UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

BULLETIN 1751H-705

SUBJECT: **Fundamentals of Cellular Radio Service**

TO: Telephone Borrowers
REA Telephone Staff

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PREVIOUS INSTRUCTIONS: None - this bulletin is new information.

FILING INSTRUCTIONS: Place this document in Section 1751H, Transmission Design Bulletins.

PURPOSE: Provide a tutorial on Cellular Radio Systems and include definitions, fundamentals, system architecture and equipment, and future developments.

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FUNDAMENTALS OF CELLULAR RADIO SYSTEMS

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DEFINITIONS

Access The process of trying to gain entrance to the cellular network for the purpose of transferring information or data.

BETRS Basic Exchange Telecommunications Radio Service. A rural radio telephone service.

Bypass The use of any facilities or services as an alternative to the local telephone company.

Call Traffic Customer activity on the cellular network.

Cell Depicted as hexagonal in shape, it represents the coverage area of a base station within a cellular system.

CGSA Cellular Geographic Service Area. The service area of a cellular radio system operator.

Central Office (CO) Location where the switching system and other related equipment are housed and user lines are terminated in a PSTN.

Channel A pair of frequencies used to carry a conversation, that is, to transmit and receive simultaneously.

Cluster A group of cells that forms a pattern that can be duplicated many times in the same CGSA.

Co-channel Interference Interference caused by two or more transmissions sharing the same channel.

CDMA Code Division Multiple Access. Modulation technique where several calls are able to be transmitted simultaneously over a wide bandwidth with each call assigned its own unique code.

Common Carrier A company that furnishes telecommunications facilities or service to the public and cannot control message content over the network.

CPU Central Processing Unit. The part of the computer that contains the logic, computation, and control circuits.

CT-2 Second Generation Cordless Telephone.

CTIA Cellular Telecommunications Industry Association.

Directional Antenna An antenna that radiates power in a specific area.

Duplex Transmission Simultaneous but independent two-way transmission in both directions.

FCC Federal Communications Commission.

FDMA Frequency Division Multiple Access. Modu-lation technique where several signals are sent simultaneously by dividing the frequency.

Frequency Reuse The principle of using the same frequencies in different cells within the same CGSA.

Handoff The process of automatically changing the voice channel of a mobile unit to minimize call degradation as the unit travels throughout the service area.

IMTS Improved Mobile Telephone Service.

Interference The reception of unwanted signals mixed with the desired signal.

MSA Metropolitan Statistical Area. As defined in cellular telephony, a region defined as an urban area that is designated by the FCC to have two operators licensed to provide cellular service.

Off-hook Condition indicating a seizure, request for service, or a busy signal on a telephone line or trunk.

On-hook Condition indicating a disconnect, unanswered call, or an idle signal on a telephone line or trunk.

Omnidirectional Antenna An antenna that ideally radiates power in a spherical pattern.

Paging The process of determining the availability of a mobile unit to receive a call.

PCM Pulse Code Modulation. Technique by which the modulating signal is sampled, then quantized and coded.

PCN Personal Communications Network.

PCS Personal Communications Service.

PSTN Public Switched Telephone Network. The network of the wireline common carrier telephone company.

Radio Channel A band of frequencies capable of carrying radio communications.

Roaming Operating the mobile unit outside of the designated "home" service area.

RSA Rural Service Area. A region defined as a rural area that is designated by the FCC to have two operators licensed to provide cellular service.

RSSI Received Signal Strength Indicator.

SAT Supervisory Audio Tone. One of three tones in the 6 kHz band with one assigned to each sector.

Sectorization The process of creating subdivisions within a cell for the purpose of reusing the allocated frequencies for that cell.

ST Signaling Tone A 10 kHz tone transmitted by the mobile unit on a voice channel. Indicates call confirmation or call completion.

TDMA Time Division Multiple Access. Modulation technique where users are assigned individual time slots within the same frequency band.

TIA Telecommunications Industry Association.

Traffic The volume of calls in progress.

Transceiver A transmitter and receiver combined into one unit such as a mobile telephone.

1. INTRODUCTION

1.1 General

1.1.1 Cellular mobile radio technology is complex and diverse both in theory and application. This bulletin provides a practical and comprehensive overview of the cellular mobile radio environment. Cellular radio definitions, terminology, and concepts are described to give the reader a broad understanding of the topic. In addition, detailed descriptions of network architecture and equipment, as well as system functions and parameters are discussed.

1.1.2 Discussion on cellular radio system design recommendations and application guidelines involves a further in-depth study of the cellular network, and therefore are not discussed in this bulletin but will be included in future REA bulletins.

1.2 Overview

1.2.1 Although a variety of new services have been introduced, the telephone is considered a means of communicating from a stationary location. The ability to make or receive calls depended on your proximity to a telephone set. Technology continued to mature and inspired the concept of providing communications facilities in a vehicle. Consequently, the mobile telephone was introduced.

1.2.2 Evolving technology led to more compact mobile units that resulted in the creation of portable telephones. Telephone service now offers users a variety of communications tools to match their lifestyles and needs.

1.2.3 Cellular radio describes a technology primarily designed to provide mobile radio service. Classified as a common carrier telephone service, cellular mobile radio service provides an extension to the wireline telephone network. Cellular radio technology was also developed to counter the limitations associated with conventional mobile radio service.

1.2.4 The popularity of mobile communications proved to be a service both desirable and practical. Although demand for mobile service was high, available frequencies were limited. Each conversation is conducted using a pair of frequencies, one transmitting from the base station and the other from the mobile station. These frequencies are chosen from a finite group of radio waves capable of carrying voice communications. Each service area that offers mobile service is allocated a pool of frequencies from the radio spectrum (see Figure 1). Many mobile service customers encountered delayed and blocked calls caused by the few available channels. In most cities, prospective mobile users had to wait many years for service. The allocated frequency spectrum could only handle a few conversations, consequently restricting the number of customers served.

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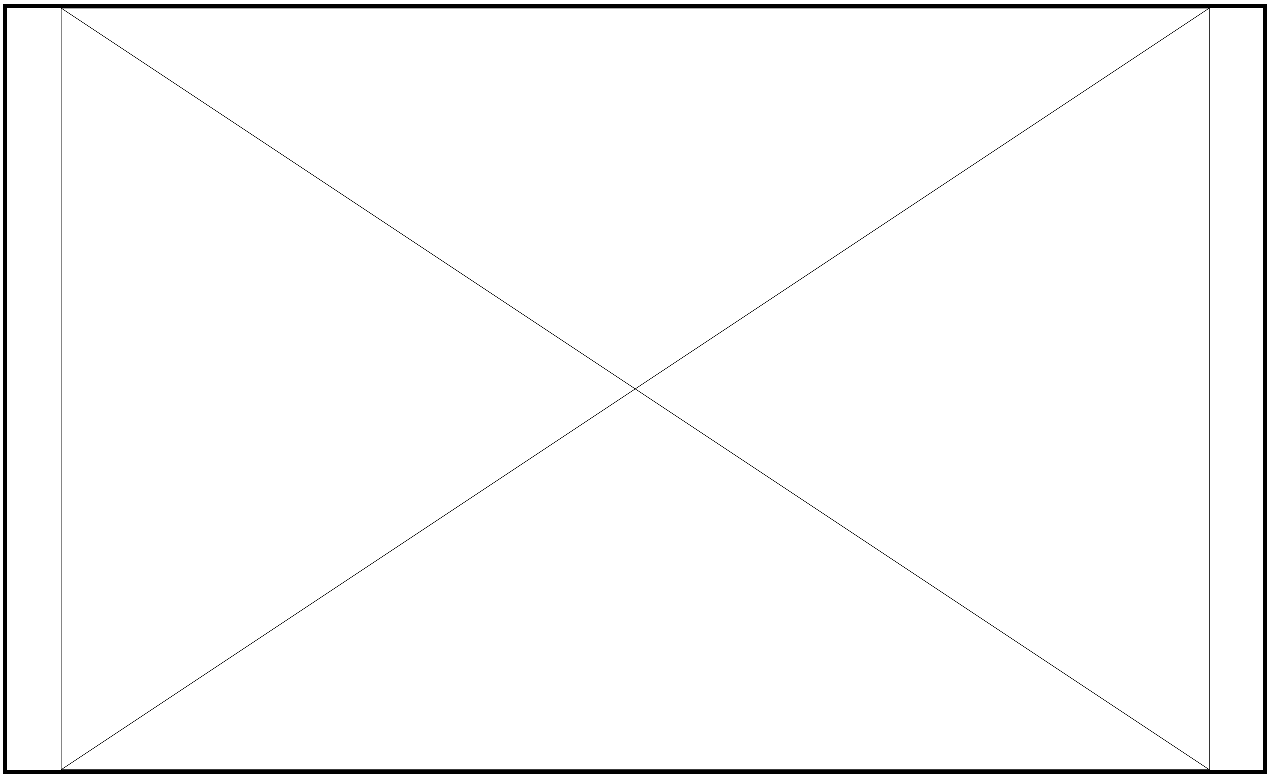
1.2.5 Since each service area was allocated a set of frequencies for mobile service, customers had to redial when they drove outside their original service area. Conventional mobile service was poor and at times inconvenient. However, the demand and popularity of mobile telephones increased in metropolitan areas. Consequently, the telecommunications industry reassessed the potential impact of mobile communications and directed further attention on promoting more efficient mobile services.

1.2.6 One means of developing improved mobile service was to address the problem of limited radio spectrum. More frequencies could not be created so a scheme to maximize usage of what was available needed to be explored. Consequently, the development and implementation of cellular radio increased spectral efficiency over conventional mobile radio technology.

1.2.7 Usually, conventional mobile service had one base station with a high-power transmit antenna (see Figure 1). Antennas were located on high structures to serve a wide area. The high level of power emitted often caused interference problems in neighboring service areas. Under these conditions, frequency reuse in adjacent areas was nearly impossible.

1.2.8 On the other hand, the cellular concept uses many base stations with low power transmit antennas. Each base station serves a much smaller area and these regions are called cells (see Figure 2). Frequencies can be reused increasing the traffic carrying capacity within the service area. Delayed and blocked calls are reduced and the quality of service is improved. Also, service can be made available to more potential customers. Cellular radio operates in the 800 MHz band while conventional mobile telephone service operates in the 150 MHz and 450 MHz bands.



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1.2.9 When cellular telephones first emerged on the scene, they were used by a limited group of executives and status-seekers capable of affording the high cost of service. Lower prices and increased features attracted other types of users. Many business professionals used cellular telephones to increase productivity and capitalize on saving time and making money. The public is also using cellular telephones to call towing garages or emergency personnel: promoting a sense of additional safety and peace of mind. The capacity to answer the growing popularity and usage of cellular has opened a window for new revenue and marketing possibilities for those providing cellular service.

1.3 History

1.3.1 Mobile radio service has been available in the United States since 1921. Police departments were the first to use mobile radio and they operated at a frequency of 2 MHz. Over the years, in response to the demand, the Federal Communications Commission (FCC) made spectrum available for mobile use between 30-50 MHz, 150-174 MHz, and 450-512 MHz.

1.3.2 In 1946, mobile systems were allocated six radio channels in the 150 MHz band with a channel spacing of 60 kHz. In the 1950's the creation of new channels between existing channels was accomplished by reducing the channel spacing to 30 kHz. By 1956, additional radio channels were allocated for mobile service, including 11 channels in the 150 MHz band and 12 channels in the 450 MHz band.

1.3.3 Initially, conventional mobile communications were manually operated and required an operator to connect calls to and from mobile units. Mobile units had no dialing capability or dial-tone. For rural applications, mobile communication technology had to devise a technique to eliminate operator assisted calls because rural exchange offices were usually unattended.

1.3.4 The Rural Electrification Administration (REA) issued a specification outlining performance requirements for an automatic dial operated system. The specification was circulated among manufacturers with an invitation to bid on the development of this type of equipment. Two manufacturers developed prototypes and a system was installed in 1958 and operated with favorable results.

1.3.5 The technical and economic feasibility of this type of system caused other companies to design and market similar systems. Consequently, REA telephone borrowers economically implemented two-way dial mobile telephone service through an unattended telephone exchange using a system that was the forerunner to Improved Mobile Telephone Service (IMTS).

1.4 IMTS

1.4.1 In the mid 1960s, IMTS was introduced. IMTS was a service that enabled users random access to any available channel. Mobile users were permitted to automatically search all available channels and select a specific channel for use. This technique increased the number of subscribers served by a given number of channels.

1.4.2 IMTS also offered automatic-dialing, eliminating the need for operator assistance. Formerly, mobile service consisted of a push-to-talk operation. IMTS replaced the system with channels capable of full-duplex service. Consequently, IMTS enables users to talk and listen simultaneously.

1.4.3 IMTS also offered improved audio quality. The radio equipment was designed for a wider voice frequency bandwidth which approaches that of landline telephone systems. Although IMTS improved mobile service, spectrum remained limited, restricting the number of available voice channels and customers on the network. Consequently, most prospective mobile users still experienced a considerable delay in receiving service.

2. FUNDAMENTALS OF THE CELLULAR MOBILE RADIO SYSTEM

2.1 General Description

2.1.1 The cellular mobile radio system also provides telephone service to the customer similar to the local wireline telephone network. The local wireline telephone network is also commonly called the public switched telephone network (PSTN). The cellular mobile radio network is not considered a bypass but an extension to the PSTN. Services offered by the PSTN are also enjoyed by the cellular mobile user.

2.1.2 The basic architecture of a cellular system includes the Mobile Telephone Switching Office (MTSO) and several base stations, all collectively serving many mobile, portable, and fixed units. Each base station, also commonly known as a cell site, serves the mobile units contained within its boundaries. Each system is comprised of several cell sites connected and operated by a single MTSO. The MTSO also links the cellular network to the central office (CO) of the PSTN. Larger networks contain several MTSOs but the basic configuration of the system is the same. Figure 3 illustrates a basic cellular mobile radio system.

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2.1.3 The cellular network allows mobile users to place and receive calls from their vehicles or portable telephones within the system. As mentioned before, the MTSO is the central coordinator in the cellular system. The MTSO is the switching office that serves as a link between the PSTN and each of the cell sites. The cell site is an interface between the MTSO and the mobile units providing cellular coverage to its specific area. The cell site coordinates all activities in the cell and operates with the MTSO. The mobile and portable units provide the user with an interface to the cellular radio network and a communication link to the PSTN.

2.1.4 Radio and high-speed transmission paths connect the three subsystems as illustrated in Figure 4. A radio link carries voice and data signaling between the mobile unit and the cell site. Microwave links, T1 carriers, or fiber optics carry both voice and data between the cell site and the MTSO. Voice trunks connect the MTSO to other cellular systems or to the PSTN.

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2.2 Frequency Allocation

2.2.1 The frequency spectrum is a limited resource, nearly saturated by the demands of television and radio broadcasting, mobile and fixed radio telephone service, and satellite communications to name a few. New technology and innovative applications place further demands on an already saturated spectrum. Such demands and competition require government regulation and spectrum allocation.

2.2.2 The regulatory body responsible for frequency allocation in the United States is the Federal Communications Commission (FCC). The FCC establishes regulations for public mobile service and regulates the licensing and operation of cellular systems in the 824-849 MHz and 869-894 MHz bands.

2.2.3 The FCC chose the 800 MHz band for cellular radio because the spectrum between 30 and 400 MHz was already crowded with other services. Television broadcasting services also contributed to the crowding and their usage extended to the 900 MHz band. Furthermore, problems with severe rain activity would make portions of the spectrum in the gigahertz range poor candidates for providing mobile service. Specialized programing once shown on channels 73 to 83 in the broadcast TV spectrum are now provided on cable television. Cellular now uses these channels. Therefore an opening for cellular services was created in the 800 MHz band.

2.2.4 Two cellular systems are authorized to operate in each of the 306 Metropolitan Statistical Areas (MSAs) and 428 Rural Service Areas (RSAs). The assignment of frequencies in the 824-849 MHz and 869-894 MHz bands are divided into two 25 MHz groups. Cellular Systems A and B are each allocated a block of frequencies. System B is licensed to a wireline carrier usually affiliated with the local public landline telephone company. System A is usually licensed to a non-wireline company to offer competitive cellular service in the same area. In some instances, System A is licensed to a wireline carrier that does not provide public landline telephone service in that same area.

2.2.5 The cellular frequency bands are divided between System A and B as shown in Table 1. Each block of frequencies contains 416 frequency pairs with a 30 kHz channel spacing. There are 21 control channel pairs as-signed to each system. Originally, there were only 312 voice channel pairs allocated per system. The FCC added 25 percent to the cellular radio spectrum to compensate for the sudden demand created in already congested metropolitan areas. 83 voice channels were added to each system totaling 395 voice channel pairs. The additional voice channels are currently used only in the most congested MSAs such as New York City, Los Angeles, and Chicago.

2.2.6 Each system uses a different band of frequencies for cell site transmit and mobile unit transmit. There is a spacing of 45 MHz between transmit and receive channels. The non-wireline company, System A designee, uses the band of frequencies 825-835 MHz for the mobile station transmitters and cell site receivers; and 870-880 MHz for the cell site transmitters and mobile station receivers. Cellular System B, used by wireline services, uses the 835-845 MHz band for mobile station transmitters and cell site receivers, and 880-890 MHz for cell site transmitters and mobile station receivers. Each mobile unit is capable of using any of the 333 channels on either System A or B as well as any of the additional 83 channels allocated.

.D. **Band** **Mobile** **Base** **Channel Number**
-- A
824-835 869-880 1-333, 667-716 845-846.5
890-891.5 991-1023 B 835-845 880-890
334-666 846.5-849 891.5-894 717-799
--Control
Channel A 834.390-834.990 313-333
879.390-879.990 Control Channel B 835.020-
835.620 334-354 880.020-880.620
--System A =
Non-wireline OperatorSystem B = Wireline OperatorDuplex Spacing = 45
MHzChannel Spacing = 30 kHzSystem A IDs end with an odd number.System
B IDs end with an even number

Table 1 - Transmission Frequency Allocation

2.3 Cellular Geometry

2.3.1 Within a cellular system the service area is divided into smaller subdivisions called cells. Theoretically, cells can be any shape and they do not need to be uniform. However, a geometric pattern would maintain design consistency with growth of the system. Circular shapes would represent the ideal power coverage area but would create gaps and overlaps. On the other hand, hexagonal-shaped cells would cover an area with no gaps or overlaps. Hexagonal-shaped cells are used on a layout to simplify the planning and design of a cellular system. The hexagon is a fictitious and not a real or even idealized representation of signal coverage (see Figure 5).

2.3.2 Each hexagonal-shaped cell depicts an area of signal coverage. The area is covered by signals emanating from the cell site usually located at the center of each cell. There may be one or more antennas located at each cell site.

2.3.3 A cellular system in the early stages will be able to use the available frequency spectrum without any difficulty. Thus, omnidirectional antennas are usually used at the cell site to serve a cell.

2.3.4 When call-traffic increases, the available frequency spectrum needs to be efficiently utilized. Directional antennas usually accomplish this task. Each cell can be subdivided into three or six sectors by using three or six directional antennas at the cell site. Each sector is assigned a set of frequencies from the original group of frequencies allocated to the cell. Three directional antennas create three 120 degree angle sectors. Six directional antennas create six 60 degree angle sectors (see Figure 6).

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2.4 Frequency Reuse

2.4.1 As previously discussed, conventional mobile radio systems used a powerful antenna situated on an elevated structure to cover a large service area. Each call is assigned to an available radio channel. A radio channel consists of a pair of frequencies to provide full-duplex operation. A fixed frequency spectrum restricts the number of subscribers that can be served in a given service area. A powerful antenna serves a large area but causes interference in adjacent service areas inhibiting the reuse of channels. Thus, fewer potential customers can obtain service.

2.4.2 In contrast, the cellular concept divides a service area into smaller regions known as cells. Each cell contains its own low-powered antenna reducing the coverage area radius. Each cell is responsible for providing mobile telephone service within its region. As a mobile unit moves within the CGSA, movement between cells may occur. Such cell to cell movement causes the cellular network to automatically switch the call to an available channel within the CGSA. Each service area has a fixed number of channels but the number of cells may vary. More cells carry more calls. The cellular concept allows channels to be reused which was virtually impossible in conventional mobile radio systems.

2.4.3 Frequency reuse can be applied in different situations. The same frequency can be assigned in different geographic locations, such as radio and television stations using the same frequency in different cities. Frequency reuse also can be applied repeatedly in the same general area. The service area is divided into smaller regions called cells. Cells are grouped together to form clusters or frequency reuse patterns (see Figure 7). Within one cluster no channel is used twice, but the pattern of channel assignments may be repeated in another cluster. The number of different channels in each cell is calculated by dividing the total number of allocated channels by the number of cells. For example, 416 channels divided by 12 cells gives approximately 34 channels per cell.

2.4.4 Frequency reuse is a fundamental principle of the cellular concept. The same set of frequencies can be used in different cells. Initially, omnidirectional antenna systems in low density areas use a 12-cell frequency reuse pattern. As call traffic increases, directional antennas are used to create a 7-cell frequency reuse pattern for 120 degree sectorization or a 4-cell frequency reuse pattern for 60 degree sectorization. (Refer to paragraph 2.3.4 for the number of transmit antennas required.) Other frequency reuse patterns are also possible. However, frequency reuse is prohibited in adjacent cells to prevent co-channel interference. Co-channel interference is minimized by a large geographic separation. Figure 8 illustrates frequency reuse in a CGSA.

Figure 7 - Frequency Cluster Patterns
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2.5 Channel Assignments

2.5.1 A radio channel is composed of a pair of frequencies that provides full-duplex operation. The pair of frequencies corresponds to the different bands of transmit and receive frequencies. For example, the two frequencies assigned to channel 1 are 825.030 MHz (mobile transmit) and 870.030 MHz (cell site transmit). The pair of frequencies is always separated by a spacing of 45 MHz.

2.5.2 There are 333 channels assigned to each system with an additional 83 channels used in crowded metropolitan areas (see Figure 9). As previously discussed, channels can be reused in different cells within the same CGSA. Consequently, a systematic technique for channel assignments is necessary to avoid the development of co-channel interference. The occurrence of the common use of the same channel can be minimized by maintaining adequate geographic separation. Therefore, frequency reuse cannot be applied to adjacent cells and adjacent channels must never be used in the same cell.

2.5.3 Channels are systematically assigned to each cell to maximize channel separation. For example, a 7-cell cluster system uses 21 channel sets. Each cell contains 3 channel sets. The total number of voice channels in a cell is about 45. Cell #1 would use channel sets 1, 8, and 15. Cell #2 would use channel sets 2, 9, and 16. Cell #3 would use channel sets 3, 10, and 17. The channel assignment pattern would continue for all seven cells in the cluster. In this instance, the minimum separation between adjacent channel sets within a cell is 7 channels (see Figure 10).

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2.5.4 Channel sets can be assigned to each cell or to antennas located at the cell site. Adjacent channels assigned to adjacent cells could create interference problems as shown in Figure 11. This situation can be avoided by using directional antennas to create sectors in each cell. For example, a cluster of 7 cells can be divided into 21 sector cells (see Figure 12). By using directional antennas and sectorization, the distance between co-channel cells decreases and more channels are allowed per cell. Consequently, more call traffic can be carried per cell.

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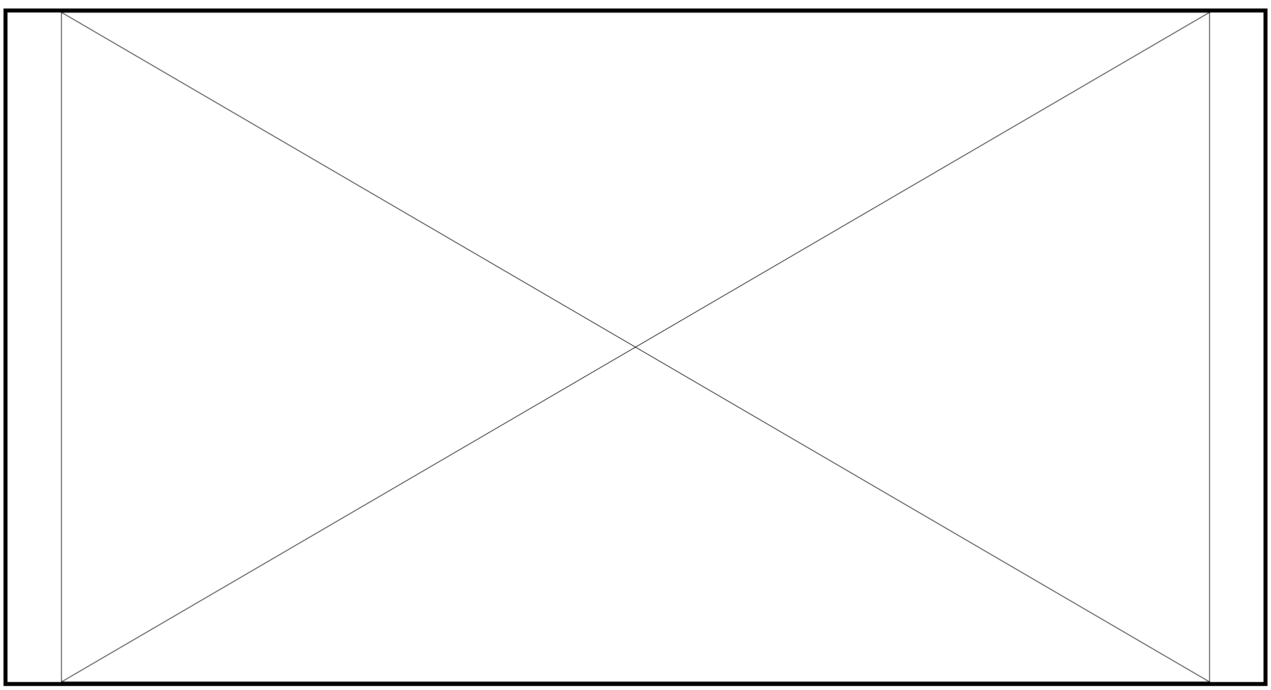
2.6 Cell Splitting

2.6.1 Cellular geographic areas are composed of cells combined into a series of clusters. Each cluster has access to all frequencies allocated for cellular radio use. These frequencies are divided among the cells within the cluster. A cell that lies outside the cluster or is part of another cluster may reuse the same frequencies.

2.6.2 When the capacity to handle calls on the allocated channels within a cell is exceeded, cell splitting is necessary. A single cell within a cluster can be subdivided into smaller cells as shown in Figure 13. The number of channels allocated to the original cell is equally divided among the new subcells created. Cell splitting decreases the area of each cell. Consequently, the number of simultaneous calls can be increased without additional spectrum allocation. Thus, frequencies are reused more often in a given service area.

2.6.3 Cell splitting accommodates an increase in mobile telephone traffic. However, if a new cell site is too costly, cell splitting may prove to be economically prohibitive.



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2.7 Cellular System Parameters

2.7.1 The FCC has mandated that mobile units used for cellular mobile service be limited to a maximum effective radiated power (ERP) of 7 watts. (ERP is not real power but radiated power relative to uniform spherical propagation in free space.) The maximum ERP for a cell site transmitter in a MSA is 100 watts. However, cell sites in RSA's that are located more than 24 miles (38.62 kilometers) from an adjacent MSA may operate at a maximum ERP of 500 watts. Radiated power at the cell site must be further reduced if the transmitting antenna is more than 500 feet (152.4 meters) above the average terrain. Usually the average antenna height is between 100 and 200 feet (30.48-60.96 meters) above the ground.

2.7.2 The cell radius is a parameter that affects the call traffic capacity of a service area. A system just starting up usually has a large cell radius with very little, if any, frequency reuse. The cell radius depends upon the ERP and antenna height at the cell site. A maximum cell radius of 30 miles (48.28 kilometers) is possible in areas with very little foliage and a flat terrain. Ultimately, a maximum cell radius is desired that will allow ample coverage without compromising transmission quality. More cells are created through cell splitting or the formation of clusters to accommodate increased calling traffic. A minimum cell radius of 1 mile (1.61 kilometers) can usually increase traffic carrying capacity without succumbing to co-channel interference problems.

2.7.3 The effectiveness of a frequency reuse cell pattern, or cluster, is measured by the D/R ratio. To accommodate areas with high calling traffic, the minimum distance that allows frequency reuse between cells is desired. The minimum distance is determined by the type of terrain, antenna height, and transmitted power at each cell site. Minimum distance is desired without creating objectionable co-channel interference. As noted in Figure 14, a set of frequencies used in a cell with a coverage radius R can be used in another cell with the same coverage radius at a distance D. The D/R ratio can be calculated by the expression:

$$D/R = (3N)^{1/2} \qquad (1)$$

where N is the number of cell sites in the frequency reuse pattern or cluster. Table 2 lists cluster patterns and their corresponding D/R ratio. When the D/R ratio increases, co-channel interference decreases.

2.7.4 Assume the area of a cluster remains the same. As the number of cells per cluster increases, the frequency reuse distance D decreases. Decreasing the distance increases the chance of co-channel interference. Since the number of allocated channels is fixed, a large cluster means few channels are assigned to each cell in the cluster. Although, theoretically a large cluster would accommodate heavy traffic demands, co-channel interference might become objectionable. A small number of cells per cluster is preferred.

2.7.5 Another parameter effecting transmission quality is the carrier to interference (C/I) ratio. According to FCC regulations, co-channel sites must maintain the appropriate D/R ratio to achieve at least a C/I ratio of 17dB over 90% of the coverage area for reliable transmission quality. This condition is usually met with a 12-cell cluster using omnidirectional antennas or a 7-cell cluster using directional antennas.

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2.8 Handoff

2.8.1 The cellular system uses a feature called handoff to provide continuous service to the mobile unit as it travels within a service area. While a call is in progress, a mobile unit may cross the boundaries of sectors within a cell or from one cell into another as illustrated in Figure 15a. Handoff is the process of transferring the mobile unit from one channel to another at the same or different cell site. Calls are handed-off to a new cell to maintain the clarity of the call.

2.8.2 The cell site monitors the received signal strength of all calls in progress and stores the signal as location information. This location measurement determines whether an antenna should continue to serve a mobile unit or handoff to another antenna at the same or different cell site. This information is continuously sent to the MTSO.

2.8.3 The MTSO monitors the number of voice channels available in each adjacent cell and the signal strength of each mobile unit. If the signal strength falls below a predetermined threshold, a report is sent to the cell site. The cell site places the call on a handoff candidate list and advises the MTSO. If the MTSO decides a handoff is necessary, then the call is transferred to an available voice channel in the same cell or to an adjacent cell.

2.8.4 The MTSO sends the new cell a set-up message and the old cell a handoff message. The cell site controller in the original cell sends an initiate handoff message to the mobile unit using a blank and burst technique. This technique blanks the voice signal for about 50ms, while a burst of data informing the mobile unit of the new channel is sent over the voice path. Once acknowledged, the cell site signals the MTSO to switch from the old to the new channel. The mobile unit tunes to the new channel. The new cell site sends confirmation to the MTSO that the mobile unit is tuned to the new channel. The handoff process is completed. The entire process occurs within a fraction of a second without noticeable interruption in the call.

2.8.5 Handoff is possible between cells within a single system. However, the Telecommunications Industry Association (TIA) has developed a standard, IS-41, that would allow handoff between neighboring cellular systems using equipment from different manufacturers as shown in Figure 15b. Intersystem handoff trials have been completed by several major cellular manufacturers and the equipment is now in commercial service.

2.9 Roaming

2.9.1 Each mobile unit operates in its assigned CGSA considered "home." Use of the mobile unit outside of the customer's subscribed service area is considered roaming. Nationwide roaming capability would allow mobile units to place or receive calls while traveling in any cellular system across the country.

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2.9.2 Recently, all cellular licenses have been issued to the 428 RSAs, many of which are beginning to offer service. The 306 MSAs serve an area that covers approximately 76 percent of the U.S. population. Over 350 wireline owned cellular systems and over 250 non-wireline owned cellular systems are in operation. It is estimated that 90 percent of the U.S. population and interstate highway system will be covered with cellular systems by the mid 1990's. Consequently, cellular subscribers will be able to use cellular telephones almost everywhere they travel. Cellular subscriber growth and cellular system expansion will increase the demand for roaming capability and draw attention to the potential revenue generated by roaming.

2.9.3 The FCC requires that all cellular system operators serve roamers. Roaming agreements between carriers have facilitated the placement of outgoing calls made by roaming mobile telephone users. On the other hand, roamers can receive calls in two ways.

2.9.4 A roamer can receive calls through a call forwarding system, when such a system exists in the area traveled. A caller from the mobile subscriber's home area simply dials the mobile unit's telephone number to make a connection. The subscriber's home cellular system forwards the call to the cellular system where the mobile unit is roaming. The host roaming cellular system pages the mobile subscriber until it finds the cell in which it is traveling. The mobile subscriber normally pays any associated long distance charges.

2.9.5 The second way involves leaving an itinerary with potential callers. The itinerary lists cities of travel and roamer access numbers for each city. Local callers that wish to call the roaming mobile unit must first dial the roamer access number. After hearing a second dial-tone, the ten digit mobile number is dialed. This allows local callers to call the roaming mobile unit free of long distance charges.

2.9.6 Currently, there are several cellular roaming handbooks that list cellular systems in operation, roaming charges, phone numbers, dialing patterns, and other related information. They serve as useful references both to the mobile user and those wishing to contact a mobile subscriber.

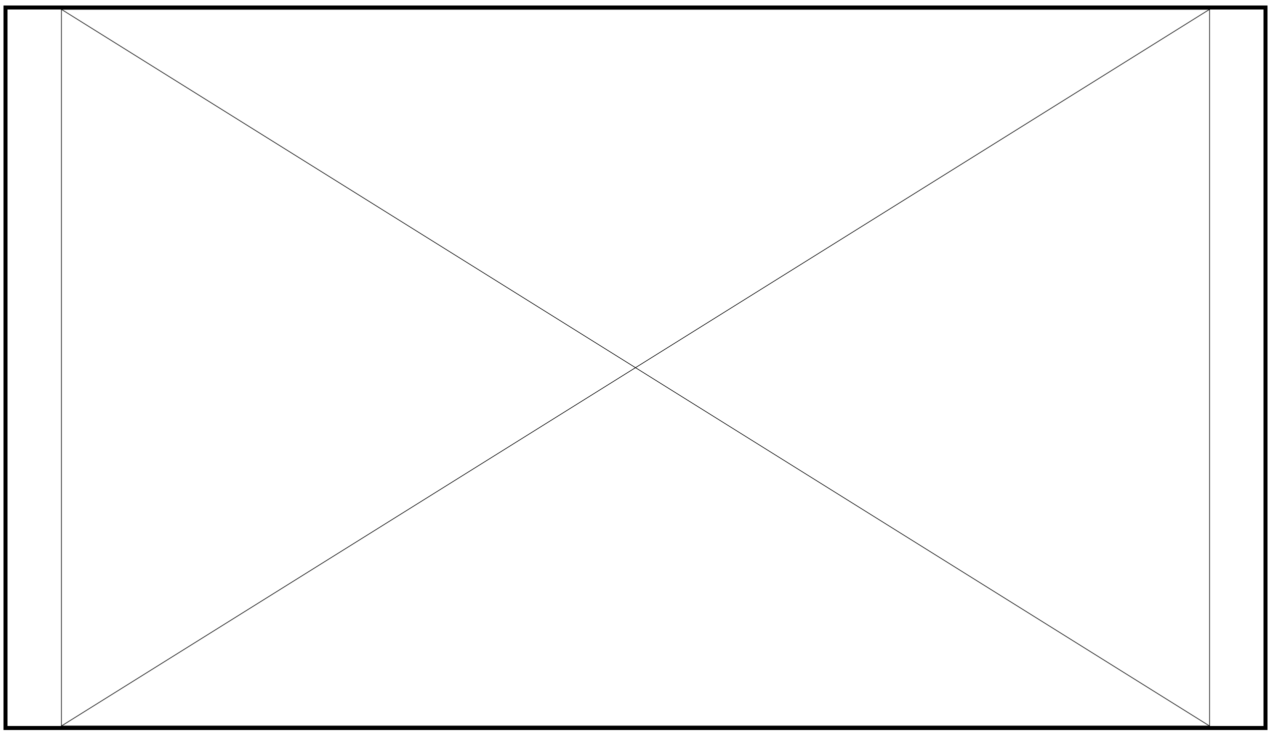
2.9.7 Roaming agreements are temporary arrangements used by cellular operators until TIA standard IS-41 is implemented by all vendors. The TR45.2 subcommittee of the Telecommunications Industry Association (TIA) created the IS-41 standard for intersystem communication. This standard will facilitate communication between switches from different manufacturers. Integrated switching would create regional roaming networks benefiting both the subscriber and cellular operator.

3. SYSTEM CONTROL TECHNIQUES

3.1 Network Structure

3.1.1 The cellular network links the mobile subscriber to the PSTN through the MTSO and cell site. Dedicated trunks for voice and data link the cell sites to the MTSO. These trunks are T-carrier or microwave links. Trunks linking the MTSO to the PSTN are usually T-carrier systems.

3.1.2 There are two types of radio channels available for transmission, voice, and control channels. Each is a full-duplex channel using one pair of carrier frequencies. A duplex voice channel is used to carry conversation and messages while a call is in progress. The duplex voice channel is divided into a forward voice channel for transmission from the cell site to the mobile unit and a reverse voice channel from the mobile unit to the cell site. Similarly, the control channel is also subdivided. Data is delivered using the forward control channel from the cell site to the mobile unit and the reverse control channel from the mobile unit to the cell site. Figure 16 illustrates the major system connections.



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3.2 Call Setup

3.2.1 There are two systems assigned to each Cellular Geographic Service Area (CGSA). Each system is allocated 416 voice channels and 21 control channels. At least one control channel is assigned to each cell site. This channel is used for the exchange of control information between the mobile unit and cell site. The control channel is also needed to setup or establish calls.

3.2.2 As previously discussed, the control channel is divided into a forward control channel and a reverse control channel. The forward control channel is used to transmit from the cell site and is used to complete a call. The reverse control channel is used to transmit from the mobile unit and used to originate a call.

3.2.3 Call setting-up, either by the mobile user or the one calling the mobile user, is provided by paging or access. Paging is the process of determining a mobile unit's availability to receive an incoming call. In contrast, access is the process by which the mobile unit initiates the call. Access is initiated when a mobile unit wishes to make a call or respond to a page. For most cellular systems, paging and access messages share the same set of control channels. In heavy traffic areas access and paging messages can occupy separate channels but this is seldom implemented today.

3.2.4 The mobile unit continually scans the control channel for a paging message indicating someone wishes to call the mobile unit. A potential phone call causes the cell site to transmit a paging command over the forward control channel. Paging signals contain a binary representation of the mobile unit's 10 digit telephone number. Also as part of the paging information, the control channel transmits a message called the overhead word. This message includes the identification of the mobile service area, the number of control channels to be scanned, and the first available channel for access.

3.2.5 As previously stated, the reverse control channel is used to transmit from the mobile unit, either to originate a call or respond to a page. All mobile units in a cell compete for the same reverse control channel during access. Collisions occur when two or more messages arrive simultaneously causing system disruption and delays in calls. There is a process performed by the system called collision avoidance to minimize these occurrences.

3.2.6 First, the mobile unit must be available to initiate or respond to a call. Then a message is transmitted over the forward control channel. The cell site acknowledges the readiness status of the mobile unit. At this time, the mobile unit attempts to seize the reverse control channel. The mobile unit opens a window in time where it expects to see a message in the forward control channel go from idle to busy. If this does not happen within the time window, the seizure attempt is cancelled. An arbitrary number of automatic attempts will continue at random intervals as permitted by the overhead word. If the attempt is still not successful, a busy signal will be heard by the mobile unit.

3.3 Fixed Station Originated Call

3.3.1 Contact with a mobile unit from a fixed station begins by dialing the mobile unit's 7 or 10 digit number. The call is routed through the PSTN to the home MTSO of the mobile unit. The MTSO converts the number to the mobile unit's identification number. Cell sites containing available paging channels are instructed to page the mobile unit over the forward control channel.

3.3.2 This paging signal is sent throughout the service area. Recognizing its page, the mobile unit will attempt to seize the reverse control channel. Successful seizure of the reverse control channel causes the mobile unit to send its identification number to the cell site. The cell site then forwards the paging reply to the MTSO over a high-speed data link.

3.3.3 Communicating through the cell site over the forward control channel, the MTSO selects an idle voice channel for the mobile unit. The mobile unit is instructed to tune to the designated voice channel. During voice transmission, two out-of-band tones are used for supervision, the supervisory audio tone (SAT) and signaling tone (ST). Both are used only on voice channels when data is not being transmitted.

3.3.4 The SAT consists of a continuous frequency modulation that is one of three frequencies, 5970 Hz, 6000 Hz, and 6030 Hz. Only one is used at each cell site with all cell sites within a given cell cluster using the same SAT frequency.

3.3.5 The SAT originates at the cell site and is returned when received, filtered, and modulated by the mobile unit. Failure to receive the same SAT sent by the cell site indicates the mobile unit is in an area of interference or the mobile transmitter is off.

3.3.6 The signaling tone (ST) consists of a burst of 10 kHz and originates at the mobile unit. When both the ST and SAT are received at the cell site, the mobile is available to receive or initiate a call.

3.3.7 The mobile unit's readiness status to receive a call is forwarded to the MTSO through the cell site. The MTSO then directs the cell site to send a data message over the forward control channel to ring the mobile unit signaling an incoming call.

3.3.8 When the subscriber answers, the ST is removed from the mobile unit. The cell site sets the landline trunk to an off-hook state. An off-hook signal indicates a seizure, request for service, or a busy condition. An on-hook signal indicates a disconnect, unanswered call, or an idle condition. The MTSO acknowledges an off-hook signal by removing the ringing message and establishing a connection for conversation to begin.

3.4 Mobile Originated Call

3.4.1 A mobile subscriber that wishes to make a call enters the appropriate telephone number into the mobile unit's register. This process, preorigination dialing, allows the dialing and storing of the number before going off-hook. Since no dial tone is used in the cellular system, preorigination dialing does not tie up voice channels and enables errors to be corrected before going off-hook. Also a number can be resent without redialing if the line is busy.

3.4.2 The call is initiated by the mobile subscriber by depressing the SEND button on the unit. A message is sent over the reverse control channel to the cell site. The message includes the mobile unit's identification number, the called number, and an access request. The cell site communicates this information to the MTSO over its data link. The MTSO indicates through the cell site the assigned voice channel for the mobile subscriber's use.

3.4.3 The mobile unit then tunes to the assigned voice channel. The MTSO determines routing and charging information by analyzing the dialed number. The call is routed through the PSTN by the MTSO. A successful connection enables communication between the mobile subscriber and called party.

3.5 Call Disconnect

3.5.1 When the mobile subscriber places the telephone on-hook, or hangs-up, the mobile unit transmits ST and turns off its transmitter. After receiving ST, the cell site places an on-hook signal on the landline trunk. The MTSO responds to the on-hook signal by idling all switching office components associated with the call and transmitting the necessary disconnect signal to the wireline network. The MTSO concludes the disconnect by commanding the cell site to turn off the radio transmitter associated with the call.

3.5.2 When a caller from a fixed station goes on-hook, a disconnect signal from the wireline network is received by the MTSO. All switching components associated with the call are idled by the MTSO and a disconnect order is sent over the data link to the serving cell. The cell site transmits the disconnect message over the voice channel to the mobile unit. The mobile unit responds by initiating the mobile disconnect (see 3.5.1) sequence. The MTSO recognizes the mobile unit's successful disconnection. A command is sent through the landline data link to turn off the cell site transmitter used for the call.

4. MOBILE SWITCHING CENTER

4.1 General Description

4.1.1 The mobile telephone switching office (MTSO) is the master control coordinator for the cellular system. The MTSO controls the switching between the PSTN and the cell sites, processing all wireline-to-mobile, mobile-to-wireline, and mobile-to-mobile calls. The MTSO is linked to each cell site and the PSTN. The switch communicates to the cell site through redundant data links. The links operate from 2400 to 9600 bits per second depending on the facilities available and anticipated traffic loads.

4.1.2 The MTSO processes data received from the cell site while noting the availability of the mobile unit to receive or initiate a call. Based on data processed from the cell site, the MTSO sends instructions through the cell site to the mobile unit to change channels or power levels. The MTSO also commands each cell site to perform automatic self-diagnostic tests periodically or upon command when necessary. Other functions include processing diagnostic information and compiling billing and statistical data.

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4.1.3 The MTSO is composed of several subsystems integrated to function as the heart of the cellular system (see Figure 17). The MTSO and the wireline central office use the same standard digital switch hardware. However, the software used in the MTSO is designed specifically for cellular system operation. Each manufacturer's MTSO and operating system is differentiated by his software and switching capabilities. Currently, the MTSO and cell site equipment must be manufactured by the same company. However, standards have been developed and manufacturers are designing equipment that will be compatible in different systems. Although available features and switching architectures may vary between manufacturers, the basic components and cellular system operation are the same.

4.2 The Switching System

4.2.1 The switching system maintains administrative and system control of the network. The switching sub-system contains processors, memory, a switching network, trunk circuits, and miscellaneous service circuits. Circuits are contained on modules easily inserted and replaced within the switch. The switching system also contains software that provides the logic to control the processing of telephone calls. The central processing unit and memory are usually duplicated to maintain the constant reliability of the system.

4.2.2 The central processing unit (CPU) is responsible for all control and routing of calls within the switch. It controls all other parts of the system through instructions received from the programs stored in the memory modules. The CPU can have a standby backup and either one can continue full system operation if the other fails. Only the active CPU can communicate with the processor memories. Systems that incorporate redundant CPUs have data ports compare information between the CPUs. If there is an inconsistency, the faulty CPU is identified, the system reconfigured, and all processing ability is recovered. Such a system is designed to maintain system integrity in the event of a component or power failure without disrupting service.

4.2.3 The MTSO memory accumulates and stores call processing information and customer data. Call processing information includes originating trunk, called number, terminating trunk, channel numbers, and notes the origination and termination of each call. Customer data includes the class of service, phone numbers, trunk identification, and the terminal to which the CPU is connected.

4.2.4 The switching network also interfaces trunks. Trunks between switching offices terminate on the switching network through channel banks or are direct digital interfaces. Four-wire telephone circuits are usually used to connect the MTSO and the cell sites. T1-carrier, which handles the equivalent of 24 channels, allows the transmission of digital data without conversion back to analog voice signals. The switching network transfers pulse code modulated (PCM) voice signals, processes the PCM bit stream, and interfaces with the CPU over data links to allow the passage of a telephone conversation. The switching network also controls digitized audio signaling.

4.2.5 Peripheral modules interconnect the switching network with analog trunks, service circuits, and digital carrier facilities. Peripheral modules contain digital trunk controllers, trunk modules, and maintenance trunk modules. Digital trunk controllers connect digital trunk lines directly to remote units. Trunk modules and maintenance trunk modules house service electronics such as receivers, audio tone detectors, announcing trunks, and testing circuits.

4.2.6 The input/output controller provides an interface between the central control and device controllers such as magnetic disks for billing, teleprinters, and visual display terminals.

4.3 Program Control

4.3.1 The switching system operates under the control of stored software programs. These programs are stored in modules for easy access to update, modify, or correct. The program store modules are program instructions for call processing, administration, maintenance, and system operation.

4.3.2 Call processing functions include call setup and termination by selecting channels and initiating ringing. Other functions include mobile unit monitoring and locating, handoff, and roaming.

4.3.3 Administration functions include telling the CPU how to obtain data stored in memory for updates and changes. Other related functions are storing customer information, collecting billing data, and monitoring system traffic.

4.3.4 Maintenance functions include recognizing failures and substituting standby units to maintain a working system. Maintenance modules are also responsible for running diagnostics on the radio and switching subsystems.

4.3.5 Maintenance and administration modules also perform routine testing, fault detection, analysis, diagnostic reporting, and system status reporting.

5. THE CELL SITE

5.1 General Description

5.1.1 The cell site, also called the base station, functions under the direction of the MTSO. Each cell site serves a designated area providing the mobile user with cellular communication with the PSTN. Many simultaneous telephone conversations are handled by the cell site through duplex radio voice channels. Unlike the MTSO where switching occurs, the cell site provides a way-station for voice and data communication links.

5.1.2 Each cell site provides services for radio frequency transmission, reception, and call distribution. It provides a data communication link between the MTSO and mobile units. The cell site performs handoff and locating functions, also handles equipment control and system administration within the cell. Furthermore, the cell site performs voice processing functions, call setup, call supervision, and call termination functions. Other functions include equipment testing and maintenance within the cell.

5.1.3 Each cell site consists of a cell site controller, an antenna system, radio channel units, RF components, and other peripheral components (see Figure 18).

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5.2 Cell Site Controller

5.2.1 Each cell has a cell site controller (CSC), or processor, that receives, interprets, and executes instructions from the MTSO. The

CSC unit is usually duplicated to assure continuation of service in the presence of equipment failure. The CSC contains subsystems acting as data links, controllers, and radio channel units.

5.2.2 The CSC manages all voice and control channels within the cell site. It supervises calls by monitoring and reporting signal strength readings from within the cell and reporting handoff availability to the MTSO. The CSC controls transmitters and receivers and sends data on the control channels to mobile users and the MTSO. It also performs diagnostic tests on cell site equipment reporting failures to the MTSO.

5.2.3 The subsystems operate cohesively to allow the CSC to maintain system reliability and organization in the cell. The data links are usually T-carrier, fiber optic links, or microwave radio systems connecting the cell site with the MTSO. Even though the cell site requires analog input, channel banks are usually used to connect the link from the MTSO. The controllers are similar to the CPU of the MTSO in operation, administration, and construction. The radio channel units transmit voice, data, and location information.

5.3 Radio Channel Units

5.3.1 There are two types of radio channels, voice and control channels. Each channel has two receivers and one transmitter. Two receivers are used to minimize the effects of fading and to achieve maximum signal strength. Each radio channel is an interface between the cell site controller and the MTSO and is physically connected to the cable trunks or microwave carrier.

5.3.2 The control channel provides a continuous stream of data to the mobile units and receives any messages transmitted by the mobile units. This data informs the mobile unit or the cell site controller that a call is being processed and which channels are being assigned to the call.

5.3.3 The voice channel permits conversation between the mobile user and others. The main functions are controlling audio paths and providing call processing signaling. The voice channel also must monitor SAT, ST, and the received signal strength indicator (RSSI). SAT uses 5970, 6000, or 6030 Hz frequencies outside the cellular frequency band to monitor the availability of a mobile unit on a channel. ST is 10 kHz and used for acknowledgment from the mobile unit. Other control functions include noting whether a mobile phone is on-hook or off-hook. The RSSI determines when a mobile unit needs to be handed-off to another cell or a signal power level change. Consequently the CSC is kept informed on the mobile unit's status.

5.3.4 To maintain good voice quality and data transmission, the mobile unit must be connected to the appropriate cell site to receive a strong signal. The locating receiver measures the SAT and the RSSI on a channel specified by the MTSO via the CSC every few seconds on each call. When the signal becomes weak, the call becomes eligible to be handed-off to an adjacent cell or antenna capable of offering a stronger signal. The CSC makes locating measurements when commanded by the MTSO. The MTSO in turn determines the best cell site antenna to handle the continuation of the call.

5.4 Radio Frequency System

5.4.1 Each cell contains at least one radio transmitter and two radio receivers. Both receivers are tuned to the same frequency but the one receiving the stronger radio signal will be the one selected. Both are components of the space diversity antenna system. The cell's radio frequency system also consists of transmitter combiner and receiver multicoupler to allow the connection of multiple radios to one antenna.

5.4.2 Cellular radio antennas usually reside on free standing towers that are 100 to 500 feet (30.48 - 152.4 meters) high or on tall buildings in downtown areas. Initially, an omnidirectional antenna is customarily used in each cell and is employed in areas that handle light to moderate traffic loads. As the system expands, directional antennas are often used to radiate more power in a concentrated area. This is a technique used to increase traffic capacity within the cell. Directional antennas are more prevalent in metropolitan and other densely populated areas to enhance area coverage and minimize interference with neighboring cells. Portable units that only emit 600 mW often experience interference from buildings. Thus, directional antennas also increase signal transmission for portable units.

6. THE MOBILE UNIT

6.1 General Description

6.1.1 The cellular mobile unit allows the mobile subscriber to communicate with the landline telephone system and other mobile subscribers. The mobile unit consists of a telephone handset combined with the control unit, transceiver with logic unit, antenna port, and power supply. There are three types of mobile units: the car phone, transportable phone, and hand-held portables. The car phone delivers the most powerful signal and is hardwired to the individual vehicle. The transportable phone matches the car phone in components and signal output. Portable units, on the other hand, have a lower power output capacity and a less powerful antenna system. Many units are being designed to function both as a mobile station within the vehicle and as a transportable unit.

6.1.2 Once the mobile unit is installed, a variety of services becomes available to the user. The transceiver is usually installed in the trunk or under the seat. Placement in the trunk rather than under the seat involves a shorter feedline to the antenna. Since transmission occurs at such high frequencies, a shorter feedline will provide a clearer and stronger signal. The telephone handset is mounted on the dashboard or console, while the antenna is mounted on the roof, trunk, or rear window. The antenna is connected via a coaxial cable to the transceiver.

6.1.3 Each mobile unit contains a unique permanent serial number and a 10 digit directory telephone number stored in the random access memory of the unit. The identity number is set by the manufacturer, giving the mobile unit a unique identification within the CGSA. The MTSO uses the number to check the mobile unit's identification. This minimizes the possibility of mobile subscribers changing assigned telephone numbers and other fraudulent usage.

6.2 Transceiver Unit

6.2.1 The transceiver unit is responsible for all control and communication between the mobile unit and the cell site controller. This includes determining the frequencies for transmitting and receiving signals. The transceiver operates on one duplex channel either to transmit or receive. It is capable of operating on any of the channels allocated by the FCC for cellular radio system operation. The frequency bands of operation are from 824 MHz to 845 MHz to transmit and from 869 MHz to 894 MHz to receive. The transceiver uses a frequency synthesizer to tune to the assigned channel.

6.2.2 The transceiver consists of two sections: a radio section and a logic section. The radio section is responsible for generating the carrier frequency to be transmitted and contains the antenna port. The logic unit interprets customer actions and system commands, and manages the transceiver and control units. The logic unit also reads the contents of the random access memory, such as called telephone number, and transmits information to the MTSO. The logic unit also monitors and controls the power response output of the transmitter. Increasing or reducing the power helps keep the transmitter at a usable minimum to prevent possible interference in adjacent cells (see Figure 19).

6.3 Control Unit

6.3.1 The control unit is the user interface to the mobile station. The unit contains the handset, various user controls, and indicators allowing the subscriber to communicate with the mobile unit and receive a response to instructions. User instruction buttons located on the control unit include SEND, LOCK, STORE, and END. Indicator lights include IN USE, NO SERVICE, and ROAM.

6.3.2 Enabling the subscriber to have control over the system, the control unit is connected to the transceiver by a multiwire cable. The control unit may consist of one or several components. The telephone headset, control unit or even a speakerphone can be combined into one unit or separated.

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7. FUTURE TRENDS

7.1 Fixed Cellular

7.1.1 Cellular radio technology has provided reliable and high quality mobile service. However, technology, equipment, and the increasingly ubiquitous nature of telecommunications has generated interest towards using cellular for fixed applications. Fixed cellular opens new avenues for growth within the cellular industry and creates a viable potential market.

7.1.2 Currently all 306 MSAs and probably 90% of all RSAs will have operating cellular systems by the end of 1991. There are still locations in rural areas where telephone service is not available or only multiparty service is offered. Fixed cellular could provide single party service in situations where landline service is unavailable or economically prohibitive. Fixed cellular also can be used for backup service to the landline network, emergency call boxes, monitoring facilities, temporary service, and payphones on public transportation.

7.1.3 Of course, cellular mobile equipment can be used for fixed cellular stations. However, to create a transparent environment for the end user, interface equipment is used to connect the cellular network with standard customer premise equipment. Currently, there are companies that manufacture these special interface devices. The cost of single line units is between $1200 and $2000.

7.1.4 The basic components of a fixed cellular installation include a power supply, transceiver, adapter card, interface circuit, ring generator, antenna, RJ11 jack, and a standard telephone (see Figure 20). The power supply typically includes a battery and charging circuit that provides 10 amp-hours of battery backup. Similar to standard telephone service, this equipment provides the end user with telephone ringing and dial-tone. Consequently, cellular service is available to virtually any customer premise equipment by using a RJ11 connecting jack.

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7.1.5 The interface circuit, together with the adapter card, differentiate the fixed cellular station from the mobile or portable unit. These circuits generate 3W of 20 Hz ringing signal and decode dialing signals, either tone or pulse at 5pps to 25pps. In effect, the circuitry functions much the same as a landline central office.

7.1.6 The interface circuit, also known as the master board, contains a logic module. This module reads as many as 16 digits being dialed, recognizes number validity, and determines when dialing is completed. The module also forwards a SEND command to the transceiver when dialing is completed.

7.1.7 The adapter card makes the master board compatible with the transceiver. It has a logic interface with the transceiver, converts receiver audio signals to recognizable messages and speech, and controls the ringing voltage generator.

7.2 Basic Exchange Telecommunications Radio Service (BETRS)

7.2.1 Basic Exchange Telecommunications Radio Service (BETRS) is a rural radio service that provides fixed telecommunications service to subscribers. BETRS equipment is licensed by the FCC to operate in the 150, 450, and 800 MHz bands under Part 22 for Public Land Mobile

Service. BETRS equipment in the 800 MHz band is also licensed under Part 90 for Private Land Mobile Service.

7.2.2 BETRS equipment licensed under Part 90 must operate at least 100 miles (160.93 kilometers) from the border of the 54 largest MSAs. BETRS can only be offered by local exchange carriers or others with state authorization. However, cellular operators and resellers can offer fixed BETRS in RSAs and rural parts of MSAs as regulated under Part 22. For further information on BETRS systems and equipment, refer to REA Bulletin 1751H-703, BETRS Radio Systems.

7.3 Digital Cellular

7.3.1 To many, the cellular telephone is a useful business tool. With advanced technology and lower prices, cellular has begun to broaden its consumer market base to those beyond the work environment. The largest MSAs are experiencing subscriber and traffic overload on their cellular systems currently using analog technology. An influx of data communications and increased mobile subscriber usage has driven carriers to consider more efficient spectrum utilization, thus the development of digital cellular. Digital cellular is being developed to address system overcrowding and provide improved features required by cellular subscribers.

7.3.2 The Telecommunications Industry Association (TIA), an organization of cellular manufacturers, is responsible for developing standards for cellular radio equipment, cellular system operation, and the implementation of digital cellular. The Cellular Telecommunications Industry Association (CTIA) is an organization consisting of representatives from cellular industry carriers. TIA works closely with CTIA to answer the problems facing the booming cellular market. They address new technological advances needed to keep pace with demand and quality of service. TIA Cellular Standards Subcommittee TR45.3 is working towards a standardized transmission format for digital cellular. By the end of the 1990's, CTIA projects digital cellular equipment will be installed and operational in many metropolitan service areas.

7.3.3 Time division multiple access (TDMA) was chosen to be the standard mode of transmission for digital cellular by the TIA. The architecture of TDMA segments the 30 kHz radio frequency channel into 6 time slots occurring every 24 milliseconds. The 6-slot frame would produce a total bit rate of 48 kb/s. TDMA allows 3 calls to be carried on each channel. By the mid 1990's, industry experts project TDMA will allow six 8 kb/s calls per voice channel with improved speech coding and compression.

7.3.4 Speech coding and compression of information are major features of digital cellular that respond to the need for increased capacity and improved quality of service. Speech coding is a digital representation of the sound of speech that provides efficient storage, transmission, recovery, and reconstruction of the original voice signal. For example, the analog representation of the voice spoken into the cellular phone is sampled and converted to a digital representation inside the cellular transceiver. Compressing the information can triple the capacity of the voice channel and allow transmission at a bit rate of 8 kb/s. The compressed information is transmitted over communication links and reconverted back to analog. Voice compression can also cause noise levels to increase, data speed to decrease, and overall network delay to increase.

7.3.5 Digital cellular can increase spectrum and channel efficiency. Analog cellular uses a 30 kHz channel bandwidth but digital would only require a 10 kHz channel thus tripling the capacity. Consequently, digital transmission allows three times as many phone conversations on a single channel.

7.3.6 Other characteristics of digital cellular include transmission that is less sensitive to noise, crosstalk, and distortion: interference factors that increase with system growth. Digital cellular is also less susceptible to conversation tapping common with wireless portable phones. Digital technology allows the equipment to be smaller and lighter, an added convenience to the subscriber.

7.4 Narrow Advanced Mobile Phone Service (NAMPS)

7.4.1 The evolution of cellular service will eventually turn towards digital cellular to accommodate increased usage and service. While TIA has already chosen TDMA as the mode of transmission for digital cellular, Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA) have not been removed from consideration. The industry is moving towards digital to accommodate overcrowded systems. However, discussions continue on which modulation technique to use and when digital can be practically implemented.

7.4.2 Motorola, a cellular manufacturer, has developed NAMPS to operate on current systems and provide an immediate solution to system overcrowding. Based on Narrow Channel Frequency Division Multiple Access (NC-FDMA), NAMPS is able to reduce the amount of radio frequency used by using narrow channels. In other words, the present 30 kHz channel is subdivided into three 10 kHz bands within the original channel. Using this method, the currently available 832 channels can be expanded to 2412 channels. (There are 42 signaling channels that are not divided therefore {{832-42}*3}+42=2412.) The added advantage is the telephones using NAMPS are also compatible with current analog cellular systems.

7.5 Personal Communication Services (PCS)

7.5.1 The widespread popularity of mobile communications is an indication of the public's desire for portability. Both business and an increasing number of residential customers are taking advantage of the new advances in wireless voice technologies. There are many innovative developments such as personal communication networks (PCNs), second generation cordless telephones (CT-2), wireless private branch exchanges (PBXs) and local area networks (LANs).

These are a few examples of personalizing communications and possibly creating a competitive medium for local exchange carriers.

7.5.2 The forerunner among the cluster of technological innovations in the arena of PCSs is a group of technologies called personal communications networks (PCNs). Similar to existing mobile cellular radio networks, PCNs also divide the service area into cells. PCNs contain many low-powered microcells usually spaced 200 meters apart. This architecture enables PCNs to deploy a high degree of frequency reuse.

7.5.3 PCNs are intended to complement and not compete with cellular telephone service. PCNs will be able to serve portable hand-held units as well as mobile units. However, handoff is not possible in vehicles traveling faster than 20 miles per hour. PCNs intend to make the telephone number an attribute of the person and not an outlet. Some companies are willing to commercially implement PCNs using the FCC's Part 15 ruling. This regulation allows cellular companies to use their allocated 25 MHz for any communication service as long as the quality of cellular service is not adversely effected.

7.5.4 Second generation cordless telephone technology (CT-2) is the technical standard used for telepoint service. Telepoint compares with cellular and paging services, allowing the subscriber to use a pocket-sized cordless telephone to make calls from any location. However, subscribers cannot receive calls and handoff is not possible with telepoint service. Outgoing calls can be made within 200 yards (182.88 meters) of the base station. Charges are billed to the caller's home or office. Base stations connected to the public network would widen the subscriber's calling service area.

7.5.5 Future developments in the area of wireless communications will expand service usage. Technological innovations such as spread spectrum and other modulation techniques will augment available services to the mobile user. Cellular systems will likewise improve and only benefit from these developments.