CHAPTER 10

CELLULAR WIRELESS NETWORKS

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Provide an overview of cellular network organization.
- Distinguish among four generations of mobile telephony.
- Understand the relative merits of time-division multiple access (TDMA) and code division multiple access (CDMA) approaches to mobile telephony.
- Present an overview of LTE-Advanced.

Antes lujo, ahora es algo normal. Se popularizó

Of all the tremendous advances in data communications and telecommunications, perhaps the most revolutionary is the development of **cellular networks**. Cellular technology is the foundation of mobile wireless communications and supports users in locations that are not easily served by wired networks. Cellular technology is the underlying technology for mobile telephones, personal communications systems, wireless Internet and wireless Web applications, and much more.

We begin this chapter with a look at the basic principles used in all cellular networks. Then we look at specific cellular technologies and standards, which are conveniently grouped into four generations. Finally, we examine LTE-Advanced, which is the standard for the fourth generation, in more detail.

La telefonía móvil comenzó en 1973 cuando Martin Cooper hizo su primera llamada

10.1 PRINCIPLES OF CELLULAR NETWORKS

Cellular radio is a technique that was developed to increase the capacity available for mobile radio telephone service. Prior to the introduction of cellular radio, mobile radio telephone service was only provided by a high-power transmitter/receiver. A typical system would support about 25 channels with an effective radius of about 80 km. The way to increase the capacity of the system is to use lower-power systems with shorter radius and to use numerous transmitters/receivers.

Un Tx/Rx potente de largo alcance y pocos usuarios vs. muchos pequeños con muchos usuarios

Cellular Network Organization

The essence of a cellular network is the use of multiple low-power transmitters, on the order of 100 W or less. Because the range of such a transmitter is small, an area can be divided into cells, each one served by its own antenna. Each cell is allocated

foto de abril 2013

A principios de los años 80 empezaron a desplegarse redes de telefonía móvil por todos los países desarrollados.
No existía un estándar y normalmente salirse del país era sinónimo de perder la capacidad de comunicarse.

Potencia menor a 100W
Muchos Tx/Rx que determinan un área llamada Celdas.
Cada celda tiene su estación base.
Celdas contíguas evitan crosstalk o interferencias (!= frecuencias)

a band of frequencies and is served by a **base station**, consisting of transmitter, receiver, and control unit. Adjacent cells are assigned different frequencies to avoid interference or crosstalk. However, cells sufficiently distant from each other can use the same frequency band.

1) Forma de la Celda?

The first design decision to make is the shape of cells to cover an area. A matrix of square cells would be the simplest layout to define (Figure 10.1a). However, this geometry is not ideal. If the width of a square cell is d, then a cell has four neighbors at a distance d and four neighbors at a distance $\sqrt{2}d$. As a mobile user within a cell moves toward the cell's boundaries, it is best if all of the adjacent antennas are equidistant. This simplifies the task of determining when to switch the user to an adjacent antenna and which antenna to choose. A hexagonal pattern provides for equidistant antennas (Figure 10.1b). The radius of a hexagon is defined to be the radius of the circle that circumscribes it (equivalently, the distance from the center to each vertex; also equal to the length of a side of a hexagon). For a cell radius R, the distance between the cell center and each adjacent cell center is $d = \sqrt{3}R$.

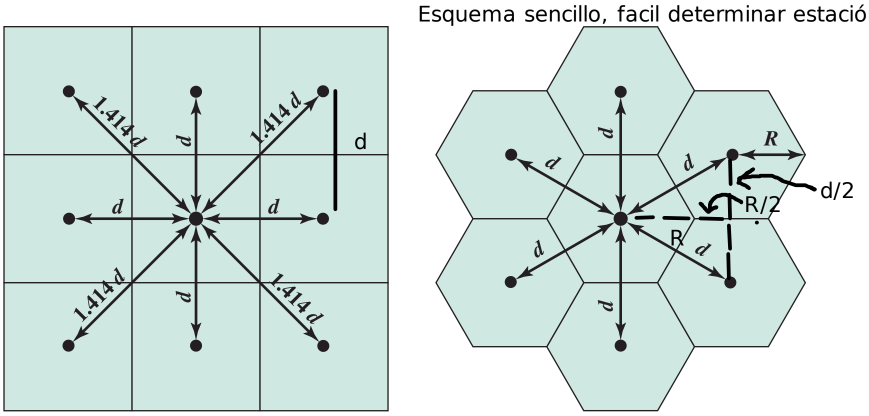
In practice, a precise hexagonal pattern is not used. Variations from the ideal are due to topographical limitations, local signal propagation conditions, and practical limitation on siting antennas.

A wireless cellular system limits the opportunity to use the same frequency for different communications because the signals, not being constrained, can interfere with one another even if geographically separated. Systems supporting a large number of communications simultaneously need mechanisms to conserve spectrum.

Frequency Reuse In a cellular system, each cell has a base transceiver. The transmission power is carefully controlled (to the extent that it is possible in the highly variable mobile communication environment) to allow communication within the cell using a given frequency, while limiting the power at that frequency that escapes the cell into adjacent ones. The objective is to use the same frequency in other nearby (but not adjacent) cells, thus allowing the frequency to be used for multiple simultaneous conversations. Generally, 10 to 50 frequencies are assigned to each cell, depending on the traffic expected.

Esquema sencillo, pero no son equidistantes

Esquema sencillo, facil determinar estación mas cercana



(a) Square pattern

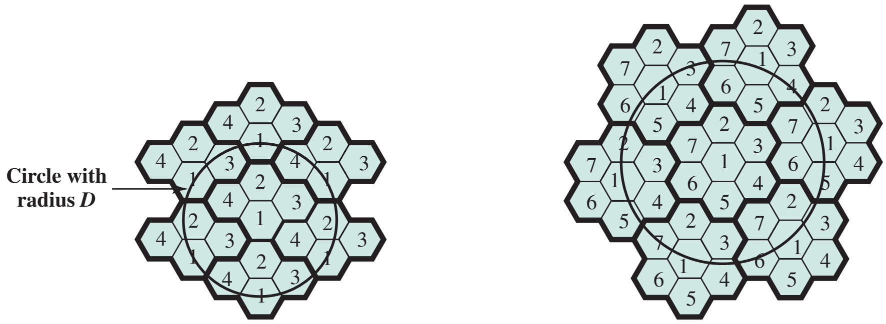
(b) Hexagonal pattern

Figure 10.1 Cellular Geometries

$$x^2=d^2+d^2 \rightarrow x^2=2*d^2 \rightarrow x=\sqrt{2}d$$

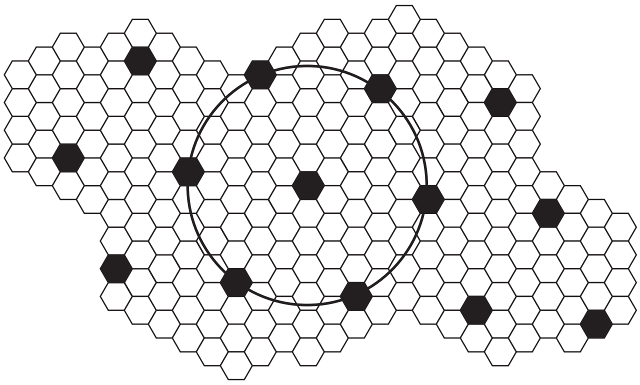
$$d^2=(R+R/2)^2+(d/2)^2 \rightarrow d=\sqrt{3}R$$

El objetivo es utilizar la misma frecuencia en otros celdas cercanas (pero no adyacentes),
lo que permite que la frecuencia se utilice para múltiples conversaciones simultáneas.



(a) Frequency reuse pattern for $N = 4$

(b) Frequency reuse pattern for $N = 7$



(c) Black cells indicate a frequency reuse for $N = 19$

Figure 10.2 Frequency Reuse Patterns

Cuantas celdas entre medio para evitar inteferencias?

The essential issue is to determine how many cells must intervene between two cells using the same frequency so that the two cells do not interfere with each other. Various patterns of frequency reuse are possible. Figure 10.2 shows some examples. If the pattern consists of N cells and each cell is assigned the same number of frequencies, each cell can have K/N frequencies, where K is the total number of frequencies allotted to the system.

In characterizing frequency reuse, the following parameters are commonly used:

D = minimum distance between centers of cells that use the same band of frequencies (called cochannels)

R = radius of a cell

d = distance between centers of adjacent cells ($d = \sqrt{3}R$)

N = number of cells in a repetitious pattern (each cell in the pattern uses a unique band of frequencies), termed the **reuse factor**

In a hexagonal cell pattern, only the following values of N are possible:

$$N = I^2 + J^2 + (I \times J) \qquad I, J = 0, 1, 2, 3, \ldots$$

Hence, possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, and so on. The following relationship holds:

$$\frac{D}{R} = \sqrt{3N}$$

D: distancia entre celdas colaterales que
usen la misma frecuencia.
R: Radio de la celda.
N:Número de celdas.
d: Distancia entre celdas adyacentes

This can also be expressed as $D/d = \sqrt{N}$.

+ usuarios
=> + frecuencias

Increasing Capacity In time, as more customers use the system, traffic may build up so that there are not enough frequencies assigned to a cell to handle its calls. A number of approaches have been used to cope with this situation, including the following:

+Canales

Si no usas esta
Frecuencia, prestame

Densidad de usuarios
en el centro no es lo
mismo que en la
periferia. (=> microceldas)

- **Adding new channels:** Typically, when a system is set up in a region, not all of the channels are used, and growth and expansion can be managed in an orderly fashion by adding new channels.
- **Frequency borrowing:** In the simplest case, frequencies are taken from adjacent cells by congested cells. The frequencies can also be assigned to cells dynamically.
- **Cell splitting:** In practice, the distribution of traffic and topographic features is not uniform, and this presents opportunities for capacity increase. Cells in areas of high usage can be split into smaller cells. Generally, the original cells are about 6.5 to 13 km in size. The smaller cells can themselves be split; however, 1.5-km cells are close to the practical minimum size as a general solution (but see the subsequent discussion of microcells). To use a smaller cell, the power level used must be reduced to keep the signal within the cell. Also, as the mobile units move, they pass from cell to cell, which requires transferring of the call from one base transceiver to another. This process is called a handoff. As the cells get smaller, these handoffs become much more frequent. Figure 10.3 indicates schematically how cells can be divided to provide more

Handoff: pasaje de la llamada de una
celda a otra, mientras se desplaza
el movil.

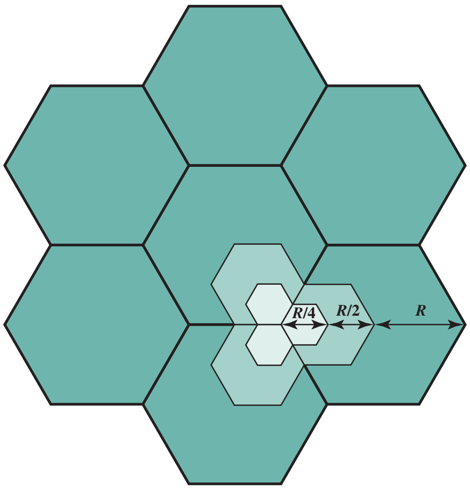


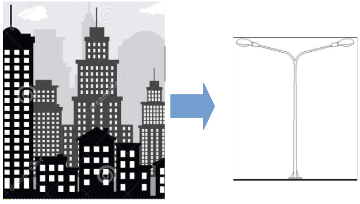
Figure 10.3 Cell Splitting with Cell Reduction Factor of $F = 2$

capacity. A radius reduction by a factor of F reduces the coverage area and increases the required number of base stations by a factor of F^2.

- **Cell sectoring:** With cell sectoring, a cell is divided into a number of wedge-shaped sectors, each with its own set of channels, typically three or six sectors per cell. Each sector is assigned a separate subset of the cell's channels, and directional antennas at the base station are used to focus on each sector.

Antenas Direccionales
Cada sector,tiene
su propio set de canales

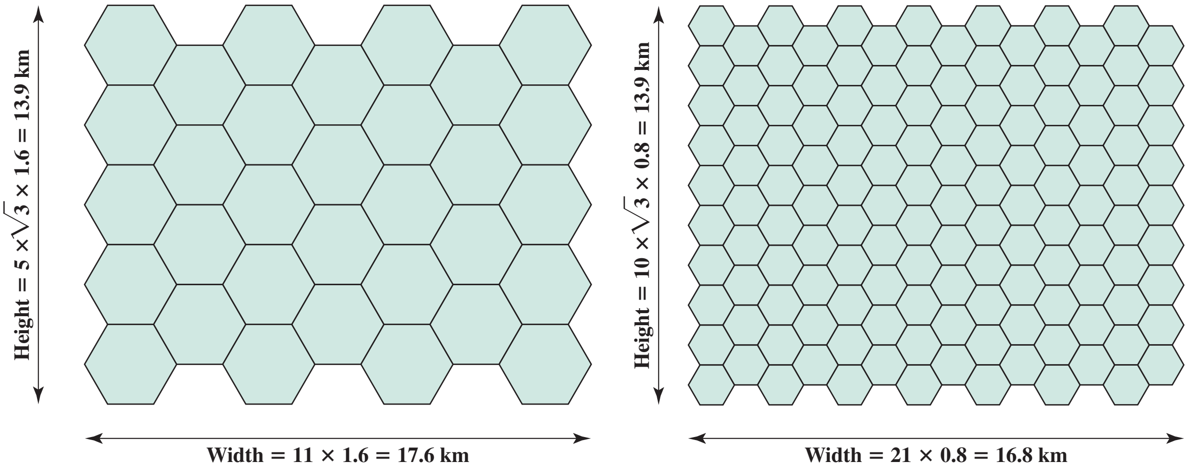
- **Microcells:** As cells become smaller, antennas move from the tops of tall buildings or hills to the tops of small buildings or the sides of large buildings, and finally to lamp posts, where they form microcells. Each decrease in cell size is accompanied by a reduction in the radiated power levels from the base stations and the mobile units. Microcells are useful in city streets in congested areas, along highways, and inside large public buildings.



- potencia.
bueno en lugares
congestionados

EXAMPLE 10.1 Assume a system of 32 cells with a cell radius of 1.6 km, a total frequency bandwidth that supports 336 traffic channels, and a reuse factor of $N = 7$. If there are 32 total cells, what geographic area is covered, how many channels are there per cell, and what is the total number of concurrent calls that can be handled? Repeat for a cell radius of 0.8 km and 128 cells.

Figure 10.4a shows an approximately square pattern. The area of a hexagon of radius R is $1.5R^2\sqrt{3}$. A hexagon of radius 1.6 km has an area of 6.65 km^2, and the total area covered is $6.65 \times 32 = 213\,\text{km}^2$. For $N = 7$, the number of channels per cell is $336/7 = 48$, for a total channel capacity of $48 \times 32 = 1536$ channels. For the layout of Figure 10.4b, the area covered is $1.66 \times 128 = 213\text{km}^2$. The number of channels per cell is $336/7 = 48$, for a total channel capacity of $48 \times 128 = 6144$ channels.



(a) Cell radius = 1.6 km

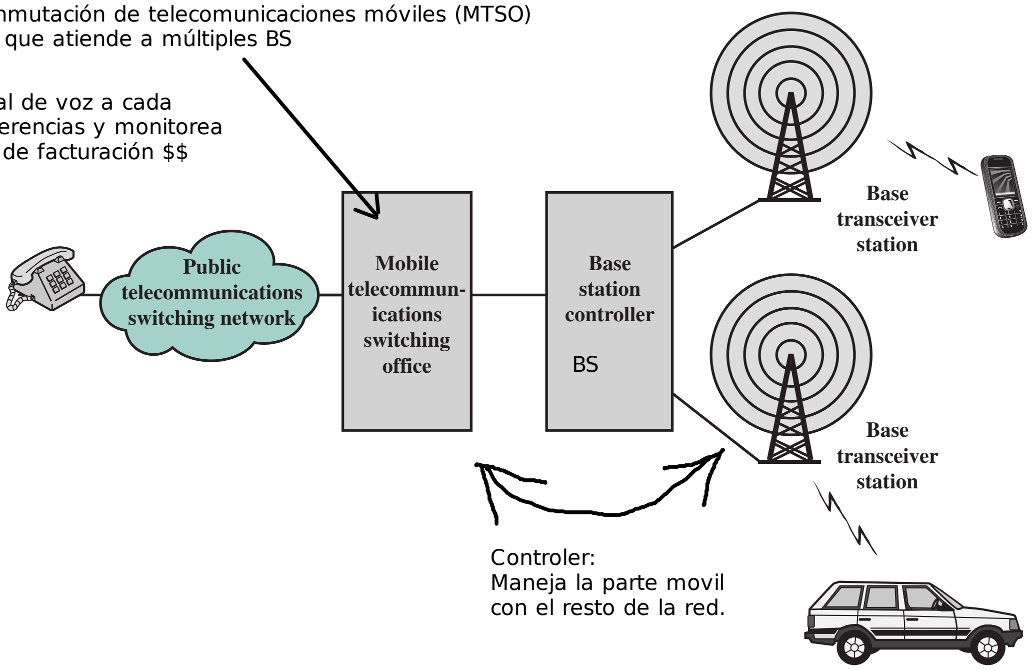
(b) Cell radius = 0.8 km

Figure 10.4 Frequency Reuse Example

BS:
*Maneja varias antenas
*Tiene el Controlador
*Transeivers p/ comunicarse con la Celda

Oficina de conmutación de telecomunicaciones móviles (MTSO) con un MTSO que atiende a múltiples BS

El MTSO asigna el canal de voz a cada llamada, realiza transferencias y monitorea la llamada para Datos de facturación $$



Controler:
Maneja la parte movil
con el resto de la red.

Figure 10.5 Overview of Cellular System

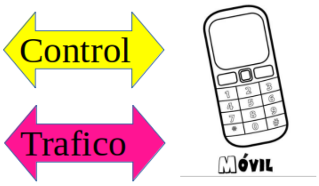
Operation of Cellular Systems

Figure 10.5 shows the principal elements of a cellular system. In the approximate center of each cell is a base station (BS). The BS includes one or more antennas, a controller, and a number of transceivers for communicating on the channels assigned to that cell. The controller is used to handle the call process between the mobile unit and the rest of the network. At any time, a number of mobile user units may be active and moving about within a cell, communicating with the BS. Each BS is connected to a mobile telecommunications switching office (MTSO), with one MTSO serving multiple BSs. Typically, the link between an MTSO and a BS is by a wire line, although a wireless link is also possible. The MTSO connects calls between mobile units. The MTSO is also connected to the public telephone or telecommunications network and can make a connection between a fixed subscriber to the public network and a mobile subscriber to the cellular network. The MTSO assigns the voice channel to each call, performs handoffs, and monitors the call for billing information.

The use of a cellular system is fully automated and requires no action on the part of the user other than placing or answering a call. Two types of channels are available between the mobile unit and the base station: control channels and traffic channels. **Control channels** are used to exchange information having to do with setting up and maintaining calls and with establishing a relationship between a mobile unit and the nearest BS. **Traffic channels** carry a voice or data connection between

BS

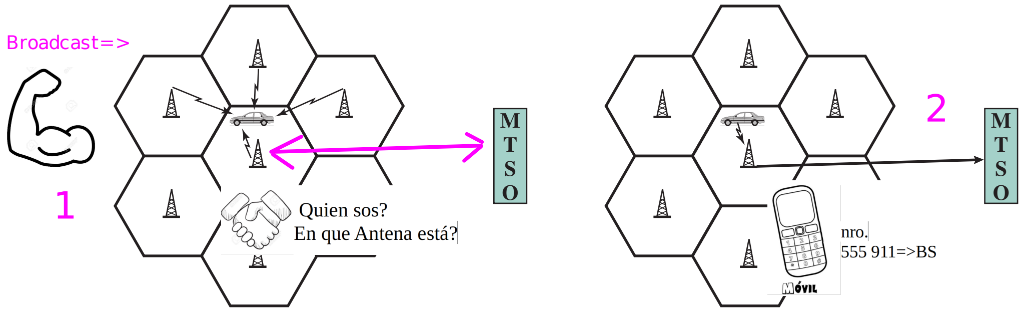
BS



users. Figure 10.6 illustrates the steps in a typical call between two mobile users within an area controlled by a single MTSO:

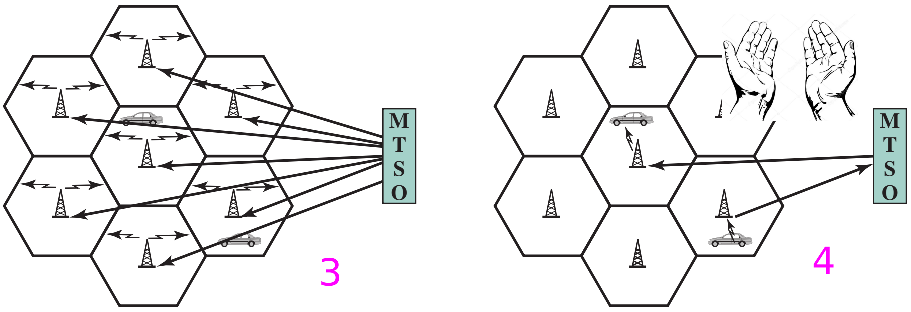
- **Mobile unit initialization:** When the mobile unit is turned on, it scans and selects the strongest setup control channel used for this system (Figure 10.6a). Cells with different frequency bands repetitively broadcast on different setup channels. The receiver selects the strongest setup channel and monitors that channel. The effect of this procedure is that the mobile unit has automatically selected the BS antenna of the cell within which it will operate.[1] Then

1

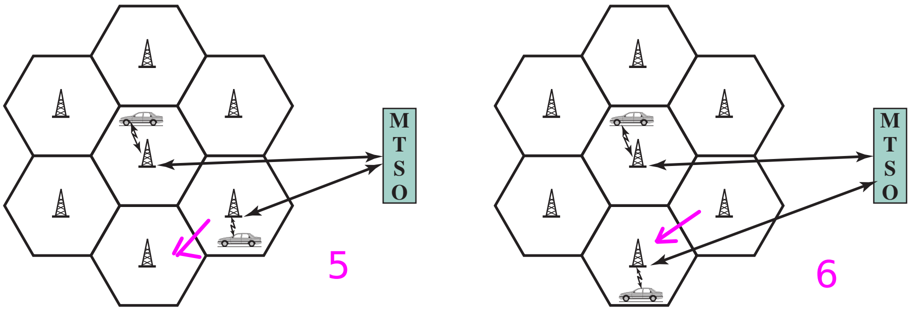


(a) Monitor for strongest signal (b) Request for connection

Localizador:
Donde estas?



(c) Paging (d) Call accepted



(e) Ongoing call (f) Handoff

Figure 10.6 Example of Mobile Cellular Cell

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[1] Usually, but not always, the antenna and therefore the base station selected is the closest one to the mobile unit. However, because of propagation anomalies, this is not always the case.

a handshake takes place between the mobile unit and the MTSO controlling this cell, through the BS in this cell. The handshake is used to identify the user and register its location. As long as the mobile unit is on, this scanning procedure is repeated periodically to account for the motion of the unit. If the unit enters a new cell, then a new BS is selected. In addition, the mobile unit is monitoring for pages, discussed subsequently.

- **Mobile-originated call:** A mobile unit originates a call by sending the number of the called unit on the preselected setup channel (Figure 10.6b). The receiver at the mobile unit first checks that the setup channel is idle by examining 2 information in the forward (from the BS) channel. When an idle condition is detected, the mobile may transmit on the corresponding reverse (to BS) channel. The BS sends the request to the MTSO.
- **Paging:** The MTSO then attempts to complete the connection to the called unit. The MTSO sends a paging message to certain BSs depending on the 3 called mobile number (Figure 10.6c). Each BS transmits the paging signal on its own assigned setup channel.
- **Call accepted:** The called mobile unit recognizes its number on the setup channel being monitored and responds to that BS, which sends the response to the MTSO. The MTSO sets up a circuit between the calling and called 4 BSs. At the same time, the MTSO selects an available traffic channel within each BS's cell and notifies each BS, which in turn notifies its mobile unit (Figure 10.6d). The two mobile units tune to their respective assigned channels.
- **Ongoing call:** While the connection is maintained, the two mobile units exchange voice or data signals, going through their respective BSs and the 5 MTSO (Figure 10.6e).
- **Handoff:** If a mobile unit moves out of range of one cell and into the range of another during a connection, the traffic channel has to change to one assigned to the BS in the new cell (Figure 10.6f). The system makes this change without 6 either interrupting the call or alerting the user.

Other functions performed by the system but not illustrated in Figure 10.6 include the following:

- **Call blocking:** During the mobile-initiated call stage, if all the traffic channels assigned to the nearest BS are busy, then the mobile unit makes a preconfigured number of repeated attempts. After a certain number of failed tries, a busy tone is returned to the user.
- **Call termination:** When one of the two users hangs up, the MTSO is informed and the traffic channels at the two BSs are released.
- **Call drop:** During a connection, because of interference or weak signal spots in certain areas, if the BS cannot maintain the minimum required signal strength for a certain period of time, the traffic channel to the user is dropped and the MTSO is informed.
- **Calls to/from fixed and remote mobile subscriber:** The MTSO connects to the public switched telephone network. Thus, the MTSO can set up a connection

between a mobile user in its area and a fixed subscriber via the telephone network. Further, the MTSO can connect to a remote MTSO via the telephone network or via dedicated lines and set up a connection between a mobile user in its area and a remote mobile user.

Mobile Radio Propagation Effects

Mobile radio communication introduces complexities not found in wire communication or in fixed wireless communication. Two general areas of concern are signal strength and signal propagation effects.

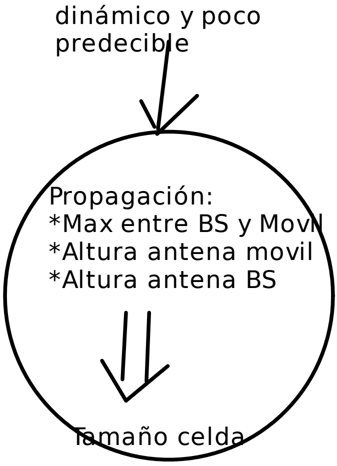
1
- **Signal strength:** The strength of the signal between the base station and the mobile unit must be strong enough to maintain signal quality at the receiver but not so strong as to create too much cochannel interference with channels in another cell using the same frequency band. Several complicating factors exist. Human-made noise varies considerably, resulting in a variable noise level. For example, automobile ignition noise in the cellular frequency range is greater in the city than in a suburban area. Other signal sources vary from place to place. The signal strength varies as a function of distance from the BS to a point within its cell. Moreover, the signal strength varies dynamically as the mobile unit moves.

Fuerte pero no tanto!

La fuente de ruido, varía según el entorno.

La calidad de la señal, es función de la distancia aBS

2
- **Fading:** Even if signal strength is within an effective range, signal propagation effects may disrupt the signal and cause errors. Fading is discussed subsequently in this section.



In designing a cellular layout, the communications engineer must take account of these various propagation effects, the desired maximum transmit power level at the base station and the mobile units, the typical height of the mobile unit antenna, and the available height of the BS antenna. These factors will determine the size of the individual cell. Unfortunately, as just described, the propagation effects are dynamic and difficult to predict. The best that can be done is to come up with a model based on empirical data and to apply that model to a given environment to develop guidelines for cell size. One of the most widely used models was developed by Okumura et al. [OKUM68] and subsequently refined by Hata [HATA80]. The original was a detailed analysis of the Tokyo area and produced path loss information for an urban environment. Hata's model is an empirical formulation that takes into account a variety of environments and conditions. For an urban environment, predicted path loss is

Solución:Modelo de Okumura mejorado por Hata.

$$L_{dB} = 69.55 + 26.16 \log f_c - 13.82 \log h_t - A(h_r) + (44.9 - 6.55 \log h_t) \log d \qquad \textbf{(10.1)}$$

where

f_c = carrier frequency in MHz from 150 to 1500 MHz
h_t = height of transmitting antenna (base station) in m, from 30 to 300 m
h_r = height of receiving antenna (mobile station) in m, from 1 to 10 m
d = propagation distance between antennas in km, from 1 to 20 km
$A(h_r)$ = correction factor for mobile antenna height

For a small- or medium-sized city, the correction factor is given by

$$A(h_r) = (1.1 \log f_c - 0.7)\, h_r - (1.56 \log f_c - 0.8) \text{ dB}$$

And for a large city it is given by

$$A(h_r) = 8.29\,[\log(1.54\, h_r)]^2 - 1.1 \text{ dB} \qquad \text{for } f_c \leq 300 \text{ MHz}$$
$$A(h_r) = 3.2\,[\log(11.75\, h_r)]^2 - 4.97 \text{ dB} \qquad \text{for } f_c \geq 300 \text{ MHz}$$

To estimate the path loss in a suburban area, the formula for urban path loss in Equation (10.1) is modified as:

$$L_{\text{dB}}(\text{suburban}) = L_{\text{dB}}(\text{urban}) - 2[\log(f_c/28)]^2 - 5.4$$

And for the path loss in open areas, the formula is modified as

$$L_{\text{dB}}(\text{open}) = L_{\text{dB}}(\text{urban}) - 4.78(\log f_c)^2 - 18.733\,(\log f_c) - 40.98$$

The Okumura/Hata model is considered to be among the best in terms of accuracy in path loss prediction and provides a practical means of estimating path loss in a wide variety of situations [FREE07].

EXAMPLE 10.2 Let $f_c = 900$ MHz, $h_t = 40$ m, $h_r = 5$ m, and $d = 10$ km. Estimate the path loss for a medium-size city.

$$\begin{aligned} A(h_r) &= (1.1 \log 900 - 0.7)\, 5 - (1.56 \log 900 - 0.8) \text{ dB} \\ &= 12.75 - 3.8 = 8.95 \text{ dB} \end{aligned}$$

$$\begin{aligned} L_{\text{dB}} &= 69.55 + 26.16 \log 900 - 13.82 \log 40 - 8.95 + (44.9 - 6.55 \log 40) \log 10 \\ &= 69.55 + 77.28 - 22.14 - 8.95 + 34.4 = 150.14 \text{ dB} \end{aligned}$$

Fading in the Mobile Environment

Fadding:
Variación de la potencia de la señal causada por el medio o los recorridos del medio.

Perhaps the most challenging technical problem facing communications systems engineers is fading in a mobile environment. The term *fading* refers to the time variation of received signal power caused by changes in the transmission medium or path(s). In a fixed environment, fading is affected by changes in atmospheric conditions, such as rainfall. But in a mobile environment, where one of the two antennas is moving relative to the other, the relative location of various obstacles changes over time, creating complex transmission effects.

MULTIPATH PROPAGATION Three propagation mechanisms, illustrated in Figure 10.7, play a role. **Reflection** occurs when an electromagnetic signal encounters a surface that is large relative to the wavelength of the signal. For example, suppose a ground-reflected wave near the mobile unit is received. Because the ground-reflected wave has a 180° phase shift after reflection, the ground wave and the line-of-sight (LOS) wave may tend to cancel, resulting in high signal loss.[2] Further, because the mobile antenna is lower than most human-made structures in the area, multipath

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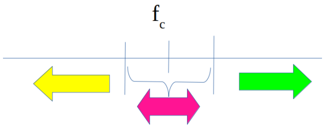
[2] On the other hand, the reflected signal has a longer path, which creates a phase shift due to delay relative to the unreflected signal. When this delay is equivalent to half a wavelength, the two signals are back in phase.

La señal reflejada recorre un camino más largo, lo cual ocasiona un desplazamiento de fase debido al retardo relativo a la señal no reflejada.
Cuando este retardo es equivalente a la mitad de la longitud de onda, las dos señales vuelven a poseer la misma fase.

superficie que es grande en relación con la longitud de onda de la señal



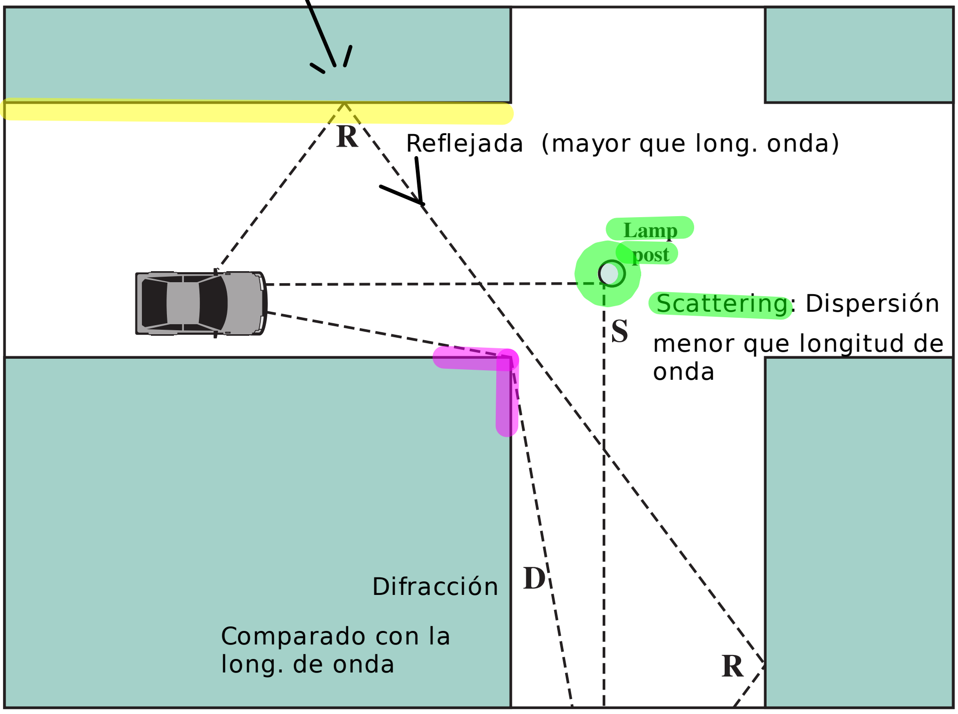


Figure 10.7 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

interference occurs. These reflected waves may interfere constructively or destructively at the receiver.

Diffraction occurs at the edge of an impenetrable body that is large compared to the wavelength of the radio wave. When a radio wave encounters such an edge, waves propagate in different directions with the edge as the source. Thus, signals can be received even when there is no unobstructed LOS from the transmitter.

If the size of an obstacle is on the order of the wavelength of the signal or less, **scattering** occurs. An incoming signal is scattered into several weaker outgoing signals. At typical cellular microwave frequencies, there are numerous objects, such as lamp posts and traffic signs, that can cause scattering. Thus, scattering effects are difficult to predict.

These three propagation effects influence system performance in various ways depending on local conditions and as the mobile unit moves within a cell. If a mobile unit has a clear LOS to the transmitter, then diffraction and scattering are generally minor effects, although reflection may have a significant impact. If there is no clear LOS, such as in an urban area at street level, then diffraction and scattering are the primary means of signal reception.

THE EFFECTS OF MULTIPATH PROPAGATION As just noted, one unwanted effect of multipath propagation is that multiple copies of a signal may arrive at different phases. If these phases add destructively, the signal level relative to noise declines, making signal detection at the receiver more difficult.

1: Multiples copias con distinta fase!

(ISI) :la interferencia entre símbolos es una forma de distorsión de una señal en la cual un símbolo interfiere con símbolos posteriores.
Es un fenómeno no deseado ya que los símbolos anteriores tiene un efecto similar al del ruido

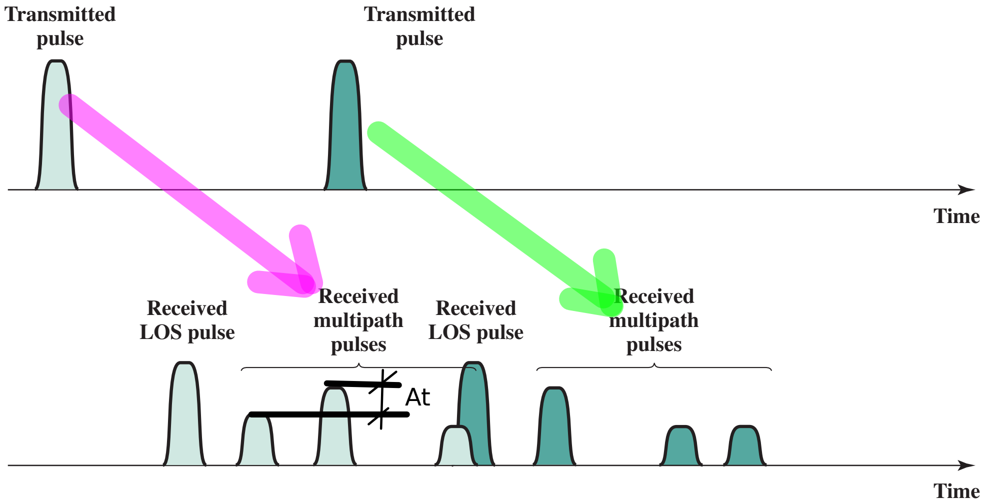


Figure 10.8 Two Pulses in Time-Variant Multipath

2: ISI , interfernecia intersímbolo.

A second phenomenon, of particular importance for digital transmission, is intersymbol interference (ISI). Consider that we are sending a narrow pulse at a given frequency across a link between a fixed antenna and a mobile unit. Figure 10.8 shows what the channel may deliver to the receiver if the impulse is sent at two different times. The upper line shows two pulses at the time of transmission. The lower line shows the resulting pulses at the receiver. In each case the first received pulse is the desired LOS signal. The magnitude of that pulse may change because of changes in atmospheric attenuation. Further, as the mobile unit moves farther away from the fixed antenna, the amount of LOS attenuation increases. But in addition to this primary pulse, there may be multiple secondary pulses due to reflection, diffraction, and scattering. Now suppose that this pulse encodes one or more bits of data. In that case, one or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit. These delayed pulses act as a form of noise to the subsequent primary pulse, making recovery of the bit information more difficult.

As the mobile antenna moves, the location of various obstacles changes; hence the number, magnitude, and timing of the secondary pulses change. This makes it difficult to design signal-processing techniques that will filter out multipath effects so that the intended signal is recovered with fidelity.

Types of Fading Fading effects in a mobile environment can be classified as either fast or slow. Referring to Figure 10.7, as the mobile unit moves down a street in an urban environment, rapid variations in signal strength occur over distances of about one-half a wavelength. At a frequency of 900 MHz, which is typical for mobile cellular applications, the wavelength is 0.33 m. Changes of amplitude can be as much as 20 or 30 dB over a short distance. This type of rapidly changing fading phenomenon, known as **fast fading**, affects not only mobile phones in automobiles, but even a mobile phone user walking down an urban street.

$$3x10^8/900x10^6=0.33m$$

900MHz => 0.33m esta distancia es pequeña por lo que diremos que el desvanecimiento es Rápido. => 20 a 30dB en menos de un metro!

Los cambios que suceden por cambios de alturas, o distancias mayores, se denominan slow fading
los que nos son fast fading son slow fading

As the mobile user covers distances well in excess of a wavelength, the urban environment changes, as the user passes buildings of different heights, vacant lots, intersections, and so forth. Over these longer distances, there is a change in the average received power level about which the rapid fluctuations occur. This is referred to as **slow fading**.

Fading Effects:
*Flat fading
*Selective fading.

Fading effects can also be classified as flat or selective. **Flat fading**, or nonselective fading, is that type of fading in which all frequency components of the received signal fluctuate in the same proportions simultaneously. **Selective fading** affects unequally the different spectral components of a radio signal. The term *selective fading* is usually significant only relative to the bandwidth of the overall communications channel. If attenuation occurs over a portion of the bandwidth of the signal, the fading is considered to be selective; nonselective fading implies that the signal bandwidth of interest is narrower than, and completely covered by, the spectrum affected by the fading.

ERROR COMPENSATION MECHANISMS The efforts to compensate for the errors and distortions introduced by multipath fading fall into three general categories: forward error correction, adaptive equalization, and diversity techniques. In the typical mobile wireless environment, techniques from all three categories are combined to combat the error rates encountered.

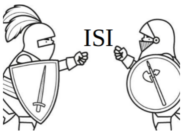
3 cat

x2 ó x3
Overhead!!

1

Forward error correction is applicable in digital transmission applications: those in which the transmitted signal carries digital data or digitized voice or video data. Typically in mobile wireless applications, the ratio of total bits sent to data bits sent is between 2 and 3. This may seem an extravagant amount of overhead, in that the capacity of the system is cut to one-half or one-third of its potential, but the mobile wireless environment is so difficult that such levels of redundancy are necessary. Chapter 6 discusses forward error correction.

digital



los denominados circuitos
analógicos de nudos hasta
sofisticados algoritmos de
procesamiento digital
de señales.

2

Adaptive equalization can be applied to transmissions that carry analog information (e.g., analog voice or video) or digital information (e.g., digital data, digitized voice or video) and is used to combat intersymbol interference. The process of equalization involves some method of gathering the dispersed symbol energy back together into its original time interval. Equalization is a broad topic; techniques include the use of so-called lumped analog circuits as well as sophisticated digital signal processing algorithms.

digital ó
analógica

3

Diversity is based on the fact that individual channels experience independent fading events. We can therefore compensate for error effects by providing multiple logical channels in some sense between transmitter and receiver and sending part of the signal over each channel. This technique does not eliminate errors but it does reduce the error rate, since we have spread the transmission out to avoid being subjected to the highest error rate that might occur. The other techniques (equalization, forward error correction) can then cope with the reduced error rate.

Dividir=>
Reducir

Some diversity techniques involve the physical transmission path and are referred to as **space diversity**. For example, multiple nearby antennas may be used to receive the message, with the signals combined in some fashion to reconstruct the most likely transmitted signal. Another example is the use of collocated multiple directional antennas, each oriented to a different reception angle with the incoming signals again combined to reconstitute the transmitted signal.

space diversity: colaborativamente las antenas trabajan para reconstruir la señal mas probable.

More commonly, the term *diversity* refers to frequency diversity or time diversity techniques. With **frequency diversity**, the signal is spread out over a larger-frequency bandwidth or carried on multiple frequency carriers. The most important example of this approach is spread spectrum, which is examined in Chapter 17.

10.2 CELLULAR NETWORK GENERATIONS

1980

Since their introduction in the mid-1980s, cellular networks have evolved rapidly. For convenience, industry and standards bodies group the technical advances into "generations." We are now up to the fourth generation (4G) of cellular network technology. In this section, we give a brief overview of the four generations. The following section is devoted to 4G.

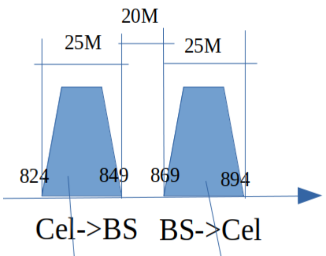
Table 10.1 lists some of the key characteristics of the cellular network generations.

First Generation

tráfico analógico
Ladrillos
Analogía red tel analógica.
Desarrollado AT&T

The original cellular networks, now dubbed 1G, provided analog traffic channels and were designed to be an extension of the public switched telephone networks. Users with brick-sized cell phones placed and received calls in the same fashion as landline subscribers.

The most widely deployed 1G system was the **Advanced Mobile Phone Service (AMPS)**, developed by AT&T. This approach was also common in South America, Australia, and China.



In North America, two 25-MHz bands were allocated to AMPS, one for transmission from the base station to the mobile unit (869–894 MHz) and the other for transmission from the mobile to the base station (824–849 MHz). Each of these bands is split in two to encourage competition (i.e., in each market two operators can be accommodated). An operator is allocated only 12.5 MHz in each direction for its system. The channels are spaced 30 kHz apart, which allows a total of 416 channels per operator. Twenty-one channels are allocated for control, leaving 395 to carry calls. The control channels are data channels operating at 10 kbps. The conversation

416 canales x
30KHz=12.48

P/ 2 operadores

Table 10.1 Wireless Network Generations

Technology	1G	2G	2.5G	4G
Design began	1970	1980	1985	2000
Implementation	1984	1991	1999	2012
Services	Analog voice	Digital voice	Higher capacity packetized data	Completely IP based
Data rate	1.9. kbps	14.4 kbps	384 kbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	OFDMA, SC-FDMA
Core network	PSTN	PSTN	PSTN, packet network	IP backbone

módulo de asignación de número (NAM, Numeric Assignment Module)

Voz ,analógico -> x FM , Canal de control van datos digitales x FSK