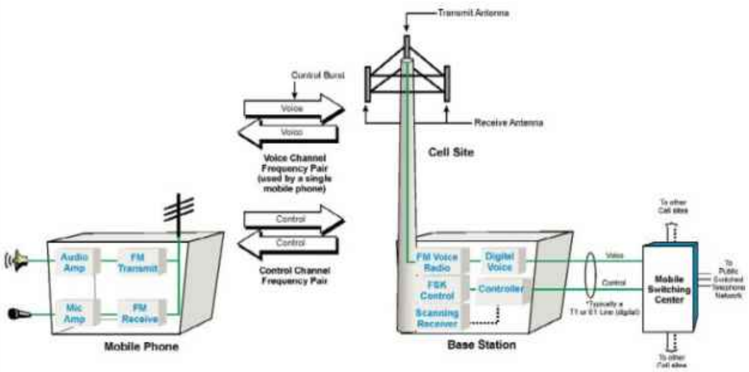
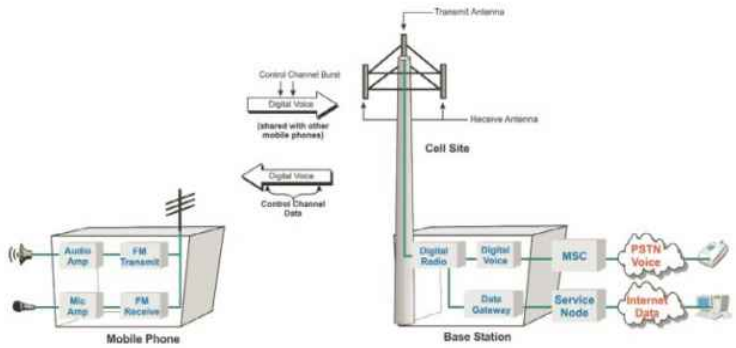
Introduction To Mobile Telephone Systems

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

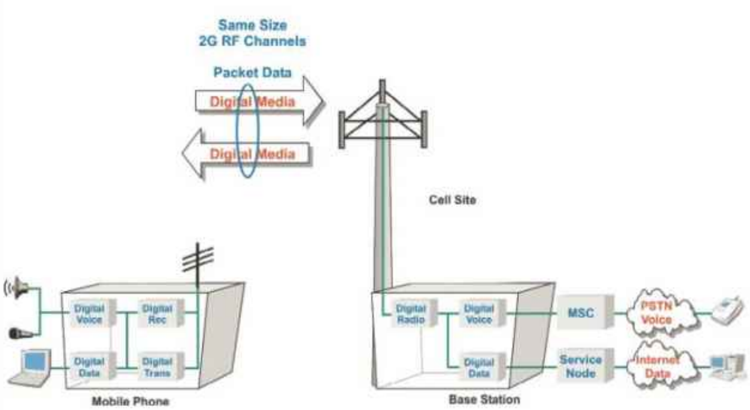
Lawrence Harte, David Bowler



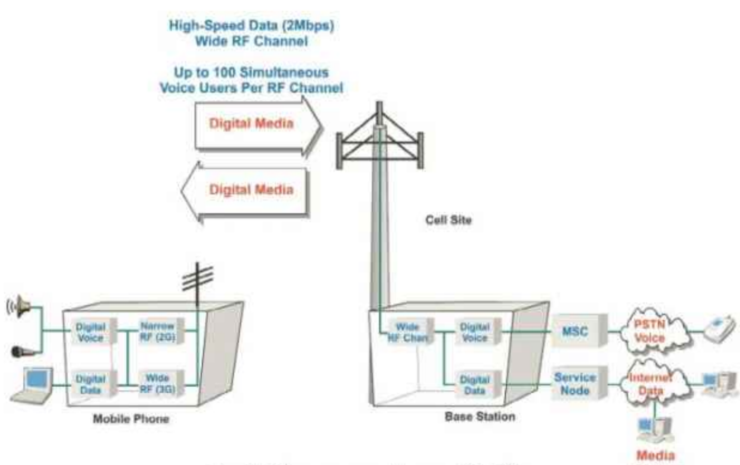
1st Generation (1G)
Analog Cellular



2nd Generation (2G)
Digital Cellular



2.5 Generation (2.5G)
Packet Digital Cellular



3rd Generation (3G)
Broadband Digital

Excerpted From:

Wireless Systems

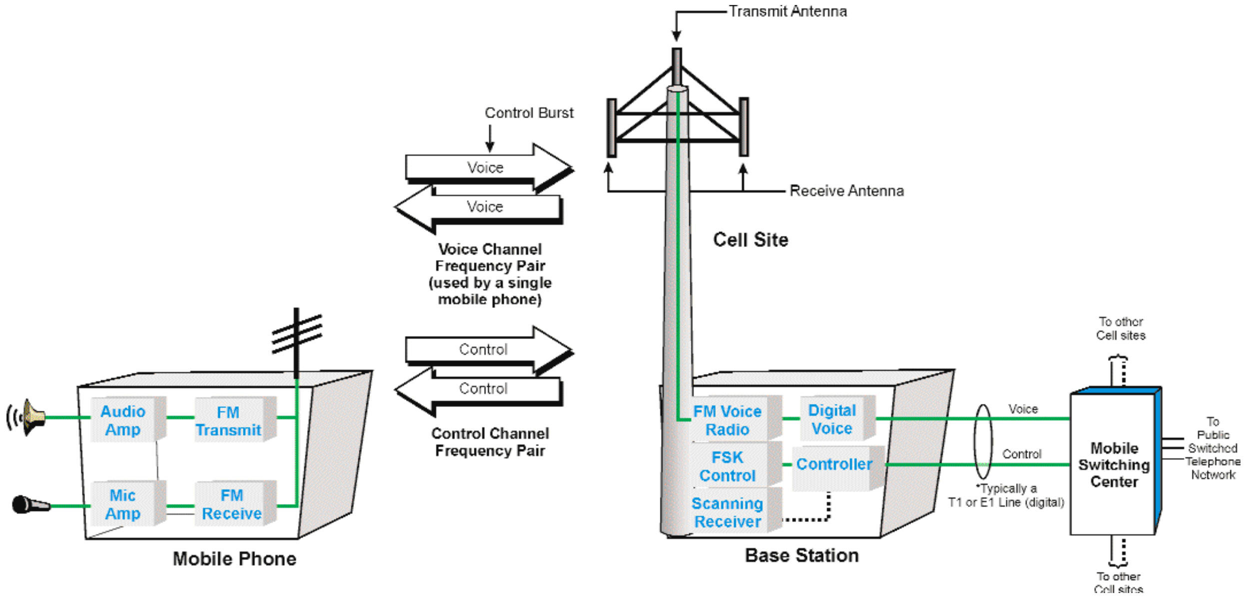
With Updated Information

ALTHOS Publishing

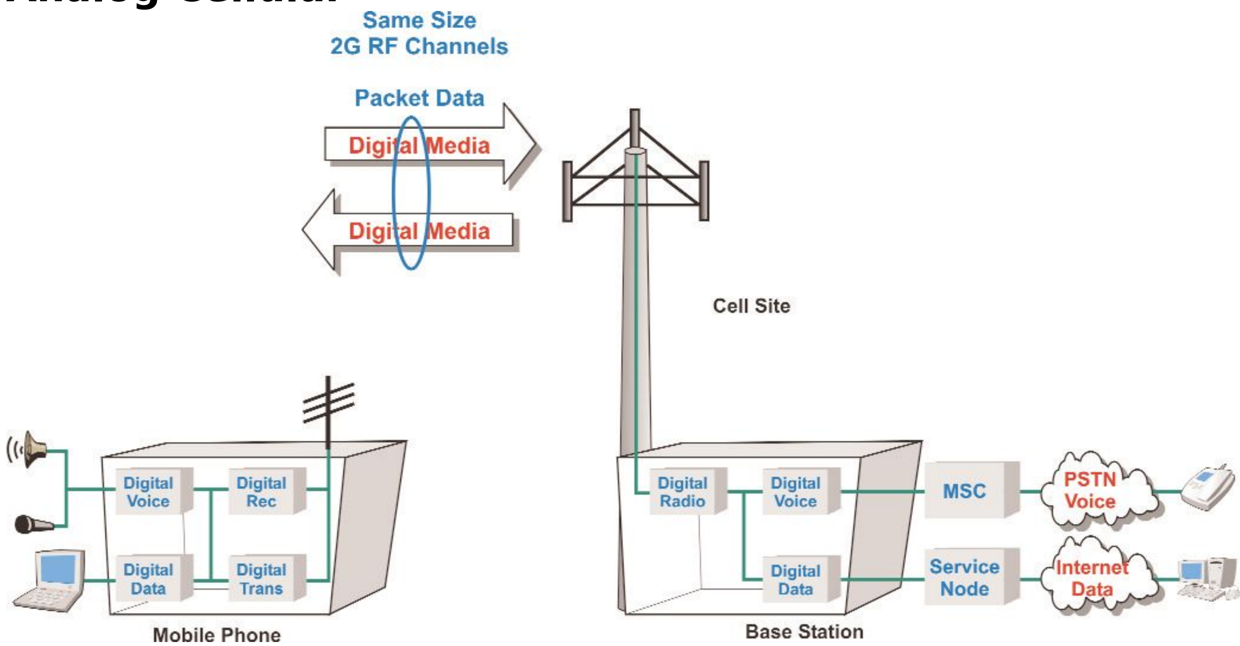
Introduction to Mobile Telephone Systems

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

Lawrence Harte, Dave Bowler



1st Generation (1G) Analog Cellular

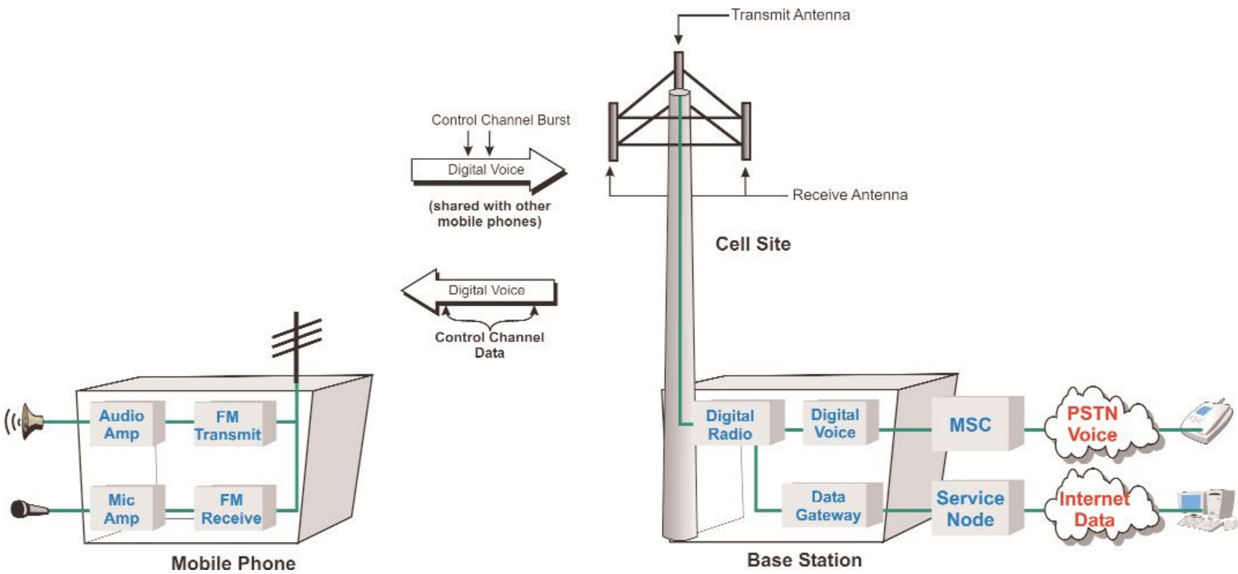


2.5 Generation (2.5G) Packet Digital Cellular

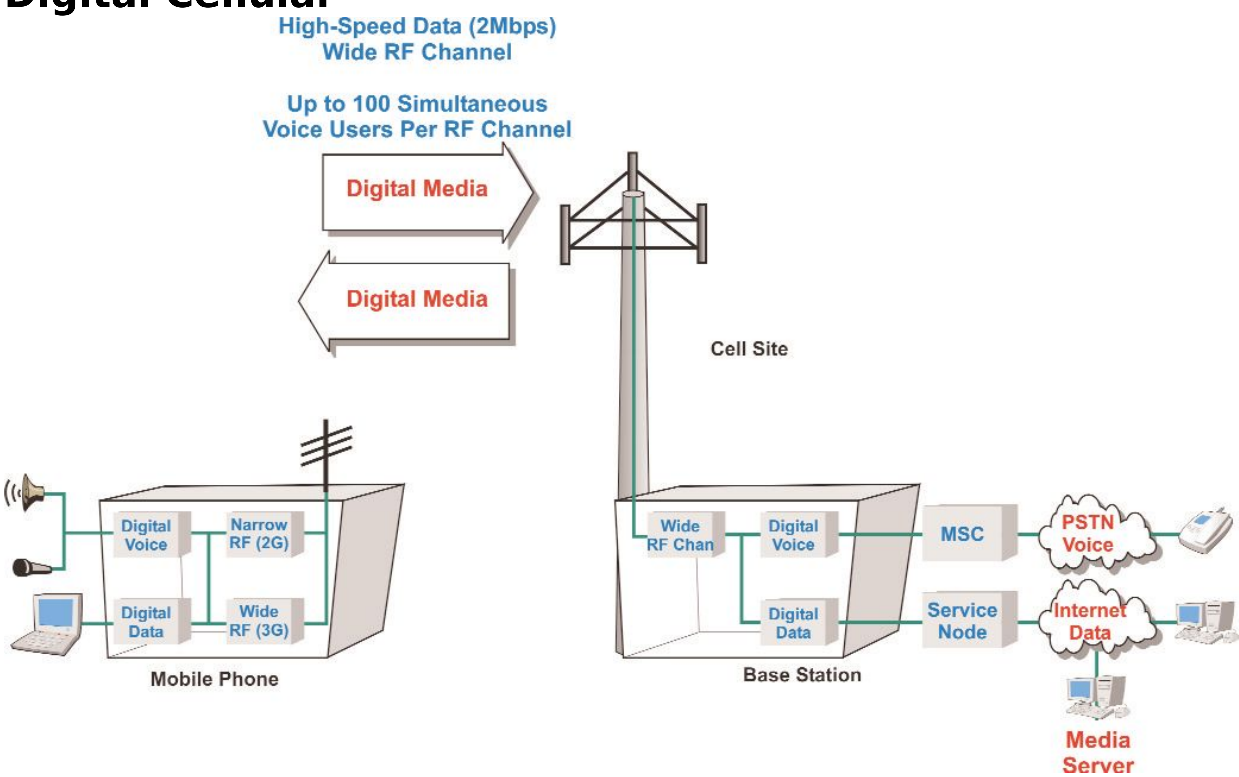
Excerpted From:

Wireless Systems

With Updated Information

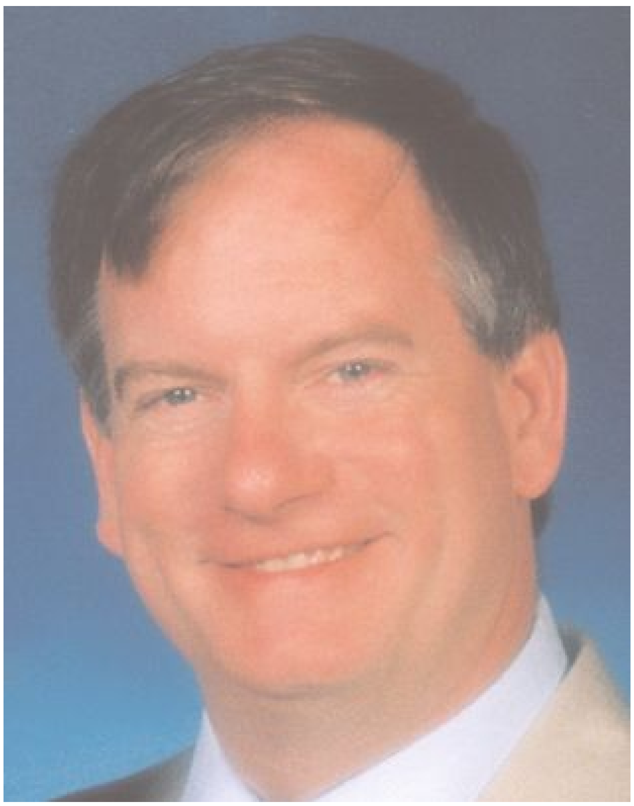


2nd Generation (2G) Digital Cellular



3rd Generation (3G)

About the Authors



Mr. Harte is the president of Althos, an expert information provider covering the communications industry. He has over 29 years of technology analysis, development, implementation, and business management experience. Mr. Harte has worked for leading companies including Ericsson/General Electric, Audiovox/Toshiba and Westinghouse and consulted for hundreds of other companies. Mr. Harte continually researches, analyzes, and tests new communication technologies, applications, and services. He has authored over 30 books on telecommunications technologies on topics including Wireless Mobile, Data Communications, VoIP, Broadband, Prepaid Services, and Communications Billing. Mr. Harte's holds many degrees and certificates include an Executive MBA from Wake Forest University (1995) and a BSET from the University of the State of New York, (1990).

Mr. Bowler is an independent telecommunications training consultant. He has almost 20 years experience in designing and delivering training in the areas of wireless networks and related technologies, including CDMA, TDMA, GSM and 3G systems. He also has expertise in Wireless Local Loop and microwave radio systems and has designed and delivered a range of training courses on SS7 and other network signaling

protocols. Mr. Bowler has worked for a number of telecommunications operators including Cable and Wireless and Mercury Communications and also for Wray Castle a telecommunications training company where he was responsible for the design of training programmes for delivery on a global basis. Mr. Bowler was educated in the

United Kingdom and holds a series of specialized maritime electronic engineering certificates.

ALTHOS Publishing

ISBN: 0-9746943-2-0

ALTHOS electronic books (ebooks) and images are available for use in educational, promotional materials, training programs, and other uses. For more information about using tional materials, training programs, and other uses. For more information about using 2260

Terms of Use

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 area 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 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.

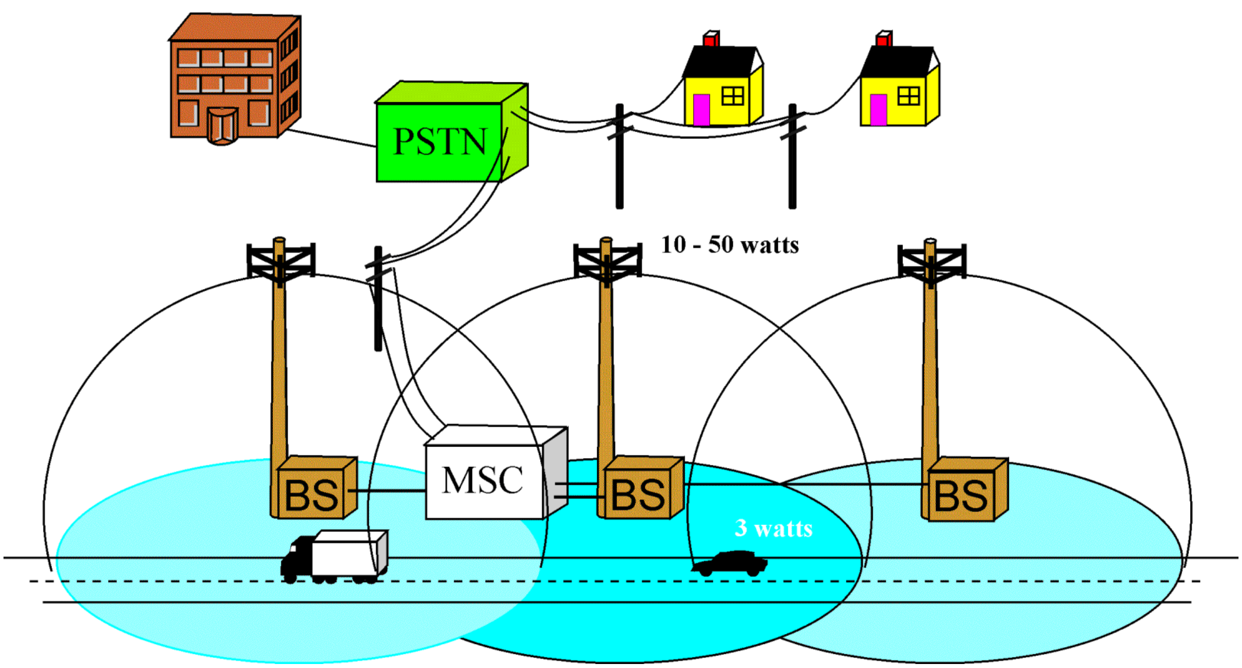


Figure 1.1., Basic Cellular System

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 “hand-off” 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.

Market Growth

Key drivers for the mobile telephone market growth include new wireless technology (3G) service availability and the replacement market for mobile phones with new capabilities such as camera phones, color displays, and increased accessory capabilities.
The mobile phone industry is transitioning from first-generation analog

technology (1st generation – 1G), through second-generation digital technology (2nd generation – 2G), to high-capacity third-generation digital sys

tems (3G). Because mobile telephone service providers gain increased system efficiency (more customers per tower) and have the ability to offer new and advanced service (that can be billed), this is resulting in aggressive offers from carriers to upgrade existing customers and add new customers to the new high-capacity systems. The number of mobile users reached 1.3 billion in 2003 [[i]].

As manufacturers offer mobile phones that have new capabilities that offer significantly improved lifestyles, customers will upgrade their mobile telephones to devices with these increased capabilities. Some of the key capabilities include camera phones, color displays, and wireless personal area network (WPAN) communications ability. The market for camera phones reached 3 million units in 2001, achieved 17 million units in 2002, and it should reach 60 million units by the end of 2003, and predictions show that camera phones will reach 165 million units by 2006 [ii]. The leading WPAN system in 2003 is Bluetooth. The upgrade or inclusion of Bluetooth with mobile telephone devices allows the connection of mobile telephones with many service-enhancing accessories such as wireless headsets, data transfer to PDAs and laptops, and printing.

Figure 1.2 shows the number of subscribers (left axis) and the growth in percentage right (axis) of the worldwide mobile telephone industry. This graph shows during the early 1990s, the industry growth had exceeded more than 30% each year. In the 2000’s, the growth had begun to decrease due to the high percentage of global market penetration (almost 25% of all people in the world had mobile telephones in 2003).

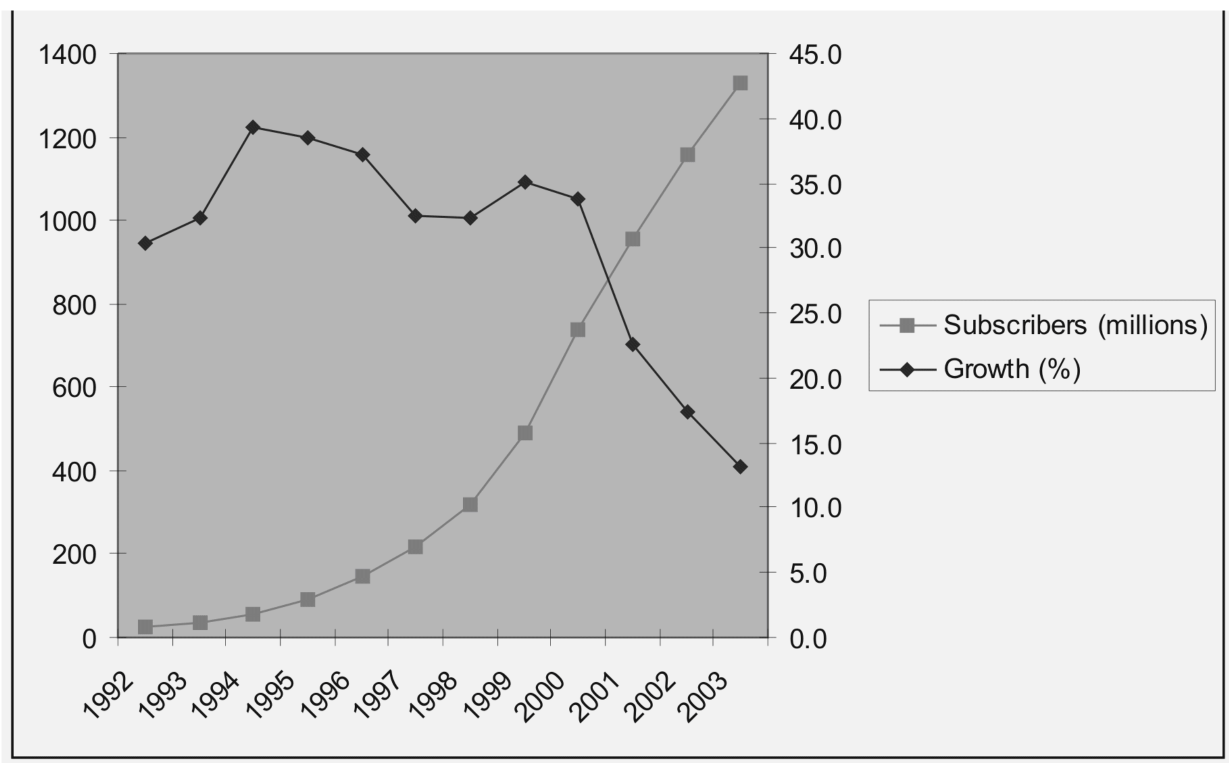


Figure 1.2., Global Cellular Market Growth 2003
Source: International Telecommunications Union (ITU)

Technologies
The key technologies used in cellular mobile radio include cellular frequen
cy reuse, analog cellular (1st generation), digital mobile radio (2nd generation), packet based digital radio (2 ½ generation), and wideband radio (3rd
generation).

Cellular Frequency Reuse

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 simply 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. But it is difficult to account for enough propagation factors to precisely position the towers, so the cell site position and power levels are usually adjusted later.

Figure 1.3 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.

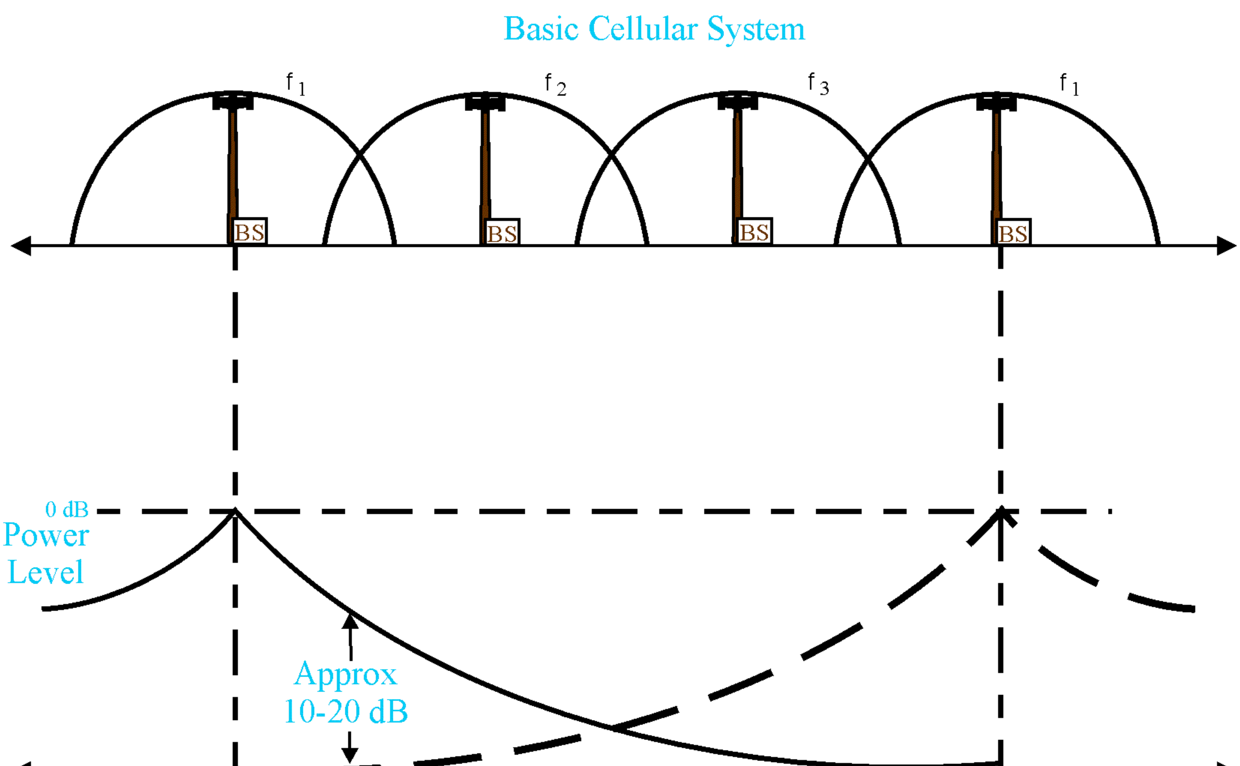


Figure 1.3., Frequency Reuse

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 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.

Analog Cellular

To allow for the conversion from analog systems to digital systems, some cellular technologies allow for the use of dual mode or multi-mode mobile telephones. These handsets are capable of operating on an analog or digital radio channel, depending on whichever is available. Most dual mode phones prefer to use digital radio channels, in the event both are available. This allows them to take advantage of the additional capacity and new features such as short messaging and digital voice quality, as well as offering greater capacity.

Cellular systems have several key differences that include the radio channel bandwidth, access technology type (FDMA, TDMA, and CDMA), data signaling rates of their control channel(s) and power levels. Analog cellular systems have very narrow radio channels that vary from 10 kHz to 30 kHz. Digital systems channel bandwidth ranges from 30 kHz to 1.25 MHz. Access technologies determine how mobile telephones obtain service and how they share each radio channel. 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.

One of the key characteristics of cellular systems is their ability to handoff (also called handover) calls from one radio tower to another while a call is in process. Handoff is an automatic process that is a result of system monitoring and short control messages that are sent between the mobile phone and the system while the call is in progress. The control messages are so short that the customer usually cannot perceive that the handoff has occurred.

Analog cellular systems are regularly characterized by their use of analog modulation (commonly FM modulation) to transfer voice information. Ironically, almost all analog cellular systems use separate radio channels for sending system control messages. These are digital radio channels.

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 receive 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 influences system capacity. However, a typical subscriber uses the system for only a few minutes a day, so 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 algorithm internally 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 1.4 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.

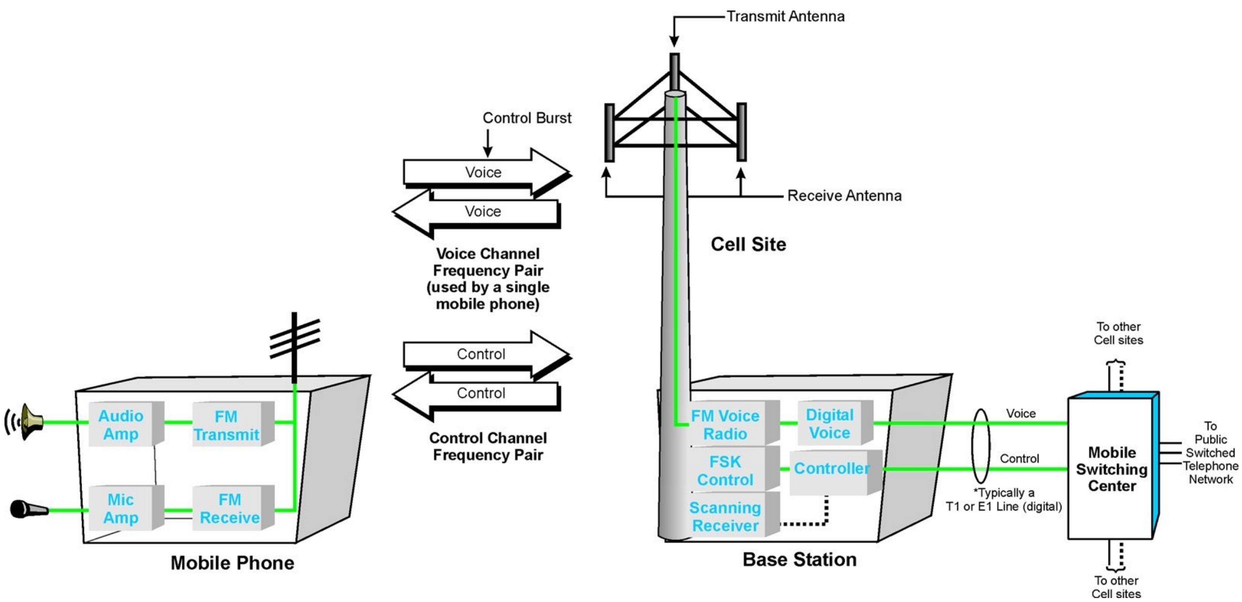


Figure 1.4., Analog Cellular System (1st Generation)

Digital Mobile Radio

There are two basic types of systems; analog and digital. Analog systems commonly use FM modulation to transfer voice information and digital systems use some form of phase modulation to transfer digital voice and data information. Although analog systems are capable of providing many of the services that digital systems offer, digital systems offer added flexibility as many of the features can be created by software changes. The trend at the end of the 1990’s was for analog systems to convert to digital systems.

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 ordinarily 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.

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 vocoder characterizes the input signal. It looks up codes in a code book table that represents various digital patterns to choose the 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 1.5 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 increases 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.

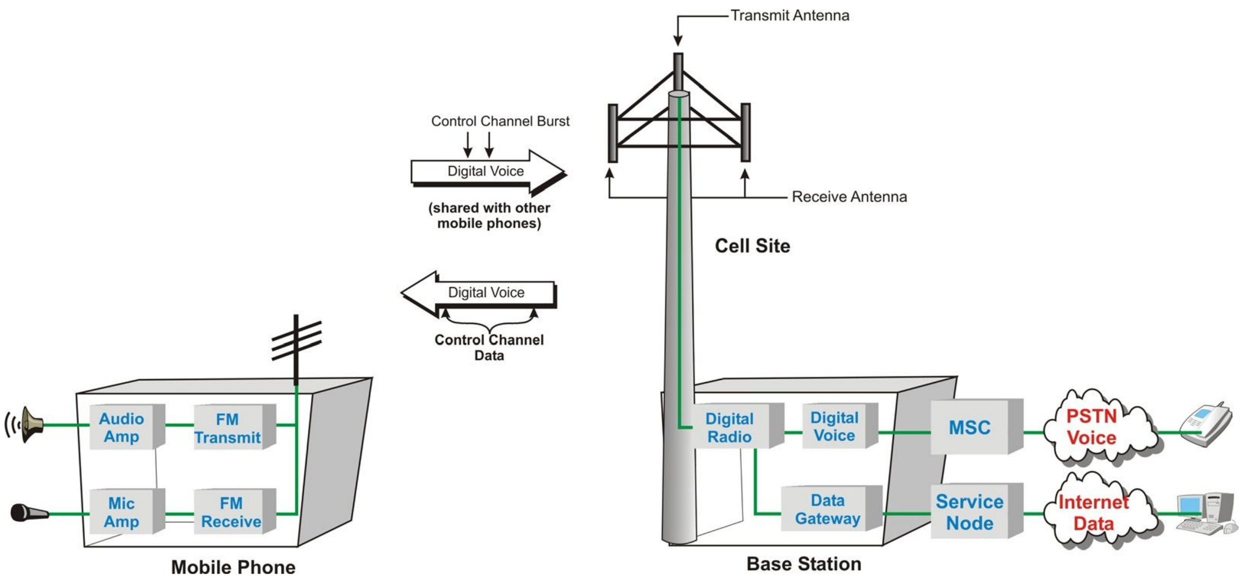


Figure 1.5., Digital Cellular System (2nd Generation)

Packet Based Digital Cellular (Generation 2.5)

Packet Based Cellular (commonly called - generation 2.5, or 2.5G) are 2nd

Generation cellular technologies that have been enhanced to provide for advanced communication applications. Packet based digital cellular systems help the industry transition from one capability to a much more advanced capability. In cellular telecommunications, 2.5G systems used improved digital radio technology to increase their data transmission rates and new packet based technology to increase the system efficiency for data users.

Figure 1.6 shows a 2nd generation digital cellular system that has been upgraded to offer similar features as 3rd generation systems. This diagram shows 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.

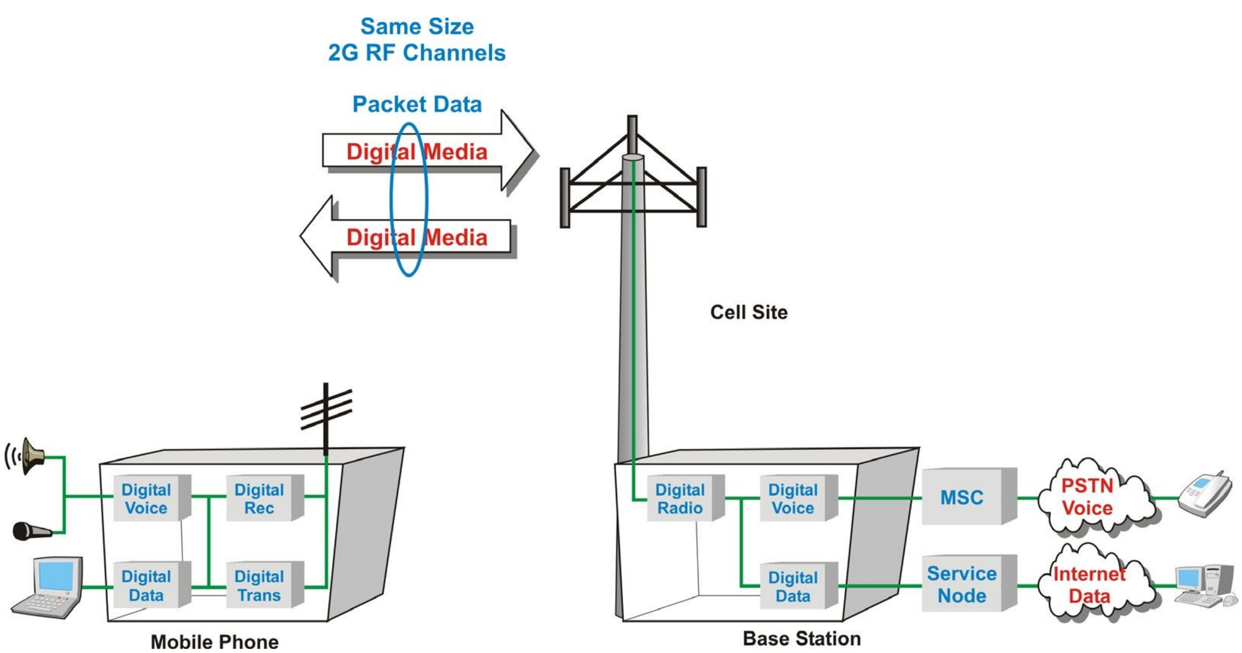


Figure 1.6., Upgraded Digital Cellular System (2 1/2 Generation)

Wideband Digital Cellular (3rd Generation)

Wideband Digital Cellular (commonly called 3rd generation) is cellular tech
nology that uses wideband digital radio technology as compared to 2nd generation narrowband digital radio.

Figure 1.7 shows a wideband digital cellular system that permits very highspeed 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 cel

lular systems to send high-speed data to communication devices. This system also uses communication servers to help to manage multimedia communication sessions. Aside from the use of wideband radio channels and

enhanced packet data communication, this diagram shows that 3rd genera
tion systems typically use the same voice network switching systems (such
as the MSC) as 2nd generation mobile communications systems.

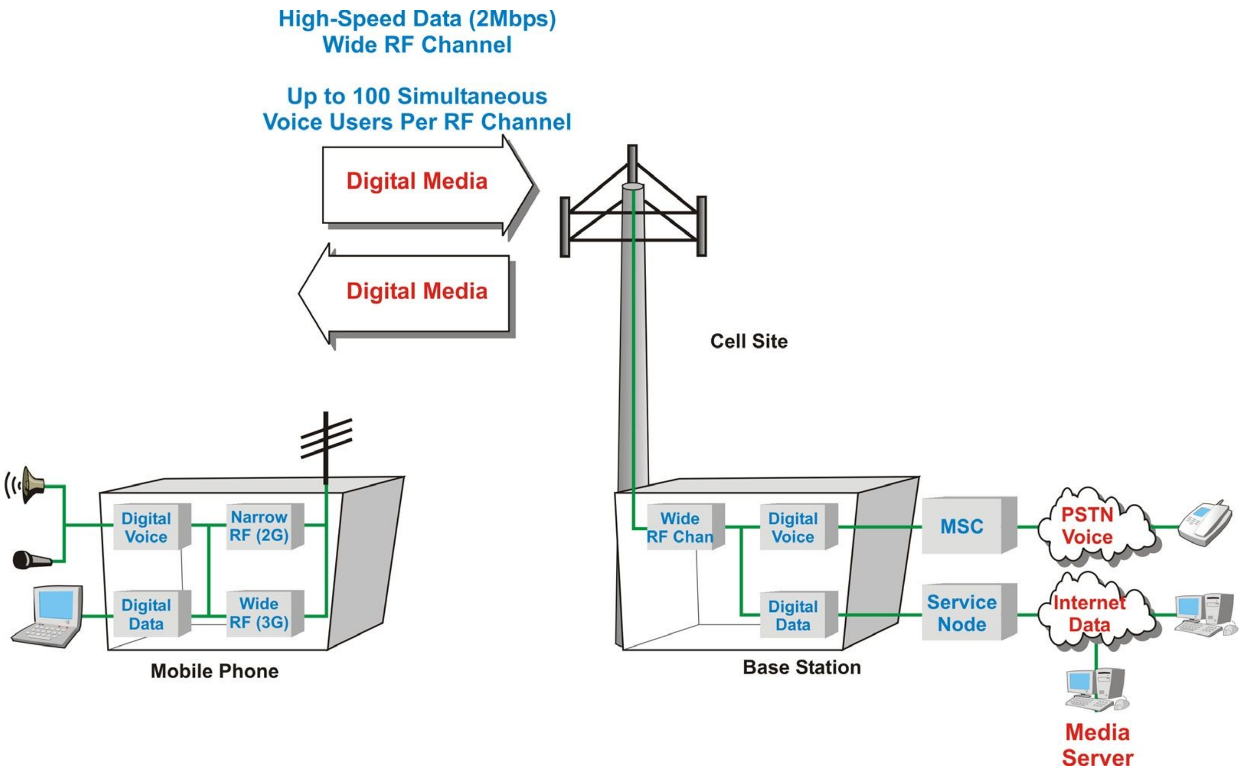


Figure 1.7., Wideband Digital Cellular System (3rd Generation)

Analog Systems (1st Generation)

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.

Advanced Mobile Phone Service (AMPS)

Advanced Mobile Phone Service (AMPS) was the original analog cellular system in the United States. It is still in widespread use and by1997; AMPS systems were operating in over 72 countries [3]. The AMPS system continues to evolve to allow advanced features such as increased standby time, narrowband radio channels, and anti-fraud authentication procedures. In 1974, 40 MHz of spectrum was allocated for cellular service [4] that provided only 666 channels. In 1986, an additional 10 MHz of spectrum was added to facilitate expansion [5] 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 frequency duplex with its channels separated by 45 MHz. The control channel and voice channel signaling is 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)

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 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 signaling is 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)

There are two Nordic Mobile Telephone (NMT) systems; NMT 450 that 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 [6]. 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. There are now over 40 countries that have NMT service available. Some of these countries use different frequency bands or reduced number of channels.
The NMT 450 system uses a lower frequency (450 MHz) and higher maximum transmitter power level which 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 [7]. This allows 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 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) [8]. 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 [9].

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 Advanced Mobile Phone Service (NAMPS) is an analog cellular system that 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, MCSL2, 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 receive 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 [10]. 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 [11].

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 [12]. 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 [13]. 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 subband digital audio signaling with a data rate of 150 bps

Digital Cellular Systems (2nd Generation)

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) system 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. 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. By the middle of 2003, 510 networks in 200 countries offered GSM service. The GSM system is a digital-only system and was not designed to be backward-compatible with the established analog systems. The GSM radio band is shared temporarily with analog cellular systems in some European nations.

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, but a single GSM digital radio channel or time slot is capable of transferring only 1/8th of that, 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 IS136 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 800Mhz 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 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 and 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 being sent. 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, and some 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 [14], 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 [15]). 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^{TM} 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 and a total of 60 million subscribers are served by this technology.

Upgraded Digital Cellular System (Generation 2.5)
The types of upgraded 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 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 that uses three times the spectrum of IS-95, that is 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.

By the middle of 2003 there were a total of 60 commercial 1xRTT networks offering service.

Evolution Data Only (1xEVDO)

The evolution of existing systems for data only (1xEVDO) is an evolved ver

sion 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 is 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.

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.

A large number of GSM operators have secured spectrum for WCDMA and many network launches are imminent, with live networks presently in Japan, the United Kingdom and Italy.

Code Division Multiple Access 2000 (CDMA2000)

CDMA2000 is a family of standards that represent an evolution from the IS95 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 standards 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 likely that WCDMA and CDMA2000™ will dominate the 3G market, however in China there is growing support for a homegrown standard known as Time Division Synchronous CDMA (TD-SCDMA). TDSCDMA 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.

Services

There are three basic services offered by cellular systems; voice, messaging and data. Advanced services such as voice mail and paging are often bundled into a basic service program.

Voice

The most well known application for wireless communications is voice communications. Voice communication can be telephony; wide area (cellular), business location (wireless office) or home cordless (residential) or 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, plus 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 1.8 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 1.8., Typical Mobile Telephone Voice Service Rate Plan
Some mobile telephone systems are now offering dispatch push to talk (PTT) services. Dispatch services provide the user with the ability a single user to simultaneously communicate with many members in a group (group call). 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 service involves the transfer of data to or from the mobile telephone.
2nd and 3rd generation cellular and PCS systems offer higher speed data

services (100 kbps to 2 Mbps). These data services may include circuit switched data or packet switched data. Packet data services such as general packet radio service (GPRS) are more efficient than circuit switched services and have become the most popular type of data service.

When using circuit switched data, the user typically pays only for the air
time used. Circuit switched data transfer rates on analog and 2nd genera

tion 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 1996, cellular packet services started to be offered on cellular systems. 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 kilobyte ($1 to $20 per megabyte).

Web Access

In the early 2000s, most mobile devices came equipped with software that allowed the user to access information services through the Internet. Because of the limitations of the screen size (small), screen type (monochrome), and control ability (no mouse), web access has generally been limited to specifically designed web sites.

The cost of web access usually involves a monthly subscription fee of approximately $3 and it may involve a usage fee for the amount of information transferred.

Software Downloads

Intelligent mobile telephones have the capability of running small programs and these programs are made available to the user as a software download. Examples of these software downloads include games, screen savers, and ringer tones. To purchase and obtain these programs, the user browses through a list of available downloads and selects to purchase the software. These software downloads are generally inexpensive (less than $10.00) and may be time limited (e.g. a game that can be used for 2 months). The mobile telephone service provider usually splits the fees for the software programs with the developer of the software.

Future Enhancements

There are likely to be many future enhancements to mobile radio. Some of the key innovations include software defined radios, spatial division multi
ple access (SDMA), and 4th generation mobile telephones.

Software Defined Radios

Software defined radios are transceiver devices that use digital signal processing to create and decode radio messages. Because they use digital signal processing for almost all functions, it is possible to change access technologies and radio transmission characteristics through software changes. Thus it may be possible in the future for a handset or other terminal to download the necessary parameters of a network as the mobile moves from one technology to another.

Spatial Division Multiple Access (SDMA)

Spatial Division Multiple Access (SDMA) is a technology that increases the quality and capacity of wireless communications systems. Using advanced algorithms and adaptive digital signal processing; Base Stations equipped with multiple antennas can more actively reject interference and use spectral resources more efficiently. This would allow for larger cells with less radiated energy, greater sensitivity for portable cellular phones, and greater network capacity.

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).

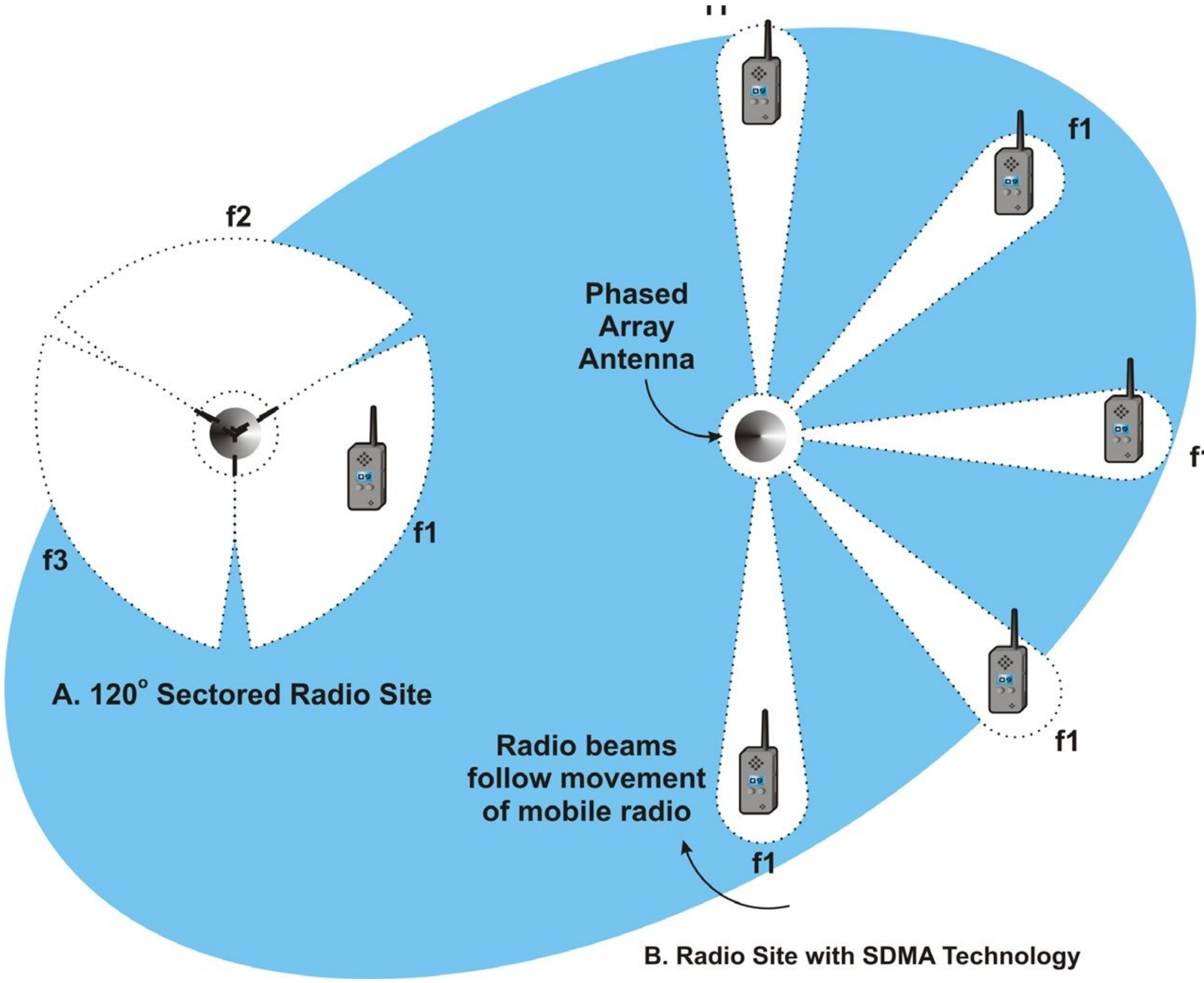


Figure 1.9., Spatial Division Multiple Access (SDMA)

Fourth Generation (4G) Networks

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, offer data rates up to 100 Mbps and support true global mobility. One route towards this vision is the convergence of technologies such as 3G cellular and Wireless LANs (WLANs).

References:

i. “Key Global Telecom Indicators for the World Telecommunications Service Sector,” International

Telecommunications Union,
http://www.itu.int/ITUD/ict/statistics/at_glance/KeyTelecom99.html, September 3, 2003.
ii. "The Worldwide Camera Phone Market," Rober, Bitflux, July 28, 2003, www.bitflux.ch/english
iii William Lee, "Mobile Cellular Telecommunications Systems", p.2, McGraw Hill, 1989.
iv Personal interview, Industry expert, 2 September, 2003.
v. Lawrence Harte, "Cellular and PCS/PCN Telephones and Systems", APDG Publishing, pgs. 377-381.
vi William Lee, "Mobile Cellular Telecommunications Systems", McGraw Hill, 1989, p.5.
vii William Lee, "Mobile Cellular Telecommunications Systems", McGraw Hill, 1989, p.265.
viii. Cellular Radio, Analog and Digital Systems, Mehrotra, Pg 177. ix. Asha, K Mehrotra, "Cellular Radio: Analog and Digital Systems", Artech House, 1994,, pg 74.
x. Asha, K Mehrotra, "Cellular Radio: Analog and Digital Systems", Artech House, 1994,, pg. 177.
1. D. M. Balston (Editor), R.C.V. MacArio, "Cellular Radio Systems", Artech House, 1993, pg 77.
xi. Asha, K Mehrotra, "Cellular Radio: Analog and Digital Systems", Artech House, 1994, pg. 193
xii. Mehrotra, Cellular Radio, Analog and Digital Systems, Mehrotra, pg. 186 xiii. Asha, K Mehrotra, "Cellular Radio: Analog and Digital Systems", Artech House, 1994,, pg. 188.
xiv. Asha, K Mehrotra, "Cellular Radio: Analog and Digital Systems", Artech House, 1994,, pg. 193.
xv "Digital Cellular, Economics and Comparative Technologies," EMCI, May, 1993, pg. 75.
xvi Lawrence Harte, "Cellular and PCS, The Big Picture," McGraw-Hill, 1997, Pg. 130