The Cellular Concept

1.4.3 Cellular Telephone Systems

A cellular telephone system provides a wireless connection to the PSTN for any user location within the radio range of the system. Cellular systems accommodate a large number of users over a large geographic area, within a limited frequency spectrum. Cellular radio systems provide high quality service that is often comparable to that of the landline telephone systems. High capacity is achieved by limiting the coverage of each base station transmitter to a small geographic area called a *cell* so that the same radio channels may be reused by another base station located some distance away. A sophisticated switching technique called a *handoff* enables a call to proceed uninterrupted when the user moves from one cell to another.

Figure 1.5 shows a basic cellular system which consists of *mobile stations, base stations* and a *mobile switching center* (MSC). The mobile switching center is sometimes called a *mobile telephone switching office* (MTSO), since it is responsible for connecting all mobiles to the PSTN in a cellular system. Each mobile communicates via radio with one of the base stations and may be handed-off to any number of base stations throughout the duration of a call. The mobile station contains a transceiver, an antenna, and control circuitry, and may be mounted in a vehicle or used as a portable hand-held unit. The base stations consist of several transmitters and receivers which simultaneously handle full duplex communications and generally have towers which support several transmitting and receiving antennas. The base station

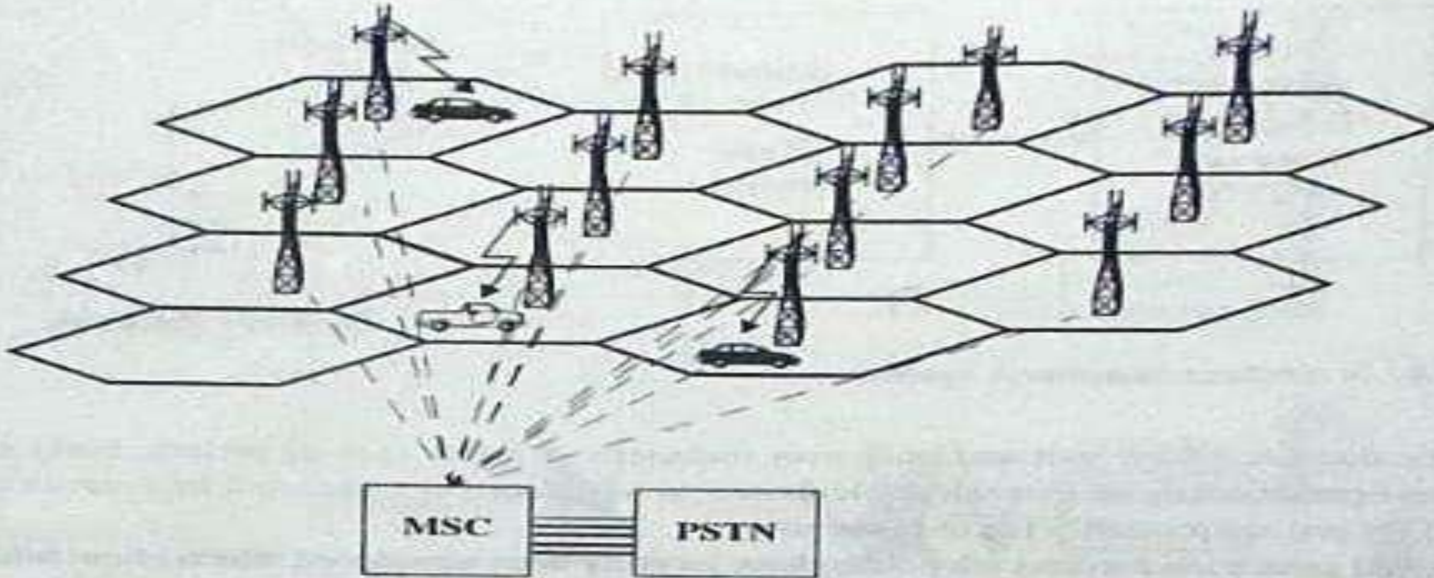


Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

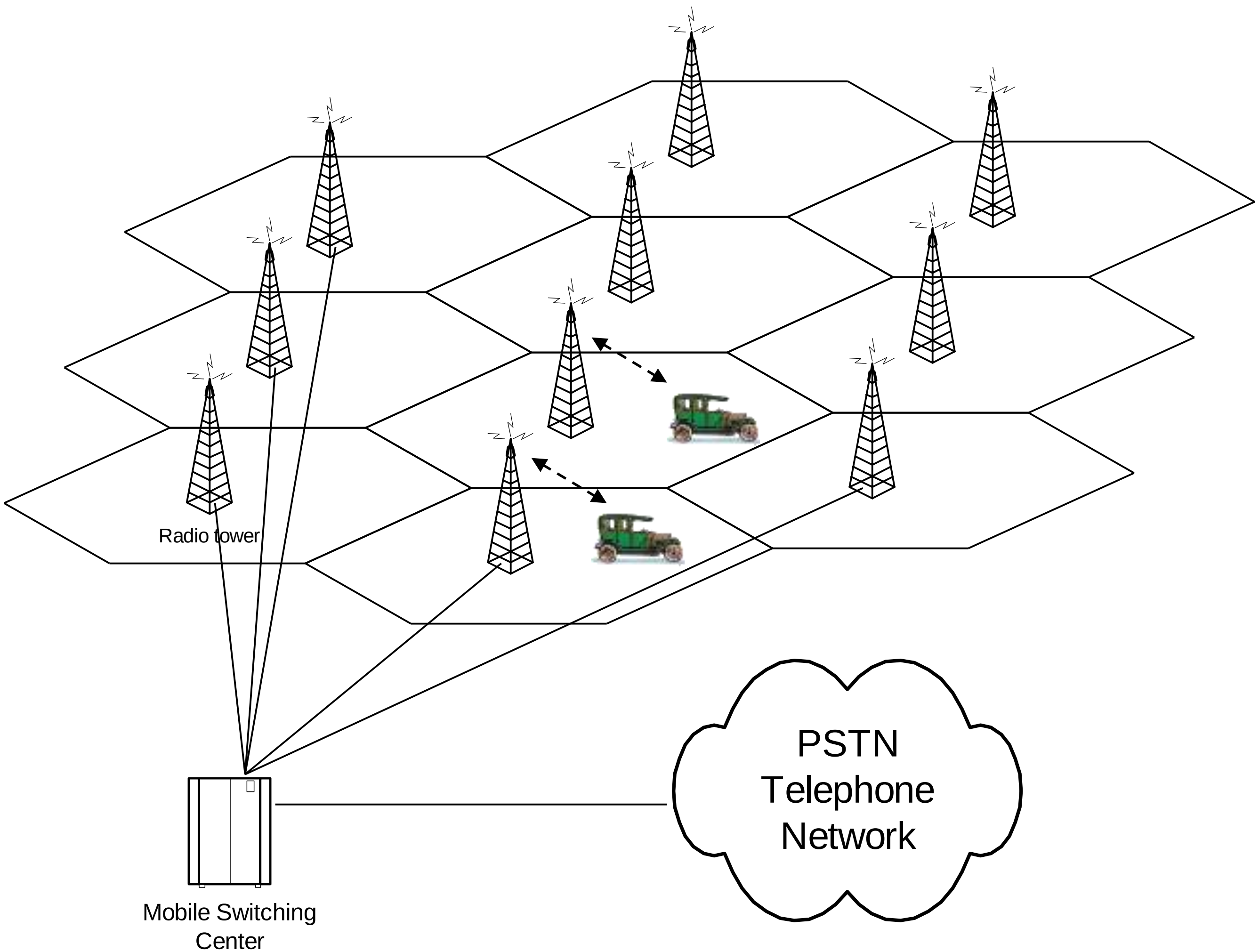
serves as a bridge between all mobile users in the cell and connects the simultaneous mobile calls via telephone lines or microwave links to the MSC. The MSC coordinates the activities of all of the base stations and connects the entire cellular system to the PSTN. A typical MSC handles 100,000 cellular subscribers and 5,000 simultaneous conversations at a time, and accommodates all billing and system maintenance functions, as well. In large cities, several MSCs are used by a single carrier.

Communication between the base station and the mobiles is defined by a standard *common air interface* (CAI) that specifies four different channels. The channels used for voice transmission from the base station to mobiles are called *forward voice channels* (FVC), and the channels used for voice transmission from mobiles to the base station are called *reverse voice channels* (RVC). The two channels responsible for initiating mobile calls are the *forward control channels* (FCC) and *reverse control channels* (RCC). Control channels are often called *setup channels* because they are only involved in setting up a call and moving it to an unused voice channel. Control channels transmit and receive data messages that carry call initiation and service requests, and are monitored by mobiles when they do not have a call in progress. Forward control channels also serve as beacons which continually broadcast all of the traffic requests for all mobiles in the system. As described in Chapter 11, supervisory and data messages are sent in a number of ways to facilitate automatic channel changes and handoff instructions for the mobiles before and during a call.

Cellular Telephony

- Characterized by
  - High mobility provision
  - Wide-range
  - Two-way tetherless voice communication
  - Handoff and roaming support
  - Integrated with sophisticated public switched telephone network (PSTN)
  - High transmit power requires at the handsets (~2W)

Cellular Telephony - Architecture



Cellular Telephony Systems

- Mobile users and handsets
  - Very complex circuitry and design
- Base stations
  - Provides gateway functionality between wireless and wireline links
  - ~1 million dollar
- Mobile switching centers
  - Connect cellular system to the terrestrial telephone network

Basic Concept

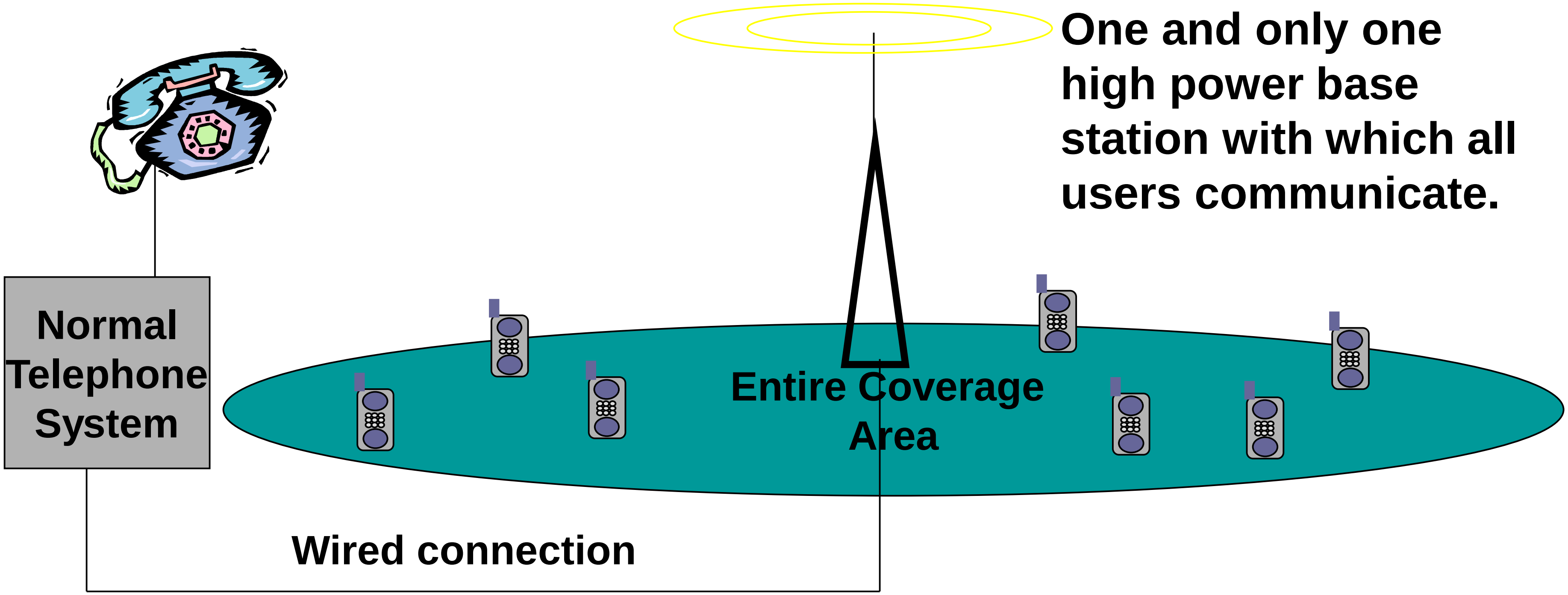
- Cellular system developed to provide mobile telephony: telephone access "anytime, anywhere."
- First mobile telephone system was developed and inaugurated in the U.S. in 1945 in St. Louis, MO.
- This was a simplified version of the system used today.

System Architecture

- A base station provides coverage (communication capabilities) to users on mobile phones within its coverage area.
- Users outside the coverage area receive/transmit signals with too low amplitude for reliable communications.
- Users within the coverage area transmit and receive signals from the base station.
- The base station itself is connected to the wired telephone network.

First Mobile Telephone System

One and only one high power base station with which all users communicate.



Problem with Original Design

- Original mobile telephone system could only support a handful of users at a time…over an entire city!
- With only one high power base station, users phones also needed to be able to transmit at high powers (to reliably transmit signals to the distant base station).
- Car phones were therefore much more feasible than handheld phones, e.g., police car phones.

Improved Design

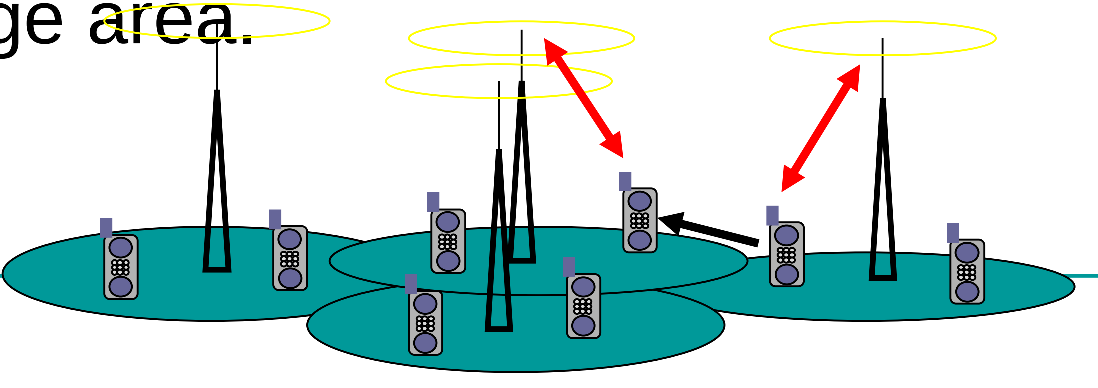
- Over the next few decades, researchers at AT&T Bell Labs developed the core ideas for today’s cellular systems.

- Although these core ideas existed since the 60’s, it was not until the 80’s that electronic equipment became available to realize a cellular system.

- In the mid 80’s the first generation of cellular systems was developed and deployed.

The Core Idea: Cellular Concept

- The core idea that led to today's system was the cellular concept.
- **The cellular concept**: multiple lower-power base stations that service mobile users within their coverage area and **handoff** users to neighboring base stations as users move. Together base stations **tessellate** the system coverage area.



Cellular Concept

- Thus, instead of one base station covering an entire city, the city was broken up into **cells**, or smaller coverage areas.

- Each of these smaller coverage areas had its own lower-power base station.

- User phones in one cell communicate with the base station in that cell.

3 Core Principles

- Small cells tessellate overall coverage area.
- Users handoff as they move from one cell to another.
- Frequency reuse.

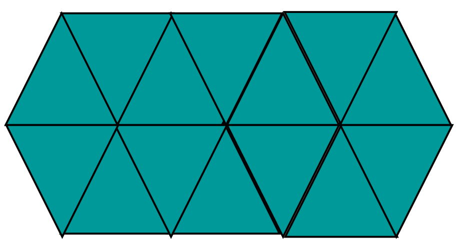
Tessellation

- Some group of small regions tessellate a large region if they over the large region without any gaps or overlaps.

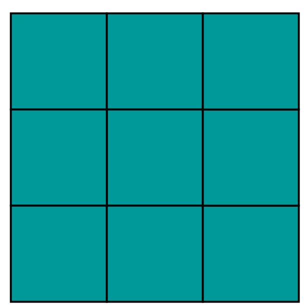
- There are only three regular polygons that tessellate any given region.

Tessellation (Cont'd)

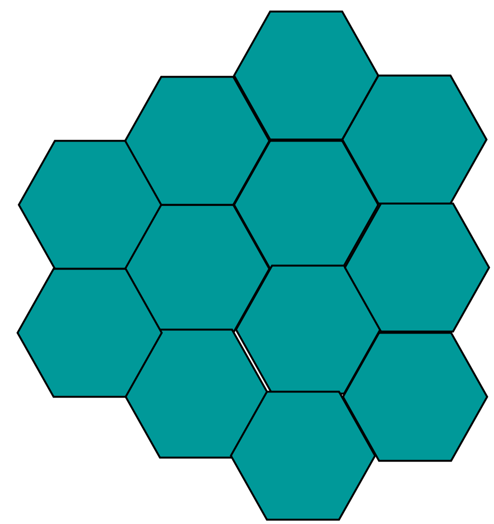
- Three regular polygons that always tessellate:
  - Equilateral triangle
  - Square
  - Regular Hexagon



Triangles



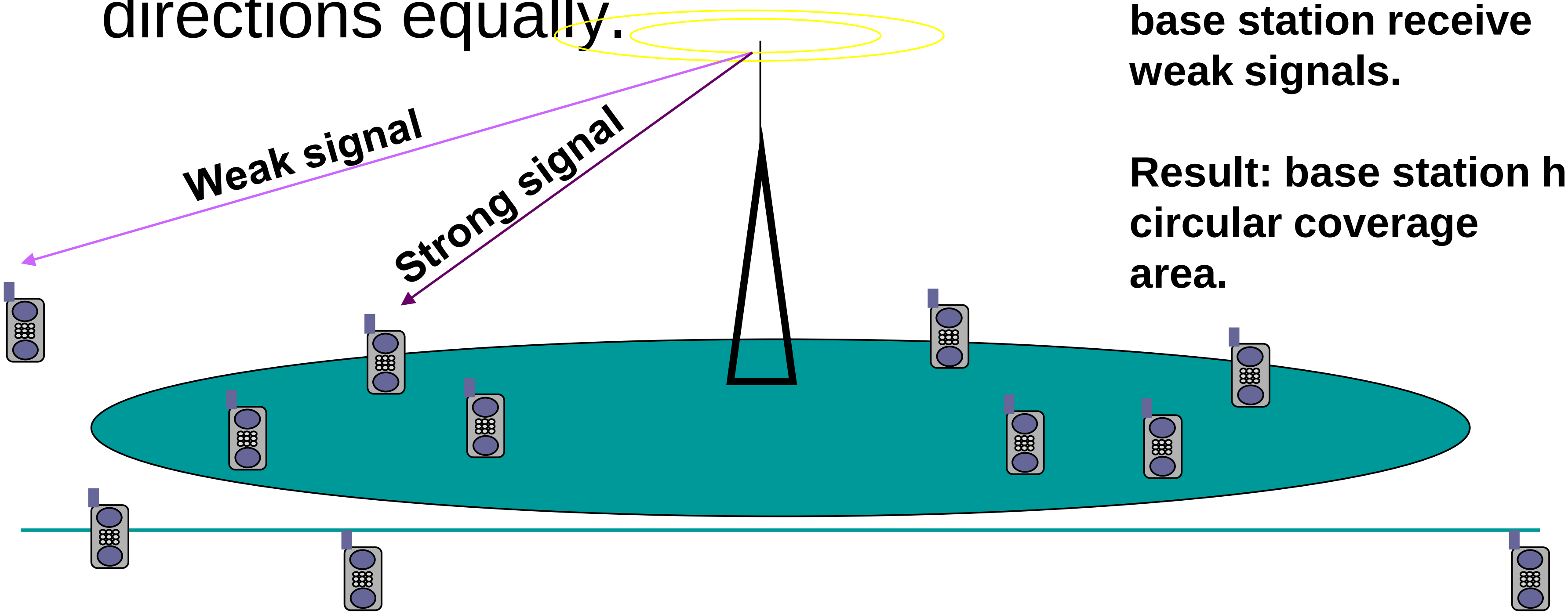
Squares



Hexagons

Circular Coverage Areas

- Original cellular system was developed assuming base station antennas are omnidirectional, i.e., they transmit in all directions equally.



Users located outside some distance to the base station receive weak signals.

Result: base station has circular coverage area.

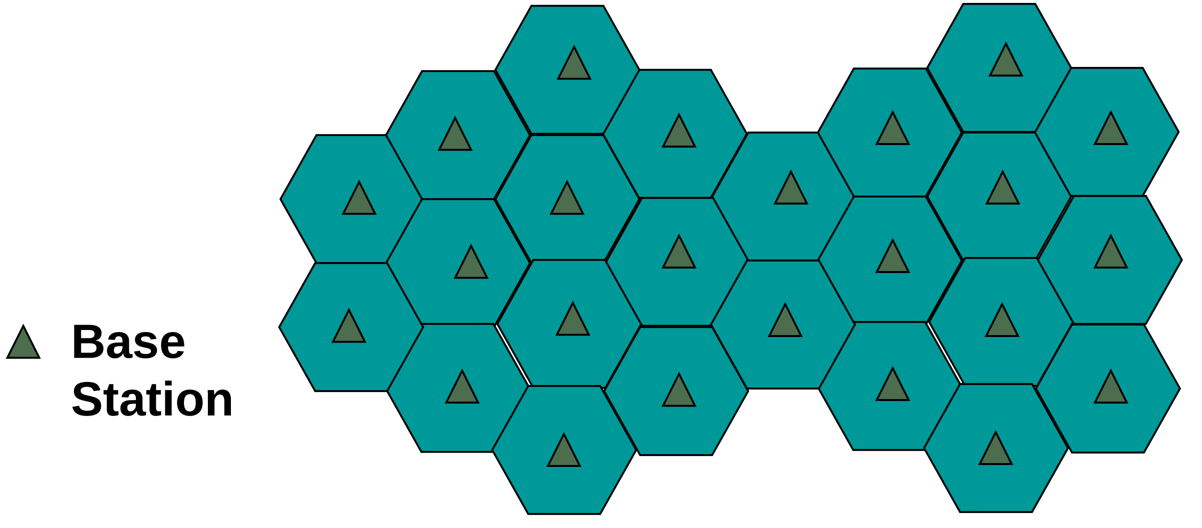
Circles Don’t Tessellate

- Thus, ideally base stations have identical, circular coverage areas.
- Problem: Circles do not tessellate.

- The most circular of the regular polygons that tessellate is the hexagon.
- Thus, early researchers started using hexagons to represent the coverage area of a base station, i.e., a cell.

Thus the Name Cellular

- With hexagonal coverage area, a cellular network is drawn as:



- Since the network resembles cells from a honeycomb, the name cellular was used to describe the resulting mobile telephone network.

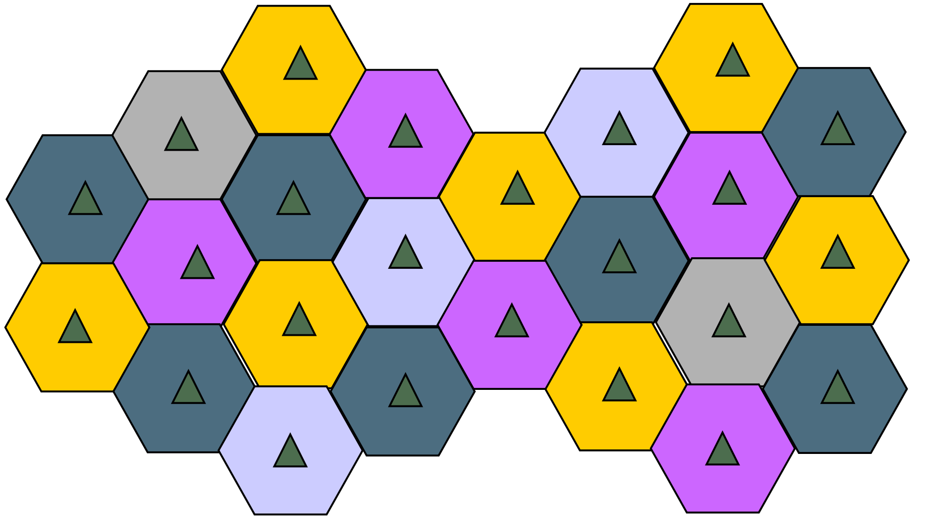
Frequency Reuse

- Extensive frequency reuse allows for many users to be supported at the same time.
- Total spectrum allocated to the service provider is broken up into smaller bands.
- A cell is assigned one of these bands. This means all communications (transmissions to and from users) in this cell occur over these frequencies only.

Frequency Reuse (Cont'd)

- Neighboring cells are assigned a different frequency band.
- This ensures that nearby transmissions do not interfere with each other.
- The same frequency band is reused in another cell that is far away. This large distance limits the interference caused by this co-frequency cell.
- More on frequency reuse a bit later.

Example of Frequency Reuse



Cells using the same frequencies

3.2 Frequency Reuse

Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region [Oet83]. Each cellular base station is allocated a group of radio channels to be used within a small geographic area called a *cell*. Base stations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells. The base station antennas are designed to achieve the desired coverage within the particular cell. By limiting the coverage area to within the boundaries of a cell, the same group of channels may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits. The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called *frequency reuse* or *frequency planning* [Mac79].

Figure 3.1 illustrates the concept of cellular frequency reuse, where cells labeled with the same letter use the same group of channels. The frequency reuse plan is overlaid upon a map to indicate where different frequency channels are used. The hexagonal cell shape shown in Figure 3.1 is conceptual and is a simplistic model of the radio coverage for each base station, but it has been universally adopted since the hexagon permits easy and manageable analysis of a cellular system. The actual radio coverage of a cell is known as the *footprint* and is determined from field measurements or propagation prediction models. Although the real footprint is amorphous in nature, a regular cell shape is needed for systematic system design and adaptation for future growth. While it might seem natural to choose a circle to represent the coverage area of a base station, adjacent circles cannot be overlaid upon a map without leaving gaps or creating overlapping regions. Thus, when considering geometric shapes which cover an entire region without overlap and with equal area, there are three sensible choices—a square, an equilateral triangle, and a hexagon. A cell must be designed to serve the weakest mobiles within the footprint, and these are typically located at the edge of the cell. For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area of the three. Thus, by using the hexagon geometry, the fewest number of cells can cover a geographic region, and the hexagon closely approximates a circular radiation pattern which would occur for an omnidirectional base

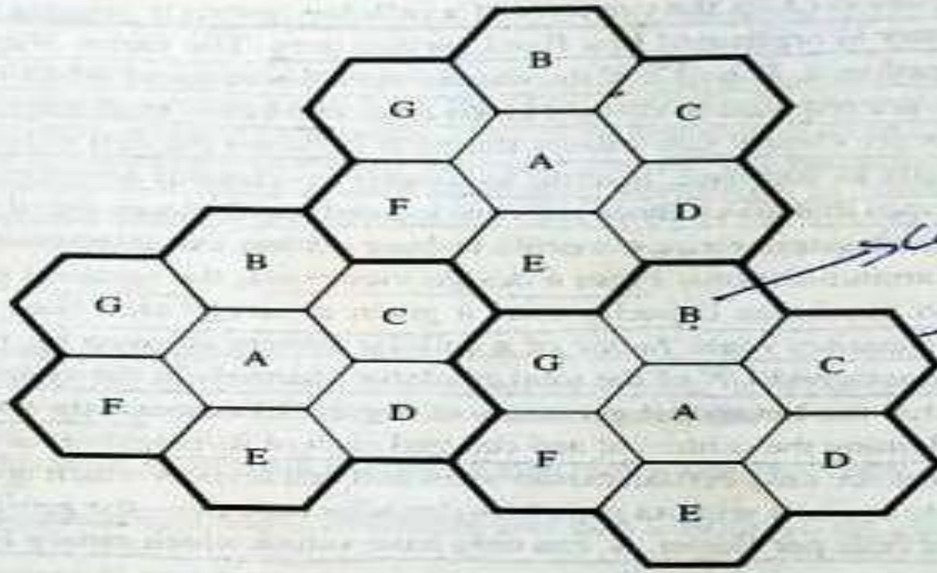


Figure 3.1 Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, N, is equal to seven, and the frequency reuse factor is 1/7 since each cell contains one-seventh of the total number of available channels.

station antenna and free space propagation. Of course, the actual cellular footprint is determined by the contour in which a given transmitter serves the mobiles successfully.

When using hexagons to model coverage areas, base station transmitters are depicted as either being in the center of the cell (center-excited cells) or on three of the six cell vertices (edge-excited cells). Normally, omnidirectional antennas are used in center-excited cells and sectored directional antennas are used in corner-excited cells. Practical considerations usually do not allow base stations to be placed exactly as they appear in the hexagonal layout. Most system designs permit a base station to be positioned up to one-fourth the cell radius away from the ideal location.

To understand the frequency reuse concept, consider a cellular system which has a total of S duplex channels available for use. If each cell is allocated a group of k channels ($k < S$), and if the S channels are divided among N cells into unique and disjoint channel groups which each have the same number of channels, the total number of available radio channels can be expressed as

$$S = kN \tag{3.1}$$

The N cells which collectively use the complete set of available frequencies is called a *cluster*. If a cluster is replicated M times within the system, the total number of duplex channels, C, can be used as a measure of capacity and is given by

$$C = MkN = MS \tag{3.2}$$

As seen from Equation (3.2), the capacity of a cellular system is directly proportional to the number of times a cluster is replicated in a fixed service area. The factor N is called the *cluster size* and is typically equal to 4, 7, or 12. If the cluster size N is reduced while the cell size is kept constant, more clusters are required to cover a given area, and hence more capacity (a larger value of C) is achieved. A larger cluster size causes the ratio between the cell radius and the distance between co-channel cells to decrease, leading to weaker co-channel interference. Conversely, a small cluster size indicates that co-channel cells are located much closer together. The value for N is a function of how much interference a mobile or base station can tolerate while maintaining a sufficient quality of communications. From a design viewpoint, the smallest possible value of N is desirable in order to maximize capacity over a given coverage area (i.e., to maximize C in Equation (3.2)). The *frequency reuse factor* of a cellular system is given by $1/N$, since each cell within a cluster is only assigned $1/N$ of the total available channels in the system.

Due to the fact that the hexagonal geometry of Figure 3.1 has exactly six equidistant neighbors and that the lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees, there are only certain cluster sizes and cell layouts which are possible [Mac79]. In order to tessellate—to connect without gaps between adjacent cells—the geometry of hexagons is such that the number of cells per cluster, N, can only have values which satisfy Equation (3.3).

$$N = i^2 + ij + j^2 \tag{3.3}$$

where i and j are non-negative integers. To find the nearest co-channel neighbors of a particular cell, one must do the following: (1) move i cells along any chain of hexagons and then (2) turn 60 degrees counter-clockwise and move j cells. This is illustrated in Figure 3.2 for $i = 3$ and $j = 2$ (example, $N = 19$).

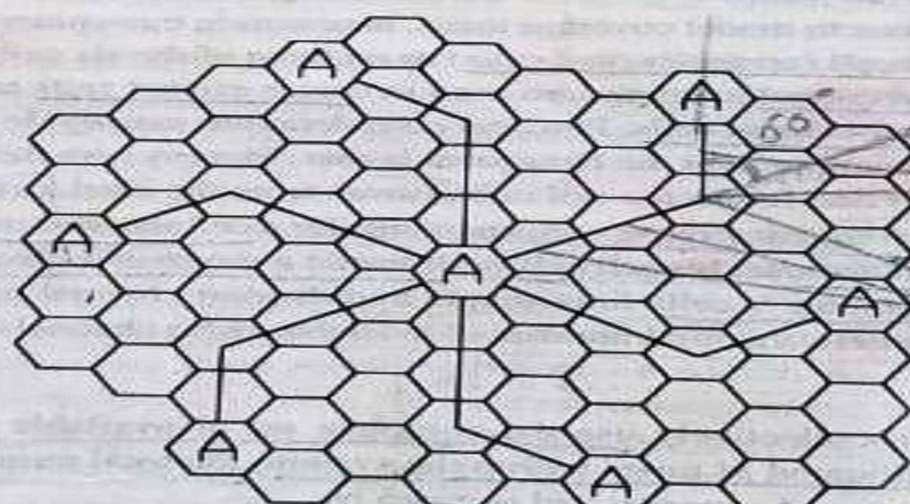


Figure 3.2 Method of locating co-channel cells in a cellular system. In this example, $N = 19$ (i.e., $i = 3$, $j = 2$). (Adapted from [Oet83] © IEEE.)

For efficient utilization of the radio spectrum, a frequency reuse scheme that is consistent with the objectives of increasing capacity and minimizing interference is required. A variety of channel assignment strategies have been developed to achieve these objectives. Channel assignment strategies can be classified as either *fixed* or *dynamic*. The choice of channel assignment strategy impacts the performance of the system, particularly as to how calls are managed when a mobile user is handed off from one cell to another [Tek91], [LiC93], [Sun94], [Rap93b].

In a fixed channel assignment strategy, each cell is allocated a predetermined set of voice channels. Any call attempt within the cell can only be served by the unused channels in that particular cell. If all the channels in that cell are occupied, the call is *blocked* and the subscriber does not receive service. Several variations of the fixed assignment strategy exist. In one approach, called the *borrowing strategy*, a cell is allowed to borrow channels from a neighboring cell if all of its own channels are already occupied. The mobile switching center (MSC) supervises such borrowing procedures and ensures that the borrowing of a channel does not disrupt or interfere with any of the calls in progress in the donor cell.

In a dynamic channel assignment strategy, voice channels are not allocated to different cells permanently. Instead, each time a call request is made, the serving base station requests a channel from the MSC. The switch then allocates a channel to the requested cell following an algorithm that takes into account the likelihood of future blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions.

Accordingly, the MSC only allocates a given frequency if that frequency is not presently in use in the cell or any other cell which falls within the minimum restricted distance of frequency reuse to avoid co-channel interference. Dynamic channel assignment reduce the likelihood of blocking, which increases the trunking capacity of the system, since all the available channels in a market are accessible to all of the cells. Dynamic channel assignment strategies require the MSC to collect real-time data on channel occupancy, traffic distribution, and *radio signal strength indications* (RSSI) of all channels on a continuous basis. This increases the storage and computational load on the system but provides the advantage of increased channel utilization and decreased probability of a blocked call.

3.4 Handoff Strategies

When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station. This handoff operation not only involves identifying a new base station, but also requires that the voice and control signals be allocated to channels associated with the new base station.

Processing handoffs is an important task in any cellular radio system. Many handoff strategies prioritize handoff requests over call initiation requests when allocating unused channels in a cell site. Handoffs must be performed successfully and as infrequently as possible, and be imperceptible to the users. In order to meet these requirements, system designers must specify an optimum signal level at which to initiate a handoff. Once a particular signal level is specified as the minimum usable

Handoffs

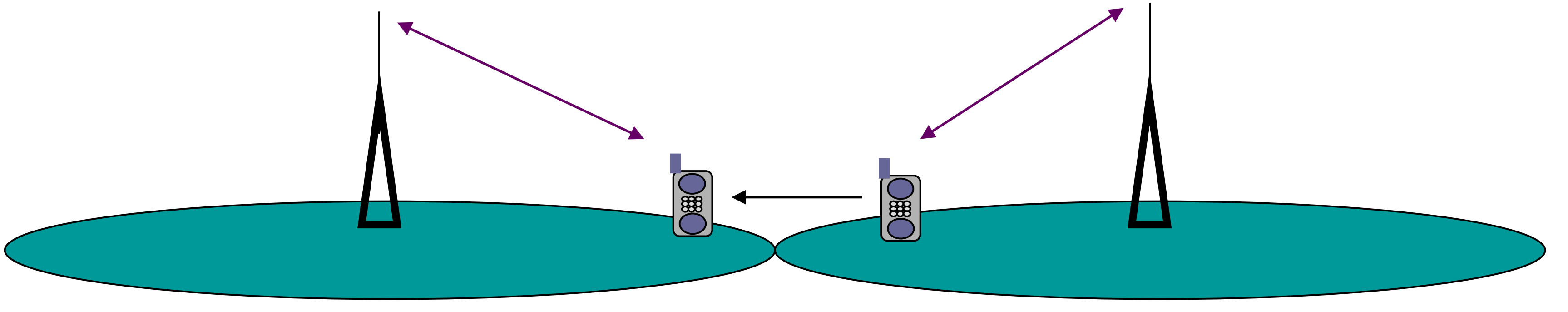
- A crucial component of the cellular concept is the notion of handoffs.
- Mobile phone users are by definition mobile, i.e., they move around while using the phone.
- Thus, the network should be able to give them continuous access as they move.
- This is not a problem when users move within the same cell.
- When they move from one cell to another, a **handoff** is needed.

A Handoff

- A user is transmitting and receiving signals from a given base station, say B_1.
- Assume the user moves from the coverage area of one base station into the coverage area of a second base station, B_2.
- B_1 notices that the signal from this user is degrading.
- B_2 notices that the signal from this user is improving.

A Handoff (Cont'd)

- At some point, the user's signal is weak enough at B_1 and strong enough at B_2 for a handoff to occur.
- Specifically, messages are exchanged between the user, B_1, and B_2 so that communication to/from the user is transferred from B_1 to B_2.



signal for acceptable voice quality at the base station receiver (normally taken as between –90 dBm and –100 dBm), a slightly stronger signal level is used as a threshold at which a handoff is made. This margin, given by $\Delta = P_{r\ handoff} - P_{r\ minimum\ usable}$, cannot be too large or too small. If Δ is too large, unnecessary handoffs which burden the MSC may occur, and if Δ is too small, there may be insufficient time to complete a handoff before a call is lost due to weak signal conditions. Therefore, Δ is chosen carefully to meet these conflicting requirements. Figure 3.3 illustrates a handoff situation. Figure 3.3(a) demonstrates the case where a handoff is not made and the signal drops below the minimum acceptable level to keep the channel active. This dropped call event can happen when there is an excessive delay by the MSC in assigning a handoff or when the threshold Δ is set too small for the handoff time in the system. Excessive delays may occur during high traffic conditions due to computational loading at the MSC or due to the fact that no channels are available on any of the nearby base stations (thus forcing the MSC to wait until a channel in a nearby cell becomes free).

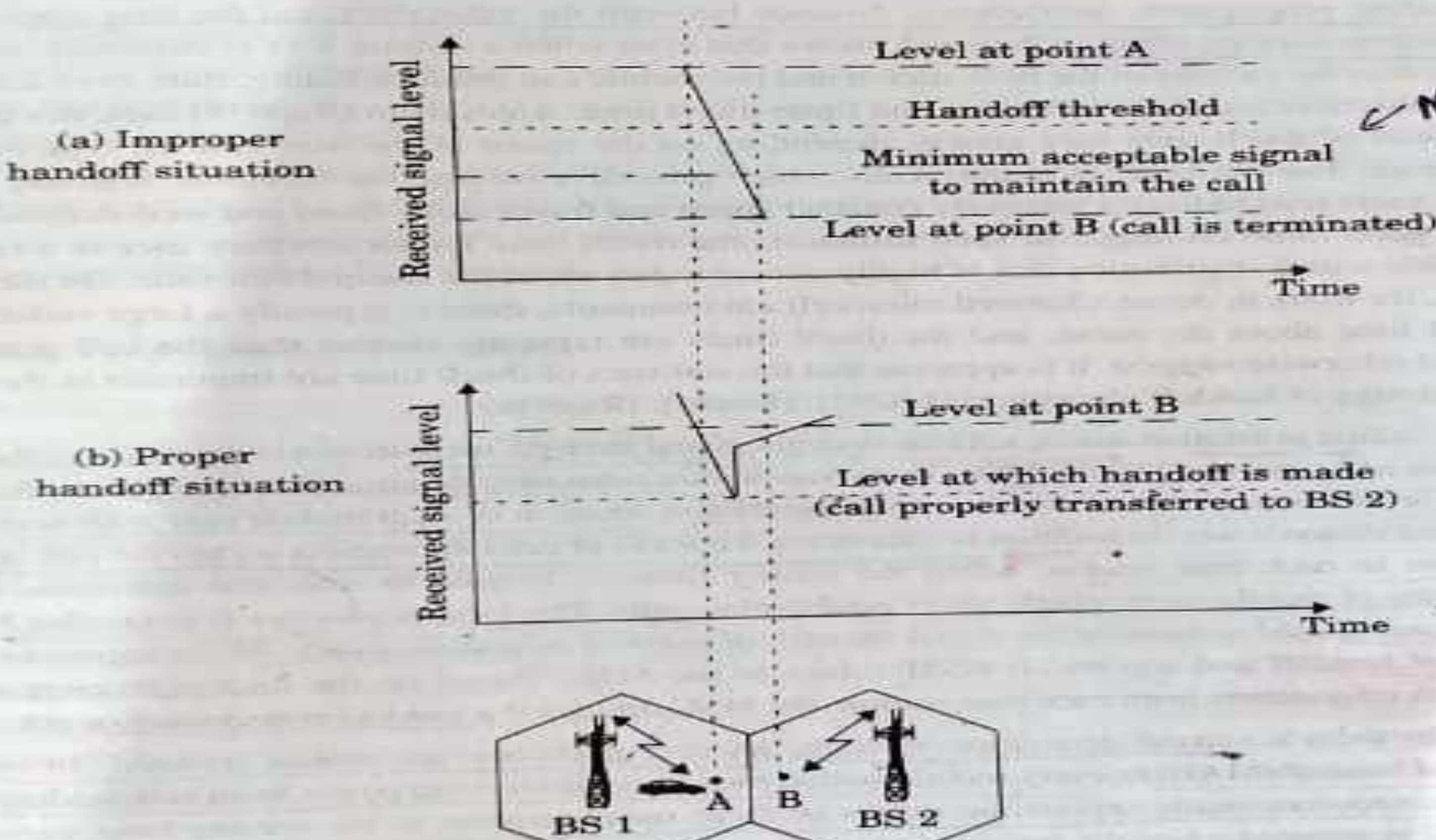


Figure 3.3 Illustration of a handoff scenario at cell boundary.

In deciding when to handoff, it is important to ensure that the drop in the measured signal level is not due to momentary fading and that the mobile is actually moving away from the serving base station. In order to ensure this, the base station monitors the signal level for a certain period of time before a handoff is initiated. This running average measurement of signal strength should be optimized so that unnecessary handoffs are avoided, while ensuring that necessary handoffs are completed before a call is terminated due to poor signal level. The length of time needed to decide if a handoff is necessary depends on the speed at which the vehicle is moving. If the slope of the short-term average received signal level in a given time interval is steep, the handoff should be made quickly. Information about the vehicle speed, which can be useful in handoff decisions, can also be computed from the statistics of the received short-term fading signal at the base station.

The time over which a call may be maintained within a cell, without handoff, is called the *dwell time* [Rap93b]. The dwell time of a particular user is governed by a number of factors, including propagation, interference, distance between the subscriber and the base station, and other time varying effects. Chapter 5 shows that even when a mobile user is stationary, ambient motion in the vicinity of the base station and the mobile can produce fading; thus, even a stationary subscriber may have a random and finite dwell time. Analysis in [Rap93b] indicates that the statistics of dwell time vary greatly, depending on the speed of the user and the type of radio coverage. For example, in mature cells which provide coverage for vehicular highway users, most users tend to have a relatively constant speed and travel along fixed and well-defined paths with good radio coverage. In such instances, the dwell time for an arbitrary user is a random variable with a distribution that is highly concentrated about the mean dwell time. On the other hand, for users in dense, cluttered microcell environments, there is typically a large variation of dwell time about the mean, and the dwell times are typically shorter than the cell geometry would otherwise suggest. It is apparent that the statistics of dwell time are important in the practical design of handoff algorithms [LiC93], [Sun94], [Rap93b].

In first generation analog cellular systems, signal strength measurements are made by the base stations and supervised by the MSC. Each base station constantly monitors the signal strengths of all of its reverse voice channels to determine the relative location of each mobile user with respect to the base station tower. In addition to measuring the RSSI of calls in progress within the cell, a spare receiver in each base station, called the locator receiver, is used to scan and determine signal strengths of mobile users which are in neighboring cells. The *locator receiver* is controlled by the MSC and is used to monitor the signal strength of users in neighboring cells which appear to be in need of handoff and reports all RSSI values to the MSC. Based on the locator receiver signal strength information from each base station, the MSC decides if a handoff is necessary or not.

In today's second generation systems, handoff decisions are *mobile assisted*. In *mobile assisted handoff* (MAHO), every mobile station measures the received power from surrounding base stations and continually reports the results of th...

time. The MAHO method enables the call to be handed over between base stations at a much faster rate than in first generation analog systems since the handoff measurements are made by each mobile, and the MSC no longer constantly monitors signal strengths. MAHO is particularly suited for microcellular environments where handoffs are more frequent.

During the course of a call, if a mobile moves from one cellular system to a different cellular system controlled by a different MSC, an *intersystem handoff* becomes necessary. An MSC engages in an intersystem handoff when a mobile signal becomes weak in a given cell and the MSC cannot find another cell within its system to which it can transfer the call in progress. There are many issues that must be addressed when implementing an intersystem handoff. For instance, a local call may become a long-distance call as the mobile moves out of its home system and becomes a roamer in a neighboring system. Also, compatibility between the two MSCs must be determined before implementing an intersystem handoff. Chapter 10 demonstrates how intersystem handoffs are implemented in practice.

Different systems have different policies and methods for managing handoff requests. Some systems handle handoff requests in the same way they handle originating calls. In such systems, the probability that a handoff request will not be served by a new base station is equal to the blocking probability of incoming calls. However, from the user's point of view, having a call abruptly terminated while in the middle of a conversation is more annoying than being blocked occasionally on a new call attempt. To improve the quality of service as perceived by the users, various methods have been devised to prioritize handoff requests over call initiation requests when allocating voice channels.

3.4.1 Prioritizing Handoffs

One method for giving priority to handoffs is called the *guard channel concept*, whereby a fraction of the total available channels in a cell is reserved exclusively for handoff requests from ongoing calls which may be handed off into the cell. This method has the disadvantage of reducing the total carried traffic, as fewer channels are allocated to originating calls. Guard channels, however, offer efficient spectrum utilization when dynamic channel assignment strategies, which minimize the number of required guard channels by efficient demand-based allocation, are used.

Queuing of handoff requests is another method to decrease the probability of forced termination of a call due to lack of available channels. There is a tradeoff between the decrease in probability of forced termination and total carried traffic. Queuing of handoffs is possible due to the fact that there is a finite time interval between the time the received signal level drops below the handoff threshold and the time the call is terminated due to insufficient signal level. The delay time and size of the queue is determined from the traffic pattern of the particular service area. It should be noted that queuing does not guarantee a zero probability of forced termination, since large delays will cause the received signal level to drop below the minimum required level to maintain communication and hence lead to forced termination.

How to made a call

Example 1.2 Cellular systems rely on the frequency reuse concept, which requires that the forward control channels (FCCs) in neighboring cells be different. By defining a relatively small number of FCCs as part of the common air interface, cellular phones can be manufactured by many companies which can rapidly scan all of the possible FCCs to determine the strongest channel at any time. Once finding the strongest signal, the cellular phone receiver stays "camped" to the particular FCC. By broadcasting the same setup data on all FCCs at the same time, the MSC is able to signal all subscribers within the cellular system and can be certain that any mobile will be signaled when it receives a call via the PSTN.

1.4.3.1 How a Cellular Telephone Call is Made

When a cellular phone is turned on, but is not yet engaged in a call, it first scans the group of forward control channels to determine the one with the strongest signal, and then monitors that control channel until the signal drops below a usable level. At this point, it again scans the control channels in search of the strongest base station signal. For each cellular system described in Tables 1.1 through 1.3, the control channels are defined and standardized over the entire geographic area covered and typically make up about 5% of the total number of channels available in the system (the other 95% are dedicated to voice and data traffic for the end-users). Since the control channels are standardized and are identical throughout different markets within the country or continent, every phone scans the same channels while idle. When a telephone call is placed to a mobile user, the MSC dispatches the request to all base stations in the cellular system. The *mobile identification number* (MIN), which is the subscriber's telephone number, is then broadcast as a paging message over all of the forward control channels throughout the cellular system. The mobile receives the paging message sent by the base station which it monitors, and responds by identifying itself over the reverse control channel. The base station relays the acknowledgment sent by the mobile and informs the MSC of the handshake. Then, the MSC instructs the base station to move the call to an unused voice channel within the cell (typically, between ten to sixty voice channels and just one control channel are used in each cell's base station). At this point, the base station signals the mobile to change frequencies to an unused forward and reverse voice channel pair, at which point another data message (called an *alert*) is transmitted over the forward voice channel to instruct the mobile telephone to ring, thereby instructing the mobile user to answer the phone. Figure 1.6 shows the sequence of events involved with connecting a call to a mobile user in a cellular telephone system. All of these events occur within a few seconds and are not noticeable by the user.

Once a call is in progress, the MSC adjusts the transmitted power of the mobile and changes the channel of the mobile unit and base stations in order to maintain call quality as the subscriber moves in and out of range of each base station. This is called a *handoff*. Special control signaling is applied to the voice channels so that the mobile unit may be controlled by the base station and the MSC while a call is in progress.

Timing diagram illustrating how a call to a mobile user initiated by a landline subscriber is established

MSC		Receives call from PSTN. Sends the requested MIN to all base stations.			Verifies that the mobile has a valid MIN, ESN pair.	Requests BS to move mobile to unused voice channel pair.		Connects the mobile with the calling party on the PSTN.
Base Station	FCC		Transmits page (MIN) for specified user.				Transmits data message for mobile to move to specific voice channel.	
	RCC			Receives MIN, ESN, Station Class Mark and passes to MSC.				
	FVC							Begin voice transmission.
	RVC							Begin voice reception.
Mobile	FCC		Receives page and matches the MIN with its own MIN.				Receives data messages to move to specified voice channel.	
	RCC			Acknowledges receipt of MIN and sends ESN and Station Class Mark.				
	FVC							Begin voice reception.
	RVC							Begin voice transmission.

time →

Figure 1.6 Timing diagram illustrating how a call to a mobile user initiated by a landline subscriber is established.

Timing diagram illustrating how a call initiated by a mobile is established.

MSC			Receives call initiation request from base station and verifies that the mobile has a valid MIN, ESN pair.	Instructs FCC of originating base station to move mobile to a pair of voice channels.		Connects the mobile with the called party on the PSTN.	
Base Station	FCC				Page for called mobile, instructing the mobile to move to voice channel.		
	RCC	Receives call initiation request and MIN, ESN, Station Class Mark.					
	FVC						Begin voice transmission.
	RVC						Begin voice reception.
Mobile	FCC				Receives page and matches the MIN with its own MIN. Receives instruction to move to voice channel.		
	RCC	Sends a call initiation request along with subscribe MIN and number of called party.					
	FVC						Begin voice reception.
	RVC						Begin voice transmission.

time →

Figure 1.7 Timing diagram illustrating how a call initiated by a mobile is established.

When a mobile originates a call, a call initiation request is sent on the reverse control channel. With this request the mobile unit transmits its telephone number (MIN), *electronic serial number* (ESN), and the telephone number of the called party. The mobile also transmits a *station class mark* (SCM) which indicates what the maximum transmitter power level is for the particular user. The cell base station receives this data and sends it to the MSC. The MSC validates the request, makes connection to the called party through the PSTN, and instructs the base station and mobile user to move to an unused forward and reverse voice channel pair to allow the conversation to begin. Figure 1.7 shows the sequence of events involved with connecting a call which is initiated by a mobile user in a cellular system.

All cellular systems provide a service called *roaming*. This allows subscribers to operate in service areas other than the one from which service is subscribed. When a mobile enters a city or geographic area that is different from its home service area, it is registered as a roamer in the new service area. This is accomplished over the FCC, since each roamer is camped on to an FCC at all times. Every several minutes, the MSC issues a global command over each FCC in the system, asking for all mobiles which are previously unregistered to report their MIN and ESN over the RCC. New unregistered mobiles in the system periodically report back their subscriber information upon receiving the registration request, and the MSC then uses the MIN/ESN data to request billing status from the home location register (HLR) for each roaming mobile. If a particular roamer has roaming authorization for billing purposes, the MSC registers the subscriber as a valid roamer. Once registered, roaming mobiles are allowed to receive and place calls from that area, and billing is routed automatically to the subscriber's home service provider. The networking concepts used to implement roaming are covered in Chapter 10.

Major Mobile Radio Standards USA

Standard	Type	Year Intro	Multiple Access	Frequency Band (MHz)	Modulation	Channel BW (KHz)
AMPS	Cellular	1983	FDMA	824-894	FM	30
USDC	Cellular	1991	TDMA	824-894	DQPSK	30
CDPD	Cellular	1993	FH/Packet	824-894	GMSK	30
IS-95	Cellular/PCS	1993	CDMA	824-894 1800-2000	QPSK/BPSK	1250
FLEX	Paging	1993	Simplex	Several	4-FSK	15
DCS-1900 (GSM)	PCS	1994	TDMA	1850-1990	GMSK	200
PACS	Cordless/PCS	1994	TDMA/FDMA	1850-1990	DQPSK	300

Major Mobile Radio Standards - Europe

Standard	Type	Year Intro	Multiple Access	Frequency Band (MHz)	Modulation	Channel BW (KHz)
ETACS	Cellular	1985	FDMA	900	FM	25
NMT-900	Cellular	1986	FDMA	890-960	FM	12.5
GSM	Cellular/PCS	1990	TDMA	890-960	GMSK	200KHz
C-450	Cellular	1985	FDMA	450-465	FM	20-10
ERMES	Paging	1993	FDMA4	Several	4-FSK	25
CT2	Cordless	1989	FDMA	864-868	GFSK	100
DECT	Cordless	1993	TDMA	1880-1900	GFSK	1728
DCS-1800	Cordless/PCS	1993	TDMA	1710-1880	GMSK	200

Cellular Networks

- First Generation
  - Analog Systems
  - Analog Modulation, mostly FM
  - AMPS
  - Voice Traffic
  - FDMA/FDD multiple access
- Second Generation (2G)
  - Digital Systems
  - Digital Modulation
  - Voice Traffic
  - TDMA/FDD and CDMA/FDD multiple access
- 2.5G
  - Digital Systems
  - Voice + Low-datarate Data
- Third Generation
  - Digital
  - Voice + High-datarate Data
  - Multimedia Transmission also

2G Technologies

	cdmaOne (IS-95)	GSM, DCS-1900	IS-54/IS-136 PDC
Uplink Frequencies (MHz)	824-849 (Cellular) 1850-1910 (US PCS)	890-915 MHz (Eurpe) 1850-1910 (US PCS)	800 MHz, 1500 Mhz (Japan) 1850-1910 (US PCS)
Downlink Frequencies	869-894 MHz (US Cellular) 1930-1990 MHz (US PCS)	935-960 (Europa) 1930-1990 (US PCS)	869-894 MHz (Cellular) 1930-1990 (US PCS) 800 MHz, 1500 MHz (Japan)
Deplexing	FDD	FDD	FDD
Multiple Access	CDMA	TDMA	TDMA
Modulation	BPSK with Quadrature Spreading	GMSK with BT=0.3	$\pi/4$ DQPSK
Carrier Seperation	1.25 MHz	200 KHz	30 KHz (IS-136) (25 KHz PDC)
Channel Data Rate	1.2288 Mchips/sec	270.833 Kbps	48.6 Kbps (IS-136) 42 Kbps (PDC)
Voice Channels per carrier	64	8	3
Speech Coding	CELP at 13Kbps EVRC at 8Kbps	RPE-LTP at 13 Kbps	VSELP at 7.95 Kbps

2G and Data

- 2G is developed for voice communications
- You can send data over 2G channels by using modem
- Provides a data rates in the order of ~9.6 Kbps
- Increased data rates are requires for internet application
- This requires evolution towards new systems: 2.5 G

2.5 Technologies

- Evolution of TDMA Systems
  - HSCSD for 2.5G GSM
    - Up to 57.6 Kbps data-rate
  - GPRS for GSM and IS-136
    - Up to 171.2 Kbps data-rate
  - EDGE for 2.5G GSM and IS-136
    - Up to 384 Kbps data-rate
- Evolution of CDMA Systems
  - IS-95B
    - Up to 64 Kbps

3G Systems

- Goals
  - Voice and Data Transmission
    - Simultanous voice and data access
  - Multi-megabit Internet access
    - Interactive web sessions
  - Voice-activated calls
  - Multimedia Content
    - Live music

3G Systems

- Evolution of Systems
  - CDMA sysystem evaolved to CDMA2000
    - CDMA2000-1xRTT: Upto 307 Kbps
    - CDMA2000-1xEV:
    - CDMA2000-1xEVDO: upto 2.4 Mbps
    - CDMA2000-1xEVDV: 144 Kbps datarate
  - GSM, IS-136 and PDC evolved to W-CDMA (Wideband CDMA) (also called UMTS)
    - Up to 2.048 Mbps data-rates
    - Future systems 8Mbps
    - Expected to be fully deployed by 2010-2015
  - New spectrum is allocated for these technologies

Interest to 3G Applications

	Western Europe	Eastern Europe	USA
Emails	4.5	4.7	4.3
City maps/directions	4.3	4.2	4.2
Latest news	4.0	4.4	4.0
Authorize/enable payment	3.4	3.8	3.0
Banking/trading online	3.5	3.4	3.2
Downloading music	3.1	3.4	3.2
Shopping/reservation	3.0	3.1	2.9
Animated images	2.4	2.7	2.6
Chat rooms, forums	2.3	2.9	2.2
Interactive games	2.0	2.2	2.4
Games for money	1.8	1.8	1.8

(Means based upon a six-point interest scale, where 6 indicates high interest and 1 indicates low interest.)

Upgrade Paths for 2G Technologies