision avoidance process is used. Before a mobile device attempts access to the system, it first waits until the channel is available (not busy serving other users). The mobile device then begins transmitting an access request message (called an access probe) on a random access control channel at very low power. An access attempt (an access probe) contains a preamble that is followed by the access channel data message. The access request preamble uses a predefined sequence that allows the system to easily detect an access request message. The access request indicates the type of service the mobile device is requesting (e.g. call origination or a response to a paging message).

If an access request message does not gain the attention of the system in a short period of time, the mobile device will increase its transmitter power level and send another access request message. This process will repeat until either the system responds to the access request or if the mobile device reaches a maximum allowable transmission power level established by the system.

If the system acknowledges the mobile device’s request for service, the mobile device will send additional information to the system that allows it to setup a dedicated communications channel where conversation or data transmission can begin.

Figure 1.14 shows the process used by mobile devices to gain access to a mobile system. This diagram shows that the mobile device transmits an access probe packet to the system to attempt to gain the attention of the system. This example shows that the mobile device transmits the first access request message at low power. If the system does not respond within a short amount of time, the mobile device will transmit another access probe at a higher RF power level. This process of sending an access request message at a higher power level and waiting for the system to respond continues until either the system responds to the access request or the mobile device reaches its maximum access request message RF power level that is assigned by the system.

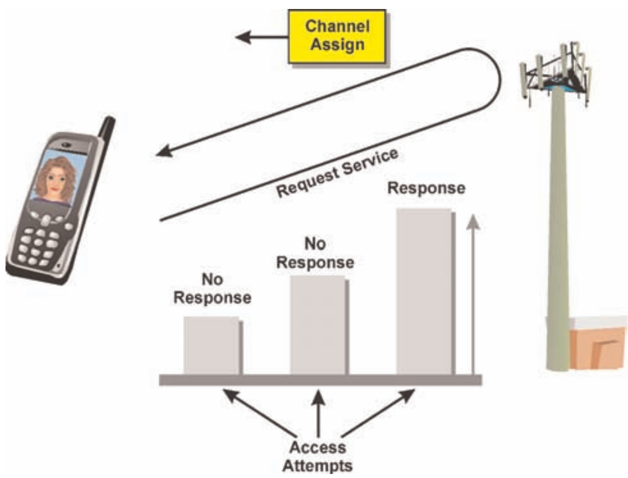

Figure 1.14., Mobile System Access

Authentication

Authentication is a process of exchanging information between a communications device (typically a user device such as a mobile phone) and a communications network that allows the carrier or network operator to confirm the true identity of the user (or device). This validation of the authenticity of the user or device allows a service provider to deny service to users that cannot be identified. Thus, authentication inhibits fraudulent use of a communication device that does not contain the proper identification information. The mobile system may require the mobile device to authenticate with the system during the system access process.

Paging

Paging is a process used to alert mobile devices when they are receiving a call, command, or message. Mobile devices listen for paging messages for their identification code (associated with their telephone number) on a paging channel.

After a mobile device has registered with the system, it may be assigned to a paging group. The use of paging groups allows a mobile telephone to sleep during paging groups that it does not belong to. The paging group is identified by a paging indicator (PI) that is provided at the beginning of the paging message group. The mobile device first reads the PI to determine if it should remain awake to receive the paging group or if it can go to sleep as its identification code is not associated with the particular paging group.

Connected Mode

Connected mode is the process of managing the communication session when a mobile device is transferring data to and from a Base Station. When in the connected mode, the base transceiver station (BTS) continuously controls the mobile device during the communication session. These control tasks include power level control, hand-over, alerting, etc. The base station exercise control during the communication session through dedicated control channels.

To enter the connected mode, the base station must open a communication channel with the mobile device. When the connection is opened, each frame or packet that is received by the base station can be transferred to the assigned communication line (for a voice call) or IP address (for a data communications session). When a communication session is complete (e.g. the user presses end or closes their email or web browsing application), the connection is closed and the base station may assign other users to the radio resources.

The mobile device does not have to continuously transmit data while in the connected mode. When in the connected mode, the base station associates (maps) the radio link to the circuit switched communication channel (for voice) or to an IP address (for data). When the connected mode is used for data transmission such as web browsing, the typical data transmission activity is less than 10%. Other mobile devices can use the channels during inactive data transmission periods allowing a system to serve many (possibly hundreds) simultaneous data users for each mobile telephone radio channel.

During the connected mode, communication session processing tasks include the insertion and extraction of control messages that allow functions such as power control monitoring and control, handover operation, adding or terminating additional communication sessions (logical channels), and other mobile device operational functions.

Packet Data Scheduling Algorithm

A packet data-scheduling algorithm is a program that coordinates the sequences of processes or information. The packet data-scheduling algorithm in the mobile system is used to coordinate the flow of data to multiple packet data users.

Mobile data usage such as Internet web browsing involves data transmission that is not continuous. The ratio of data transmitted by a single device compared to the overall data transmission by all the devices is the activity factor. The lower the activity factor, the higher the number of mobile data devices that can access the system.

Packet scheduling can assign different priority levels based on user and application types. Packets for specific types of users such as public safety officers can be given higher priority. Packets for specific applications such as IP Telephony can be given priority over other applications such as web browsing or email access.

Registration

Registration is the process that is used by mobile devices to inform the wireless system of their location and availability to receive communications services (such as incoming calls). The reception of registration requests allows a wireless system to route incoming messages to the radio base station or transmitter where the mobile device has recently registered.

The process of registration is typically continuous. Mobile devices register when they power on, when they move between new radio coverage areas, when requested by the system, and when the mobile device is power off.

Because the registration process consumes resources of the system (channel capacity and system-servicing capacity), there is a tradeoff between regularly maintaining registration information and the capacity of the system. During periods of high system usage activity, registration processes may be reduced.

Analog Systems (1st Generation)

Analog cellular is an industry term given to first generation (1G) cellular systems that transmit voice information using a form of analog modulation (e.g. FM). Analog cellular systems may have digital control channels. Analog cellular systems primarily provide voice and low-speed data communication services over a wide geographic area.

Analog cellular systems use very narrow radio channel (small amount of bandwidth) that varies from 10 kHz to 30 kHz. Analog systems usually send control information in digital (data) form. The data signaling rates determine how fast messages can be sent on control channels. The RF power level of mobile telephones and how the power level is controlled ordinarily determines how far away the mobile telephone can operate from the base station (radio tower).

Regardless of the size and type of radio channels, all cellular and PCS systems allow for full duplex operation. Full duplex operation is the ability to have simultaneous communications between the caller and the called person. This means a mobile telephone must be capable of simultaneously transmitting and receiving to the radio tower. The radio channel from the mobile telephone to the radio tower is called the uplink and the radio transmission channel from the base station to the mobile telephone is called the downlink. The uplink and downlink radio channels are normally separated by 45 MHz to 80 MHz.

In early mobile radio systems, a mobile telephone scanned the limited number of available channels until it found an unused one, which allowed it to initiate a call. Because the analog cellular systems in use today have hundreds of radio channels, a mobile telephone cannot scan them all in a reasonable amount of time. To quickly direct a mobile telephone to an available channel, some of the available radio channels are dedicated as control channels. Most cellular systems use two types of radio channels, control channels and voice channels. Control channels carry only digital messages and signals, which allow the mobile telephone to retrieve system control information and compete for access.

Control channels only carry control information such as paging (alert) and channel assignment messages. Voice channels are primarily used to transfer voice information. However, voice channels must also be capable of sending and receiving some digital control messages to allow for necessary frequency and power changes during a call.

Current analog systems serve only one subscriber at a time on a radio channel so the number of radio channels available influence system capacity. However, a typical subscriber uses the system for only a few minutes a day, on a daily basis, and many subscribers share a single channel. As a rule, 20 - 32 subscribers share each radio channel [2], depending upon the average talk time per hour per subscriber. Generally, a cell with 50 channels can support 1000 - 1600 subscribers.

The basic operation of an analog cellular system involves initiation of the phone when it is powered on, listening for paging messages (idle), attempting access when required and conversation (or data) mode.

When a mobile telephone is first powered on, it initializes itself by searching (scanning) a predetermined set of control channels and then tuning to the strongest one. During the initialization mode, it listens to messages on the control channel to retrieve system identification and setup information.

After initialization, the mobile telephone enters the idle mode and waits to be paged for an incoming call and senses if the user has initiated (dialed) a call (access). When a call begins to be received or initiated, the mobile telephone enters system access mode to try to access the system via a control channel. When it gains access, the control channel sends an initial voice channel designation message indicating an open voice channel. The mobile telephone then tunes to the designated voice channel and enters the conversation mode. As the mobile telephone operates on a voice channel, the system uses Frequency Modulation (FM) similar to commercial broadcast FM radio. To send control messages on the voice channel, the voice information is either replaced by a short burst (blank and burst) message or in some systems, control messages can be sent along with the audio signal.

A mobile telephone's attempt to obtain service from a cellular system is referred to as access. Mobile telephones compete on the control channel to obtain access from a cellular system. Access is attempted when a command is received by the mobile telephone indicating the system needs to service that mobile telephone (such as a paging message indicating a call to be received) or as a result of a request from the user to place a call. The mobile telephone gains access by monitoring the busy/idle status of the control channel both before and during transmission of the access attempt message. If the channel is available, the mobile station begins to transmit and the base station simultaneously monitors the channel's busy status. Transmissions must begin within a prescribed time limit after the mobile station finds that the control channel access is free, or the access attempt is stopped on the assumption that another mobile telephone has possibly gained the attention of the base station control channel receiver.

If the access attempt succeeds, the system sends out a channel assignment message commanding the mobile telephone to tune to a cellular voice channel. When a subscriber dials the mobile telephone to initiate a call, it is called “origination”. A call origination access attempt message is sent to the cellular system that contains the dialed digits, identity information along with other information. If the system allows service, the system will assign a voice channel by sending a voice channel designator message, if a voice channel is available. If the access attempt fails, the mobile telephone waits a random amount of time before trying again. The mobile station uses a random number generating (an internal algorithm) to determine the random time to wait. The design of the system minimizes the chance of repeated collisions between different mobile stations, which are both trying to access the control channel since each one waits a different random time interval before trying again if they have already collided on their first, simultaneous attempt.

To receive calls, a mobile telephone is notified of an incoming call by a process called paging. A page is a control channel message that contains the telephone’s Mobile Identification Number (MIN) or telephone number of the desired mobile phone. When the telephone determines it has been paged, it responds automatically with a system access message that indicates its access attempt is the result of a page message and the mobile telephone begins to ring to alert the customer of an incoming telephone call. When the customer answers the call (user presses “SEND” or “TALK”), the mobile telephone transmits a service request to the system to answer the call. It does this by sending the telephone number and an electronic serial number to provide the users identity.

After a mobile telephone has been commanded to tune to a radio voice channel, it sends mostly voice or other customer information. Periodically, control messages may be sent between the base station and the mobile telephone. Control messages may command the mobile telephone to adjust its power level, change frequencies, or request a special service (such as three way calling).

To conserve battery life, a mobile phone may be permitted by the base station to only transmit when it senses the mobile telephone's user is talking. When there is silence, the mobile telephone may stop transmitting for brief periods of time (several seconds). When the mobile telephone user begins to talk again, the transmitter is turned on again. This is called discontinuous transmission.

Figure 1.15 shows a basic analog cellular system. This diagram shows that there are two types of radio channels; control channels and voice channels. Control channels typically use frequency shift keying (FSK) to send control messages (data) between the mobile phone and the base station. Voice channels typically use FM modulation with brief bursts of digital information to allow control messages (such as handoff) during conversation. Base stations typically have two antennas for receiving and one for transmitting. Dual receiver antennas increases the ability to receive the radio signal from mobile telephones which typically have a much lower transmitter power level than the transmitters in the base station. Base stations are connected to a mobile switching center (MSC) typically by a high speed telephone line or microwave radio system. This interconnection must allow both voice and control information to be exchanged between the switching system and the base station. The MSC is connected to the telephone network to allow mobile telephones to be connected to standard landline telephones.

There are many types of analog and digital cellular systems in use throughout the world. Analog systems include AMPS, TACS, JTACS, NMT, MCS and CNET.

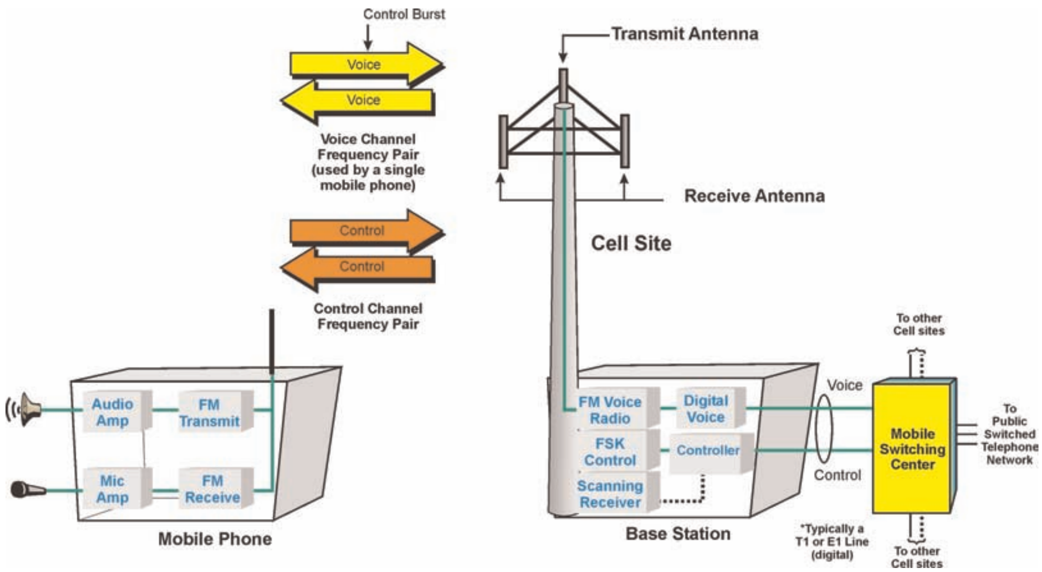

Figure 1.15, Analog Cellular System (1st Generation)

Advanced Mobile Phone Service (AMPS)

Advanced mobile phone service (AMPS) is an analog cellular communications system that uses frequency-division multiple Access (FDMA) for control and frequency division duplex (FDD) for two transmission. The AMPS radio channel types include 30 kHz FSK control channels and 30 kHz voice channels and it operates in the 825 MHz to 890 MHz frequency range.

In 1974, 40 MHz of spectrum was allocated in the United States for cellular service [3] that provided only 666 channels. In 1986, an additional 10 MHz of spectrum was added to facilitate expansion [4] of the system to 832 channels.

The frequency bands for the AMPS system are 824 MHz to 849 MHz (uplink) and 869 MHz to 894 MHz (downlink). Of the 832 channels, AMPS systems are divided into A and B bands to allow for 2 different service providers. There are two types of radio channels in an AMPS system; dedicated control channels and voice channels. On each system (A or B), mobile telephones scan and tune to one of 21 dedicated control channels to listen for pages and compete for access to the system. The control channel continuously sends system identification information and access control information. Although the control channel data rate is 10 kbps, messages are repeated 5 times, which reduces the effective channel rate to below 2 kbps. This allows a control channel to send 10 to 20 pages per second.

The AMPS cellular system is a frequency duplex with its channels separated by 45 MHz. The control channel and voice channel signals are transferred at 10 kbps. AMPS cellular phones have three classes of maximum output power. A class 1 mobile telephone has a maximum power output of 6 dBW (4 Watts), class 2 has a maximum output power of 2 dBW (1.6 Watts), and the class 3 units are capable of delivering only -2 dBW (0.6 Watts). The output power can be adjusted in 4 dB steps and has a minimum output power of -22 dBW (approximately 6 milliwatts).

Total Access Communication System (TACS)

Total access communications system is an analog mobile telephone system that is an enhanced version of AMPS (analog cellular). It was developed and deployed in the United Kingdom and it primarily operates on the 900 MHz frequency range. In the late 1990s, TACS systems began converting to GSM systems.

The Total Access Communication System (TACS) is very similar to the US EIA-553 AMPS system. Its primary differences include changes to the radio channel frequencies, radio channel bandwidths and data signaling rates. The TACS was introduced to the U.K. in 1985. After its introduction in the UK in 1985, over 25 countries offered TACS service. The introduction of the TACS system was very successful and the system was expanded to add more channels through what is called Extended TACS (ETACS).

The TACS system was deployed in 25kHz radio channels compared to the 30kHz channels used in AMPS. This narrower radio bandwidth reduced the data speed of the signaling channel.

The frequency ranges of most TACS systems are 890 MHz to 915 MHz for the uplink and 935 MHz to 960 MHz for the downlink. The TACS system was initially allocated at 25 MHz although 10 MHz of the 25 MHz was reserved for future pan-European systems in the UK. An additional 16 MHz of radio channel bandwidth was added to allow for Extended TACS (ETACS). The ETACS system is a frequency duplex system with its channels separated by 45 MHz.

The control channel and voice channel signals are transferred at 8 kbps. There are 4 power classes for ETACS mobile telephones. Class 1 mobile telephones have a maximum output of 10 Watts, class 2 has 4 Watts, class 3 has 1.6 Watts, and class 4 has 0.6 Watts. Similar to AMPS, mobile telephones can be adjusted in 4 dB steps and have a minimum transmit power level of approximately 6 milliwatts.

The TACS system has also been modified for use in Japan. This Japanese version is called JTACS. The only significant changes were the frequency bands and number of channels. The TACS system has also been modified to create the Narrowband TACS (NTACS) system. NTACS reduced the radio channel bandwidth from 25 kHz to 12.5 kHz and changed the in-band 8 kbps signaling on the voice channel to 100 bps sub-band digital signaling.

Nordic Mobile Telephone (NMT)

Nordic mobile telephone is a mobile cellular telephone system that was introduced to Europe in 1981. The NMT system has been deployed on two frequency bands; 450 MHz and 900 MHz. These systems use FM (analog) radio modulation. In the 1990s, NMTS systems were converted to the GSM (digital) system.

The NMT 450 system is a low capacity system and NMT 900 that is a high capacity system. The Nordic mobile telephone (NMT) system was developed by the telecommunications administrations of Sweden, Norway, Finland, and Denmark to create a compatible mobile telephone system in the Nordic countries [5]. The first commercial NMT 450 cellular system was available at the end of 1981. Due to the rapid success of the initial NMT 450 system and limited capacity of the original system design, the NMT 900-system version was introduced in 1986.

The NMT 450 system uses a lower frequency (450 MHz) and higher maximum transmitter power level. This allows a larger cell site coverage areas while the NMT 900 system uses a higher frequency (approximately the same 900 MHz band used for TACS and GSM) and a lower maximum transmitter power, which increases system capacity. NMT 450 and NMT 900 systems can co-exist which permits them to use the same switching center [6]. This allowed some NMT service providers to start offering service with an NMT 450 system and progress up to a NMT 900 system when the need arises.

Some operations of the NMT systems are very different from most other cellular systems. When NMT mobile telephones access the cellular system, they can either find an unused voice channel and negotiate access directly or begin conversation without the assistance of a dedicated control channel. Because scanning for free voice channels can be very time consuming, the NMT 900 system does allow for the use of a dedicated control channel that is called the calling channel. The NMT 900 system also allows discontinuous reception, which increases the standby time of the portable phones.

The NMT 450 system is frequency duplex with 180 channels (except Finland which only has 160 channels) [7]. The radio channel bandwidth is 25 kHz and the frequency duplex spacing is 10 MHz. The NMT 900 system has 999 channels or 1999 interleaved channels.

Signaling on the NMT systems is performed at 1200 bps on the control (calling) channel (NMT 900) and voice channel. Because of the slow signaling rate and robust error detection/correction capability, no repeated messages are necessary.

NMT 450 base stations can transmit up to 50W. This high power combined with the lower 450 MHz frequency allows cell site size of up to approximately 40 km radius. NMT 900 base stations are limited to a maximum of 25W that allows a maximum cell size radius of up to approximately 20 km [8].

There are three power levels (high, medium, and low) for NMT mobile phones and two power levels (high and low) for portables. NMT 450 mobile telephone power levels are: High 15W, Medium 1.5W, and Low 0.15W, NMT 450 portable telephones; High 1.0W, Low 0.1W. NMT 900 mobile telephones: High 6.0W, Medium 1.0W, Low 0.1W and NMT 900 portable telephones: High 1.0W, Low 0.1W.

The NMT system is unique as it included various types of anti-fraud protection. NMT mobile telephones hold a three-digit password that is stored in the telephone and cellular switching center and is unknown to the customer. This password is sent to the cellular system during system access along with the mobile telephone number. The NMT system has also added a Subscriber Identity Security (SIS) system that provides additional anti-fraud protection. Not all NMT telephones have SIS capability.

Narrowband AMPS (NAMPS)

Narrowband AMPS is a cellular system that allows the use of either 30 kHz or 10 kHz FM modulated (analog) channels. The NAMPS system was developed to increase the serving system capacity by allowing each base station to contain more channels (transceivers). NAMPS adds sub-band signaling operation to the signaling control channels used in the AMPS system.

NAMPS was commercially introduced by Motorola in late 1991 and was deployed worldwide. Like the existing AMPS technology, NAMPS uses analog FM radio for voice transmissions. The distinguishing feature of NAMPS is its use of a “narrow” 10 kHz bandwidth for radio channels, a third of the size of AMPS channels. Because more of these narrower radio channels can be installed in each cell site, NAMPS systems can serve more subscribers than AMPS systems without adding new cell sites. NAMPS also shifts some control commands to the sub-audible frequency range to facilitate simultaneous voice and data transmissions.

In 1991, the first NAMPS standard, named IS-88, evolved from the US AMPS specification (EIA-553). The IS-88 standard identified parameters needed to begin designing NAMPS radios, such as radio channel bandwidth, type of modulation, and message format. During development, the NAMPS specification benefited from the narrowband JTACS radio system specifications. During the following years, advanced features such as ESN authentication, caller ID, and short messaging were added to the NAMPS specification.

Japanese Mobile Cellular System (MCS)

Japan launched the world's first commercial cellular system in 1979. Because this system had achieved great success, several different types of cellular systems have evolved in Japan. These include the MCS-L1, MCS-L2, JTACS and NTACS systems.

The MCS-L1 was the first cellular system in Japan, which was developed and operated by NTT. The system operates in the 800 MHz band. The channel bandwidth is 25 kHz and the signaling is at 300 bps. The control channels are simulcast from all base stations in the local area. This limits the maximum capacity of the MCS-L1 system.

Because the MCS-L1 system could only serve a limited number of customers, the MCS-L2 system was developed. It uses the same frequency bands as the MCS-L1 system. The radio channel bandwidth was reduced from 25 kHz to 12.5 kHz with 6.25 kHz interleaving. This gives the MCS-L2 system 2,400 channels. The control channels transfer information at 2,400 bps and the voice channels can use either in-band (blank and burst) signaling at 2,400 bps or sub-band digital audio signaling at 150 bps. MCS-L2 mobile telephones have diversity reception (similar to diversity reception used in base stations). While this increases the cost and size of the mobile telephones, it also increases the performance and range of the cellular system.

CNET

CNET is an analog cellular system that is used in Germany, Portugal, and South Africa [9]. The first CNET system started operation in Germany in 1985. The primary objective of the CNET system was to bridge the gap of cellular systems in Germany until the digital European system could be introduced [10].

The CNET system operates at 450 MHz with 4.44 MHz transmit and receive bands. The frequency bands are 461.3 to 465.74 MHz and 451.3 to 455.74 MHz. The primary channel bandwidth is 20 kHz with 10 kHz channel interleaving.

The CNET system continuously exchanges digital information between the mobile telephone and the base station. Every 12.5 msec, 4 bits of information are sent during compressed speech periods [11]. CNET mobile telephones also use an Identification Card (IC), which slides into the telephone to identify the customer. This allows customers to use any compatible CNET telephone.

MATS-E

The MATS-E system is used in France and Kuwait [12]. The MATS-E system combines many of the features used in different cellular systems. MATS-E uses the standard European mobile telephone frequency bands; 890-915 MHz and 935-960 MHz. The channel bandwidth is 25 kHz that provides 1,000 channels. The MATS-E is a frequency duplex system separated by 45 MHz. Each cell site has at least one dedicated control channel with a signaling rate of 2400 bps. Voice channels use FM modulation with sub-band digital audio signaling with a data rate of 150 bps

Digital Cellular Systems (2nd Generation)

Digital cellular is an industry term given to the new cellular technology that transmits voice information in digital form. This differs from Analog cellular in that the method of transmission for voice/data information is by means of digital signals. Digital mobile radio systems are often characterized by their type of access technology (TDMA or CDMA). The access technology determines how that digital information is transferred to and from the cellular system.

Digital cellular systems can usually serve several subscribers on a single radio channel at the same time. Depending on the type of system, this can range from 3 to over 20. To allow this, almost all digital cellular systems share the fundamental characteristics of digitizing and compressing voice information to accomplish this. This allows a single radio channel to be divided into several sub-channels (communication channels). Each communication channel can serve a single customer.

Because each subscriber typically uses the cellular system for only a few minutes a day, several subscribers can share each one of these communication channels during the day. As a rule, 20 - 32 subscribers can share each communication channel. So, if a digital radio channel has 8 communications channels (sub-channels), a cell site with 25 radio channels can support 4000 to 6400 subscribers (25 radio channels x 8 users per channel x 20 to 32 subscribers per communication channel).

Digital cellular systems use two key types of communication channels, control channels and voice channels. A control channel on a digital system is usually one of the sub-channels on the radio channel. This allows digital systems to combine a control channel and one or more voice channels on a single radio channel. The portion of the radio channel that is dedicated as a control channel carries only digital messages and signals that allow the mobile telephone to retrieve system control information and compete for access. The other sub-channels on the radio channel carry voice or data information.

The basic operation of a digital cellular system involves initiation of the phone when it is powered on, listening for paging messages (idle), attempting access when required and conversation (or data) mode.

When a digital mobile telephone is first powered on, it initializes itself by searching (scanning) a predetermined set of control channels and then tuning to the strongest one. During the initialization mode, it listens to messages on the control channel to retrieve system identification and setup information. Compared to analog systems, digital systems have more communication and control channels. This can result in the mobile phone taking more time to search for control channels. To quickly direct a mobile telephone to an available control channel, digital systems use several processes to help a mobile telephone to find an available control channel. These include having the phone memorize its last successful control channel location, a table of likely control channel locations and a mechanism for pointing to the location of a control channel on any of the operating channels.

After a digital mobile telephone has initialized, it enters an idle mode where it waits to be paged for an incoming call or for the user to initiate a call. When a call begins to be received or initiated, the mobile telephone enters system access mode to try to access the system via a control channel. When it gains access, the control channel sends a digital traffic channel designation message indicating an open communications channel. This channel may be on a different time slot on the same frequency or to a time slot on a different frequency. The digital mobile telephone then tunes to the designated communications channel and enters the conversation mode. As the mobile telephone operates on a digital voice channel, the digital system commonly uses some form of phase modulation (PM) to send and receive digital information.

A mobile telephone's attempt to obtain service from a cellular system is referred to as "access". Digital mobile telephones compete on the control channel to obtain access from a cellular system. Access is attempted when a command is received by the mobile telephone indicating the system needs to service that mobile telephone (such as a paging message indicating a call to be received) or as a result of a request from the user to place a call. Digital mobile telephones usually have the ability to validate their identities more securely during access than analog mobile telephones. This is made possible by a process called authentication. Authentication processes share secret data between the digital mobile phone and the cellular system.

If the authentication is successful, the system sends out a channel assignment message commanding the mobile telephone to change to a new communication channel and conversation can begin.

After a mobile telephone has been commanded to tune to a radio voice channel, it sends digitized voice or other customer data. Periodically, control messages may be sent between the base station and the mobile telephone. Control messages may command the mobile telephone to adjust its power level, change frequencies, or request a special service (such as three way calling). To send control messages while the digital mobile phone is transferring digital voice, the voice information is either replaced by a short burst (called blank and burst or fast signaling), or else control messages can be sent along with the digitized voice signals (called slow signaling).

Most digital telephones automatically conserve battery life as they transmit only for short periods of time (bursts). In addition to savings through digital burst transmission, digital phones ordinarily have the capability of discontinuous transmission that allows the inhibiting of the transmitter during periods of user silence. When the mobile telephone user begins to talk again, the transmitter is turned on again. The combination of the power savings allows some digital mobile telephones to have 2 to 5 times the battery life in the transmit mode.

Digital technology increases system efficiency by voice digitization, speech compression (coding), channel coding, and the use of spectrally efficient radio signal modulation. Standard voice digitization in the Public Switched Telephone Network (PSTN) produces a data rate of 64 kilobits per second (kbps). Because transmitting a digital signal via radio requires about 1 Hz of radio bandwidth for each bps, an uncompressed digital voice signal would require more than 64 kHz of radio bandwidth. Without compression, this bandwidth would make digital transmission less efficient than analog FM cellular, which uses only 25-30 kHz for a single voice channel. Therefore, digital systems compress speech information using a voice coder or Vocoder. Speech coding removes redundancy in the digital signal and attempts to ignore data patterns that are not characteristic of the human voice. The result is a digital signal that represents the voice audio frequency spectrum content, not a waveform.

A voice coder (vocoder) characterizes the input signal, looks up codes in a code book table that represents various digital patterns and chooses a pattern that comes closest to the input digitized signal. The amount of digitized speech compression used in digital cellular systems varies. For the IS-136 TDMA system, the compression is 8:1. For CDMA, the compression varies from 8:1 to 64:1 depending on speech activity. GSM systems compress the voice by 5:1.

As a general rule, with the same amount of speech coding analysis, the fewer bits used to characterize the waveform, the poorer the speech quality. If the complexity (signal processing) of the speech coder can be increased, it is possible to get improved voice quality with fewer bits.

Voice digitization and speech coding take processing time. Typically, speech frames are digitized every 20 msec and inputted to the speech coder. The compression process, time alignment with the radio channel, and decompression at the receiving end all delay the voice signal. The combined delay can add up to 50-100 msec. Although such a delay is not usually noticeable in two-way conversation, it can cause an annoying echo when a speakerphone is used, or the side tone of the signal is high (so the users can hear themselves). However, an echo canceller can be used in the MSC to process the signal and remove the echo.

Once the digital speech information is compressed, control information bits must be added along with extra bits to protect from errors that will be introduced during radio transmission. The combined digital signal (compressed digitized voice and control information) is sent to the radio modulator where it is converted to a digitized RF signal. The efficient conversion to the RF signal constantly involves some form of phase shift modulation.

Figure 1.16 shows a basic digital cellular system. This diagram shows that there usually is only one type of digital radio channel called a digital traffic channel (DTC). The digital radio channel is ordinarily sub-divided into control channels and digital voice channels. Both the control channels and voice channels use the same type of digital modulation to send control and content data between the mobile phone and the base station. When used for voice, the digital signal is usually a compressed digital signal that is from a speech coder. When conversation is in progress, some of the digital bits are usually dedicated for control information (such as handoff). Similar to analog systems, digital base stations have two antennas that increase the ability to receive weak radio signals from mobile telephones. Base stations are connected to a mobile switching center (MSC) normally by a high speed telephone line or microwave radio system. This interconnection may allow compressed digital information (directly from the speech coder) to increase the number of voice channels that can be shared on a single connection line. The MSC is connected to the telephone network to allow mobile telephones to be connected to standard landline telephones.

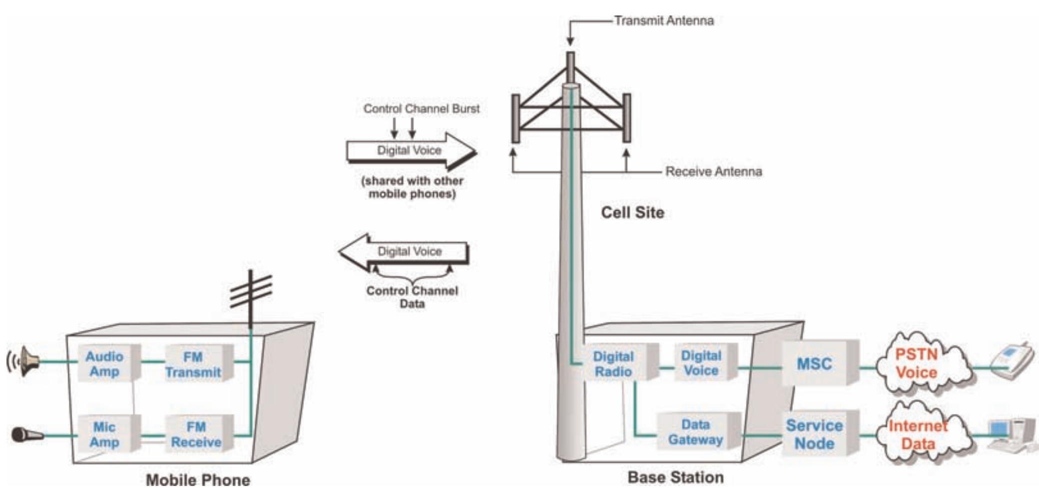

Figure 1.16, Digital Cellular System (2nd Generation)

Second generation (2G) cellular is a term commonly used to describe digital cellular radio technology with advanced messaging and data transmission capabilities. The types of 2nd generation digital cellular systems include GSM, IS-136 TDMA and CDMA.

Global System for Mobile Communication (GSM)

The Global System for Mobile Communications (GSM) is a global digital radio system that uses Time Division Multiple Access (TDMA) technology. GSM is a digital cellular technology that was initially created to provide a single-standard pan-European cellular system. The GSM system is a digital-only system and was not designed to be backward compatible with the established analog systems.

GSM began development in 1982, and the first commercial GSM digital cellular system was activated in 1991. GSM technology has evolved to be used in a variety of systems and frequencies (900 MHz, 1800 MHz and 1900 MHz) including Personal Communications Services (PCS) in North America and Personal Communications Network (PCN) systems throughout the world.

When communicating in a GSM system, users can operate on the same radio channel simultaneously by sharing time slots. The GSM cellular system allows 8 mobile telephones to share a single 200 kHz bandwidth radio carrier waveform for voice or data communications. To allow duplex operation, GSM voice communication is conducted on two 200 kHz wide carrier frequency waveforms.

The GSM system has several types of control channels that carry system and paging information, and coordinates access like the control channels on analog systems. The GSM digital control channels have many more capabilities than analog control channels such as broadcast message paging, extended sleep mode, and others. Because the GSM control channels use only a portion (one or more slots), they typically co-exist on a single radio channel with other time slots that are used for voice communication.

A GSM carrier transmits at a bit rate of 270 kbps. A single GSM digital radio channel or time slot is capable of transferring only $1/8^{th}$ of that, which is about 33 kbps of information (actually less than that, due to the use of some bit time for non-information purposes such as synchronization bits).

Time intervals on full rate GSM channels are divided into frames with 8 time slots on two different radio frequencies. One frequency is for transmitting from the mobile telephone; the other is for receiving to the mobile telephone. During a voice conversation at the mobile set, one time slot period is dedicated for transmitting, one for receiving, and six remain idle. The mobile telephone uses some of the idle time slots to measure the signal strength of surrounding cell carrier frequencies in preparation for handover.

On the 900 MHz band, GSM digital radio channels transmit on one frequency and receive on another frequency 45 MHz higher, but not at the same time. On the 1.9 GHz band, the difference between transmit and receive frequencies is 80 MHz. The mobile telephone receives a burst of data on one frequency, then transmits a burst on another frequency, and then measures the signal strength of at least one adjacent cell, before repeating the process.

North American TDMA (IS-136 TDMA)

The North American TDMA system (IS-136) is a digital system that uses TDMA access technology. It evolved from the IS-54 specification that was developed in North America in the late 1980's to allow the gradual evolution of the AMPS system to digital service. The IS-136 system is sometimes referred to as Digital AMPS (DAMPS) or North American digital cellular (NADC).

In 1988, the Cellular Telecommunications Industry Association created a development guideline for the next generation of cellular technology for North America. This guideline was called the User Performance Requirements (UPR) and the Telecommunications Industry Association (TIA) used this guideline to create a TDMA digital standard, called IS-54. This digital specification evolved from the original EIA-553 AMPS specification. The first revision of the IS-54 specification (Rev 0) identified the basic parameters (e.g. time slot structure, type of radio channel modulation, and message formats) needed to begin designing TDMA cellular equipment. There have been several enhancements to IS-54 since its introduction and in 1995; IS-54 was incorporated as part of the IS-136 specification.

A primary feature of the IS-136 systems is their ease of adaptation to the existing AMPS system. Much of this adaptability is due to the fact that IS-136 radio channels retain the same 30 kHz bandwidth as AMPS system channels. Most base stations can therefore replace TDMA radio units in locations previously occupied by AMPS radio units. Another factor in favor of adaptability is that new dual mode mobile telephones were developed to operate on either IS-136 digital traffic (voice and data) channels or the existing AMPS radio channels as requested in the CTIA UPR document. This allows a single mobile telephone to operate on any AMPS system and use the IS-136 system whenever it is available.

The IS-136 specification concentrates on features that were not present in the earlier IS-54 TDMA system. These include longer standby time, short message service functions, and support for small private or residential systems that can coexist with the public systems. In addition, IS-136 defines a digital control channel to accompany the Digital Traffic Channel (DTC). The digital control channel allows a mobile telephone to operate in a single digital-only mode. Revision A of the IS-136 specification now supports operation in the 800 MHz range for the existing AMPS and DAMPS systems as well as the newly allocated 1900MHz bands for PCS systems. This permits dual band, dual mode phones (800 MHz and 1900 MHz for AMPS and DAMPS). The primary difference between the two bands is that mobile telephones cannot transmit using analog signals at 1900MHz.

The IS-136 cellular system allows for mobile telephones to use either 30 kHz analog (AMPS) or 30 kHz digital (TDMA) radio channels. The IS-136 TDMA radio channel allows multiple mobile telephones to share the same radio frequency channel by time-sharing. All IS-136 TDMA digital radio channels are divided into frames with 6 time slots. The time slots used for the correspondingly numbered forward and reverse channels are time-related so that the mobile telephone does not simultaneously transmit and receive.

The IS-136 system allows a standard time slot on a TDMA radio channel to be used as a digital control channel (DCC). The DCC carries the same system and paging information as the analog control channel (ACC). In addition to the control messages, the DCC has more capabilities than the ACC such as extended sleep mode, short message service (SMS), private and public control channels, and others.

The total bit rate of the carrier frequency waveform is 48.6 kbps. This is time-shared and some of the transmitted bits are used for synchronization and other control purposes; this results in a user-available data rate of 13 kbps. Some of the 13 kbps are used for error detection and correction, so only 8 kbps of data are available for full rate digitally coded speech.

The RF power levels for the mobile phones are almost exactly the same as for the AMPS telephones. The primary difference in the power levels is a reduction in minimum power level that mobile telephones can be instructed to reduce to. This allows for very small cell coverage areas, typically the size of cells that would be used for wireless office or home cordless systems.

Extended TDMA (E-TDMA)™

Extended TDMA™ was developed by Hughes Network Systems in 1990 as an extension to the existing IS-136 TDMA industry standard. ETDMA uses the existing TDMA radio channel bandwidth and channel structure. Its receivers are tri-mode as they can operate in AMPS, TDMA, or ETDMA modes. While a TDMA system assigns a mobile telephone fixed time slot numbers for each call, ETDMA dynamically assigned time slots on an as needed basis. The ETDMA system contains a half-rate speech coder (4 kb/s) that reduces the number of information bits that must be transmitted and received each second. This makes use of voice silence periods to inhibit slot transmission so other users may share the transmit slot. The overall benefit is that more users can share the same radio channel equipment and improved radio communications performance. The combination of a low bit rate speech coder, voice activity detection and interference averaging increases the radio channel efficiency to beyond 10 times the existing AMPS capacity.

ETDMA radio channels are structured into the same frames and slots structures as the standard IS-54 radio channels. Some or all of the time slots on all of the radio channels are shared for ETDMA communication, which is similar to IS-54 and IS-136 radio channels, or else slots can be shared on different frequencies. When a Mobile telephone is operating in extended mode, the ETDMA system must continually coordinate time slot and frequency channel assignments. The ETDMA system performs this by using a time slot control system. On an ETDMA capable radio channel some of the time slots are dedicated as control slots on an as needed basis. ETDMA systems can assign an AMPS channel, a TDMA full-rate or half-rate channel, or an ETDMA channel. The existing 30 kHz AMPS control channels are used to assign analog voice and digital traffic channels

In an ETDMA system, some of the radio channels include a control slot that coordinates time slot allocation. This usually accounts for an estimated 15% of available time slots in a system. The control time slots assign an ETDMA subscriber to voice time slots on multiple radio channels.

ETDMA uses the following process to allocate time slots from moment to moment as needed. The cellular radio maintains constant communications with the Base Station through the control time slot. When a conversation begins, the cellular radio uses the control slot to request a voice time slot from the Base Station. Through the control slot, the Base Station assigns a voice time slot and sets the cellular radio to transmit in that assigned voice time slot. During each momentary lull in phone conversation, the transmitting cellular radio gives up its voice time slot, which is then placed back into the Base Station's pool of available time slots.

When a cellular radio is ready to receive a voice conversation, the Base Station uses the control slot to tell it which voice time slot has the conversation. The cellular radio receiver then tunes to the appropriate slot. Through the control slot, the Base Station constantly monitors the cellular radio to determine whether it has given up a slot or needs a slot. In turn, the cellular radio constantly monitors the control slot to learn which time slot contains voice conversation being sent to it.

Integrated Dispatch Enhanced Network (iDEN)

Integrated Dispatch Enhanced Network (iDEN) a digital radio system that provides for voice, dispatch and data services. iDEN was formerly called Motorola Integrated Radio System (MIRS). iDEN was deployed in 1996 for enhanced specialized mobile radio (E-SMR) service. The iDEN system radio channel bandwidth is 25 kHz and it is divided into frames that have 6 times slots per frame. The iDEN system allows 6 mobile radios to simultaneously share a single radio channel for dispatch voice quality and up to 3 mobile radios can simultaneously share a radio channel for cellular like voice quality.

Code Division Multiple Access (IS-95 CDMA)

Code Division Multiple Access (CDMA) system (IS 95) is a digital cellular system that uses CDMA access technology. IS-95 technology was initially developed by Qualcomm in the late 1980's. CDMA cellular service began testing in the United States in San Diego, California during 1991. In 1995, IS-95 CDMA commercial service began in Hong Kong and now many CDMA systems are operating throughout the world, including a 1.9 GHz all-digital system in the USA that has been operating since November 1996.

Spread spectrum radio technology has been used for many years in military applications. CDMA is a particular form of spread spectrum radio technology. In 1989, CDMA spread spectrum technology was presented to the industry standards committee but it did not meet with immediate approval. The standards committee had just resolved a two-year debate between TDMA and FDMA and was not eager to consider another access technology.

The IS-95 CDMA system allows for voice or data communications on either a 30 kHz AMPS radio channel (when used on the 800 MHz cellular band) or a new 1.25 MHz CDMA radio channel. The IS-95 CDMA radio channel allows multiple mobile telephones to communicate on the same frequency at the same time by special coding of their radio signals.

CDMA radio channels carry control, voice, and data signals simultaneously by dividing a single traffic channel (TCH) into different sub-channels. Each of these channels is identified by a unique code. When operating on a CDMA radio channel, each user is assigned to a code for transmission and reception. Some codes in the TCH transfer control channel information while others transfer voice channel information.

The control channel that is part of a digital traffic channel on a CDMA system has new advanced features. This digital control channel (DCC) carries system and paging information, and coordinates access similar to the analog control channel (ACC). The DCC has many more capabilities than the ACC such as a precision synchronization signal, extended sleep mode and others. Because each CDMA radio channel has many codes, more than one control channel can exist on a single CDMA radio channel and the CDMA control channels co-exist with other coded channels that are used for voice.

The IS-95 CDMA cellular system has several key attributes that are different from other cellular systems. The same CDMA radio carrier frequencies may be optionally used in adjacent cell sites, which eliminates the need for frequency planning. The wide-band radio channel provides less severe fading, which the inventors claim results in consistent quality voice transmission under varying radio signal conditions. The CDMA system is compatible with the established access technology and it allows analog (EIA-553) and dual mode (IS-95) subscribers to use the same analog control channels. Some of the voice channels are replaced by CDMA digital transmissions, allowing several users to be multiplexed (shared) on a single RF channel. As with other digital technologies, CDMA produces capacity expansion by allowing multiple users to share a single digital RF channel.

The IS-95 CDMA radio channel divides the radio spectrum into wide 1.25 MHz digital radio channels. CDMA radio channels differ from those of other technologies in that CDMA multiplies (and therefore spreads the spectrum bandwidth of) each signal with a unique pseudo-random noise (PN) code that identifies each user within a radio channel. CDMA transmits digitized voice and control signals on the same frequency band. Each CDMA radio channel contains the signals of many ongoing calls (voice channels) together with pilot, synchronization, paging, and access (control) channels. Digital mobile telephones select the signal they are receiving by correlating (matching) the received signal with the proper PN sequence. The correlation enhances the power level of the selected signal and leaves others unenhanced.

Each IS-95 CDMA radio channel is divided into 64 separate logical (PN coded) channels. A few of these channels are used for control, and the remainders carry voice information and data. Because CDMA transmits digital information combined with unique codes, each logical channel can transfer data at different rates (e.g. 4800 b/s, 9600 b/s).

CDMA systems use a maximum of 64 coded (logical) traffic channels, but they cannot always use all of these. A CDMA radio channel of 64 traffic channels can transmit at a maximum information throughput rate of approximately 192 kbps [13], so the combined data throughput for all users cannot exceed 192 kbps. To obtain a maximum of 64 communication channels for each CDMA radio channel, the average data rate for each user should approximate 3 kbps. If the average data rate is higher, less than 64 traffic channels can be used. CDMA systems can vary the data rate for each user dependent on voice activity (variable rate speech coding), thereby decreasing the average number of bits per user to about 3.8 kbps [14]). Varying the data rate according to user requirement allows more users to share the radio channel but with slightly reduced voice quality. This is called soft capacity limit.

In 1997 the CDMA Development Group (CDG) registered the trademark cdmaOne™ as a label to identify second-generation digital systems based on the IS-95 standard and related technologies.

Japanese Personal Digital Cellular (PDC)

The PDC system is a TDMA technology with a radio interface that is very similar to IS-136, in that it has six timeslots and an almost identical data rate, and a core network architecture that is very similar to GSM. PDC operates in both the 900 MHz and 1,400 MHz regions of the radio spectrum.

Packet Digital Cellular Systems (Generation 2.5)

Generation 2.5 (2.5G) is a term commonly used to describe the second technology used in a specific application or industry. 2.5G systems provide more services and features than second generation (2G) technology but less than the third generation (3G).

One of the key attributes of 2.5G mobile systems is their ability to transmit data in packet data form. These systems are usually designed to allow the same radio channel to share packet data and voice signals. To ad packet data capability, mobile devices and base stations are modified to include new software that allows them to differentiate and schedule the transmission of data and voice signals (new protocols). Packet data switching equipment is then added to the mobile system allowing it to route data packets within the network or to other data networks (such as to the Internet).

Figure 1.17 shows a 2nd generation digital cellular system that has been upgraded to offer medium speed packet data services. This diagram shows

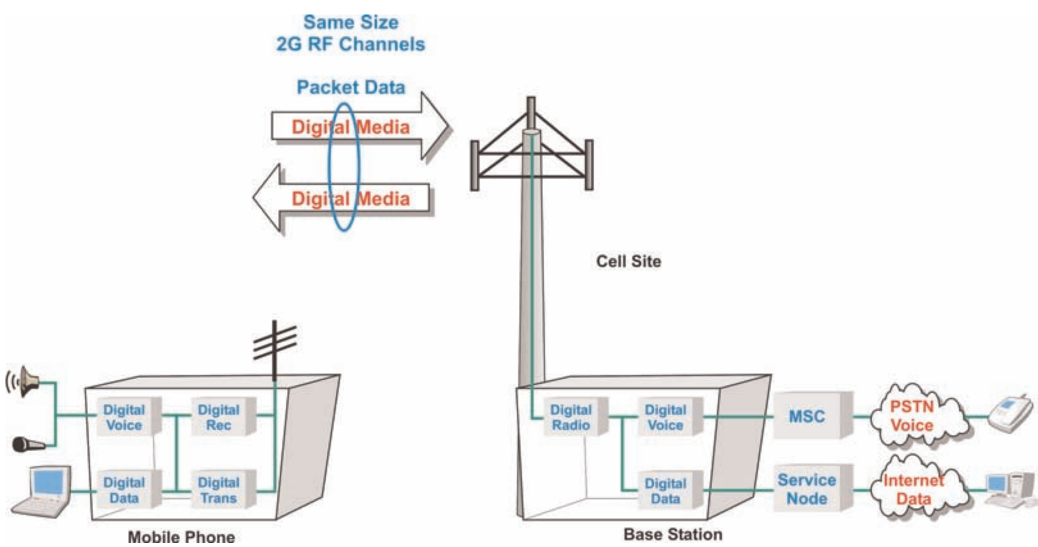

Figure 1.17, Packet Digital Cellular System (2 1/2 Generation)

that the existing 2nd generation digital radio channel bandwidth is reused. In some cases, the modulation technology has been changed to allow for higher data transfer rates. In all cases, the digital traffic channel (DTC) is upgraded to allow for both circuit switched and packet data transmission capability. This is accomplished by dividing the digital radio channel into more control channels and digital communication channels (voice and data). This diagram shows that the digital radio channel can be connected to the existing mobile communication network for voice services or it can be connected (sometimes simultaneously) to a packet data network (such as the Internet) to allow for multimedia communication services.

The types of packet based 2nd generation digital cellular systems (generation 2.5) include GPRS, EDGE, and CDMA2000™ 1xRTT.

General Packet Radio Service (GPRS)

General Packet Radio Service (GPRS) is a portion of the GSM specification that allows packet radio service on the GSM system. The GPRS system adds (defines) new packet channels and switching nodes within the GSM system. The GPRS system provides for theoretical data transmission rates up to 172 kbps.

Enhanced Data Rates for Global Evolution (EDGE)

Enhanced Data Rates for Global Evolution (EDGE) is an evolved version of the global system for mobile (GSM) radio channel that uses new phase modulation and packet transmission to provide for advanced high-speed data services. The EDGE system uses 8 levels of Phase Shift Keying (8PSK) to allow one symbol change to represent 3 bits of information. This is 3 times the amount of information that is transferred by a standard 2 level Gaussian Minimum Shift Keying (GMSK) signal used by the first generation of GSM system. This results in a radio channel data transmission rate of 604.8 kbps and a net maximum delivered theoretical data transmission rate of 384 kbps. The advanced packet transmission control system allows for constantly varying data transmission rates in either direction between mobile radios.

CDMA2000™ 1xRTT

CDMA2000™ is a 3G standard that allows operators to evolve from their existing IS-95 networks to offer 3G services. The original CDMA2000™ proposal contained two distinct evolutionary phases, the first known as 1xRTT used the same 1.25 MHz channels as IS-95 but delivered increased capacity and data rates compared to IS-95. The second phase was known as 3xRTT, which uses three times the spectrum of IS-95 and is equivalent to 3.75 MHz. The 3xRTT concept would deliver data rates up to 2 Mbps, a requirement for any 3G technologies. However recent evolutions of 1xRTT are offering data rates in excess of this and therefore it is unlikely that 3xRTT is required.

Evolution Data Only (1xEVDO)

The evolution of existing systems for data only (1xEVDO) is an evolved version of the CDMA2000™ 1xRTT system. The 1xEVDO system uses the same 1.25 MHz radio channel bandwidth as the existing IS-95 system that provides for multiple voice channels and medium rate data services. The 1xEVDO version changes the modulation technology to allow for data transmission rates up to 2.5 Mbps. The 1xEVDO system has an upgraded packet data transmission control system that allows for bursty data transmission rather than for more continuous voice data transmission.

Evolution Data and Voice (1xEVDV)

The evolution of existing systems for data and voice (1xEVDV) is an evolved version of the CDMA2000™ 1xRTT system that can be used for data and voice service. The 1xEVDV system provides for both voice and high-speed data transmission services in the same 1.25 MHz radio channel bandwidth as the existing IS-95 system. The 1xEVDV Vision allows for a maximum data transmission rate of approximately 2.7 Mbps.

Wideband Digital Cellular Systems (3rd Generation)

The 3rd generation wireless requirements are defined in the International Mobile Telecommunications "IMT-2000" project developed by the International Telecommunication Union (ITU). The IMT-2000 project that defined requirements for high-speed data transmission, Internet Protocol (IP)-based services, global roaming, and multimedia communications. After many communication proposals were reviewed, two global systems are emerging; wideband code division multiple access (WCDMA) and CDMA2000.

Figure 1.18 shows a wideband digital cellular system that permits very high-speed data transmission rates through the use of relatively wide radio channels. In this system, the radio channels are much wider many tens of times wider than 2nd generation radio channels. This allows wideband digital cellular systems to send high-speed data to communication devices. This system also uses communication servers to help manage multimedia communication sessions. Aside from the use of wideband radio channels and enhanced packet data communication, this diagram shows that 3rd generation systems typically use the same voice network switching systems (such as the MSC) as 2nd generation mobile communications systems.

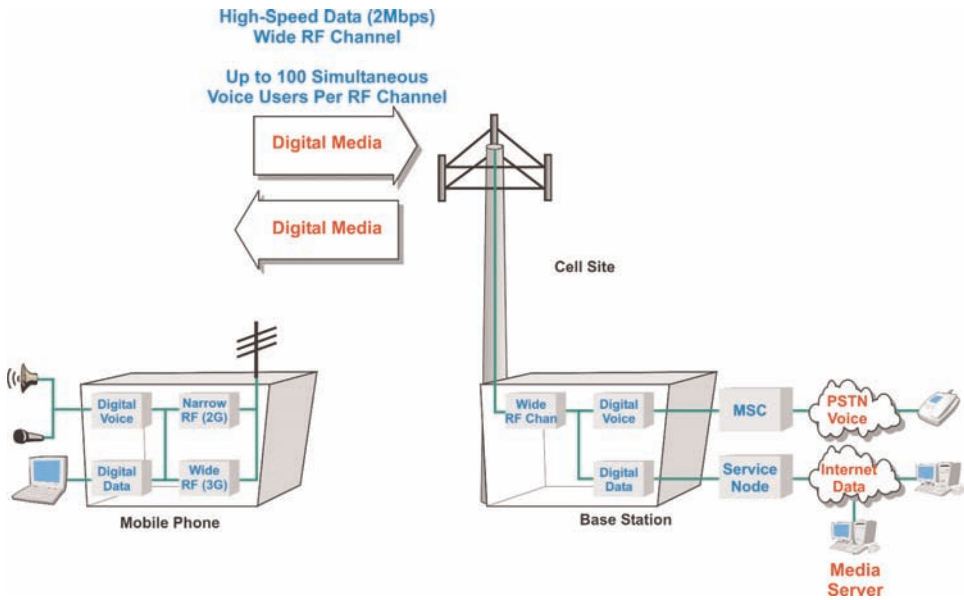

Figure 1.18, Wideband Digital Cellular System (3rd Generation)

Wideband Code Division Multiple Access (WCDMA)

WCDMA is a 3rd generation digital cellular system that uses radio channels that have a wider bandwidth than 2nd generation digital cellular systems such as GSM or IS-95 CDMA. WCDMA is normally deployed in a 5 MHz channel plan.

The Third Generation Partnership Project (3GPP) oversees the creation of industry standards for the 3rd generation of mobile wireless communication systems (WCDMA). The key members of the 3GPP include standards agencies from Japan, Europe, Korea, China and the United States. The 3GPP technology, also known as the Universal Mobile Telecommunications System (UMTS), is based on an evolved GSM core network that contains 2.5G elements, namely GPRS switching nodes. This concept allows a GSM network operator to migrate to WCDMA by adding the necessary 3G radio elements to their existing network, thus creating 'islands' of 3G coverage when the networks first launch.

Code Division Multiple Access 2000 (CDMA2000)

CDMA2000 is a family of standards that represent an evolution from the IS-95 code division multiple access (CDMA) system that offer enhanced packet transmission protocols to provide for advanced high-speed data services. The CDMA2000 technologies operate in the same 1.25 MHz radio channels as used by IS-95 and offer backward compatibility with IS-95.

The CDMA2000 system is overseen by the Third Generation Partnership Project 2 (3GPP2). The 3GPP2 is a standard setting project that is focused on developing global specifications for 3rd generation systems that use ANSI/TIA/EIA-41 Cellular Radio Intersystem Signaling.

Time Division Synchronous CDMA (TD-SCDMA)

On a global basis it is likely that WCDMA and CDMA2000™ will dominate the 3G market. However, in China there is growing support for a home-grown standard known as Time Division Synchronous CDMA (TD-SCDMA). TD-SCDMA offers voice services and data services, both circuit-switched and packet-switched, at rates up to 2 Mbps. It uses a Time Division Duplex (TDD) technique in which transmit and receive signals are sent on the same frequency but at different times. The timeslots on the radio carrier can either be allocated symmetrically for services such as speech or asymmetrically for data services where the bit rates in the two directions of transmission may differ significantly.

Fourth Generation (4G) Networks

Fourth Generation wireless networks with bandwidth reaching 100 Mbps that allow for voice and data applications that will run 50 times faster than 3G. This capacity will enable three dimensional (3D) renderings and other virtual experiences on the mobile device.

Even before 3G networks are fully launched and utilized, various study groups are considering the shape of the next generation of cellular technology, so called 4G. There is no single global vision for 4G as yet but the next generation of network is likely to be all IP-based, offering local (in building) data rates up to 1 Gbps, wide area data rates of 100 Mbps (rural) and support global mobility. One route towards this vision is the convergence of technologies such as 3G cellular and Wireless LANs (WLANs).

Mobile Services

Mobile services are the providing of wireless data transmission and/or information processing services to customers by a mobile system service operator. The services that mobile systems can provide include voice services, data services, multicast services, location-based services (LBS), and multimedia communication services that have various levels of quality of service (QoS).

Voice Services

Voice service is a type of communication service where two or more people can transfer information in the voice frequency band (not necessarily voice signals) through a communication network. Voice service involves the setup of communication sessions between two (or more) users that allows for the real time (or near real time) transfer of voice type signals between users. A mobile system may offer several types of voice services including

The voice service quality on the mobile systems can vary based on a variety of factors. Mobile systems may assign different levels of voice quality by using different types of speech compression. The service provider can select and control which speech compression process (voice coding) is used. The selection of voice coders that have higher levels of speech compression (higher compression results in less digital bits transmitted) allows the service provider to increase the number of customers it can provide service to with the tradeoff of providing lower quality audio signals.

Circuit Switched Voice

Circuit switched voice service is a communication method that maintains a dedicated communications path between two communication devices regardless of the amount of information that is sent between the devices. This gives to communications equipment the exclusive use of the circuit that connects them, even when the circuit is momentarily idle.

Voice communication can be telephony; wide area (cellular), business location (wireless office), home cordless (residential), voice paging, dispatch (fleet coordination) or group voice (audio broadcasting). Service rates for voice applications typically involve an initial connection charge, basic monthly minimum fee, more likely a monthly access fee that includes some free airtime minutes, and an airtime usage charge. When the customer uses service in a system other than their home registered system (roaming), there may be a daily roaming fee and/or a higher per minute roaming usage fee.

Figure 1.19 shows a sample service rate plan for mobile telephone voice services. This example shows that there is usually a fee to activate service (connection charge), a recurring monthly charge ($29.95 per month), a bundled amount of peak and off-peak minutes (500 peak, 2000 off-peak), a fee for usage of airtime minutes in excess of the subscribed amount ($0.40 per minute), and a higher-usage fee when operating (roaming) in other systems ($0.90). This rate plan also shows that advanced services may be offered for free (to increase the number of minutes used).

Item	Amount
Activation Fee	$40.00
Monthly Fee	$29.95
- Peak Minutes Included (7am-9pm)	500
- Off-Peak Minutes Included	2000
Airtime (excess minutes)	$0.40 per minute
Roaming Fee	$0.90 per minute
Call Waiting, Call Forwarding, 3-Way	Free

Figure 1.19, Typical Mobile Telephone Voice Service Rate Plan

Push to Talk (PTT)

Push to talk (PTT) is a process of initiating transmission through the use of a push-to-talk button. The push to talk process involves the talker pressing a talk button (usually part of a handheld microphone) that must be pushed before the user can transmit. If the system is available for PTT service (other users in the group not talking), the talker will be alerted (possibly with an acknowledgement tone) and the talker can transmit their voice by holing the talk button. If the system is not available, the user will not be able to transmit/talk.

Most mobile telephone systems have the capability of offering dispatch push to talk (PTT) services. Until the early 2000s, many mobile telephone companies were not permitted to offer push to talk services. The billing rates for dispatch services usually involve a reduced per minute rate for each subscriber that is connected to a group call.

Messaging

Messaging services for mobile telephones involve the sending or receiving of short messages. Messaging services are commonly limited to approximately 160 characters per message. The cost of messaging service usually involves a specific cost per message when the number of messages exceeds a certain number of messages.

Data Service

Data Services are communication services that transfer information between two or more devices. Data services may be provided in or outside the audio frequency band through a separate data communication network. Data service involves the establishment of physical and logical communication sessions between two (or more) users that allows for the non-real time or near-real time transfer of data (binary) type signals between users.

When data signals are transmitted on a non-digital channel (such as an analog telephone line), a data modem must be used. The data modem converts the data signal (digital bits) into tones that can be transferred in the audio frequency band. Because the speech coder used in the digital mobile systems system only compresses voice signals and not data modem signals, analog modem data cannot be sent on a digital mobile telephone (voice) channel.

When data signals are transmitted on a digital radio channel, a data transfer adapter (DTA) is used. The DTA converts the data bits from a computing device into a format that is suitable for transmission on a communication channel that has a different data transmission format. DTAs are used to connect communication devices (such as a PDA or laptop) to a mobile device when it is operating on a digital radio channel. The data service on 2^{nd} and 3^{rd} generation mobile systems can range from low-speed packet data up to more than 2 Mbps. Data services may be offered as circuit switched data (continuous connections) or packet switched data.

When using circuit switched data, the user typically pays only for the air-time used. Circuit switched data transfer rates on analog and 2nd generation digital systems are usually limited to about 14.4 kbps. For continuous data transmission of over 30 seconds, this results in a cost of less than 1 cent per kilobyte of data transferred. For very short burst of data transmission, circuit switched data can cost over $1 per kilobyte ($1000 per megabyte) of data because the call setup time is much longer than the data transmission and most cellular systems charge a minimum of 1 minute fee per call.

In 2006, a majority of the data services offered on mobile systems were packet data services. The service charges for packet data commonly include a monthly minimum charge and a usage fee that is based on the number of packets or the amount of kilobytes of user information that is transferred. The typical usage charge for packet data services ranged from approximately 1 cent to 20 cents per megabyte.

Circuit Switched Data

Circuit switched data is a data communication method that maintains a dedicated communications path between two communication devices regardless of the amount of data that is sent between the devices. This gives to communications equipment the exclusive use of the circuit that connects them, even when the circuit is momentarily idle.

To establish a circuit-switched data connection, the address is sent first and a connection (possibly a virtual non-physical connection) path is established. After this path is setup, data is continually transferred using this path until the path is disconnected by request from the sender or receiver of data.

Packet Switched Data

Packet switch data is the transfer of information between two points through the division of the data into small packets. The packets are routed (switched) through the network and reconnected at the other end to recreate the original data. Each data packet contains the address of its destination. This allows each packet to take a different route through the network to reach its destination.

Mobile packet-switched data service is an "always-on" type of service. When the mobile device is initially turned on, it takes only a few seconds to obtain an IP address that is necessary to communicate with the network. Even when the mobile device is inactive and placed in the dormant state, reconnection is typically less than 1/2 a second.

Location Based Services (LBS)

Location based services are information or advertising services that vary based on the location of the user. Mobile system may be capable of using different types of location information sources including the system itself or through the use of a global positioning system (GPS).

Multicast Services

Multicast service is a one-to-many media delivery process that sends a single message or information transmission that contains an address (code) that is designated for several devices (nodes) in a network. Devices must contain the matching code to successfully receive or decode the message. Mobile multicast services can include news services or media (digital audio) broadcasts.

Quality of Service (QoS)

Quality of service (QoS) is one or more measurements of desired performance and priorities of a communications system. QoS measures may include service availability, maximum bit error rate (BER), minimum committed bit rate (CBR) and other measurements that are used to ensure quality communications service.

The later generation mobile systems (e.g. 3G) can offer different types of quality of service (QoS) for different types of customers and their applications. A key QoS attribute includes priority access for different types of users. For example, real time priority access typically applies to voice services and reliable data transfer is applied to interactive data services.

Conversation Class

Conversation class is the providing of communication service (typically voice) through a network with minimal delay in two directions. While conversation has stringent maximum time delay limits (typically tens of milliseconds), it is typically acceptable to loose some data during transmission due to errors or discarding packets during system over capacity.

Streaming Class

Streaming class is the delivering of audio or video signals through a network by establishing and managing of a continuous flow (a stream) of information. Upon request of streaming class of service, a server system (information source) will deliver a stream of audio and/or video (usually compressed) to a client. The client will receive the data stream and (after a short buffering delay) decode the audio and play it to a user. Internet audio streaming systems are used for delivering audio from 2 kbps (for low-quality speech) up to hundreds of kbps (for audiophile-quality music).

Streaming class provides a continuous stream of information that is commonly used for the delivery of audio and video content with minimal delay (e.g. real-time). Streaming signals are usually compressed and error protected to allow the receiver to buffer, decompress, and time sequence information before it is displayed in its original format.

Interactive Class

Interactive class is the providing of data and control information through a network with minimal delays and with very few data errors. Interactive class allows a user or system to interact with a software application (typically a web host) in near-real time (limited transmission delays). Interactive class allows the communication channel to be shared by other users during periods of inactivity such as when the user is thinking about a response to a web page question.

Background Class

Background class is the process of providing information transfer services on a best-effort basis. Background class is used for non-time critical services (such as Internet web browsing).

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Appendix 1

Acronyms

1G-First Generation
1xEVDO-One Channel Evolution Version Data Only
1xEVDV-One Channel Evolution Version Data and Voice
2.5G-Second And A Half Generation
2G-Second Generation
3G-Third Generation
3GPP-3rd Generation Partnership Project
3GPP2-3rd Generation Partnership Project 2
4G-Fourth Generation
8-PSK-8 Level PSK
AAA-Authentication, Authorization, Accounting
ACC-Analog Control Channel
AMPS-Advanced Mobile Phone Service
AuC-Authentication Center
BC-Billing Center
BCH-Broadcast Channel
BER-Bit Error Rate
BS-Base Station
BSC-Base Station Controller
BTS-Base Transceiver Station
CBR-Constant Bit Rate
CDG-CDMA Development Group
CDMA-Code Division Multiple Access
CDMA2000-Code Division Multiple Access 2000
CDR-Call Detail Record
CN-Core Network
D/R-Distance to Reuse Ratio
DAMPS-Digital Advance Mobile Phone Service
DCC-Digital Color Code
DTA-Data Transfer Adapter
DTC-Digital Traffic Channel
EDGE-Enhanced Data Rates For Global Evolution
EDI-Electronic Data Interchange
EIR-Equipment Identity Register
ESMR-Enhanced Specialized Mobile Radio
ETACS-Extended TACS
ETDMA-Extended Time Division Multiple Access
FDD-Frequency Division Duplex
FDM-Frequency Division Multiplexing
FDMA-Frequency Division Multiple Access
FM-Frequency Modulation
FSK-Frequency Shift Keying
GGSN-Gateway GPRS Support Node
GMSC-Gateway Mobile Switching Center
GMSK-Gaussian Minimum Shift Keying
GPRS-General Packet Radio Service
GPS-Global Positioning System
GSM-Global System For Mobile Communications

GSN-GPRS Support Node
HLR-Home Location Register
IC-Interchange Carrier
iDEN-Integrated Dispatch Enhanced Network
IMEI-International Mobile Equipment Identifier
IMSI-International Mobile Subscriber Identity
ITU-International Telecommunication Union
IWF-Interworking Function
LBS-Location Based Services
LMR-Land Mobile Radio
MC-Message Center
MC-Multicarrier Mode
MCS-Mobile Cellular System
ME-Mobile Equipment
MIN-Mobile Identification Number
MIRS-Motorola Integrated Radio System
MSC-Mobile Station Class
MSC-Mobile Switching Center
MTS-Mobile Telephone Service
NAMPS-Narrowband Advanced Mobile Phone Service
NMT-Nordic Mobile Telephone
NPDB-Number Portability Database
NTACS-Narrowband Total Access Communication System
PAD-Packet Assembler And Disassembler
PCM-Pulse Coded Modulation
PCN-Personal Communications Network
PCS-Personal Communication Services
PDA-Personal Digital Assistant
PDC-Personal Digital Cellular
PDSN-Packet Data Switched Network
PM-Phase Modulation
PM-Pulse Modulation
PN-Packet Number
PN-Pseudo-Random Noise
PPDN-Public Packet Data Network
PSTN-Public Switched Telephone Network
PTT-Post, Telephone And Telegraph
PTT-Push To Talk
QoS-Quality Of Service
RAN-Radio Access Network
RNC-Radio Network Controller
SCH-Synchronization Channel
SDMA-Spatial Division Multiple Access
SGSN-Serving General Packet Radio Service Support Node
SIM-Subscriber Identity Module
SIS-Subscriber Identity Security
SMS-Short Message Service
SMSC-Short Message Service Center
TACS-Total Access Communications System
TCH-Traffic Channel
TDD-Time Division Duplex
TDMA-Time Division Multiple Access
TD-SCDMA-Time Division Synchronous Code Division Multiple Access
TIA-Telecommunications Industry Association
UE-User Equipment
UMTS-Universal Mobile Telecommunications System
UPR-User Performance Requirements
USB-Universal Serial Bus
VLR-Visitor Location Register
VMS-Voice Mail System
WCDMA-Wideband Code Division Multiple Access
WLAN-Wireless Local Area Network

Index

2.5G, 59, 63
3rd Generation Partnership Project (3GPP), 63
3rd Generation Partnership Project 2 (3GPP2), 64
8 Level PSK (8-PSK), 60
Access Channel, 30
Access Probe, 30-31
Advanced Mobile Phone Service (AMPS), 38-41, 43-44, 52-56
Analog Control Channel (ACC), 54, 57
Antenna, 4, 13, 20-21
Audio Broadcasting, 66
Authentication, 22, 24, 26, 31, 44, 48
Authentication Center (AuC), 26
Authentication Key (A-key), 71
Authentication Procedure, 26
Authentication, Authorization, Accounting (AAA), 22
Bandwidth, 3, 7-8, 12, 34, 41-45, 48-49, 51, 53-54, 56-57, 60-64
Base Station (BS), 1, 3, 6, 14, 19-21, 23, 32-38, 43, 45, 48, 50, 55
Base Station Antenna, 21
Base Station Controller (BSC), 20, 23
Base Transceiver Station (BTS), 23, 32
Battery, 38, 48
Billing, 15, 24-26, 67
Billing Center (BC), 26
Bit Error Rate (BER), 70
Bit Rate, 52, 54, 70
Bits Per Second (bps), 41-42, 44-46, 48
Blank and Burst, 36, 45, 48
Blank and Burst Signaling, 45
Blocking, 5
Broadcast, 27-29, 36, 51
Broadcast Channel (BCH), 29
Call Processing, 2
Carrier, 8, 10-11, 22, 25, 31, 51-52, 54, 57, 64
Carrier Frequency, 51, 54
CDMA Development Group (CDG), 58
CDMA2000, 60-62, 64
Cell Site, 3, 5-6, 13, 20, 28, 42-43, 45-46
Cell Splitting, 4-5
Cellular System, 1-3, 5, 36-40, 42-48, 50-51, 53, 56-57, 59, 62-63
Cellular Telecommunications Industry Association (CTIA), 52-53
Channel Coding, 48
Channel Structure, 54
Circuit Switched Data, 22, 68-69
Code Division Multiple Access (CDMA), 9, 12, 46, 49, 51, 56-58, 62-64
Code Division Multiple Access 2000 (CDMA2000), 60-62, 64
Constant Bit Rate (CBR), 70
Control Channel, 21, 27-30, 36-37, 40-42, 45-47, 53-54, 57
Controller, 20, 23, 25
Core Network (CN), 19, 58, 63
Data Services, 14, 18-19, 56, 59-61, 64-65, 68-69, 71
Data Transfer Adapter (DTA), 68
Data Transmission, 2, 30, 33, 51, 60-62, 65, 68-69
Decibel (dB), 40-41
Dedicated Control Channel, 42, 45
Digital Advance Mobile Phone Service (DAMPS), 52-53
Digital Color Code (DCC), 54, 57
Digital Traffic Channel (DTC), 47, 50, 53, 57, 60
Discontinuous Reception (DRx), 29, 42
Discontinuous Transmission (DTx), 38, 48

Dispatch, 21, 56, 66-67
Diversity Reception, 45
Dual Band, 53
Dual Mode, 15, 18, 53, 57
Dual-Tone Multifrequency (DTMF), 24
Duplex, 35, 39-42, 45, 51, 64
Electronic Data Interchange (EDI), 26
Electronic Serial Number (ESN), 37, 44
Enhanced Data Rates for Global Evolution (EDGE), 60
Enhanced Specialized Mobile Radio (ESMR), 56
Equipment Identity Register (EIR), 24-26
Error Detection, 42, 54
Extended TACS (ETACS), 40-41
Extended Time Division Multiple Access (ETDMA), 54-55
Facsimile Communications (FAX)
Fading, 57
First Generation (1G), 34
Fourth Generation (4G), 64-65
Frame, 11, 32, 56
Fraud, 26
Frequency Allocation, 10
Frequency Bands, 39, 41, 44-45
Frequency Division Duplex (FDD), 39
Frequency Division Multiple Access (FDMA), 9-10, 39, 56
Frequency Division Multiplexing (FDM), 10
Frequency Modulation (FM), 34, 36, 38, 41, 43, 46, 49
Frequency Planning, 57
Frequency Reuse, 2-4
Frequency Shift Keying (FSK), 8, 38-39
Full Rate, 52, 54
Gateway GPRS Support Node (GGSN), 19, 23
Gateway Mobile Switching Center (GMSC), 19
General Packet Radio Service (GPRS), 14, 19, 23, 60, 63
Global Positioning System (GPS), 70
Global System For Mobile Communications (GSM), 4, 14, 40-42, 49, 51-52, 58, 60-61, 63
GPRS Support Node (GSN), 14, 19, 23
Handoff, 5-6, 38, 50
Handover, 2, 5-6, 28, 32-33, 52
Hertz (Hz), 48
Home Location Register (HLR), 24-25
Integrated Dispatch Enhanced Network (iDEN), 56
Interchange Carrier (IC), 45
Interconnection, 19, 38, 50
Interference, 3-4, 21, 54
Interleaving, 44-45
International Mobile Equipment Identity (IMEI), 25
International Mobile Subscriber Identity (IMSI), 25
International Telecommunications Union (ITU), 62
Internet Protocol Address (IP Address), 32-33, 70
Internet Protocol Telephony (IP Telephony), 33
Intersystem Signaling, 64
Interworking Function (IWF), 22
IS-136 (US TDMA), 49, 51-55, 58
IS-54 (TDMA), 52-53, 55
IS-88 (NAMPS), 44
IS-95 (CDMA), 56-58, 61-64
Land Mobile Radio (LMR), 21
Line of Sight (LOS), 3
Location Based Services (LBS), 65, 70
Message Center (MC), 23
Mobile Cellular System (MCS), 38, 44
Mobile Equipment (ME), 19, 25
Mobile Identification Number (MIN), 37
Mobile Station (MS), 36-37

Mobile Station Class (MSC), 1-2, 5-6, 14, 19-20, 22-23, 25, 38, 49-50, 62
Mobile Switching Center (MSC), 1-2, 5-6, 14, 19-20, 22-23, 25, 38, 49-50, 62
Mobile Telephone Service (MTS), 1
Mobile Telephone, 1-74
Modems, 15, 17-18
Modulation, 2, 8-9, 34, 36, 38, 41, 44, 46-50, 53, 60-61
Motorola Integrated Radio System (MIRS), 56
Multicarrier Mode (MC), 23
Multiple Access, 9-13, 39, 51, 56, 62-64
Multiplexing, 9-10
Narrowband Advanced Mobile Phone Service (NAMPS), 43-44
Narrowband Total Access Communication System (NTACS), 41, 44
Nordic Mobile Telephone (NMT), 38, 41-43
Number Portability Database (NPDB), 26
One Channel Evolution Version Data and Voice (1xEVDV), 61-62
One Channel Evolution Version Data Only (1xEVDO), 61
Packet Assembler and Disassembler (PAD), 14
Packet Data, 2, 6, 14, 19, 23-24, 33, 59-62, 68-69
Packet Data Serving Node (PDSN), 19
Packet Data Switched Network (PDSN), 19
Packet Number (PN), 57-58
Paging, 21, 28-30, 32, 35-37, 47-48, 51, 54, 57, 66
Paging Channel, 32
Paging Group, 32
Personal Communication Services (PCS), 1, 35, 51, 53, 73
Personal Communications Network (PCN), 51
Personal Communications Services (PCS), 1, 35, 51, 53, 73
Personal Digital Assistant (PDA), 68
Personal Digital Cellular (PDC), 58
Phase Modulation (PM), 8, 47, 60
Pilot Channel, 29
Point to Point Microwave (PTP), 21
Post, Telephone and Telegraph (PTT), 67
Power Control, 33
Power Level, 4, 28, 30-32, 34, 38, 41-42, 48, 54, 58
Propagation, 3
Pseudo-Random Noise(PN), 57-58
Public Packet Data Network (PPDN), 24
Public Switched Telephone Network (PSTN), 1, 19, 22, 24, 48
Pulse Coded Modulation (PCM), 7
Pulse Modulation (PM), 47
Push To Talk (PTT), 67
Quadrature Amplitude Modulation (QAM), 8
Quality of Service (QoS), 65, 70-71
Radio Access Network (RAN), 14, 19
Radio Carrier, 51, 57, 64
Radio Channel, 1, 3-4, 10-12, 14, 18, 21, 27, 29, 33-35, 39-42, 44, 46-47, 49-62, 68
Radio Coverage, 5, 13, 28, 34
Radio Network Controller (RNC), 23
Receiver, 20, 29, 36, 38, 55, 69, 71
Registration, 29, 34
Roaming, 62, 66
Second And A Half Generation (2.5G), 59, 63
Second Generation (2G), 18, 51, 59
Sector, 13
Serving General Packet Radio Service Support Node (SGSN), 19, 23

Short Message Service (SMS), 23, 53-54
Short Message Service Center (SMSC), 19
Signaling Channel, 41
Simulcast, 44
Single Mode, 18
Sleep Mode, 29, 51, 54, 57
Soft Capacity, 58
Spatial Division Multiple Access (SDMA), 9, 13
Specialized Mobile Radio (SMR), 56
Speech Activity, 49
Speech Coder, 7, 49-50, 54, 68
Speech Coding, 7, 49, 58
Spread Spectrum, 56
Standards, 56, 63-64
Subscriber Identity Module (SIM), 15-16, 19, 29
Subscriber Identity Security (SIS), 43
Synchronization Channel (SCH), 29
System Identification (SID), 29, 36, 40, 47
Telecommunications Industry Association (TIA), 52, 64
Third Generation (3G), 1, 18, 59, 61, 63-65, 70
Time Delay, 71
Time Division Duplex (TDD), 64
Time Division Multiple Access (TDMA), 4, 9, 11, 46, 49, 51-56, 58
Time Division Synchronous Code Division Multiple Access (TD-SCDMA), 64
Time Slot, 11, 47, 52-55
Total Access Communications System (TACS), 38, 40-42
Traffic Channel (TCH), 47, 50, 53, 57, 60
Transceiver, 11, 14, 20-21, 23, 32
Transmit Power, 41
Universal Mobile Telecommunications System (UMTS), 63
Universal Serial Bus (USB), 17
User Equipment (UE), 19
User Performance Requirements (UPR), 52-53
Variable Rate Speech Coding, 58
Visitor Location Register (VLR), 23-25
Voice Channel, 21, 36-37, 40-42, 47-49, 57, 68
Voice Coding, 7, 49, 58, 65
Voice Mail System (VMS), 24
Voice Message System (VMS), 24
Voice Paging, 66
Voice Services, 60, 64-66, 71
Wideband, 57, 62-63
Wideband Code Division Multiple Access (WCDMA), 17, 23, 62-64

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