DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

MOBILE COMMUNICATIONS AND NETWORKS (J324B)

[R20]

B.TECH ECE
(III YEAR – II SEM)
(2023-24)

J. B. INSTITUTE OF ENGINEERING AND TECHNOLOGY

(UGC AUTONOMOUS)
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Bhaskar Nagar, Yenkapally(V), Moinabad(M), Ranaga Reddy(D),Hyderabad – 500 075,
Telanagana, India.

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onwards</td><td>J. B. Institute of Engineering and Technology
(UGC Autonomous)</td><td colspan="4">B.Tech ECE
III Year – II Sem</td></tr>
<tr><td>Course Code:
J324B</td><td rowspan="2">MOBILE COMMUNICATIONS AND NETWORKS</td><td>L</td><td>T</td><td>P</td><td>D</td></tr>
<tr><td>Credits: 3</td><td>3</td><td>0</td><td>0</td><td>0</td></tr>
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Pre-requisite: Analog and Digital Communications

Course Objectives:

This course will enable students to:

1. provide with an understanding of the cellular concept, frequency reuse, handoff strategies.
2. illustrate the concepts of Co-channel and Non Co-Channel interferences.
3. provide understanding of diversity techniques and channel assignment techniques.
4. get an understanding of various types of handoff.
5. understand challenges and application of Ad-hoc wireless Networks.

Module 1

Unit 1 (Introduction to Cellular Mobile Radio Systems)

Limitations of Conventional Mobile Telephone Systems. Basic Cellular Mobile System, First, Second, Third and Fourth Generation Cellular Wireless Systems. Uniqueness of Mobile Radio Environment-Fading-Tie Dispersion Parameters, Coherence Bandwidth, Doppler Spread and Coherence Time.

Unit 2 (Fundamentals of Cellular Radio System Design)

Concept of Frequency Reuse, Co-Channel Interference, Co-Channel Interference Reduction Factor, Desired C/I from a Normal Case in a Omni Directional Antenna System, System Capacity Improving Coverage and Capacity in Cellular Systems- Cell Splitting, Sectoring, Microcell Zone Concept.

Module 2

Unit 1 (Co-Channel Interference)

Measurement of Real Time Co-Channel Interference, Design of Antenna System, Antenna Parameters and their effects, diversity techniques-space diversity, polarization diversity, frequency diversity, time diversity.

Unit 2 (Non Co-Channel Interference)

Adjacent Channel Interference, Near end far end interference, cross talk, effects on coverage and interference by power decrease, antenna height decrease, effects of cell site components.

Module 3:

Unit 1 (Frequency Management and Channel Assignment)

Numbering and Grouping, Setup Access and Paging Channels, Channel Assignments to Cell Sites and Mobile Units.

Unit 2 (Multiple Access Techniques for Wireless Communication)

Introduction to multiple access, FDMA, TDMA, Spread spectrum multiple access, Space division multiple access, Packet radio, Capacity of a cellular systems.

Module 4:

Unit 1 (Handoffs)

Handoff Initiation, types of Handoff, Delaying Handoff, advantages of Handoff, Power Difference Handoff, Forced Handoff, Mobile Assisted and Soft Handoff, Intersystem handoff,

Unit 2 (Dropped Calls)

Introduction to Dropped Call Rates and their Evaluation.

Module 5:

Unit 1 (Ad Hoc Wireless Networks)

Introduction, Cellular and Ad Hoc wireless Networks, Applications and Ad Hoc Wireless Networks, Issues in Ad Hoc Wireless Networks, Ad Hoc Wireless Internet.

Unit 2 (Orthogonal Frequency Division Multiplexing)

Basic Principles of Orthogonality, Single Versus Multi channel Systems, OFDM Block Diagram and its explanation, OFDM Signal mathematical representation.

Text Books:

1. Mobile Cellular Telecommunications-W.C.Y. Lee, Mc Graw Hill, 2nd Edn., 1989.
2. Wireless Communications-Theodore. S. Rapport, Pearson Education, 2nd Ed., 2002.

Reference Books:

1. Ad Hoc Wireless Networks: Architectures and Protocols-C. Siva ram Murthy and B.S. Manoj, 2004, PHI.
2.Modern Wireless Communications-Simon Haykin, Michael Moher, Pearson Education, 2005.
3. Wireless Communications and Networking, Vijay Garg, Elsevier Publications, 2007.
4. Wireless Communications-Andrea Goldsmith, Cambridge University Press, 2005.

E - Resources:

1. https://www.electronics-notes.com/articles/connectivity/cellular-mobile-phone/handover-handoff.php
2. https://www.youtube.com/watch?v=whYljse4Abc
3. https://nptel.ac.in/courses/106/106/106106167/
4. https://www.coursera.org/learn/wireless-communications.

Course Outcomes:

On completion of the course, the students will be able to:

1. describe the fundamentals of Cellular radio system design.
2. illustrate the concepts of Co-Channel and Non Co-Channel interferences.
3. discuss the various multiple access techniques for wireless communication.

4. familiarize with diversity techniques, frequency management, Channel assignment and types of handoff.
5. differentiate between cellular and Ad-hoc Networks and gain knowledge about concepts of Orthogonal Frequency Division Multiplexing.

CO-PO/PSO Mapping Chart (3/2/1 indicates strength of correlation) 3 – Strong; 2 – Medium; 1 – Weak														
Course Outcomes (COs)	**Program Outcomes (POs)**												**Program Specific Outcomes**	
	PO 1	**PO 2**	**PO 3**	**PO 4**	**PO 5**	**PO 6**	**PO 7**	**PO 8**	**PO 9**	**PO 10**	**PO 11**	**PO 12**	**PSO 1**	**PSO 2**
CO1	1	1	-	-	-	-	-	-	-	-	-	2	-	1
CO2	3	2	1	1	-	-	-	-	-	2	2	2	-	2
CO3	2	1	-	-	-	-	-	-	-	-	-	2	-	1
CO4	2	2	2	-	-	2	-	-	-	-	2	3	-	2
CO5	2	1	-	-	-	-	-	-	-	-	-	2	-	1
Average	2	1.4	0.6	0.2	-	0.4	-	-	-	0.4	0.8	2.2	-	1.4

A Structured Note for Students

MOBILE COMMUNICATIONS AND NETWORKS

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MOBILE COMMUNICATIONS AND NETWORKS

LIMITATIONS OF CONVENTIONAL MOBILE TELEPHONE SYSTEMS:

One of many reasons for developing a cellular mobile telephone system and deploying it in many cities is the operational limitations of conventional mobile telephone systems: limited service capability, poor service performance, and inefficient frequency spectrum utilization.

LIMITED SERVICE CAPABILITY:

A conventional mobile telephone system is usually designed by selecting one or more channels from a specific frequency allocation for use in autonomous geographic zones, as shown in Fig.1. The communications coverage area of each zone is normally planned to be as large as possible, which means that the transmitted power should be as high as the federal specification allows. The user who starts a call in one zone has to reinitiate the call when moving into a new zone because the call will be dropped. This is an undesirable radio telephone system since there is no guarantee that a call can be completed without a handoff capability. The handoff is a process of automatically changing frequencies as the mobile unit moves into a different frequency zone so that the conversation can be continued in a new frequency zone without redialing. Another disadvantage of the conventional system is that the number of active users is limited to the number of channels assigned to a particular frequency zone.

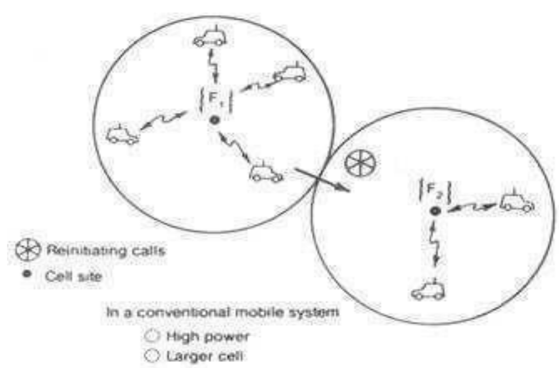


Fig.1 Conventional Mobile System

POOR SERVICE PERFORMANCE:

In the past, a total of 33 channels were all allocated to three mobile telephone systems: Mobile Telephone Service (MTS), Improved Mobile Telephone Service (IMTS) MJ systems, and Improved Mobile Telephone Service (IMTS) MK systems. MTS operates around 40 MHz and MJ operates at 150 MHs; both provide 11 channels; IMTS MK operates at 450 MHz and provides 12 channels. These 33 channels must cover an area 50 mi in diameter. In 1976, New York City had 6 channels of(MJ serving 320 customers, with another 2400 customers on a waiting list. New York City also had 6 channels of MK serving 225 customers, with another 1300 customers on a waiting list. The largenumber of subscribers created a high blocking probability during busy hours. Although service performance was undesirable, the demand was still great. A high-capacity system for mobile telephones was needed.

Inefficient Frequency Spectrum Utilization:

In a conventional mobile telephone system, the frequency utilization measurement Mo*,* is defined as the maximum number of customers that could be served by one channel at the busy hour.

Mo = Number of customers/channel

Mo = 53 for MJ

37 for MK

The offered load can then be obtained by

A = Average calling time (minutes) x total customers / 60 min (Erlangs)

Assume average calling time = 1.76 min.

A1 = 1.76 * 53 * 6 / 60= 9.33 Erlangs (MJ system)

A2 = 1.76 * 37 * 6 / 60= 6.51 Erlangs (MK system)

If the number of channels is 6 and the offered loads are A1 = 9.33 and A2 = 6.51, then from the Erlang B model the blocking probabilities*,* B1 = 50 percent (MJ system) and B2 =30 percent (MK system), respectively. It is likely that half the initiating calls will be blocked in the MJ system, a very high blocking probability. As far as frequency spectrum utilization is concerned the conventional system does not utilize the spectrum efficiently since each channel can only serve one customer at a time in a whole area. This is overcome by the new cellular system.

BASIC CELLULAR SYSTEMS

A basic analog cellular system consists of three subsystems: a mobile unit, a cell site, and a mobile telephone switching office (MTSO), as Fig. 1.1 shows, with connections to link the three subsystems.

Mobile units: A mobile telephone unit contains a control unit, a transceiver, and an antenna system.

Cell site: The cell site provides interface between the MTSO and the mobile units. It has a control unit, radio cabinets, antennas, a power plant, and data terminals.

MTSO: The switching office, the central coordinating element for all cell sites, con-tains the cellular processor and cellular switch. It interfaces with telephone company zone offices, controls call processing, provides operation and maintenance, and han-dles billing activities.

Connections: The radio and high-speed data links connect the three subsystems. Each mobile unit can only use one channel at a time for its communication link. But the channel is not fixed; it can be any one in the entire band assigned by the serving area, with each site having multichannel capabilities that can connect simultaneously to many mobile units.

The MTSO is the heart of the analog cellular mobile system. Its processor provides central coordination and cellular administration. The cellular switch, which can be either analog or digital, switches calls to connect mobile subscribers to other mobile subscribers and to the nationwide telephone network. It uses voice trunks similar to telephone company interoffice voice trunks. It also contains data links providing supervision links between the processor and the switch and between the cell sites and the processor. The radio link carries the voice and signaling between the mobile unit and the cell site. The high-speed data links cannot be transmitted over the standard telephone trunks and therefore must use either microwave links or T-carriers (wire lines). Microwave radio links or T-carriers carry both voice and data between cell site and the MTSO.

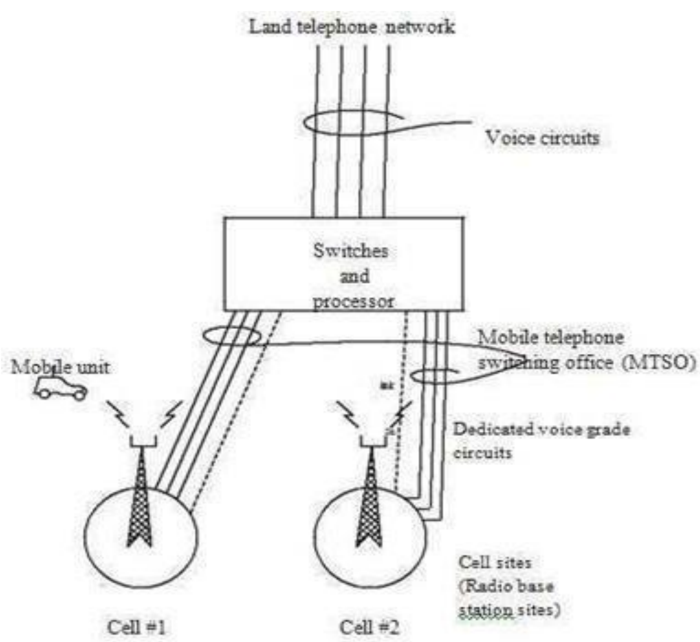


Fig: Basic cellular system

FIRST, SECOND, THIRD, AND FOURTH GENERATION CELLULAR WIRELESS SYSTEMS (1G, 2G, 3G AND 4G NETWORKS)

The "G" in wireless networks refers to the "generation" of the underlying wireless network technology. Technically generations are defined as follows:

1G networks (NMT, C-Nets, AMPS, TACS) are considered to be the first analog cellular systems, which started early 1980s. There were radio telephone systems even before that. 1G networks were conceived and designed purely for voice calls with almost no consideration of data services

2G networks (GSM, CDMAOne, D-AMPS) are the first digital cellular systems launched early 1990s, offering improved sound quality, better security and higher total capacity. GSM supports circuit-switched data (CSD), allowing users to place dial-up data calls digitally, so that the network's switching station receives actual ones and zeroes rather than the screech of an analog modem. 2G networks with theoretical data rates up to about 144kbit/s. **3G networks** (UMTS FDD and TDD, CDMA2000 1x EVDO, CDMA2000 3x, TD-SCDMA, Arib WCDMA, EDGE, IMT-2000 DECT) are newer cellular networks that have data rates of 384kbit/s and more. The UN's International Telecommunications Union IMT-2000 standard requires stationary speeds of 2Mbps and mobile speeds of 384kbps for a 3G.

4G technology refers to the fourth generation of mobile phone communication standards. LTE and WiMAX are marketed as parts of this generation, even though they fall short of the actual standard.

The ITI has taken ownership of 4G, bundling into a specification known as IMT-Advanced. The document calls for 4G technologies to deliver downlink speeds of 1Gbps when stationary and 100Mbps when mobile

Uniqueness of mobile radio environment description of mobile radio transmission medium

THE PROPAGATION ATTENUATION.

In general, the propagation path loss increases not only with frequency but also with distance. If the antenna height at the cell site is 30 to 100 m and at the mobile unit about 3 m above the ground, and the distance between the cell site and the mobile unit is usually 2 km or more, then the incident angles of both the direct wave and the reflected wave are very small, as Fig. 2.4 shows. The incident angle of the direct wave is θ1, and the incidentangle of the reflected wave is θ2. θ 1 is also called the elevation angle. The propagation path loss would be 40 dB/dec, 4where "dec" is an abbreviation of *decade*, i.e ., a period of 10. This means that a 40-dB loss at a signal receiver will be observed by the mobile unit as it moves from 1 to 10 km. Therefore *C* is inversely proportional to *R*.4

$$C \propto R^{-4} = \alpha R^{-4} \qquad (2.3\text{-}1)$$

Where *C* = received carrier power

R = distance measured from the transmitter to the receiver *α* = constant

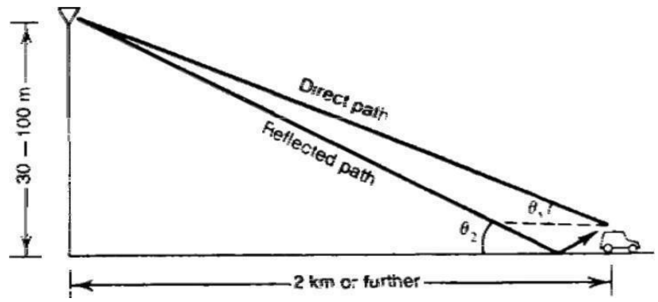


FIGURE 2.4 mobile radio transmission models.

The difference in power reception at two different distances $R1$ and $R2$ will result in

$$\frac{C_2}{C_1} = \left(\frac{R_2}{R_1}\right)^{-4} \qquad (2.3\text{-}2a)$$

and the decibel expression of Eq. (2.3-2a) is

$$\Delta C \text{ (in dB)} = C_2 - C_1 \text{ (in dB)}$$
$$= 10 \log \frac{C_2}{C_1} = 40 \log \frac{R_1}{R_2} \qquad (2.3\text{-}2b)$$

When $R_2 = 2R_1$, $\Delta C = -12$ dB; when $R_2 = 10R_1$, $\Delta C = -40$ dB.

This 40 dB/dec is the general rule for the mobile radio environment and is easy to remember. It is also easy to compare to the free-space propagation rule of 20 dB/dec. The linear and decibel scale expressions are

$$C \propto R^{-2} \quad \text{(free space)} \qquad (2.3\text{-}3a)$$

and

$$\Delta C = C_2 \text{ (in dB)} - C_1 \text{ (in dB)}$$
$$= 20 \log \frac{R_1}{R_2} \quad \text{(free space)} \qquad (2.3\text{-}3b)$$

In a real mobile radio environment, the propagation path-loss slope varies as

$$C \propto R^{-\gamma}$$
$$= \alpha R^{-\gamma} \qquad (2.3\text{-}4)$$

γ usually lies between 2 and 5 depending on the actual conditions.[5] Of course, γ cannot be lower than 2, which is the free-space condition.

γ The decibel scale expression of Eq. (2.3-4) is

$$C = 10 \log \alpha - 10\gamma \log R \text{dB} \qquad (2.3\text{-}5)$$

SEVERE FADING: Because the antenna height of the mobile unit is lower than its typical surroundings, and the carrier frequency wavelength is much less than the sizes of the surrounding structures, multipath waves are generated. At the mobile unit, the sum of the multipath waves causes a signal-fading phenomenon. The signal

fluctuates in a range of about 40 dB (10 dB above and 30 dB below the average signal). We can visualize the nulls of the fluctuation at the baseband at about every half wavelength in space, but all nulls do not occur at the same level, as Fig. 2.5 shows. If the mobile unit moves fast, the rate of fluctuation is fast. For instance, at 850 MHz, the wavelength is roughly 0.35 m (1 ft). If the speed of the mobile unit is 24 km/h (15 mi/h), or 6.7 m/s, the rate of fluctuation of the signal reception at a 10-dB level below the average power of a fading signal is 15 nulls per second (see Sec. 2.3.3).[6]

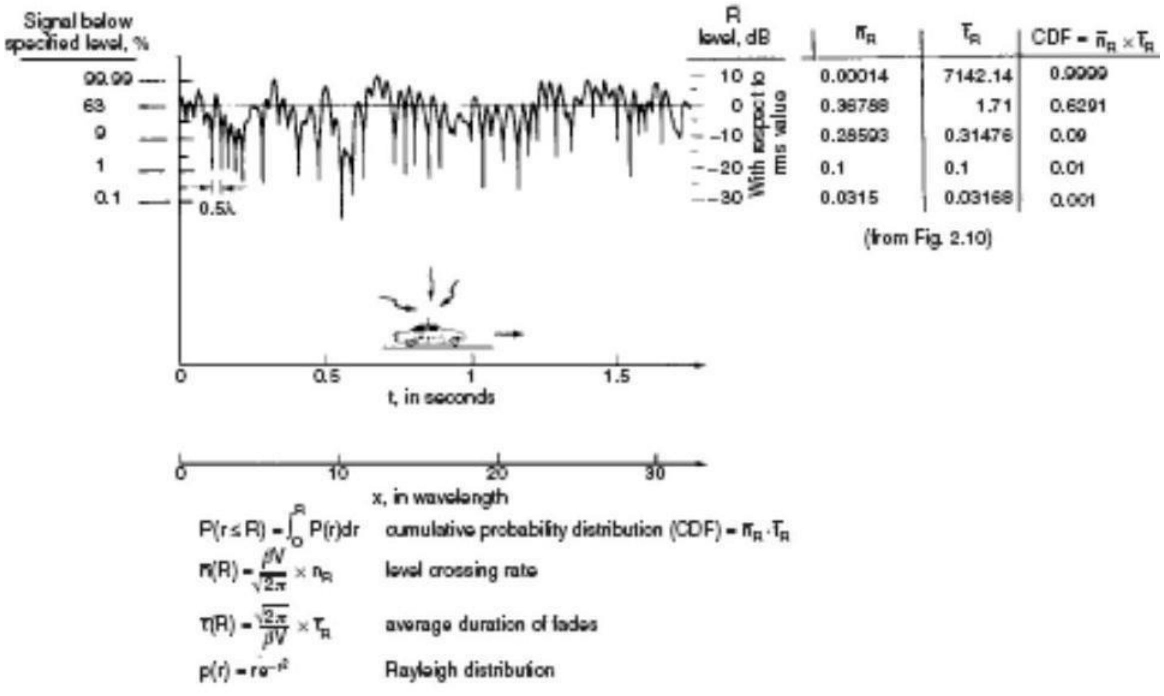


Fig: A typical fading signal while the mobile unit is moving

MODEL OF TRANSMISSION MEDIUM:

A mobile radio signal *r(t)*, illustrated in Fig. 2.6, can be artificially characterized[5] by two components *m(t)* and $r0(t)$ based on natural physical phenomena.

$$r(t) = m(t)r0(t) \quad (2.3\text{-}6)$$

The component *m(t)* is called *local mean*, *long-term fading*, or *lognormal fading* and its variation is due to the terrain contour between the base station and the mobile unit. The factor $r0$ is called *multipath fading*, *short-term fading*, or *Rayleigh fading* and its variation is due to the waves reflected from the surrounding buildings and other structures. The long-term fading *m(t)* can be obtained from Eq. (2.3-7*a*).

$$m(t_1) = \frac{1}{2T}\int_{t_1-T}^{t_1+T} r(t)\,dt \qquad (2.3\text{-}7a)$$

where 2*T* is the time interval for averaging *r(t)*. *T* can be determined based on the fading rate of *r(t)*, usually 40 to 80fades.[5] Therefore, *m(t)* is the envelope of *r(t)*, as shown in Fig.2.6*a*.

Equation (2.3-7*a*) also can be expressed in spatial scale as

$$m(x_1) = \frac{1}{2L}\int_{x_1-L}^{x_1+L} r(x)\,dx \qquad (2.3\text{-}7b)$$

The length of 2*L* has been determined to be 20 to 40 wavelengths. Using 36 or up to 50 samples in an interval of 40 wavelengths is an adequate averaging process for obtaining the local means.

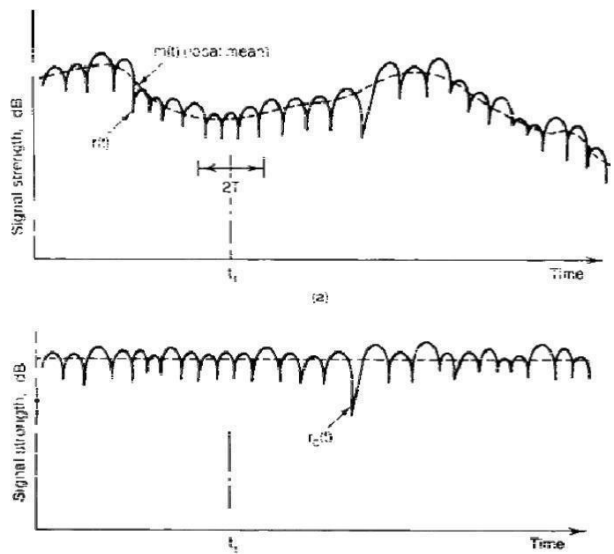


FIGURE 2.6 A mobile radio signal fading representation. (A) A mobile signal fading. (B)short-term signal fading.

The factor *m(t)* or *m(x)* is also found to be a log-normal distribution based on its char-acteristics caused by the terrain contour. The short-term fading *r*0 is obtained by

$$r_0 \text{ (in dB)} = r(t) - m(t) \text{ dB} \quad (2.3\text{-}8)$$

as shown in Fig. 2.6*b*. The factor $r_0(t)$ follows a Rayleigh distribution, assuming that only reflected waves from local surroundings are the ones received (a normal situation for the mobile radio environment). Therefore, the term *Rayleigh fading* is often used.

DIRECT WAVE PATH, LINE-OF-SIGHT PATH, AND OBSTRUCTIVE PATH:

A ***direct wave path*** is a path clear from the terrain contour.

The ***line-of-sight path*** is a path clear from buildings. In the mobile radio environment, we do not always have a line-of-sight condition.

When the terrain contour blocks the direct wave path, we call it the ***obstructive path.***

AMPLIFIER NOISE:

A mobile radio signal received by a receiving antenna, either at the cell site or at the mobile unit, will be amplified by an amplifier. We would like to understand how the signal is affected by the amplifier noise. Assume that the amplifier has an available power gain g and the available noise power at the output is N_o . The input signal- to-noise (S/N) ratio is P_s / N_i , the output signal-to-noise ratio is P_o / N_o , and the internal amplifier noise is N_α . Then the output P_o / N_o becomes

$$\frac{P_o}{N_o} = \frac{g P_s}{g(N_i) + N_\alpha} = \frac{P_s}{N_i + (N_\alpha / g)} \qquad (2.3\text{-}20)$$

The noise figure F is defined as

$$F = \frac{\text{maximum possible S/N ratio}}{\text{actual S/N ratio at output}} \qquad (2.3\text{-}21)$$

where the maximum possible S/N ratio is measured when the load is an open circuit.

Equation (2.3-21) can be used for obtaining the noise figure of the amplifier.

$$F = \frac{P_s / kTB}{P_o / N_o} = \frac{N_o}{(P_o / P_s) kTB} = \frac{N_o}{g(kTB)} \qquad (2.3\text{-}22)$$

Also substituting Eq. (2.3-20) into Eq. (2.3-22) yields

$$F = \frac{P_s / kTB}{P_s / [N_i + (N_\alpha / g)]} = \frac{N_i + (N_\alpha / g)}{kTB} \qquad (2.3\text{-}23)$$

The term kTB is the thermal noise.. The noise figure is a reference measurement between a minimum noise level due to thermal noise and the noise level generated by both the external and internal noise of an amplifier.

LONG-TERM FADING:

Long-term fading occurs when the propagation environment is changing significantly but this fading is typically much slower than short-term fading.

Long-term fading means slower variation in mean signal strength and is produced by movement over much longer distances.

Long-term is caused by terrain configuration (hill, flat area etc.), which results in local mean attenuation and fluctuation. Long term fading is also called as slow fading or shadowing.

FACTORS INFLUENCING SHORT TERM FADING:

The following physical factors influence short-term fading in the radio propagation channel:

(1) MULTIPATH PROPAGATION

Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The effects of multipath include constructive and destructive interference, and phase shifting of the signal.

(2) SPEED OF THE MOBILE

The relative motion between the base station and the mobile results in random frequency modulation due to different doppler shifts on each of the multipath components.

(3) SPEED OF SURROUNDING OBJECTS

If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components. If the surrounding objects move at a greater rate than the mobile, then this effect dominates fading.

(4) TRANSMISSION BANDWIDTH OF THE SIGNAL

If the transmitted radio signal bandwidth is greater than the “bandwidth" of the multipath channel (quantified by coherence bandwidth), the received signal will be distorted.

PARAMETERS OF MOBILE MULTIPATH FADING:

To compare the different multipath channels and to quantify them, we define some parameters. They all can be determined from the power delay profile. These parameters can be broadly divided in to two types.

Time Dispersion Parameters

These parameters include the mean excess delay,rms delay spread and excess delay spread. The mean excess delay is the first moment of the power delay profile and is defined as

$$\bar{\tau} = \frac{\sum a_k^2 \tau_k}{\sum a_k^2} = \frac{\sum P(\tau_k)\tau_k}{\sum P(\tau_k)}$$

where a_k is the amplitude, τ_k is the excess delay and $P(\tau_k)$ is the power of the individual multipath signals.

The mean square excess delay spread is defined as

$$\bar{\tau^2} = \frac{\sum P(\tau_k)\tau_k^2}{\sum P(\tau_k)}$$

Since the rms delay spread is the square root of the second central moment of the power delay profile, it can be written as

$$\sigma_\tau = \sqrt{\bar{\tau^2} - (\bar{\tau})^2}$$

COHERENCE BANDWIDTH:

Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered to pass all the frequency components with almost equal gain and linear phase. When this condition is satisfied then we say the channel to be flat.

Practically, coherence bandwidth is the minimum separation over which the two frequency components are affected differently. If the coherence bandwidth is considered to be the bandwidth over which the frequency correlation function is above 0.9, then it is approximated as

$$B_C \approx \frac{1}{50\sigma_\tau}.$$

However, if the coherence bandwidth is considered to be the bandwidth over which the frequency correlation function is above 0.5, then it is defined as

$$B_C \approx \frac{1}{5\sigma_\tau}.$$

Doppler Spread (B_d), **Coherence Time** (T_c)

RMS delay spread σ_τ and coherence bandwidth B_c are parameters which describe the time dispersive nature of the channel in a local area and they do not offer any information about the time varying nature of the channel due to the relative motion between the mobile station and base station.

Doppler Spread B_d is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel and is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero. In other words, if the baseband signal bandwidth is much greater than B_d, the effects of Doppler spread are negligible at the receiver. This is also called slow fading.

Coherence time T_c is the time domain dual of Doppler spread and is used to characterize the time varying nature of the frequency dispersiveness of the channel in the time domain. The Doppler spread and coherence time are inversely proportional to one another: $T_c \approx \frac{1}{B_d}$.

Types of small scale fading

From the discussion above, we know that the type of fading experienced by a signal propagating through a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel. Depending on the relation between the signal parameters (such as bandwidth, symbol period, etc) and the channel parameter (such as RMS delay spread and Doppler spread), different transmitted signals will undergo different types of fading. The time dispersion and frequency dispersion mechanisms in a mobile radio channel lead to four possible distinct effects, which are manifested depending on the nature of the transmitted signal, the channel, and the velocity. We will discuss them one by one below.

1. Flat Fading

If the mobile radio channel has a constant gain and linear phase response over a bandwidth which is greater that the bandwidth of the transmitted signal, which means

$$B_s << B_c \quad or \quad T_s >> \sigma_\tau$$

Then the received signal will undergo flat fading. In flat fading, the multipath structure of the channel is such that the spectral characteristics of the transmitted signal are preserved at the receiver. However the strength of the received signal changes with time, due to fluctuations in the gain of the channel caused by multipath.

2. Frequency Selective Fading

If the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, the channel creates frequency selective fading on the received signal, which means

$$B_s > B_c \quad or \quad T_s < \sigma_\tau$$

Under such conditions the channel impulse response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform. When it occurs, the received signal includes multiple versions of the transmitted waveform that are attenuated and delayed, and hence the received signal is distorted.

3. Fast Fading

In a fast fading channel, the channel impulse response changes rapidly within the symbol duration. That is, the coherence time of the channel is smaller that the symbol period of the transmitted signal. Viewed in the frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal. Therefore, a signal undergoes fast fading if

$$T_s > T_c \quad or \quad B_s < B_d$$

4. Slow Fading

In a slow fading channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal S(t). In the frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the baseband signal. There fore, a signal undergoes slow fading if

$$T_s << T_c \quad or \quad B_s >> B_d$$

It should be clear that the velocity of the mobile (or velocity of objects in the channel) and the baseband signaling determine whether a signal undergoes fast fading or slow fading.

FUNDAMENTALS OF CELLULAR RADIO SYSTEM DESIGN

CONCEPT OF FREQUENCY REUSE CHANNELS:

A radio channel consists of a pair of frequencies one for each direction of transmission that is used for full-duplex operation. Particular radio channels, say F1, used in one geographic zone to call a cell, say C1, with a coverage radius R can be used in another cell with the same coverage radius at a distance D away.

Frequency reuse is the core concept of the cellular mobile radio system. In this frequency reuse system users in different geographic locations (different cells) may simultaneously use the same frequency channel (see Fig.1.). The frequency reuse system can drastically increase the spectrum efficiency, but if the system is not properly designed, serious interference may occur. Interference due to the common use of the same channel is called co- channel interference and is our major concern in the concept of frequency reuse.

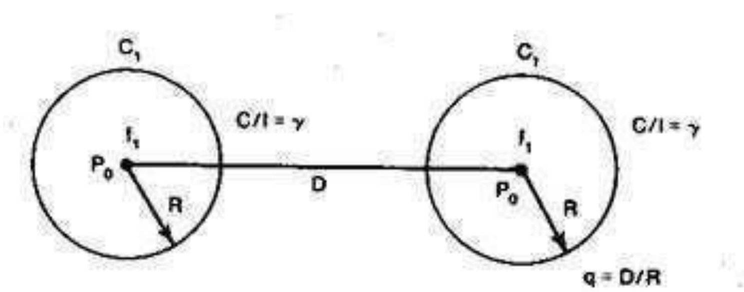


Fig.1 The ratio of D/R

FREQUENCY REUSE SCHEME: The frequency reuse concept can be used in the time domain and the space domain. Frequency reuse in the time domain results in the occupation of the same frequency in different time slots. It is called time division multiplexing (TDM). Frequency reuse in the space domain can be divided into two categories.

1. Same frequency assigned in two different geographic areas, such as A.M or FM radio stations using the same frequency in different cities.

2. Same frequency repeatedly used in a same general area in one system - the scheme is used in cellular systems. There are many co-channel cells in the system. The total frequency spectrum allocation is divided into K frequency reuse patterns, as illustrated in Fig. 2 for K — 4, 7, 12, and 19.

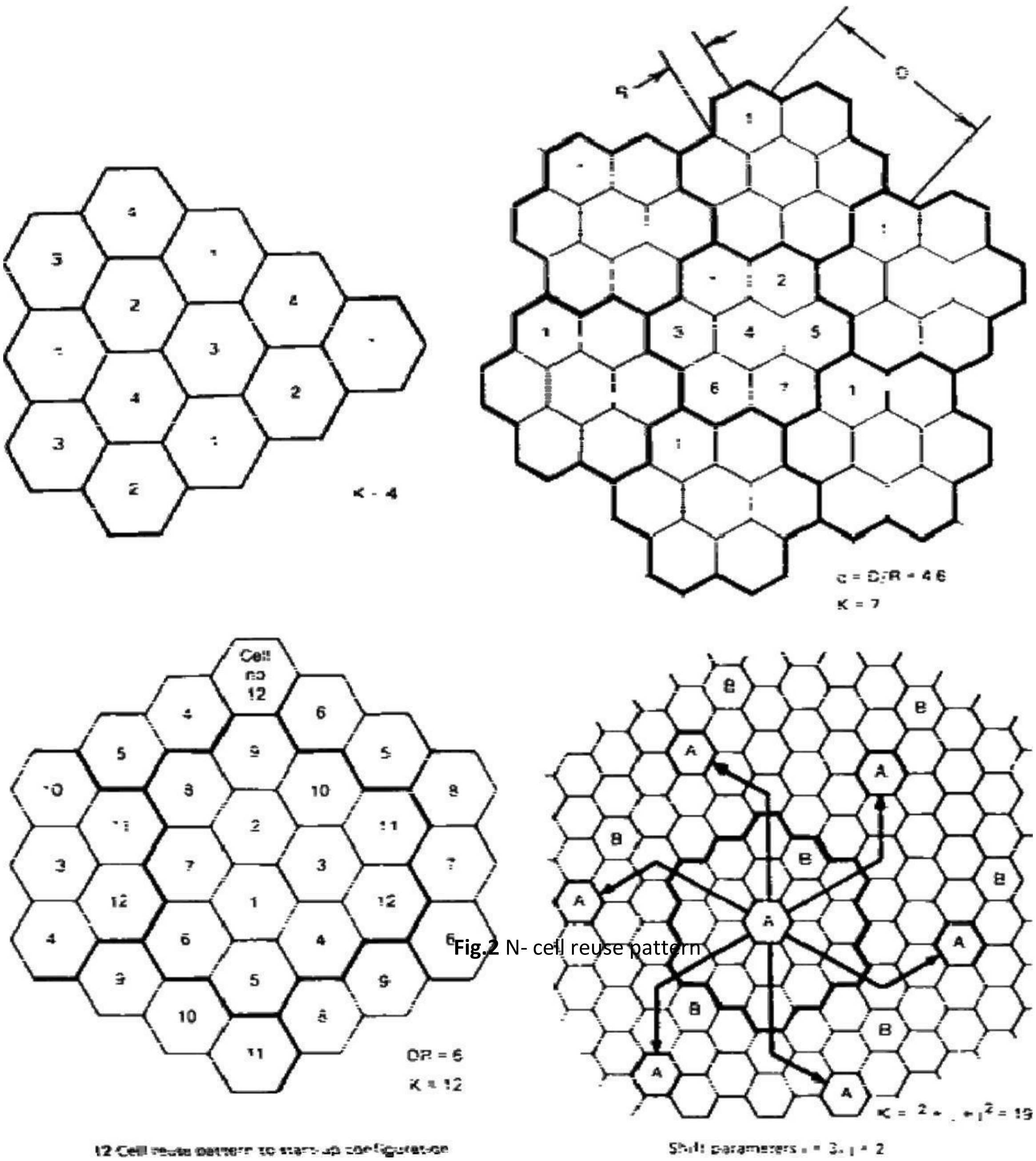


Fig.2 N- cell reuse pattern

Frequency reuses distance:

The minimum distance which allows the same frequency to be reused will depend on many factors, such as the number of co-channel cells in the vicinity of the center cell, the type of geographical terrain contour, the antenna height and the transmitted power at each cell site. The frequency reuse distance can be determined from Where K is the frequency reuse pattern shown in Fig.3, then

$$D = \begin{cases} 3.46R & K = 4 \\ 4.6R & K = 7 \\ 6R & K = 12 \\ 7.55R & K = 19 \end{cases}$$

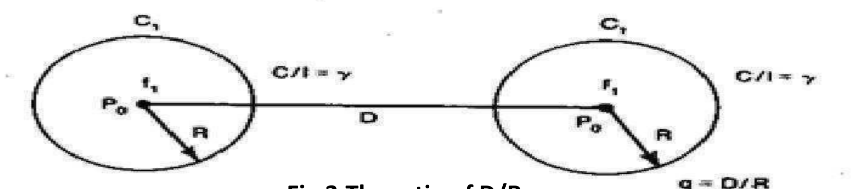


Fig.3.The ratio of D/R

If all the cell sites transmit the same power, then K increases and the frequency reuse distance D increases. This increased D reduces the chance that cochannel interference may occur.

Theoretically, a large K is desired. However, the total number of allocated channels is fixed. When K is too large, the number of channels assigned to each of K cells becomes small. It is always true that if the total number of channels in K cells is divided as K increases, trunking inefficiency results. The same principle applies to spectrum inefficiency: if the total numbers of channels are divided into two network systems serving in the same area, spectrum inefficiency increases.

Obtaining the smallest number K involves estimating cochannel interference and selecting the minimum frequency reuse distance D to reduce cochannel interference. The smallest value of K is K = 3, obtained by setting i = 1, j = 1 in the equation $K = i^2 + ij + j^2$.

CO-CHANNEL INTERFERENCE REDUCTION FACTOR

Reusing an identical frequency channel in different cells is limited by cochannel interference between cells, and the cochannel interference can become a major problem.

Assume that the size of all cells is roughly the same. The cell size is determined by the coverage area of the signal strength in each cell. As long as the cell size is fixed, cochannel interference is independent of the transmitted power of each cell. It means that the received threshold level at the mobile unit is adjusted to the size of the cell.

Actually, cochannel interference is a function of a parameter q defined as

$$q = D/R$$

The parameter q is the cochannel interference reduction factor. When the ratio q increases, cochannel interference decreases. Furthermore, the separation D is a function of K, and C/I,

$$D = f(K, C/I)$$

Where K, is the number of cochannel interfering cells in the first tier and C/I is the received carrier-to-interference ratio at the desired mobile receiver.

$$\frac{C}{I} = \frac{C}{\sum_{k=1}^{K_I} I_k}$$

In a fully equipped hexagonal-shaped cellular system, there are always six cochannel interfering cells in the fist tier, as shown in Fig.5 ; that is, K = 6. The maximum number of K, in the first tier can be shown as six. Cochannel interference can be experienced both at the cell site and at mobile units in the center cell. If the interference is much greater, then the carrier-to-interference ratio C/I at the mobile units caused by the six interfering sites is (on the average) the same as the C/I received at the center cell site caused by interfering mobile units in the six cells. According to both the reciprocity theorem and the statistical summation of radio propagation, the two C/I values can be very close. Assume that the local noise is much less than the interference level and can be neglected. C/I then can be expressed as

$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{k=1}^{K_I} D_k^{-\gamma}}$$

Where γ is a propagation path-loss slope determined by the actual terrain environment. In a mobile radio medium,

γ Usually is assumed to be 4. K is the number of co-channel interfering cells and is equal to 6 in a fully developed system, as shown in Fig. 5. The six co-channel interfering cells in the second tier cause weaker interference than those in the first tier. Therefore, the co-channel interference from the second tier of interfering cells is negligible

$$\frac{C}{I} = \frac{1}{\sum_{k=1}^{K_I} \left(\frac{D_k}{R} \right)^{-\gamma}} = \frac{1}{\sum_{k=1}^{K_I} (q_k)^{-\gamma}}, \quad q_k = \frac{D_k}{R}$$

Where *qk* is the cochannel interference reduction factor with *Kth* co-channel interfering cell

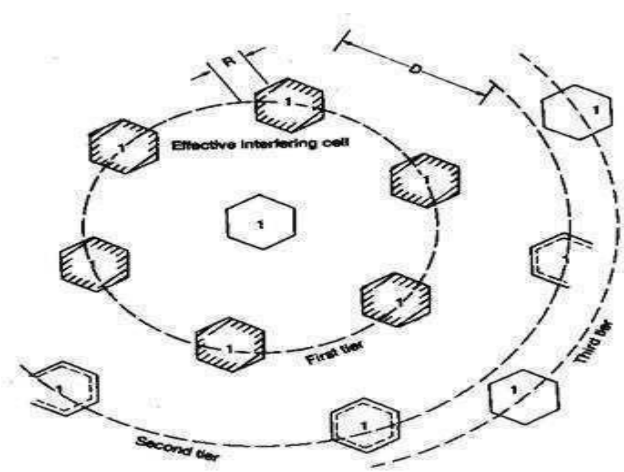


Fig 5: Six effective interfering cells of cell 1

C/I FOR NORMAL CASE IN AN OMNI DIRECTIONAL ANTENNA SYSTEM:

There are two cases to be considered: (1) the signal and co-channel interference received by the mobile unit and (2) the signal and co-channel interference received by the cell site. Both cases are shown in Fig.6. Nm and Nb are the local noises at the mobile unit and the cell site, respectively. Usually Nm and Nb are small and can be neglected as compared with the interference level. As long as the received carrier-to-interference ratios at both the mobile unit and the cell site are the same, the system is called a balanced system. In a balanced system, we can choose either one of the two cases to analyze the system requirement; the results from one case are the same for the others.

Assume that all Dk are the same for simplicity, then D = Dk and q = qk,

$$\frac{C}{I} = \frac{R^{-\gamma}}{6D^{-\gamma}} = \frac{q^{\gamma}}{6}$$

Thus

$$q^{\gamma} = 6\frac{C}{I}$$

And

$$q = \left(6\frac{C}{I}\right)^{1/\gamma}$$

The value of C/I is based on the required system performance and the specified value of is based on the terrain environment. With given values of C/I and γ, the co-channel interference reduction factor q can be determined. Normal cellular practice is to specify C/I to be 18 dB or higher based on subjective tests.

Since a C/I of 18 dB is measured by the acceptance of voice quality from present cellular mobile receivers, this acceptance implies that both mobile radio multipath fading and co-channel interference become ineffective at that level. The path-loss slope is equal to about 4 in a mobile radio environment.

$$q = D/R = (6 \times 63.1)^{1/4} = \underline{4.41}$$

The 90th percentile of the total covered area would be achieved by increasing the transmitted power at each cell; increasing the same amount of transmitted power in each cell does not affect the result. This is because q is not a function of transmitted power. The factor q can be related to the finite set of cells K in a hexagonal-shaped cellular system by

$$q = \triangleq \sqrt{3K}$$

Substituting q = 4.41 in above equation yields k=7.

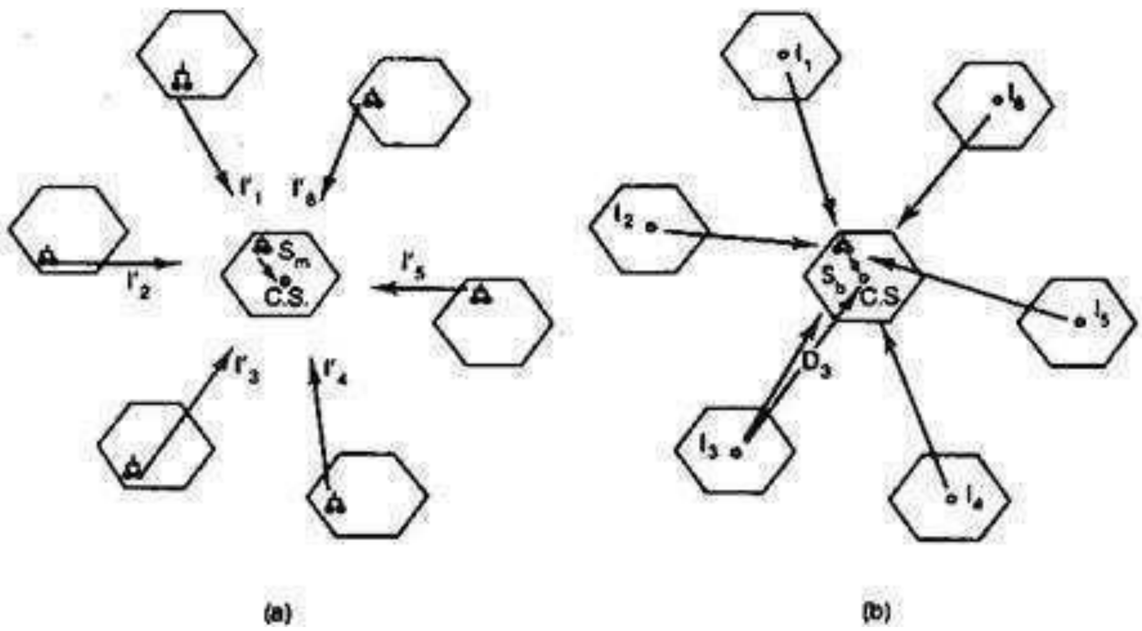


Fig 6 Cochannel interference from six interferers. (a).receiving at the cell site; (b) receiving at the mobile unit.

TRUNKING AND GRADE OF SERVICE:

Cellular radio systems rely on *trunking* to accommodate a large number of users in a limited radio spectrum. The concept of trunking allows a large number of users to share the relatively small number of channels in a cell by providing access to each user, on demand, from a pool of available channels. In a trunked radio system, each user is allocated a channel on a per call basis, and upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.

Trunking exploits the statistical behavior of users so that a fixed number of channels or circuits may accommodate a large, random user community. The telephone company uses trunking theory to determine the number of telephone circuits that need to be allocated for office buildings with hundreds of telephones, and this same principle is used in designing cellular radio systems. There is a trade-off between the number of available telephone circuits and the likelihood of a particular user finding that no circuits are available during the peak calling time. As the number of phone lines decreases, it becomes more likely that all circuits will be busy for a particular user. In a trunked mobile radio system, when a particular user requests service and all of the radio channels are already in use, the user is blocked, or denied access to the system. In some systems, a queue may be used to hold the requesting users until a channel becomes available.

To design trunked radio systems that can handle a specific capacity at a specific "grade of service," it is essential to understand trunking theory and queuing theory. The fundamentals of trunking theory were developed by Erlang, a Danish mathematician who, in the late 19th century, embarked on the study of how a large population could be accommodated by a limited number of servers [Bou88]. Today, the measure of traffic intensity bears his name. One Erlang represents the amount of traffic intensity carried by a channel that is completely occupied (i.e. one call-hour per hour or one call-minute per minute). For example, a radio channel that is occupied for thirty minutes during an hour carries 0.5 Erlangs of traffic.

The *grade of service (GOS)* is a measure of the ability of a user to access a trunked system during the busiest hour. The busy hour is based upon customer demand at the busiest hour during a week, month, or year. The busy hours for cellular radio systems typically occur during rush hours, between 4 p.m. and 6 p.m. on a Thursday or Friday evening. The grade of service is a benchmark used to define the desired performance of a particular trunked system by specifying a desired likelihood of a user obtaining channel access given a specific number of channels available in the system. It is the wireless designer's job to estimate the maximum required capacity and to allocate the proper number of channels in order to meet the *GOS*. *GOS* is typically given as the likelihood that a call is blocked, or the likelihood of a call experiencing a delay greater than a certain queuing time.

DEFINITIONS OF COMMON TERMS USED IN TRUNKING THEORY:

Set-Up Time: the time required to allocate a trunked radio channel to a requesting user.

Blocked Call: Call which cannot be completed at time of request, due to congestion. Also referred to as a lost call.

Holding Time: Average duration of a typical call. Denoted by H(in seconds).

Traffic Intensity: Measure of channel time utilization, which is the average channel occupancy measured in **Erlangs.** This is dimensionless quantity and may be used to measure the time utilization of single or multiple channels. Denoted by A.

Load: Traffic intensity across the entire trunked radio system, measured in Erlangs.

Grade of Service(GOS): A measure of congestion which is specified as the probability of a call being blocked (for Erlang B), or the probability of a call being delayed beyond a certain amount of time(for Erlang C).

Request Rate: The average number of call requests per unit time.

A number of definitions listed in Table 3.3 are used in trunking theory to make capacity estimates in trunked systems.

The traffic intensity offered by each user is equal to the call request rate multiplied by the holding time. That is, each user generates a traffic intensity of A_u Erlangs given by

$$A_u = \lambda H \tag{3.13}$$

where H is the average duration of a call and λ is the average number of call requests per unit time for each user. For a system containing U users and an unspecified number of channels, the total offered traffic intensity A, is given as

$$A = UA_u \tag{3.14}$$

Furthermore, in a C channel trunked system, if the traffic is equally distributed among the channels, then the traffic intensity per channel, A_c, is given as

$$A_c = UA_u/C \tag{3.15}$$

Note that the offered traffic is not necessarily the traffic which is *carried* by the trunked system, only that which is *offered* to the trunked system. When the offered traffic exceeds the maximum capacity of the system, the carried traffic becomes limited due to the limited capacity (i.e. limited number of channels). The maximum possible carried traffic is the total number of channels, C, in Erlangs. The AMPS cellular system is designed for a GOS of 2% blocking. This implies that the channel allocations for cell sites are designed so that 2 out of 100 calls will be blocked due to channel occupancy during the busiest hour.

There are two types of trunked systems which are commonly used. The first type offers no queuing for call requests. That is, for every user who requests service, it is assumed there is no setup time and the user is given immediate access to a channel if one is available. If no channels are available, the requesting user is blocked without access and is free to try again later. This type of trunking is called *blocked calls cleared* and assumes that calls arrive as determined by a Poisson distribution. Furthermore, it is assumed that there are an infinite number of users as well as the following: (a) there are memoryless arrivals of requests, implying that all users, including blocked users, may request a channel at any time; (b) the probability of a user occupying a channel is exponentially distributed, so that longer calls are less likely to occur as described by an exponential distribution; and (c) there are a finite number of channels available in the trunking pool. This is known as an M/M/m/m queue, and leads to the derivation of the Erlang B formula (also known as the *blocked calls cleared* formula). The Erlang B formula determines the probability that a call is blocked and is a measure of the GOS for a trunked system which provides no queuing for blocked calls. The Erlang B formula is derived in Appendix A and is given by

$$Pr[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS \tag{3.16}$$

where C is the number of trunked channels offered by a trunked radio system and A is the total offered traffic. While it is possible to model trunked systems with finite users, the resulting expressions are much more complicated than the Erlang B result, and the added complexity is not warranted for typical trunked systems which have users that outnumber available channels by orders of magnitude. Furthermore, the Erlang B formula provides a conservative estimate of the GOS, as the finite user results always predict a smaller likelihood of blocking. The capacity of a trunked radio system where blocked calls are lost is tabulated for various values of GOS and numbers of channels in Table 3.4.

Table 3.4 Capacity of an Erlang B System

Number of Channels C	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

The second kind of trunked system is one in which a queue is provided to hold calls which are blocked. If a channel is not available immediately, the call request may be delayed until a channel becomes available. This type of trunking is called *Blocked Calls Delayed*, and its measure of GOS is defined as the probability that a call is blocked after waiting a specific length of time in the queue. To find the GOS, it is first necessary to find the likelihood that a call is initially denied access to the system. The likelihood of a call not having immediate access to a channel is determined by the Erlang C formula derived in Appendix A

$$Pr[delay>0] = \frac{A^C}{A^C + C!\left(1-\frac{A}{C}\right)\sum_{k=0}^{C-1}\frac{A^k}{k!}} \quad (3.17)$$

If no channels are immediately available the call is delayed, and the probability that the delayed call is forced to wait more than t seconds is given by the probability that a call is delayed, multiplied by the conditional probability that the delay is greater than t seconds. The GOS of a trunked system where blocked calls are delayed is hence given by

$$\begin{aligned} Pr[delay>t] &= Pr[delay>0]Pr[delay>t|delay>0] \\ &= Pr[delay>0]\exp(-(C-A)t/H) \end{aligned} \quad (3.18)$$

The average delay D for all calls in a queued system is given by

$$D = Pr[delay>0]\frac{H}{C-A} \quad (3.19)$$

where the average delay for those calls which are queued is given by $H/(C-A)$.

IMPROVING COVERAGE AND CAPACITY IN CELLULAR SYSTEMS:

As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users. At this point, cellular design techniques are needed to provide more channels per unit coverage area. Techniques such as *cell splitting, sectoring*, and *coverage zone approaches* are used in practice to expand the capacity of cellular systems. Cell splitting allows an orderly growth of the cellular system. Sectoring uses directional antennas to further control the interference and frequency reuse of channels. The *zone microcell* concept distributes the coverage of a cell and extends the cell boundary to hard-to-reach places. While cell splitting increases the number of base stations in order to increase capacity, sectoring and zone microcells rely on base station antenna placements to improve capacity by reducing co-channel interference. Cell splitting and zone microcell techniques do not suffer the trunking inefficiencies experienced by sectored cells, and enable the base station to oversee all handoff chores related to the microcells, thus reducing the computational load at the MSC. These three popular capacity improvement techniques will be explained in detail.

CELL SPLITTING:

The motivation behind implementing a cellular mobile system is to improve the utilization of spectrum efficiency. The frequency reuse scheme is one concept, and cell splitting is another concept. When traffic density starts to build up and the frequency channels Fi in each cell Ci cannot provide enough mobile calls, the original cell can be split into smaller cells. Usually the new radius is one-half the original radius. There are two ways of splitting: In Fig. 8 a, the original cell site is not used, while in Fig. 8 b, it is

New cell radius = Old cell radius/2

Then,

New cell area = Old cell area/4

Let each new cell carry the same maximum traffic load of the old cell ,then

New traffic load/Unit area = 4 X Traffic load/Unit area.

There are two kinds of cell-splitting techniques:

1. **PERMANENT SPLITTING:** The installation of every new split cell has to be planned ahead of time; the number of channels, the transmitted power, the assigned frequencies, the choosing of the cell-site selection, and the traffic load consideration should all be considered. When ready, the actual service cut-over should be set at the lowest traffic point, usually at midnight on a weekend. Hopefully, only a few calls will be dropped because of this cut-over, assuming that the downtime of the system is within 2h.

2. **DYNAMIC SPLITTING:** This scheme is based on using the allocated spectrum efficiency in real time. The algorithm for dynamically splitting cell sites is a tedious job, as we cannot afford to have one single cell unused during cell splitting at heavy traffic hours.

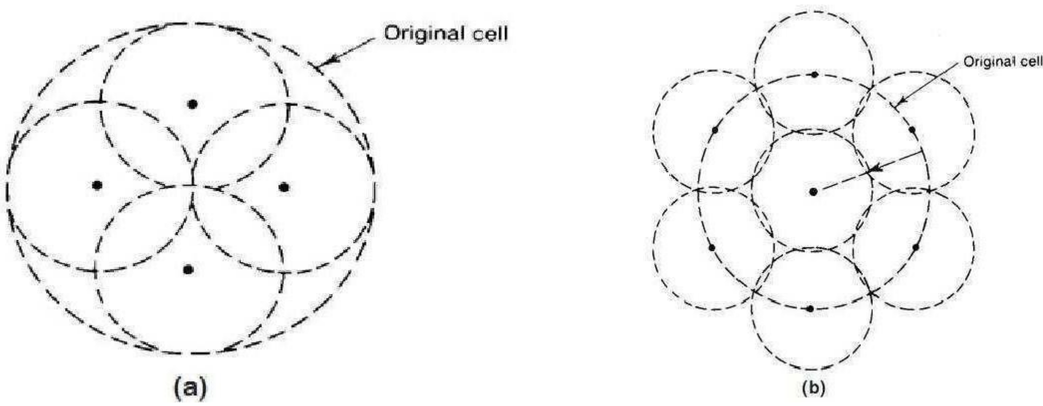


Fig.8 Cell splitting

SECTORING:

Cell splitting achieves capacity improvement by essentially rescaling the system. By decreasing the cell radius *R* and keeping the co-channel reuse ratio *D*/*R* unchanged, cell splitting increases the number of channels per unit area. However, another way to increase capacity is to keep the cell radius unchanged and seek methods to decrease a D/R ratio . as we now show sectoring increases SIR so that the cluster size may be reduced

In this approach. First the SIR is improved using directional antennas, then capacity improvement is achieved by reducing the no of cells in a cluster, thus increasing the frequency reuse. However in order to do this successfully. It is necessary to reduce the relative interference without decreasing the transmitted power.

The co-channel interference in a cellular systems may be decreased by replacing a single Omni directional antenna at the base station by several directional antennas each radiating within a specified sector. By using directional antennas, a given cell will receive interference and transmit with only a fraction of the available co-channel cells. The technique for decreasing co-channel interference and thus increasing system performance by using directional antennas is called sectoring. The factor by which the co-channel interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into three 120˚ sectors or six 60˚ sectors as shown in below figure.

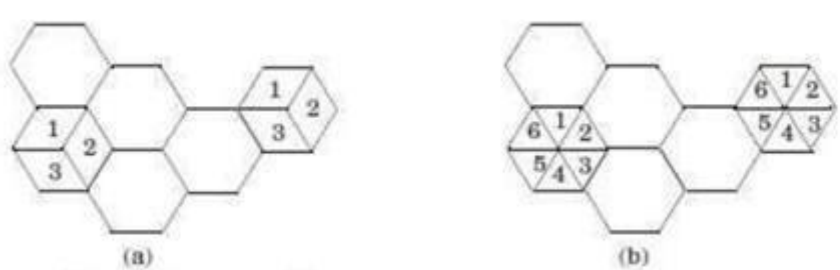


Fig: (a) 120˚ sectoring (b) 60˚ sectoring

MICROCELL ZONE CONCEPT:

The increased number of handoffs required when sectoring is employed results in an increased load on the switching and control link elements of the mobile system. A solution to this problem was presented by lee. The proposal is based on a microcell concept for seven cell reuse as illustrated in fig below. In this scheme, each of the three (or possibly more) zone sites

(represented as Tx/Rx in Figure 3.13) are connected to a single base station and share the same radio equipment. The zones are connected by coaxial cable, fiberoptic cable, or microwave link to the base station. Multiple zones and a single base station make up a cell. As a mobile travels within the cell, it is served by the zone with the strongest signal. This approach is superior to sectoring since antennas are placed at the outer edges of the cell, and any base station channel may be assigned to any zone by the base station.

As a mobile travels from one zone to another within the cell, it retains the same channel. Thus, unlike in sectoring, a handoff is not required at the MSC when the mobile travels between zones within the cell. The base station simply switches the channel to a different zone site. In this way, a given channel is active only in the particular zone in which the mobile is traveling, and hence the base station radiation is localized and interference is reduced. The channels are distributed in time and space by all three zones and are also reused in co-channel cells in the normal fashion. This technique is particularly useful along highways or along urban traffic corridors.

The advantage of the zone cell technique is that while the cell maintains a particular coverage radius, the co-channel interference in the cellular system is reduced since a large central base station is replaced by several lower powered transmitters (zone transmitters) on the edges of the cell. Decreased co-channel interference improves the signal quality and also leads to an increase in capacity without the degradation in trunking efficiency caused by sectoring. As mentioned earlier, an S/I of 18 dB is typically required for satisfactory system performance in narrowband FM. For a system with $N = 7$, a D/R of 4.6 was shown to achieve this. With respect to

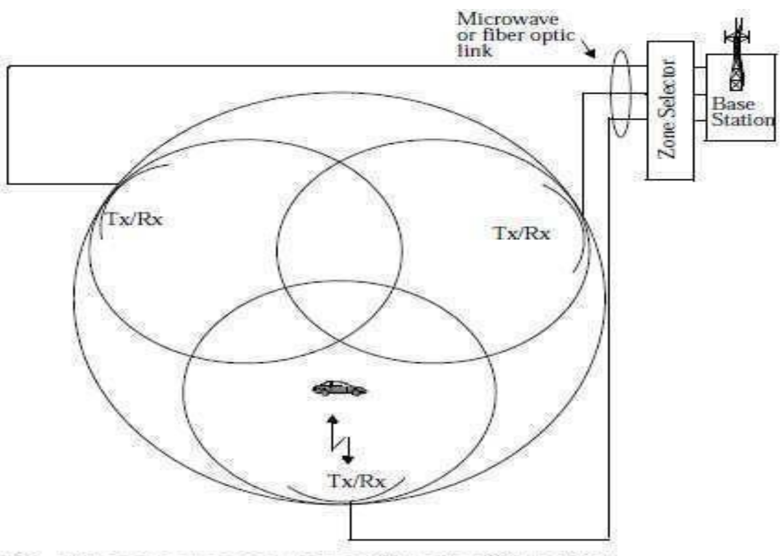


Figure 3.13 The microcell concept [adapted from [Lee91b] © IEEE].

The increased number of handoffs required when sectoring is employed results in an increased load on the switching and control link elements of the mobile system. A solution to this problem was presented by Lee [Lee91b]. This proposal is based on a microcell concept for seven cell the zone microcell system, since transmission at any instant is confined to a particular zone, this implies that a D_z/R_z of 4.6 (where D_z is the minimum distance between active co-channel zones and R_z is the zone radius) can achieve the required link performance. In Figure 3.14, let each individual hexagon represents a zone, while each group of three hexagons represents a cell. The zone radius R_z is approximately equal to one hexagon radius. Now, the capacity of the zone microcell system is directly related to the distance between co-channel cells, and not zones. This distance is represented as D in Figure 3.14. For a D_z/R_z value of 4.6, it can be seen from the geometry of Figure 3.14 that the value of co-channel reuse ratio, D/R, is equal to three, where R is the radius of the cell and is equal to twice the length of the hexagon radius. Using Equation (3.4), $D/R = 3$ corresponds to a cluster size of $N = 3$. This reduction in the cluster size from $N = 7$ to $N = 3$ amounts to a 2.33 times increase in capacity for a system completely based on the zone microcell concept. Hence for the same S/I requirement of 18 dB, this system provides a significant increase in capacity over conventional cellular planning.

By examining Figure 3.14 and using Equation (3.8) [Lee91b], the exact worst case S/I of the zone microcell system can be estimated to be 20 dB. Thus, in the worst case, the system provides a margin of 2 dB over the required signal-to-interference ratio while increasing the capacity by 2.33 times over a conventional seven-cell system using omnidirectional antennas.

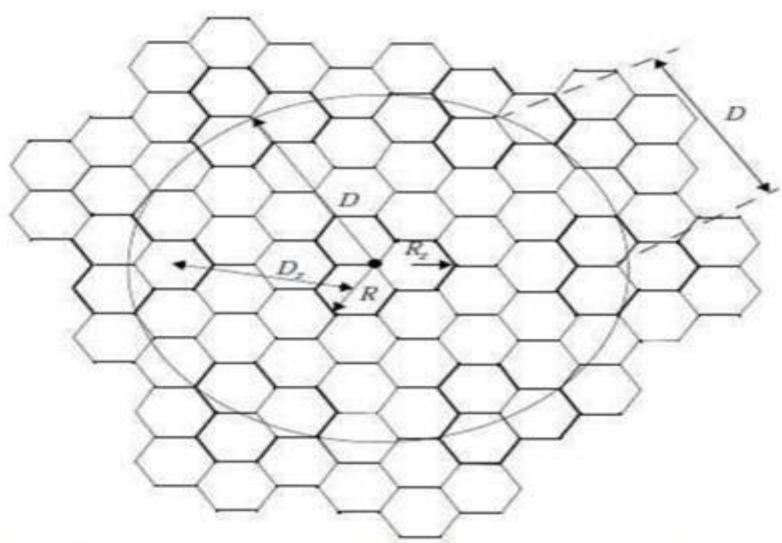


Figure 3.14 Define D, D_z, R, and R_z for a microcell architecture with $N = 7$. The smaller hexagons form zones and three hexagons (outlined in bold) together form a cell. Six nearest co-channel cells are shown.

No loss in trunking efficiency is experienced. Zone cell architectures are being adopted in many cellular and personal communication systems.

CO-CHANNEL INTERFERENCE

The frequency-reuse method is useful for increasing the efficiency of spectrum usage but results in cochannel interference because the same frequency channel is used repeatedly in different cochannel cells. Application of the cochannel interference reduction factor q= D/R = 4.6 for a seven-cell reuse pattern (K = 7).

In most mobile radio environments, use of a seven-cell reuse pattern is not sufficient to avoid cochannel interference. Increasing K > 7 would reduce the number of channels per cell, and that would also reduce spectrum efficiency. Therefore, it might be advisable to retain the same number of radios as the seven-cell system but to sector the cell radially, as if slicing a pie. This technique would reduce cochannel interference and use channel sharing and channel borrowing schemes to increase spectrum efficiency.

REAL TIME CO-CHANNEL INTERFERENCE MEASURED AT MOBILE RADIO TRANSCEIVER

When the carriers are angularly modulated by the voice signal and the RF frequency difference between them is much higher than the fading frequency, measurement of the signal carrier-to-interference ratio *C/I* reveal that the signal is

$$e_1 = S(t)\sin(\omega t + \phi_1) \qquad (9.3\text{-}1)$$

and the interference is

$$e_2 = I(t)\sin(\omega t + \phi_2) \qquad (9.3\text{-}2)$$

The received signal is

$$e(t) = e_1(t) + e_2(t) = R\sin(\omega t + \psi) \qquad (9.3\text{-}3)$$

where

$$R = \sqrt{[S(t)\cos\phi_1 + I(t)\cos\phi_2]^2 + [S(t)\sin\phi_1 + I(t)\sin\phi_2]^2} \qquad (9.3\text{-}4)$$

and

$$\psi = \tan^{-1}\frac{S(t)\sin\phi_1 + I(t)\sin\phi_2}{S(t)\cos\phi_1 + I(t)\cos\phi_2} \qquad (9.3\text{-}5)$$

The envelope R can be simplified in Eq. (9.3-4), and R^2 becomes

$$R^2 = [S^2(t) + I^2(t) + 2S(t)I(t)\cos(\phi_1 - \phi_2)] \qquad (9.3\text{-}6)$$

Following kozono and sakamoto s analysis Eq (9.3-6),the term $s^2(t)+I^2(t)$ fluctuates close to the fading frequency V/λ and the term $2S(t)+I(t)\cos(\emptyset_1-\emptyset_2)$fluctuates to a frequency close to *d/dt*($\emptyset_1$-$\emptyset_2$).which is much higher than the fading frequency. Then the two parts of the squared envelope can be separated as

$$X = S^2(t) + I^2(t) \qquad (9.3\text{-}7)$$

$$Y = 2S(t)I(t)\cos(\phi_1 - \phi_2) \qquad (9.3\text{-}8)$$

assume that the random variables s(t),I(t),$\emptyset_1$,$\emptyset_2$ are independent ;then the average processes on X and Y are

$$\overline{X} = \overline{S^2(t)} + \overline{I^2(t)} \quad (9.3\text{-}9)$$

$$\overline{Y^2} = 4\overline{S^2(t)I^2(t)}(1/2) = 2\overline{S^2(t)I^2(t)} \quad (9.3\text{-}10)$$

The signal to Interference ratio Γ becomes

$$\Gamma = \frac{\overline{S^2(t)}}{\overline{I^2(t)}} = k + \sqrt{k^2 - 1} \quad (9.3\text{-}11)$$

$$k = \frac{\overline{X^2}}{\overline{Y^2}} - 1 \quad (9.3\text{-}12)$$

Because X and Y can be separated in Eq.(9.3-6),the preceding computation of Γ in Eq.(9.3-11)could have been accomplished by means of an envelope detector ,analog to digital converter, and a micro computer. The sampling delay time Δt should be small enough to satisfy

$$S(t) \approx S(t + \Delta t), \qquad I(t) \approx I(t + \Delta t) \quad (9.3\text{-}13)$$

and

$$\mathrm{E}\left[\cos[\phi_1(t) - \phi_2(t)]\cos[\phi_1(t + \Delta t) - \phi_2(t + \Delta t)]\right] \approx 0 \quad (9.3\text{-}14)$$

Determining the delay time Δt to meet the requirement of Eq.(9.3-13) for this calculation is difficult and is a drawback to this measurement technique. Therefore, real time cochannel interference measurement is difficult to achieve in practice.

DESIGN OF ANTENNA SYSTEM

DESIGN OF AN OMNIDIRECTIONAL ANTENNA SYSTEM IN THE WORST CASE:

The value of q = 4.6 is valid for a normal interference case in a K=7 cell pattern. In this section we would like toprove that a K=7 cell pattern does not provide a sufficient frequency re-use distance separation eyen when an ideal condition of flat terrain is assumed. The worst case is at the location where the weakest signal from its own cell site but strong interferences from all interfering cell sites. In the worst case the mobile unit is at the cell boundary R, as shown in Fig. **3.** The distances from all six cochannel interfering sites are also shown in the figure: two distances of D - R, two distances of D, and two distances of D + R.

Following the mobile radio propagation rule of 40 dB/dec, we obtain

$$C \propto R^{-4} \qquad I \propto D^{-4}$$

Then the carrier-to-interference ratio is

$$\frac{C}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2(D)^{-4} + 2(D+R)^{-4}}$$
$$= \frac{1}{2(q-1)^{-4} + 2(q)^{-4} + 2(q+1)^{-4}} \qquad (9.4\text{-}1a)$$

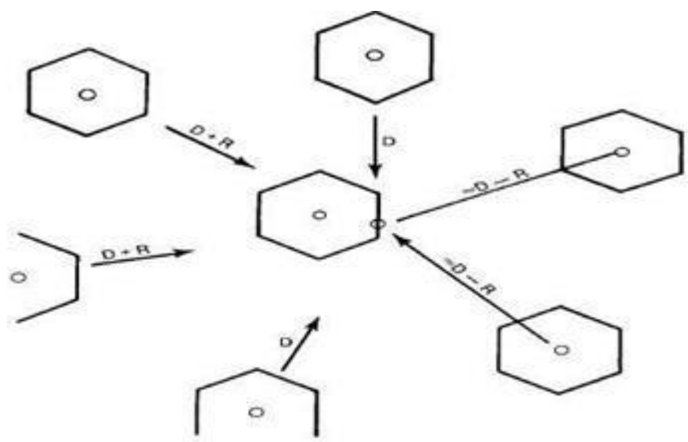


Fig.3.Cochannel interference (worst case)

Where q=4.6 is derived from the normal case. Substituting q=4.6 into above eqn. we obtain C/I =54 or 17 dB, which is lower than 18 dB. To be conservative, we may use the shortest distance D – R for all six interferers as a worst case; then we have

$$\frac{C}{I} = \frac{R^{-4}}{6(D-R)^{-4}} = \frac{1}{6(q-1)^{-4}} = 28 = 14.47 \text{ dB}$$

In reality, because of the imperfect site locations and the rolling nature of the terrain configuration, the C/I received is always worse than 17 dB and could be 14 dB and lower. Such an instance can easily our in a heavy traffic situation; therefore, the system must be designed around the C/I of the worst case. In that case, a cochannel interference reduction factor of q=4.6 is insufficient.

Therefore, in an unidirectional-cell system, K = 9 or K 12 would be a correct choice. Then the values of q are

$$q = \begin{cases} \frac{D}{R} = \sqrt{3K} \\ 5.2 \quad K = 9 \\ 6 \quad K = 12 \end{cases}$$

Substituting these values in Eq. (9.4-1), we obtain

$$\frac{C}{I} = 84.5 \,(=)\, 19.25 \text{ dB} \qquad K = 9$$
$$\frac{C}{I} = 179.33 \,(=)\, 22.54 \text{ dB} \qquad K = 12$$

DESIGN OF ANTENNA SYSTEM

Design of a Directional Antenna System:

When the call traffic begins to increase, we need to use the frequency spectrum efficiently and avoid increasing the number of cells K in a seven-cell frequency reuse pattern. When K increases, the number of frequency channels assigned in a cell must become smaller (assuming a total allocated channel divided by K) and the efficiency of applying the frequency reuse scheme decrease.

Instead of increasing the number K in a set of cells, let us keep K =7 and introduce a directional antenna arrangement. The cochannel interference can be reduced by using directional antenna. This means that each cell is divided into three or six sectors and uses three or six directional antennas at a base station. Each sector is assigned a set of frequencies (channels). The interference between two cochannel cells decreases as shown Fig.4.2 **Directional antennas in K=7 cell patterns:**

Three sector case: The three-sector case is shown in Fig.4.2. To illustrate the worst case situation, two cochannel cells are shown in Fig. 4.3(a). The mobile unit at position E will experience greater interference in the lower shaded cell sector than in the upper shaded cell-sector site. This is because the mobile receiver receives the weakest signal from its own cell but fairly strong interference from the interfering cell.

In a three-sector case, the interference is effective in only one direction because the front-to-back ratio of a cell-site directional antenna is at least 10 dB or more in a mobile radio environment. The worst-case cochannel interference in the directional-antenna sectors in which interference occurs may be calculated. Because of the use of directional antennas, the number of principal interferers is reduced from six to two (Fig.4.2). The worst case of C/I occurs when the mobile unit is at position E, at which point the distance between the mobile unit and the two interfering antennas is roughly D + (R/2); however, C/I can be calculated more precisely as follows. The value of C/I can be obtained by the following expression (assuming that the worst case is at position E at which the distances from two interferers are D + 0.7R and D).

$$\frac{C}{I}(\text{worst case}) = \frac{R^{-4}}{(D+0.7R)^{-4}+D^{-4}} = \frac{1}{(q+0.7)^{-4}+q^{-4}}$$

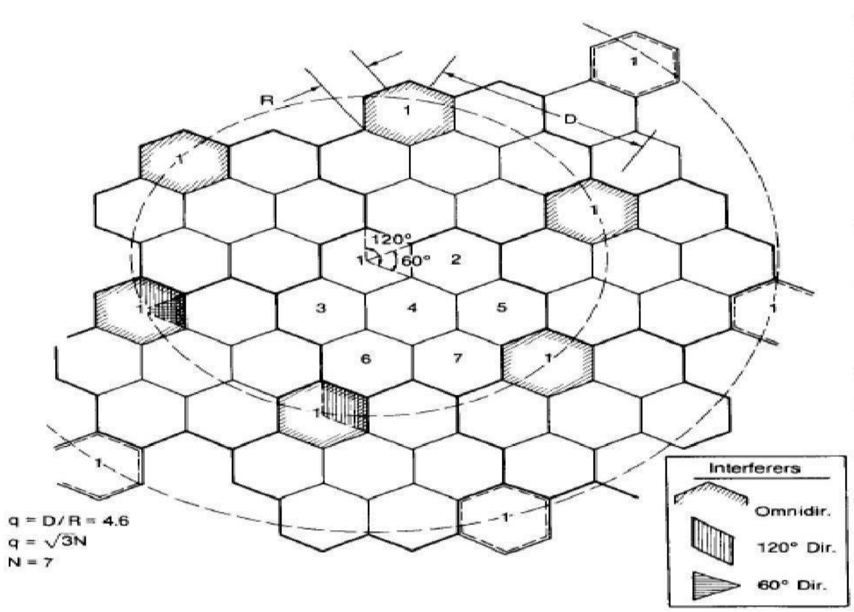


Fig.4.2. Interfering cells shown in a seven cell system (two-tiers)

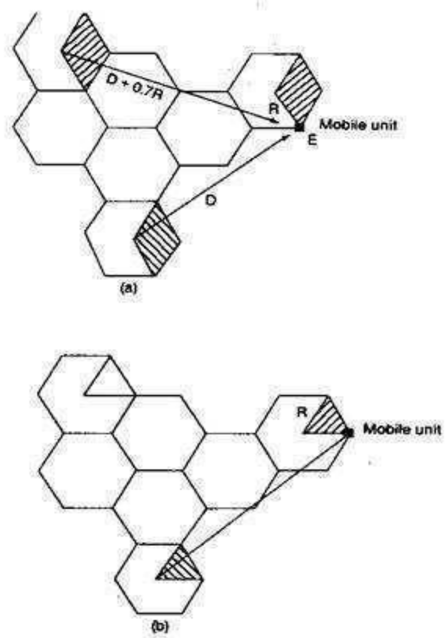


Fig.4.3. Determination of C/I in a directional antenna system. (a)Worst case in a 120 directional Antenna system (N=7); (b) worst case in a 60 directional antenna system(N=7)

Let q=4.6; then we have

$$\frac{C}{I}\text{ (worst case)} = 285\ (=)\ 24.5\text{ dB}$$

The C/I received by a mobile unit from the 120° directional antenna sector system expressed in Eq. above greatly exceeds 18 dB in a worst case. Equation above shows that using directional antenna sectors can improve the signal-to-interference ratio, that is, reduce the cochannel interference. However, in reality, the C/I could be 6 dB weaker than in Eq. given above in a heavy traffic area as a result of irregular terrain contour and imperfect site locations. The remaining 18.5 dB is still adequate.

Six-sector case: We may also divide a cell into six sectors by using six 60°-beam directional antennas as shown in Fig.4.2. In this case, only one instance of interference can occur in each sector as shown in Fig, 4.2. Therefore, the carrier-to-interference ratio in this case is which shows a further reduction of cochannel interference. If we use the same argument as we did for Eq. above and subtract 6 dB from the result of Eq. the remaining 23 dB is still more than adequate. When heavy traffic occurs, the 60°-sector configuration can be used to reduce cochannel interference. However, fewer channels are generally allowed in a 60° sector and the trunking efficiency decreases. In certain cases, more available channels could be assigned in a 60° sector.

Directional antenna in K = 4 cell pattern:

Three-sector case: To obtain the carrier-to-interference ratio, we use the same procedure as in the K = 7 cell- pattern system. The 120° directional antennas used in the sectors reduced the interferers to two as in K = 7 systems,

as shown in Fig.4.4.

We can apply Eq. here. For K = 4, the value of q = 3.46; therefore, Eq. becomes

$$\frac{C}{I}\,(\text{worst case}) = \frac{1}{(q + 0.7)^{-4} + q^{-4}} = 97 = 20 \text{ dB}$$

If, using the same reasoning used with Eq. above, 6 dB is subtracted from the result of Eq. above, the remaining 14 dB is unacceptable.

Six-sector case: There is only one interferer at a distance of D + R shown in Fig.4.4. With q=3.46, we can obtain

$$\frac{C}{I}\,(\text{worst case}) = \frac{R^{-4}}{(D + R)^{-4}} = \frac{1}{(q + 1)^{-4}} = 355 = 26 \text{ dB}$$

If 6 dB is subtracted from the above result, the remaining 20 dB is adequate.

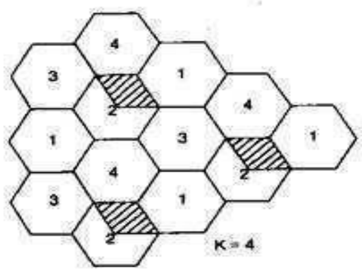


Fig. 4.4 Interference with frequency reuse pattern K=4.

Under heavy traffic conditions, there is still a great deal of concern over using a K =4 cell pattern in a 60° sector.

Comparing K =7 and N =4 systems:

A K =7 cell pattern system is a logical way to begin an omnicell system. The co-channel reuse distance is more or less adequate, according to the designed criterion. When the traffic increases, a three sector system should be implemented, that is, with three 120° directional antennas in place. In certain hot spots, 60° sectors can be used locally to increase the channel utilization.

If a given area is covered by both K=7 and K=4 cell patterns and both patterns have a six-sector configuration, then the K=7 system has a total of 42 sectors, but the K=4 system has a total of only 24 sectors and, of course, the system of K=7 and six sectors has less cochannel interference.

One advantage of 60° sectors with K=4 is that they require fewer cell sites than 120 sectors with K=7. Two disadvantages of 60 deg sectors are that (1) they require more antennas to he mounted on the antenna mast and (2) they often require more frequent handoffs because of the increased chance that the mobile units will travel across the six sectors of the call. Furthermore, assigning the proper frequency channel to the mobile unit in each sector is more difficult unless the antenna height at the cell site is increased so that the mobile unit can be located more precisely. In reality the terrain is not flat, end coverage is never uniformly distributed; in addition, the directional antenna front-to-back power ratio in the field is very difficult to predict. In small cells, interference could become uncontrollable; then the use of a K = 4 pattern with 60 deg sectors in small cells needs to be considered only for special implementations such an portable cellular systems or narrow beam applications. For small cells, a better alternative scheme is to use a K =7 pattern with 120° sectors plus the underlay-overlay configuration.

ANTENNA PARAMETERS AND THEIR EFFECTS:

LOWERING THE ANTENNA HEIGHT: Lowering the antenna height does not always reduce the co-channel interference. In some circumstances, such as on fairly flat ground or in a valley situation, lowering the antenna height will be very effective for reducing the cochannel and adjacent-channel interference, However, there are three cases where lowering the antenna height may or may not effectively help reduce the interference.

ON A HIGH HILL OR A HIGH SPOT: The effective antenna height, rather than the actual height, is always considered in the system design. Therefore, the effective antenna height varies according to the location of the mobile unit. When the antenna site is on a bill, as shown in Fig. 5.1(a), the effective antenna height is h1 + H.

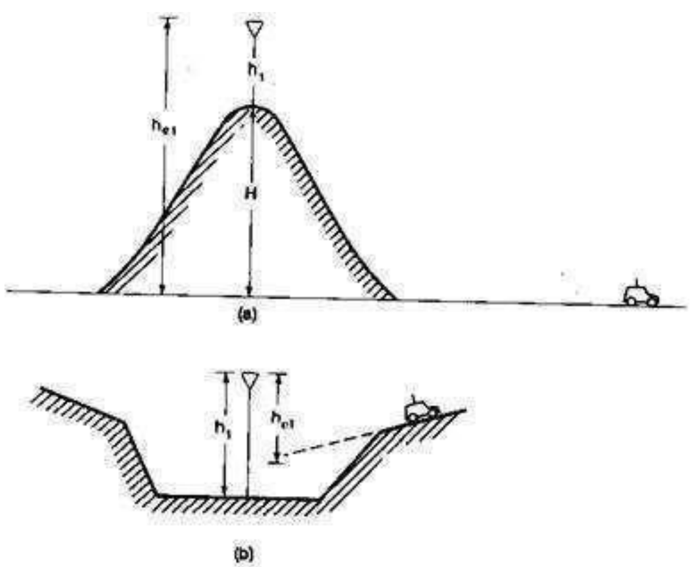


Fig. 5.1.Lowering the antenna height (a) on a high hill and (b) in a valley

If we reduce the actual antenna height to 0.5h1, the effective antenna height becomes 0.5h1 + H. The reduction in gain resulting from the height reduction is

$$G = \text{gain reduction} = 20 \log_{10} \frac{0.5h_1 + H}{h_1 + H}$$
$$= 20 \log_{10} \left(1 - \frac{0.5h_1}{h_1 + H}\right)$$

If h1<<H, then the above equation becomes

$$G = 20 \log_{10} 1 = 0 \text{ dB}$$

This simply proves that lowering antenna height on the kill does not reduce the received power at either the cell site or the mobile unit.

In a valley: The effective antenna height as seen from the mobile unit shown in Fig. 5.1(b) is he1, which is less than the actual antenna height h1. If he1= 2/3 h1, and the antenna is lowered to ½ h1, then the new effective antenna height is

$$h_{e1} = \tfrac{1}{2}h_1 - (h_1 - \tfrac{2}{3}h_1) = \tfrac{1}{6}h_1$$

Then the antenna gain is reduced by

$$G = 20 \log \frac{\tfrac{1}{6}h_1}{\tfrac{2}{3}h_1} = -12 \text{ dB}$$

This simply proves that the lowered antenna height in a valley is very effective in reducing the radiated power in a distant high elevation area. However, in the area adjacent to the cell-site antenna the effective antenna height is the same as the actual antenna height. The power reduction caused by decreasing antenna height by half isonly

$$20 \log \frac{\tfrac{1}{2}h_1}{h_1} = -6 \text{ dB}$$

In a forested area: In a forested area, the antenna should clear the tops of any trees in the vicinity, especially when they are very close to the antenna. In this case decreasing the height of the antenna would not be the proper procedure for reducing cochannel interference because excessive attenuation of the desired signal would occur in the vicinity of the antenna and in its cell boundary if the antenna were below the treetop level.

DIVERSITY TECHNIQUES:

SPACE DIVERSITY CONSIDERATIONS

Space diversity, also known as antenna diversity, is one of the most popular forms of diversity used in wireless systems. Conventional cellular radio systems consist of an elevated base station antenna and a mobile antenna close to the ground. The existence of a direct path between the transmitter and the receiver is not guaranteed and the possibility of a number of scatterers in the vicinity of the mobile suggests a Rayleigh fading signal. From this model jakes deduced that the signals received from spatially separated antennas on the mobile would have essentially uncorrelated envelopes for antenna separations of one half wavelength or more.

The concept of antenna space diversity is also used in base station design. At each cell site, multiple base station receiving antennas are used to provide diversity reception. However, since the important scatterers are generally on the ground in the vicinity of the mobile, the base station antennas must be spaced considerably far apart to achieve decorrelation. separations on the order of several tens of wavelengths are required at the base station .space diversity can thus be used at either the mobile or base station or both .figure shows general block diagram of a space diversity scheme

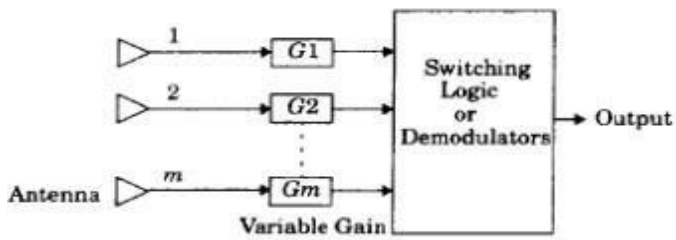


Figure 6.12 generalized block diagram for space diversity

POLARIZATION DIVERSITY:

At the base station, space diversity is considerably less practical than at the mobile because the narrow angle of incident fields requires large antenna spacing. The comparatively high cost of using space diversity at the base station prompts the consideration of using orthogonal polarization to exploit polarization diversity .while this only provides two diversity braches it does allow the antenna elements to be collocated.

In the early days of cellular radio, all subscriber units were mounted in vehicles and used vertical whip antennas. Today, however, over half of the subscriber units are portable. This means that most subscribers are no longer using vertical polarization due to hand tilting when the portable cellular phone is used. This recent phenomenon has sparked interest in polarization diversity at the base station. Measured horizontal and vertical polarization paths between a mobile and a base station are reported to be uncorrelated by lee and Yeh. The decorrelation for the signals in each polarization is caused by multiple reflections in the channel between the mobile and base station antennas. That the reflection coefficient for each polarization is different, which results in different amplitudes and phases for phases for each, or at least some, of the reflections. After sufficient random reflections, the polarizations state of the signal will be independent of the transmitted polarization. In practice; however, there is some dependence of the received polarization on the transmitted polarization.

Circular and linear polarized antennas have been used to characterize multipath inside buildings. When the path was obstructed, polarization diversity was found to dramatically reduce the multipath delay spread without significantly decreasing the received power.

FREQUENCY DIVERSITY:

Frequency diversity transmits information on more than one carrier frequency. The rationale behind this technique is that frequencies separated by more than the coherence bandwidth of the channel will not experience the same fades. Theoretically, if the channels are uncorrelated, the probability of simultaneous fading wills e the product of the individual fading probabilities.

Frequency diversity is often employed in microwave line of sight links which carry several channels in a frequency division multiplex mode (FDM).due to troposphere propagation and resulting refraction. Deep fading sometimes occurs. In practice 1: N protection switching is provided by a radio licensee. Where in one frequency is nominally idle but is available on a standby basis to provide frequency diversity switching for any one of the N other carriers (frequencies) being used on the same link, each carrying independent traffic. When diversity is needed, the appropriate traffic is simply switched to the backup frequency. This technique has the disadvantages that it not only requires spare bandwidth but also requires that there be as many receivers as there are channels used the frequency diversity. However, for critical traffic, the expense may be justified.

TIME DIVERSITY: Time diversity repeatedly transmits information at time spacing's that exceed the coherence time of the channel, so that multiple repetitions of the signal will be received with independent fading conditions, thereby providing for diversity. One modern implementation of time diversity involves the use of the RAKE receiver for spread spectrum CDMA, where the multipath channel provides redundancy in the transmitted messages.

NON CO-CHANNEL INTERFERENCE

ADJUSCENT CHANNEL INTERFERENCE:

Adjacent channel interference can be eliminated on the basis of the channel assignment, the filter characteristics and be reduction of near-end-far-end interference. Adjacent channel interference is a board term. It includes next channel interference (the channel next to the operating channel) and neighboring channel interference (more than one channel away from the operating channel). Adjacent channel interference can be reduced by the frequency assignment.

NEXT CHANNEL INTERFERENCE:

Next channel interference in an AMPS system affecting a particular mobile unit cannot be caused by transmitters in the common cell site but must originate at several other cell sites. This is because any channel combiner at the cell site must combine the selected channels. Normally 21 channels(630 kHz) away, or at least 8 or 10 channels away from the desired one. Therefore, next channel interference will arrive at the mobile unit from other cell sites if the system is not designed property .also a mobile unit initiating a call on a control channel in cell may cause interference with the next control channel at another cell site. The methods for reducing this next channel interference use the receiving end. The channel filter characteristics are a 6dB/oct slope in the voice band and a 24 dB/oct falloff outside the voice band region. If Next channel signal is stringer than 23 Db, it Will interfere with the desired signal. The filter with a sharp falloff slope can help to reduce all the adjacent channel interference, including the next channel interference. The same consideration is applied to digital systems.

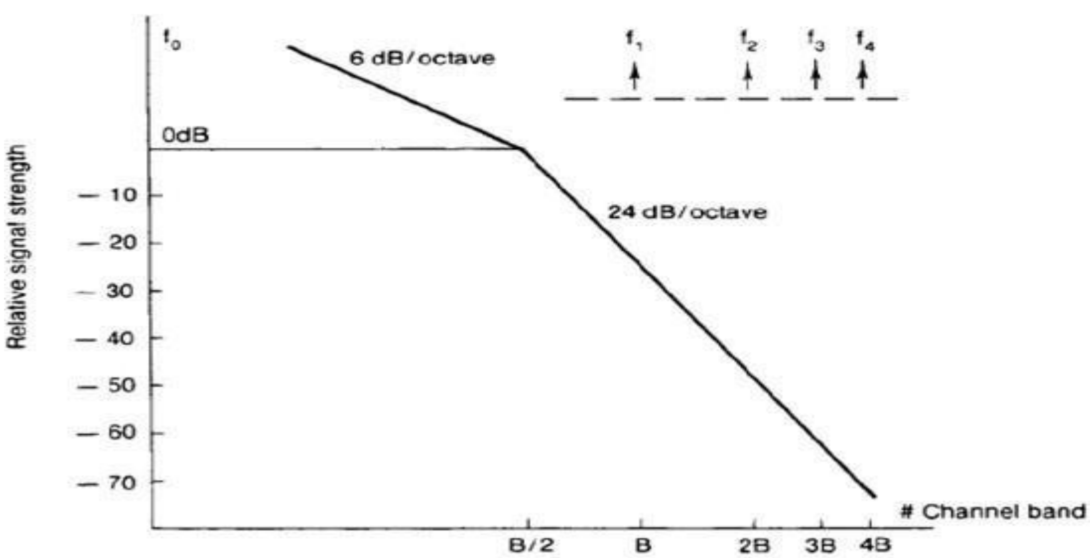


FIGURE 10.3 Characteristics of channel-band filter.

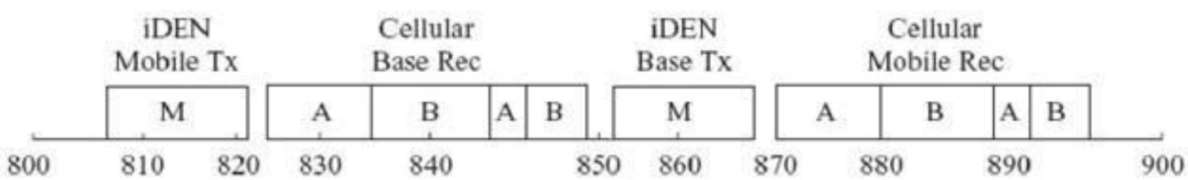
NEIGHBORING CHANNEL INTERFERENCE

The channels that are several channels away from next channel will cause interference with the desired signal. Usually, a fixed set of serving channels is assigned to each cell site. If all the channels are simultaneously transmitted at one cell site antenna; a sufficient amount of band isolation between channels is required for a multichannel combiner to reduce products. This requirement is no different from other non mobile radio systems. Assume that band separation requirements can be resolved, for example, by using multiple antennas instead of one antenna at the cell site. There will be no inter-modulation products. A truly linear broadband amplifier can realize this idea. However, it is a new evolving technology.

Another type of adjacent channel interference is unique to the mobile radio system. In the mobile radio system, most mobile units are in motion simultaneously. Their relative positions change from time to time. In principle, the optimum channel assignments that avoid adjacent channel interference must also change from time to time .one unique station that causes adjacent channel interference in mobile radio system.

TRANSMITTING AND RECEIVING CHANNELS INTERFERENCE

In FDMA and TDMA systems, the transmitting channels and receiving channels have to be separated by a guard band mostly 29MHz.it is because the transmitting channels are so strong that they can mask the weak signals received from receiving channels. The duplexer can only provide 30 dB to 40dB isolation. The band isolation is the other means to reduce the interference.



		Mobile Tx	Base Tx
A	Cellular band A	824-835, 845-846.5 MHz	869-880, 890-891.5 MHz
B	Cellular band B	835-845, 846.5-849 MHz	880-890, 891.5-894 MHz
	iDEN	806-821 MHz	851-866 MHz

FIGURE 10.4 Cellular and iDEN spectrum in 800 MHz.

INTERFERENCE FROM ADJACENT SYSTEMS

The frequency bands allocated between AMPS and iDEN in 800 MHz systems are shown in Fig 10.4 in 1993. IDEN transmitted in the band 851-866 MHz , using several broad band amplifiers to cover this band. The IM(2A- B)generated from the nonlinear amplifier interfered with the cellular base received signals. Then , the broadband amplifiers were removed.

NEAR-END–FAR-END INTERFERENCE

In One Cell

Because motor vehicles in a given cell are usually moving, some mobile units are close to the cell site and some are not. The close-in mobile unit has a strong signal that causes adjacent-channel interference (see Fig. 10.5*a*). In this situation, near-end–far-end interference can occur only at the reception point in the cell site.

If a separation of $5B$ (five channel bandwidths) is needed for two adjacent channels in a cell in order to avoid the near-end–far-end interference, it is then implied that a minimum separation of $5B$ is required between each adjacent channel used with one cell.

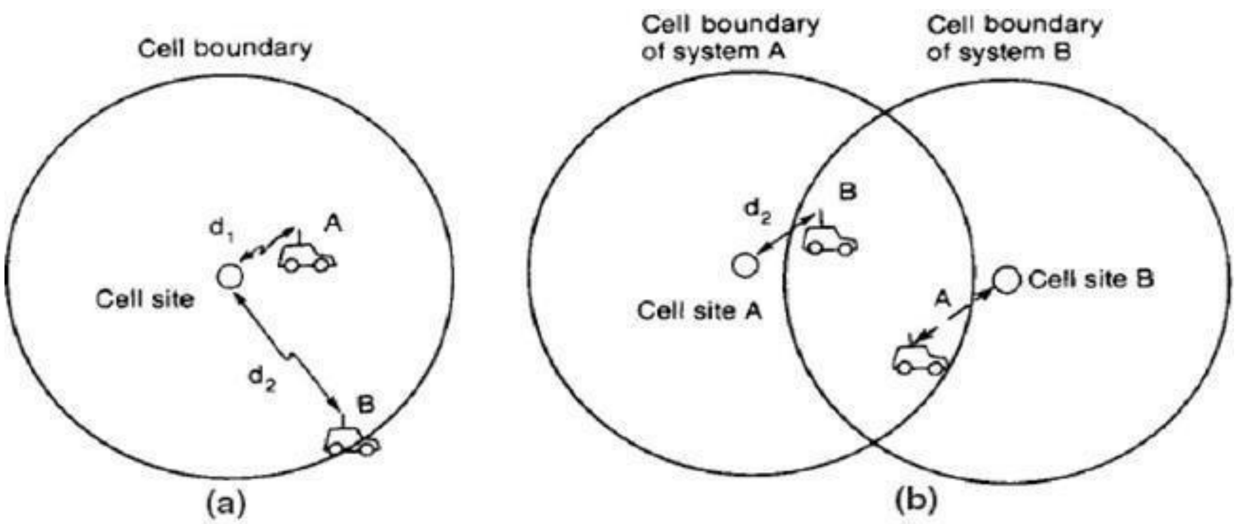


FIGURE 10.5 Near-end–far-end (ratio) interference. (*a*) In one cell; (*b*) in two-system cells.

Because the total frequency channels are distributed in a set of N cells, each cell only has $1/N$ of the total frequency channels. We denote $\{F_1\}$, $\{F_2\}$, $\{F_3\}$, $\{F_4\}$ for the sets of frequency channels assigned in their corresponding cells C_1, C_2, C_3, C_4.

The issue here is how can we construct a good frequency management chart to assign the N sets of frequency channels properly and thus avoid the problems indicated above. The following section addresses how cellular system engineers solve this problem in two different systems.

In Cells of Two Systems

Adjacent-channel interference can occur between two systems in a duopoly-market system. In this situation, adjacent-channel interference can occur at both the cell site and the mobile unit.

For instance, mobile unit A can be located at the boundary of its own home cell A in system A but very close to cell B of system B as shown in Fig 10.5*b*. The other situation would occur if mobile unit B were at the boundary of cell B of system B but very close to cell A of system A. Following the definition of near-end–far-end interference

, the solid arrow indicates that interference may occur at cell site A and the dotted arrow indicates that interference may occur at mobile unit A. Of course, the same interference will be introduced at cell site B and mobile unit B.

Thus, the frequency channels of both cells of the two systems must be coordinated in the neighborhood of the two-system frequency bands. This phenomenon causes a great concern as indicated in the additional frequency-spectrum allocation charts in Fig. 10.6 as an example.

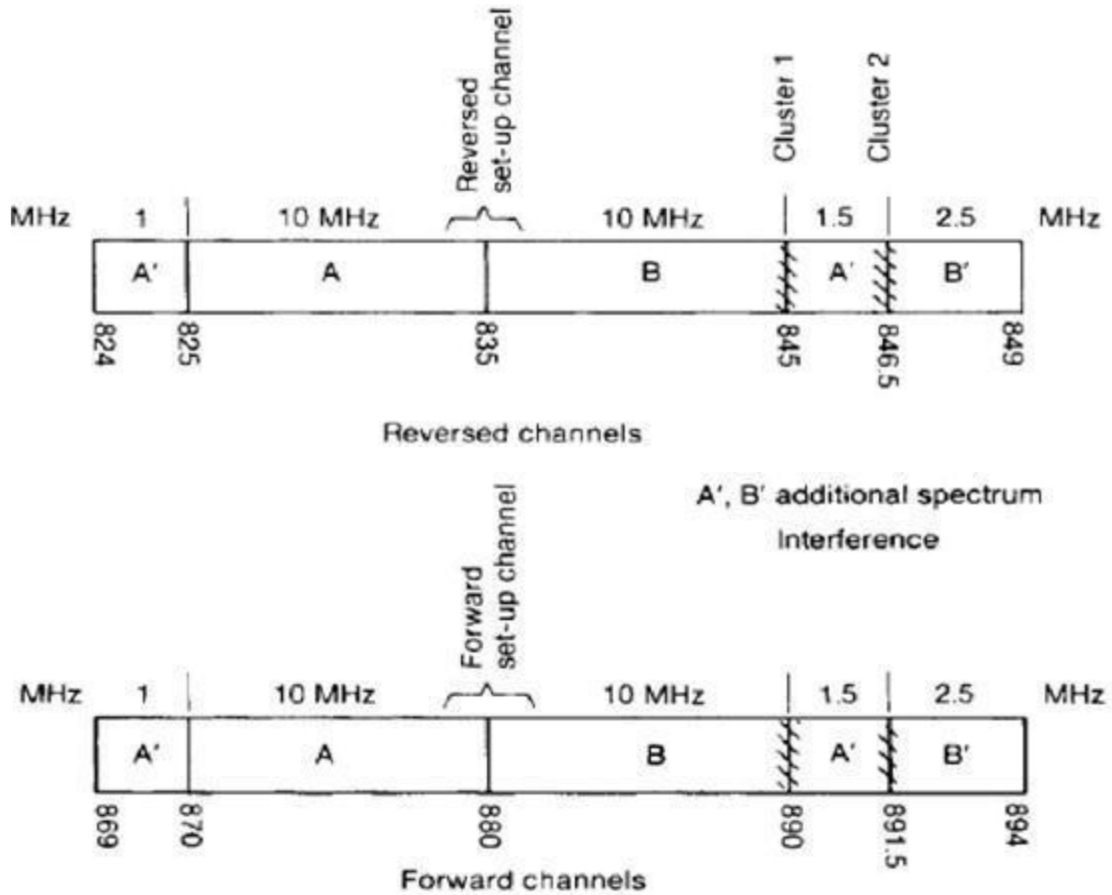


FIGURE 10.6 Spectrum allocation with new additional spectrum.

The two causes of near-end–far-end interference of concern here are

1. *Interference caused on the set-up channels.* Two systems try to avoid using the neighborhood of the set-up channels as shown in Fig. 10.6.
2. *Interference caused on the voice channels.* There are two clusters of frequency sets as shown in Fig. 10.6 that may cause adjacent-channel interference and should be avoided. The cluster can consist of 4 to 5 channels on each side of each system, that is, 8 to 10 channels in each cluster. The channel separation can be based on two assumptions.

a. *Received interference at the mobile unit.* The mobile unit is located away from its own cell site but only 0.25 mi away from the cell site of another system.

b. *Received interference at the cell site.* The cell site is located 10 mi away from its own mobile unit but only 0.25 mi from the mobile unit of another system.

CROSS TALK-

When the cellular radio system was designed, the system was intended to function like a telephone wire line. A wire pair serves both directions of traffic at the line transmission. In a mobile cellular system there is a pair of frequencies, occupying a bandwidth of 60 kHz, which we simply call a "channel." A frequency of 30 kHz serves a received path, and the other 30 kHz accommodates a transmitted path.

Because of paired-frequency (as a wire pair) coupling through the two-wire–four-wire hybrid circuitry at the telephone central office, it is possible to hear voices in both frequencies (in the frequency pair) simultaneously while scanning on only one frequency in the air. Therefore, just as with a wire telephone line, the full conversation can be heard on a single frequency (either one of the two). This phenomenon does not annoy cellular mobile users; when they talk they also listen to themselves through the phone receiver. They are not even aware that they are listening to their own voices.

This unnoticeable cross-talk phenomenon in frequency pairs has no major impact on both wire telephone line and cellular mobile performance. But when real cross talk occurs it has a larger impact on the cellular mobile system than on the telephone line, because the amount of cross talk could potentially be doubled since cross talk occurring on one frequency will be heard on the other (paired) frequency. Cross talk occurring on the reverse voice channel (RVC) can be heard on the forward voice channel (FVC), and cross talk occurring on the forward voice channel can be heard on the reverse channel. Therefore, the cross-talk effect is twofold. A number of situations are conducive to cross talk.

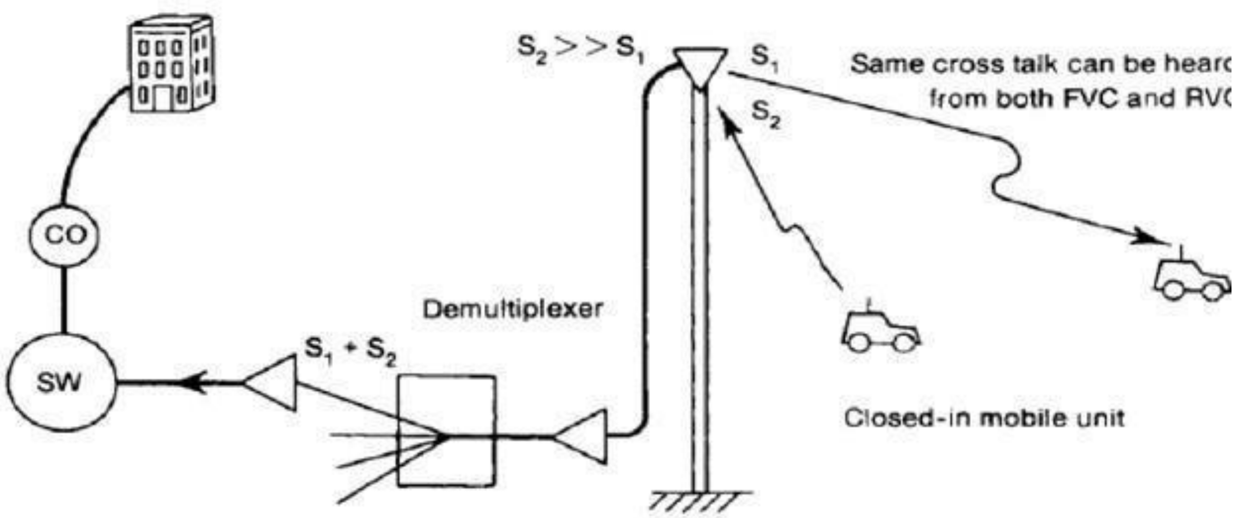


FIGURE 10.10 Cross-talk phenomenon.

Near-end mobile unit. Cross talk can occur when one mobile unit (unit A) is very close to the cell site and the other (unit B) is far from the cell site. Both units are calling to their land-line parties as shown in Fig. 10.10. The near-end mobile unit has a strong signal such that the demultiplexer cannot have an isolation (separation) of more than 30 dB. Then the strong signal can generate strong cross talk while the received signal from mobile unit B is 30 dB weaker than signal A.

Near-end mobile units can belong to one system or to another (foreign) system. If the foreign system units are operating in the new allocated spectrum channels, cross talk can occur. When the mobile unit is close to the cell site and the cell site is capable of reducing the power of the mobile unit, the near-end mobile interference can be reduced.

If the operating frequencies of both home system units and foreign system units are in the new allocated spectrum channels and the isolation of the multicoupler (demultiplexer) could be only 30 dB, cross talk would occur in the two interfering clusters of channels (Fig. 10.10) and could not be controlled by the system operator.

Close-in mobile units. When a mobile unit is very close to the cell site and if the reception at the cell site is greater than −55 dBm, the channel preamplifier at the cell site can become saturated and produce IM as a result of the nonlinear portion of the amplification. These IM products are the spurious (unwanted frequency) signal that leaks into the desired signal and produces cross talk. Also, as mentioned previously, the same cross talk can be heard from both the forward and reverse voice channels.

Cochannel cross talk. The cochannel interference reduction ratio q should be as large as possible to compensate for the cost of site construction and the limitation of available channels at each cellular site. There are other ways to increase q, as mentioned in Chap. 9. An adequate system design will help to reduce the cochannel cross talk.

The channel combiner. The signal isolation among the forward voice channels in a channel combiner is 17 dB.[4] The loss resulting from inserting the signal into the combiner is about 3 dB. The requirement of IM product suppression is about 55 dB. If one outlet is not matched well, the signal isolation is less than 17 dB. Therefore, for each channel an isolator is installed to provide an additional 30-dB of isolation with a 0.5-dB insertion loss. This isolator prevents any signal from leaking back to the power amplifier (see Sec. 10.7.1). Spurious signals can be cross-coupled to this weak channel while transmitting. This kind of cross-coupled interference can be eliminated by routinely checking impedance matching at the combiner.

Telephone-line cross talk. Sometimes cross talk can result from cable imbalance or switching error at the central office and be conveyed to the customer through the telephone line. Minimizing this type of cross talk should be given the same priority as reducing the number of call drops,

Effects on coverage and interference by power decrease and Antenna height decrease

Power Decrease

As long as the setup of the antenna configuration at the cell site remains the same, and if the cell-site transmitted power is decreased by 3 dB, then the reception at the mobile unit is also decreased by 3 dB. This is a one-on-one (i.e., linear) correspondence and thus is easy to control.

Antenna Height Decrease

When antenna height is decreased, the reception power is also decreased. However, the formula

$$\text{Antenna height gain (or loss)} = 20\log\frac{h'_{e_1}}{h_{e_1}}$$

is based on the difference between the old and new effective antenna heights and not on the actual antenna heights. Therefore, the effective antenna height is the same as the actual antenna height only when the mobile unit is traveling on flat ground. It is easy to decrease antenna height to control coverage in a flat-terrain area. For decreasing antenna height in a hilly area, the signal-strength contour shown in Fig. 10.12*a* is different from the situation of power decrease shown in Fig. 10.12*b*. Therefore, a decrease in antenna height would affect the coverage; thus, antenna height becomes very difficult to control in an overall plan. Some area within the cell may have a high attenuation while another may not.

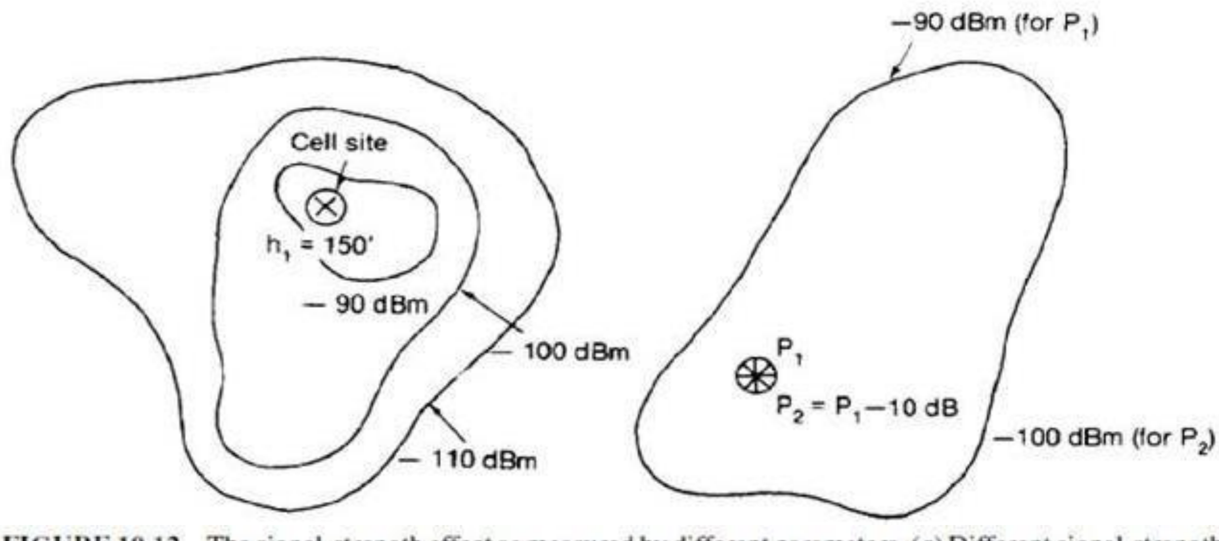


FIGURE 10.12 The signal-strength effect as measured by different parameters. (*a*) Different signal-strength contours. (*b*) Signal-strength changes with power changes.

CELL COVERAGE FOR SIGNALAND TRAFFIC

SIGNAL REFLECTIONS IN FLAT AND HILLY TERRAIN

The ground incident angle and the ground elevation angle over a communication link are described as follows. The ground incident angle 0 is the angle of wave arrival incidentally pointing to the ground as shown in Fig. 1.1. The ground elevation angle is the angle of wave arrival at the mobile unit as shown in Fig. 1.1

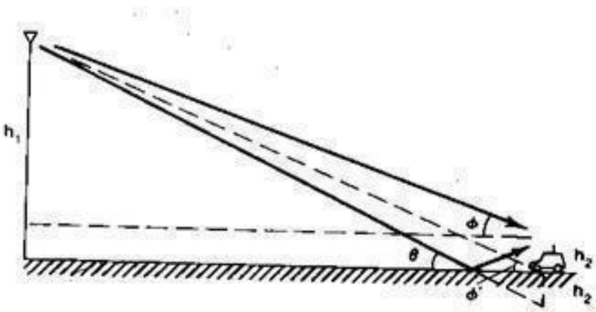


Figure 1.1 Representation of Ground Incident Angle θ and Ground Elevation Angle ϕ

Based on Snell's law, the reflection angle and incident angle are the same. Since in graphical display we usually exaggerate the hilly slope and the incident angle by enlarging the vertical scale, as shown in Fig. 1.2, then as long as the actual hilly slope is less than 100, the reflection point on a hilly slope can be obtained by following the same method as if the reflection point were on flat ground. Be sure that the two antennas (base and mobile) have been placed vertically, not perpendicular to the sloped ground. The reason is that the actual slope of the hill is usually very small and the vertical stands for two antennas are correct. The scale drawing in Fig. 1.2 is somewhat misleading however, it provides a clear view of the situation.

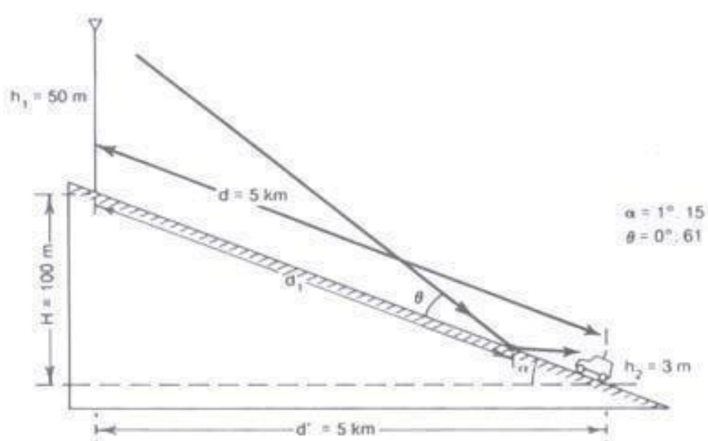


Fig 1.2 Ground reflection angle and reflection point

PHASE DIFFERENCE BETWEEN THE DIRECT PATH AND THE REFLECTED PATH

Based on a direct path and a ground reflected path, the equation

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 + a_v e^{j\Delta\phi}\right|^2$$

where a_v = the reflection coefficient
$\Delta\phi$ = the phase difference between a direct path and a reflected path
P_0 = the transmitted power
d = the distance
λ = the wavelength

Indicates a two-wave model which is used to understand the path-loss phenomenon in a mobile radio environment. It is not the model for analyzing the multipath fading phenomenon. In a mobile environment av = - 1 because of the small incident angle of the ground wave caused by a relatively low cell-site antenna height. Thus,

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 - \cos\Delta\phi - j\sin\Delta\phi\right|^2$$
$$= P_0 \frac{2}{(4\pi d/\lambda)^2}(1 - \cos\Delta\phi) = P_0 \frac{4}{(4\pi d/\lambda)^2}\sin^2\frac{\Delta\phi}{2}$$

where $\Delta\phi = \beta\,\Delta d$

and Δd is the difference, $\Delta d = d_1 - d_0$, from Fig. 4.4.

$$d_1 = \sqrt{(h_1 + h_2)^2 + d^2}$$

and $d_2 = \sqrt{(h_1 - h_2)^2 + d^2}$

Since Δd is much smaller than either d_1 or d_2,

$$\Delta\phi = \beta\,\Delta d \approx \frac{2\pi}{\lambda}\frac{2h_1h_2}{d}$$

Then the received power of Eq. (4.2-3) becomes

$$P_r = P_0 \frac{\lambda^2}{(4\pi)^2 d^2}\sin^2\frac{4\pi h_1 h_2}{\lambda d}$$

If $\Delta\phi$ is less than 0.6 rad, then $\sin(\Delta\phi/2) \approx \Delta\phi/2$, $\cos(\Delta\phi/2) \approx l$, then

$$P_r = P_0 \frac{4}{16\pi^2(d/\lambda)^2}\left(\frac{2\pi h_1 h_2}{\lambda d}\right)^2 = P_0\left(\frac{h_1h_2}{d^2}\right)^2$$

, thus

$$\Delta P = 40\log\frac{d_1}{d_2} \quad \text{(a 40 dB/dec path loss)}$$

$$\Delta G = 20\log\frac{h'_1}{h_1} \quad \text{(an antenna height gain of 6 dB/oct)}$$

Where P is the power difference in decibels between two different path lengths and G is the gain (or loss) in decibels obtained from two different antenna heights at the cell site. From these measurements, the gain from a mobile antenna height is only 3 dB/oct, which is different from the 6 dB/oct . Then

$$\Delta G'' = 10 \log \frac{h'_2}{h_2}$$

CONSTANT STANDARD DEVIATION ALONG A PATH-LOSS SLOPE

When plotting signal strengths at any given radio-path distance, the deviation from predicted value. is approximately 8 dB.1012 This standard deviation of 8 dB is roughly true in many different areas. The explanation is as follows. When a line-of-sight path exists, both the direct wave path and reflected wave path are created and are strong. When an out-of-sight path exists, both the direct wave path and the reflected wave path are weak. In either case, according to the theoretical model, the 40-dB/dec path-loss slope applies. The difference between these two conditions is the 1-mi intercept (or 1-km intercept) point. It can be seen that in the open area, the 1-mi intercept is high. In the urban area, the 1-mi intercept is low. The standard deviation obtained from the measured data remains the same along the different path-loss curves regardless of environment.

Support for the above argument can also be found from the observation that the standard deviation obtained from the measured data along the predicted path-loss curve is approximately 8 dB. The explanation is that at a distance from the cell site, some mobile unit radio paths are line-of-sight, some are partial line-of-sight, and some are out-of-sight. Thus the received signals are strong, normal, and weak, respectively. At any distance, the above situations prevail. If the standard deviation is 8 dB at one radio-path distance, the same 8dB will be found at any distance. Therefore a standard deviation of 8 dB is always found along the radio path as shown in Fig.3

The standard deviation of 8 dB from the measured data near the cell site is due mainly to the close-in buildings around the cell site. The same standard deviation from the measured data at distant locations is due to the great variation along different around the cell site. The same standard deviation from the measured data at a distant location is due to the great variation along different radio paths.

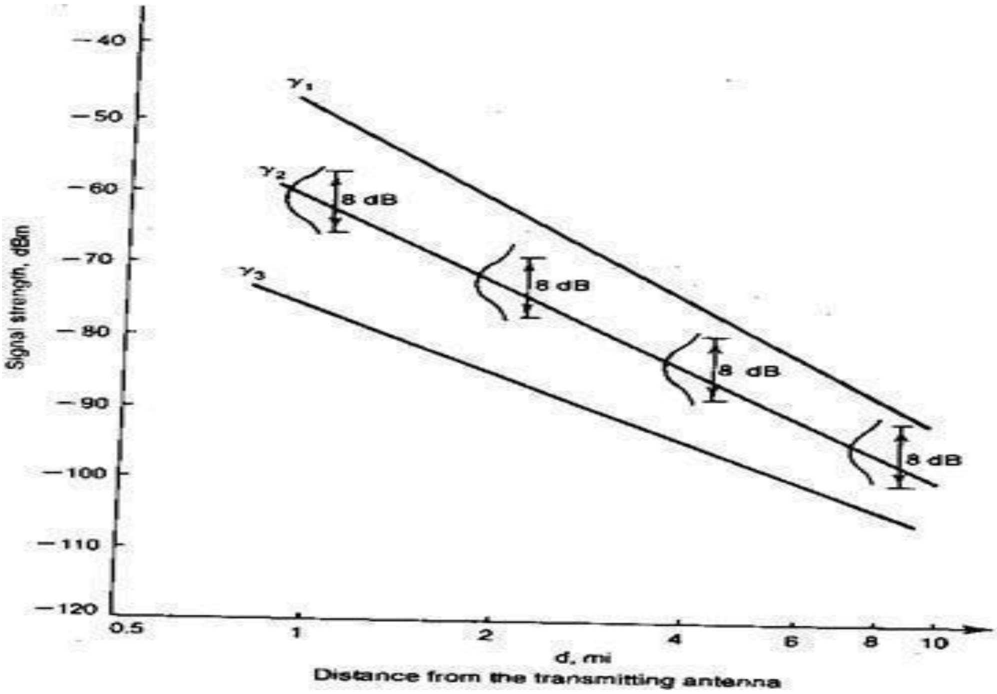


Fig 3 An 8-dB local mean spread

MERITS OF POINT-TO-POINT MODEL

The area-to-area model usually only provides an accuracy of prediction with a standard deviation of 8 dB, which means that 68 percent of the actual path-loss data are within the ± 8 dB of the predicted value. The uncertainty range is too large. The point-to-point model reduces the uncertainty range by including the detailed terrain contour information in the path-loss predictions.

The differences between the predicted values and the measured ones for the point-to-point model were determined in many areas. In the following discussion, we compare the differences shown in the Whippany, N.J., area and the Camden- Philadelphia area. First, we plot the points with predicted values at the x-axis and the measured values at the y-axis, shown in Fig. 4. The 450 line is the line of prediction without error. The dots are data from the Whippany area, and the crosses are data from the Camden-Philadelphia area. Most of them, except the one at 9 dB, are close to the line of prediction without error.

The mean value of all the data is right on the line of prediction without error. The standard deviation of the predicted value of 0.8 dB from the measured one.

In other areas, the differences were slightly larger. However, the standard deviation of the predicted value never exceeds the measured one by more than 3 dB. The standard deviation range is much reduced as compared with the maximum of 8 dB from area-to-area models. The point-to-point model is very useful for designing a mobile cellular system with a radius for each cell of 10 mi or less. Because the data follow the log- normal distribution, 68 percent of predicted values obtained from a point-to-point prediction model are within 2 to 3 dB. This point-to-point prediction can be used to provide overall coverage of all cell sites and to avoid co-channel interference. Moreover, the occurrence of handoff in the cellular system can be predicted more accurately.

The point-to-point prediction model is a basic tool that is used to generate a signal coverage map, an interference area map, a handoff occurrence map, or an optimum system design configuration, to name a few applications.

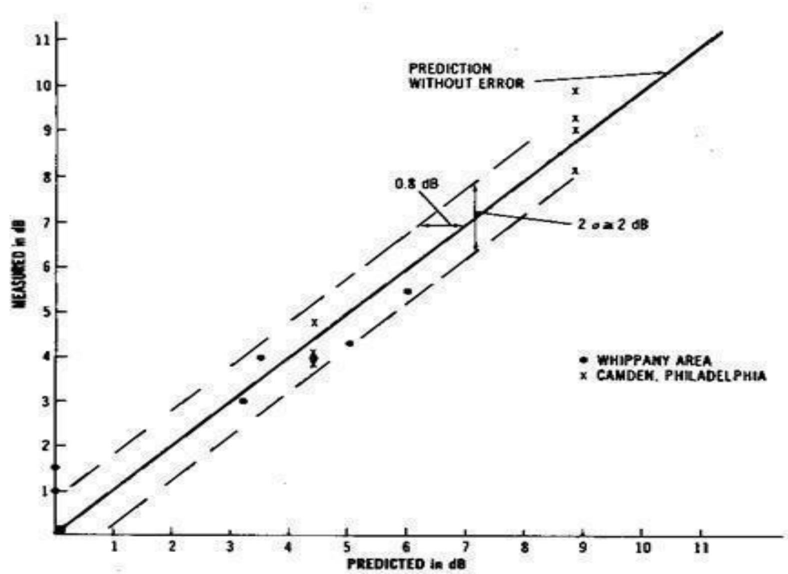


Fig.4. Indication of errors in point-to-point predictions under non obstructive conditions.

FOLIAGE LOSS

Foliage loss is a very complicated topic that has many parameters and variations. The sizes of leaves, branches, and trunks, the density and distribution of leaves, branches, and trunks, and the height of the trees relative to the antenna heights all be considered. An illustration of this prv1em is shown in Fig. 5.1. There are threelevels: trunks, branches, and leaves. In each level, there is a distribution of sizes of trunks, branches, and leaves and also of the density and spacing between adjacent trunks, branches, and leaves. The texture and thickness of the leaves also count. This unique problem can become very complicated and is beyond the scope of this book. Fora system design, the estimate of the signal reception due to foliage loss does not need any degree of accuracy.

Furthermore, some trees, such as maple or oak, lose their leaves in winter, while others, such as pine, never do. For example, in Atlanta, Georgia, there are oak, maple, and pine trees. In summer the foliage is very heavy, but in winter the leaves of the oak and maple trees fall and the pine leaves stay. In addition, when the length of pine needles reaches approximately 6 in., which is the half wavelength at 800 MHz, a great deal of energy can be absorbed by the pine trees. In these situations, it is very hard to predict the actual foliage loss.

However, a rough estimate should be sufficient for the purpose of system design. In tropic zones, the sizes of tree leaves are so large and thick that the signal can hardly penetrate. In this case, the signal will propagate from the top of the tree and deflect to the mobile receiver. We will include this calculation also.

Sometime the foliage loss can be treated as a wire-line loss, in decibels per foot or decibels per meter, when the foliage is uniformly heavy and the path lengths are short. When the path length is long and the foliage is non uniform, then decibels per octaves or decibels per decade are used. In general, foliage lose occurs with respectto the frequency to the fourth power. Also, at 800 MHz the foliage Lou along the radio path is 40 dB/dec, which is 20 dB more than the free- space loss, with the same amount of additional loss for mobile communications. Therefore, if the situation involves both foliage loss and mobile communications, the total loss would be 60 dB/dec(=20 dB/ dec of free-space loss + additional 20 dB due to foliage loss + additional 20 dB due to mobile communication).

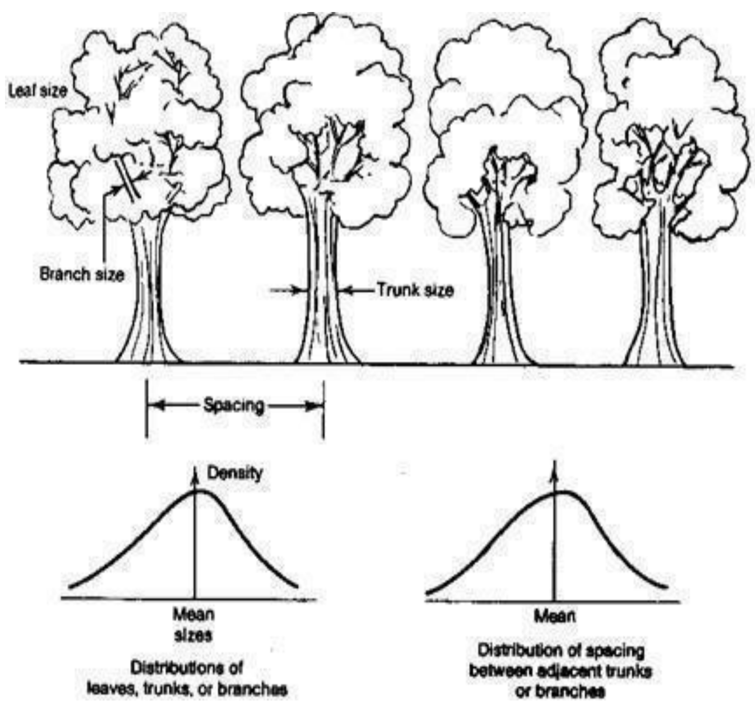


Fig.5.1. A characteristic of foliage environment

This situation would be the case if the foliage would line up along the radio path. A foliage loss in a suburban area of 58.4 dB/dec is shown in Fig.5.2. As demonstrated from the above two examples, close-in foliage at the transmitter site always heavily attenuates signal reception. Therefore, the cell site should be placed away from trees.

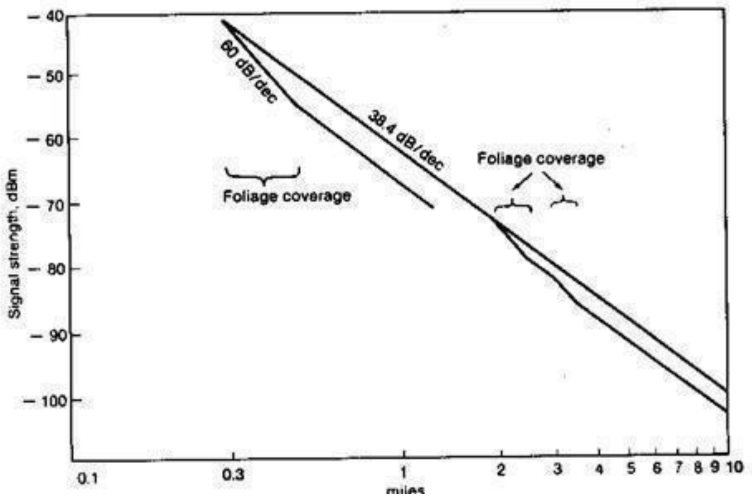


Fig.5.2. Foliage loss calculation in suburban areas

SMALL SCALE MULTIPATH PROPAGATION

The multipath propagation of radio signals over a short period of time or to travel a distance is considered to be the small scale multipath propagation. As every type of multipath propagation results in generating a faded signal at receiver, the small scale multipath propagation also results in small scale fading. Hence, the signal at the receiver is obtained by combining the various multipath waves. These waves will vary widely in amplitude and phase depending on the distribution of the intensity and relative propagation time of the waves and bandwidth of the transmitted signal.

The three fading effects that are generally observed due to the small scale multipath propagation are,

1. Fast variations in signal strength of the transmitted signal for a lesser distance or timeinterval.
2. The variations in Doppler shift on various multipath signals are responsible for random frequency modulation
3. The time dispersed signals are resulted due to multipath propagation delays.

In order to determine the small scale fading effects, we employ certain techniques. They are,

D Direct RF pulse measurement

E Spread spectrum sliding correlation measurement.

F Swept frequency measurement.

The first technique provides a local average power delay profile.

The second technique detects the transmitted signal with the help of a narrow band receiver preceded by a wide band mixer though the probing (or received) signal is wide band.

The third technique is helpful in finding the impulse response of the channel in frequency domain. By knowing the impulse response we can easily predict the signal obtained at the receiver from the transmitter.

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EFFECT OF PROPAGATION OF MOBILE SIGNALS OVER WATER AND FLAT OPEN AREA

PROPAGATION OVER WATER OR FLAT OPEN AREA:

Propagation over water or fiat open area is becoming a big concern because it is very easy to interfere with other cells if we do not make the correct arrangements. Interference resulting from propagation over the water can be controlled if we know the cause. In general, the permittivity's Er of seawater and fresh water are the same, but the conductivities of seawater and fresh water are different. We may calculate the dielectric constants Ec where Ec = Er - j60σλ. The wavelength at 850MHz is 0.35m. Then Eo (sea water) = 80 - j84 and Ec (fresh water)=80- jO.021.

However, based upon the reflection coefficients formula with a small incident angle both the reflection coefficients for horizontal polarized waves and vertically polarized waves approach 1. Since the 180* phase change occurs at the ground reflection point, the reflection coefficient is -1. Now we can establish a scenario, as shown in Fig 10.1 Since the two antennas, one at the cell site and the other at the mobile unit, are well above sea level, two reflection points are generated. The one reflected from the ground is close to the mobile unit; the other reflected from the water is away from the mobile unit. We recall that the only reflected wave we considered in the land mobile propagation is the one reflection point which is always very close to the mobile unit. We are now using the formula to find the field strength under the circumstances of a fixed point-to-point transmission and a land-mobile transmission over a water or flat open land condition.

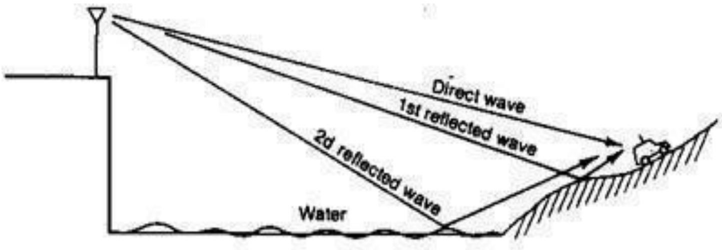


Fig 10.1.A model for propagation over water

BETWEEN FIXED STATIONS: The point -to-point transmission between the fixed stations over the water or flat open land can be estimated as follows. The received power *P,* can be expressed as (see Fig.10.2)

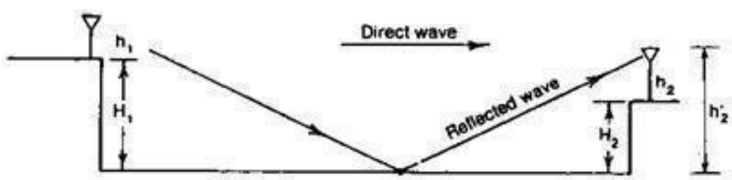


Fig 10.2.Propagation between two fixed stations over water or flat open land.

$$P_r = P_t \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 + a_v e^{-j\phi_v} \exp(j\,\Delta\phi)\right|^2$$

where P_t = transmitted power
d = distance between two stations
λ = wavelength
a_v, ϕ_v = amplitude and phase of a complex reflection coefficient, respectively

_ϕ is the phase difference caused by the path difference M between the direct wave and the reflected wave, or

$$\Delta\phi = \beta\,\Delta d = \frac{2\pi}{\lambda}\,\Delta d$$

The first part of i.e. the free-space loss formula which shows the 20 dB/dec slope; that is, a 20-dB loss will be seen when propagating from 1 to 10 km.

$$P_0 = \frac{P_t}{(4\pi d/\lambda)^2}$$

The complex reflection co-efficient and can be found from the formula

$$a_v e^{-j\phi_v} = \frac{\epsilon_c \sin\theta_1 - (\epsilon_c - \cos^2\theta_1)^{1/2}}{\epsilon_c \sin\theta_1 + (\epsilon_c - \cos^2\theta_1)^{1/2}}$$

When the vertical incidence is small, θ is very small and

$$a_v \approx -1 \qquad \text{and} \qquad \phi_v = 0$$

It can be found from equation. Ec is a dielectric constant that is different for different media. The reflection coefficient remains -1 regardless of whether the wave is propagated over water dry land, wet land, Ice, and so forth. The wave propagating between fixed stations is illustrated in Fig. 10.2.

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2}|1 - \cos\Delta\phi - j\sin\Delta\phi|^2$$
$$= P_0(2 - 2\cos\Delta\phi)$$

since _ϕ is a function of d and d can be obtained from the following calculation. The effective antenna height at antenna 1 is the height above the sea level.

$$h_1' = h_1 + H_1$$

The effective antenna height at antenna 2 is the height above the sea level.

$$h_2' = h_2 + H_2$$

As shown in Fig.10.2 where h1 and h2 are actual heights and H1and H2 are the heights of hills. In general, both antennas at fixed stations are high, so the resection point of the wave will be found toward the middle of the radio path. The path difference d can be obtained from Fig. 10.2 as

$$\Delta d = \sqrt{(h_1' + h_2')^2 + d^2} - \sqrt{(h_1' - h_2')^2 + d^2}$$

Since $d \gg h_1'$ and h_2', then

$$\Delta d \approx d\left[1 + \frac{(h_1' + h_2')^2}{2d^2} - 1 - \frac{(h_1' - h_2')^2}{2d^2}\right] = \frac{2h_1'h_2'}{d}$$

Then

$$\Delta\phi = \frac{2\pi}{\lambda}\frac{2h_1'h_2'}{d} = \frac{4\pi h_1'h_2'}{\lambda d}$$

MOBILE-TO-MOBILE PROPAGATION

In mobile-to-mobile land communication, both the transmitter and the receiver are in motion. The propagation path in this case is usually obstructed by buildings and obstacles between the transmitter and receiver. The propagation channel acts like a filter with a time-varying transfer function H (f, t) which can be found in this section. The two mobile units M1 and M2 with velocities V1 and V2 respectively are shown in Fig.11.1. Assume that the transmitted signal from M1 is

$$s(t) = u(t)e^{j\omega t}$$

The receiver signal at the mobile unit M_2 from an ith path is

$$s_i = r_i u(t - \tau_i)e^{j[(\omega_0 + \omega_{1i} + \omega_{2i})(t - \tau_i) + \phi_i]}$$

where $u(t)$ = signal
ω_0 = RF carrier
r_i = Rayleigh-distributed random variable
ϕ_i = uniformly distributed random phase
τ_i = time delay on ith path

and

$$\omega_{1i} = \text{Doppler shift of transmitting mobile unit on } i\text{th path}$$
$$= \frac{2\pi}{\lambda} V_1 \cos \alpha_{1i}$$
$$\omega_{2i} = \text{Doppler shift of receiving mobile unit on } i\text{th path}$$
$$= \frac{2\pi}{\lambda} V_2 \cos \alpha_{2i}$$

Where a1i and a2i are random angles as shown in Fig.11.1. Now assume that the received signal is the summation of n paths uniformly distributed around the azimuth.

$$s_r = \sum_{i=1}^{n} s_i(t) = \sum_{i=1}^{n} r_i u(t - \tau_i) \times \exp\{j[(\omega_0 + \omega_{1i} + \omega_{2i})(t - \tau_i) + \phi_i]\}$$
$$= \sum_{i=1}^{n} Q(\alpha_{i,t})u(t - \tau_i)e^{j\omega_0(t - \tau_i)}$$

where $Q(\alpha_i, t) = r_i \exp\{j[(\omega_{1i} + \omega_{2i})t + \phi_i']\}$

$$\phi_i' = \phi - (\omega_{1i} + \omega_{2i})\tau_i$$

CELLSITE AND MOBILE ANTENNAS

SPACES-DIVERSITY ANTENNAS

Two-branch space-diversity antennas are used at the cell site to receive the same signal with different fading envelopes, one at each antenna. The degree of correlation between two fading envelopes is determined by the degree of separation between two receiving antennas. When the two fading envelopes are combined, the degree of fading is reduced. Here the antenna setup is shown in Fig. 5a.

Equation is presented as an example for the designer to use.

$\eta = h/D = 11$ (8.13-1)

Where h is the antenna height and D is the antenna separation. From Eq., the separation $d \geq 8\lambda$ is needed for an antenna height of 100 ft (30 m) and the separation $d \geq 14\lambda$ is needed for an antenna height of 150ft (50 m). In any Omni cell system, the two space-diversity antennas should be aligned with the terrain, which should have a U shape as shown in Fig.5b. Space-diversity antennas can separate only horizontally, not vertically; thus, there is no advantage in using a vertical separation in the design.

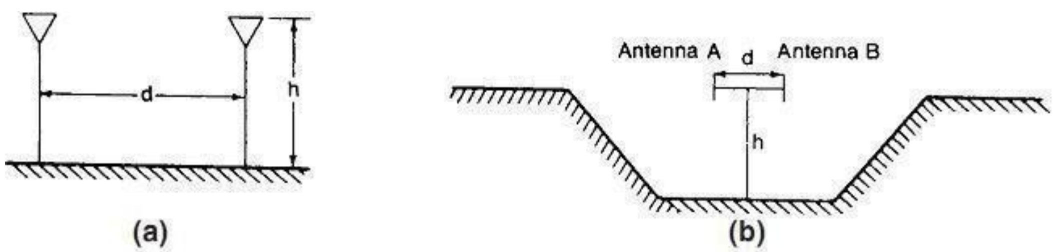


Fig.6.10.Diversity antenna spacing at cell site: (a) n=h/d (b) Proper arrangement with two antennas

UMBRELLAS-PATTERN ANTENNAS

In certain situations, umbrella-pattern antennas should be used for the cell-site antennas.

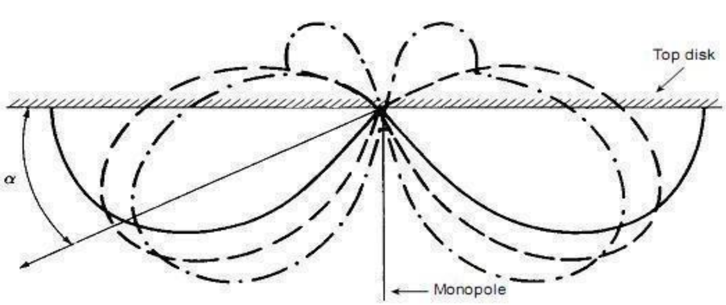


Fig. Vertical-plane patterns of quarter-wavelength stub antenna on infinite ground plane (solid) and on finite ground planes several wavelengths in diameter (dashed line) and about one wavelength in diameter (dotted line).

i) NORMAL UMBRELLA-PATTERN ANTENNA:

For controlling the energy in a confined area, the umbrella-pattern antenna can be developed by using a monopole with a top disk (top-loading) as shown in Fig. The size of the disk determines the tilting angle of the pattern. The smaller the disk, the larger the tilting angle of the umbrella pattern.

ii) BROADBAND UMBRELLA-PATTERN ANTENNA:

The parameters of a Discone antenna (a bio conical antenna in which one of the cones is extended to 180◦ to form a disk) are shown in Fig. The diameter of the disk, the length of the cone, and the opening of the cone can be adjusted to create an umbrella-pattern antenna.

iii) INTERFERENCE REDUCTION ANTENNA:

A design for an antenna configuration that reduces interference in two critical directions (areas) is shown in Fig.6.3. The parasitic (insulation) element is about 1.05 times longer than the active element.

iv) HIGH-GAIN BROADBAND UMBRELLA-PATTERN ANTENNA:

A high-gain antenna can be constructed by vertically stacking a number of umbrella-pattern antennas as shown in Fig.

$$E_0 = \frac{\sin[(Nd/2\lambda)\cos\phi]}{\sin[(d/2\lambda)\cos\phi]} \cdot \text{(individual umbrella pattern)}$$

where ϕ = direction of wave travel
N = number of elements
d = spacing between two adjacent elements

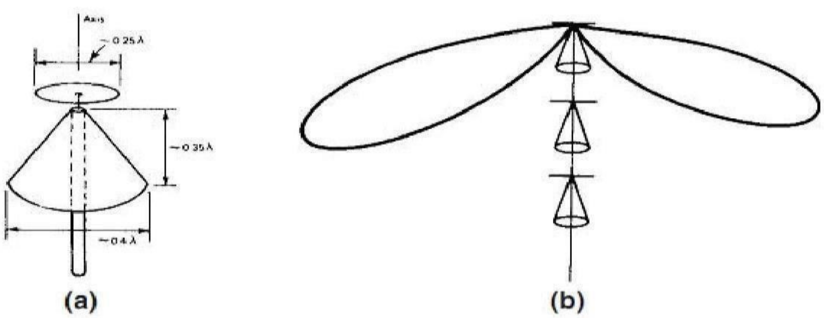


Fig. Discone antennas (a) Single antenna; (b) An array of antenna

MINIMUM SEPARATION OF CELL-SITE RECEIVING ANTENNAS

Separation between two transmitting antennas should be minimized to avoid the inter modulation. The minimum separation between a transmitting antenna and a receiving antenna is necessary to avoid receiver desensitization. Here we are describing a minimum separation between two receiving antennas to reduce the antenna pattern ripple effects. The two receiving antennas are used for a space-diversity receiver.

Because of the near field disturbance due to the close spacing, ripples will form in the antenna patterns (Fig.). The difference in power reception between two antennas at different angles of arrival is shown in Fig. . If the antennas are located closer; the difference in power between two antennas at a given pointing angle increases. Although the power difference is confined to a small sector, it affects a large section of the street as shown in Fig. . If the power difference is excessive, use of space diversity will have no effect reducing fading. At 850 MHz, the separation of eight wavelengths between two receiving antennas creates a power difference of ±2 dB, which is tolerable for the advantageous use of a diversity scheme.

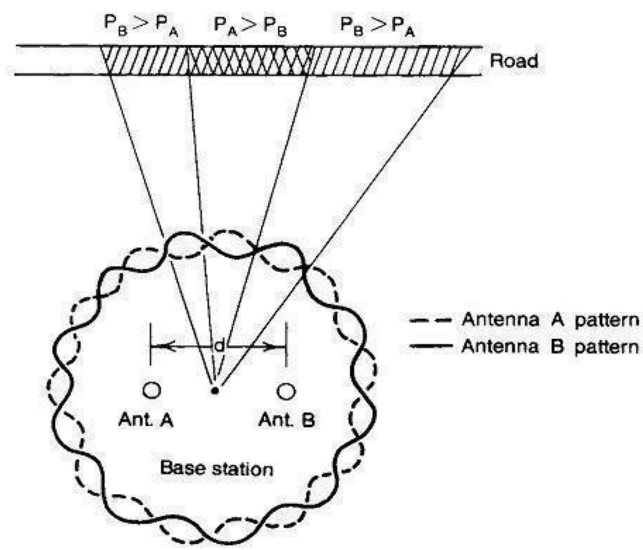


Fig. Antenna pattern ripple effect

MOBILE ANTENNAS

The requirement of a mobile (motor-vehicle–mounted) antenna is an Omni-directional antenna that can be located as high as possible from the point of reception. However, the physical limitation of antenna height on the vehicle restricts this requirement. Generally, the antenna should at least clear the top of the vehicle. Patterns for two types of mobile antenna are shown in Fig.

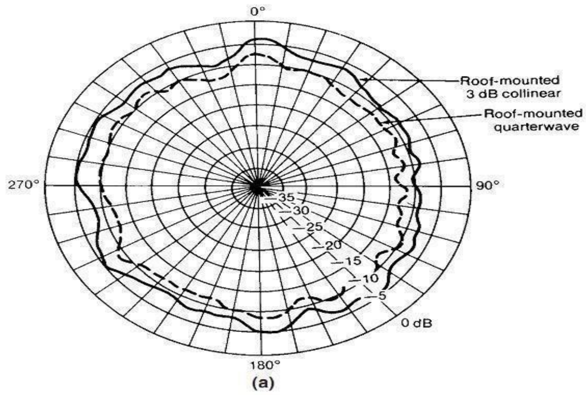


Fig. Mobile antenna patterns (a) Roof mounted 3-dB-gain collinear antenna versus roof-mounted quarter-wave antenna, (b) Window-mourned "on-glass" gain antenna versus roof-mounted quarter-wave antenna.

ROOF-MOUNTED ANTENNA:

The antenna pattern of a roof-mounted antenna is more or less uniformly distributed around the mobile unit when measured at an antenna range in free space as shown in Fig.9.2. The 3-dBhigh-gain antenna shows a 3-dBgain over the quarter-wave antenna. However, the gain of the antenna used at the mobile unit must be limited to 3 dB because the cell-site antenna is rarely as high as the broadcasting antenna and out-of-sight conditions often prevail. The mobile antenna with a gain of more than 3 dB can receive only a limited portion of the total multipath signal in the elevation as measured under the out-of-sight condition.

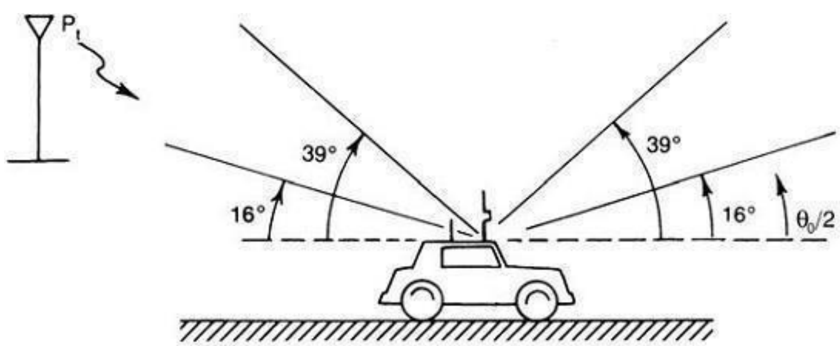


Fig. Vertical angle of signal arrival

GLASS-MOUNTED ANTENNAS:

There are many kinds of glass-mounted antennas. Energy is coupled through the glass; therefore, there is no need to drill a hole. However, some energy is dissipated on passage through the glass. The antenna gain range is 1 to 3 dB depending on the operating frequency. The position of the glass-mounted antenna is always lower than that of the roof-mounted antenna; generally there is a 3-dBdifference between these two types of antenna. Also, glass mounted antennas cannot be installed on the shaded glass found in some motor vehicles because this type of glass has a high metal content.

MOBILE HIGH-GAIN ANTENNAS:

A high-gain antenna used on a mobile unit has been studied. This type of high-gain antenna should be distinguished from the directional antenna. In the directional antenna, the antenna beam pattern is suppressed horizontally; in the high-gain antenna, the pattern is suppressed vertically.

To apply either a directional antenna or a high-gain antenna for reception in a radio environment, we must know the origin of the signal. If we point the directional antenna opposite to the transmitter site, we would in theory receive nothing. In a mobile radio environment, the scattered signals arrive at the mobile unit from every direction with equal probability. That is why an Omni directional antenna must be used.

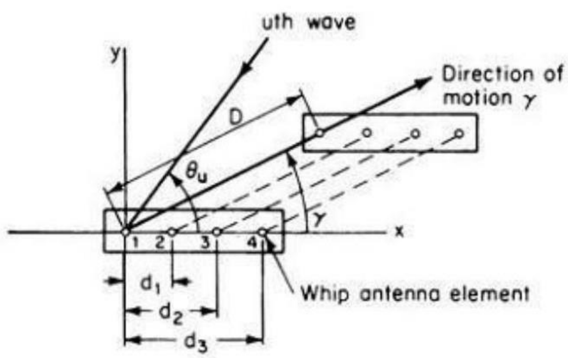
The scattered signals also arrive from different elevation angles. Lee and Brandt used two types of antenna, one $\lambda/4$ whip antenna with elevation coverage of 39◦ and one 4-dB-gain antenna (4-dB gain with respect to the gain of a dipole) with elevation coverage of 16◦ and measured the angle of signal arrival in the suburban Keyport-Matawan area of New Jersey. There are two types of test: a line-of-sight condition and an out-of-sight condition. In Lee and Brandt's study, the transmitter was located at an elevation of approximately 100 m (300 ft) above sea level.

The measured areas were about 12 m (40 ft) above sea level and the path length about 3 mi. The received signal from the 4-dB-gain antenna was 4 dB stronger than that from the whip antenna under line-of- sight conditions. This is what we would expect.

However, the received signal from the 4-dB-gain antenna was only about 2 dB stronger than that from the whip antenna under out-of-sight conditions. This is surprising. The reason for the latter observation is that the scattered signals arriving under out-of- sight conditions are spread over a wide elevation angle. A large portion of the signals outside the elevation angle of 16◦ cannot be received by the high-gain antenna. We may calculate the portion being received by the high-gain antenna from the measured beam width. For instance, suppose that a 4:1 gain (6 dBi) is expected from the high-gain antenna, but only 2.5:1 is received. Therefore, 63 percent of the signal is received by the 4-dB-gain antenna (i.e., 6 dBi) and 37 percent is felt in the region between 16 and 39◦

Therefore, a 2- to 3-dB-gain antenna (4 to 5 dBi) should be adequate for general use. An antenna gain higher than 2 to 3 dB does not serve the purpose of enhancing reception level. Moreover, measurements reveal that the elevation angle for scattered signals received in urban areas is greater than that in suburban areas.

	Gain, dBi	Linear ratio	$\theta_0/2$, degrees
Whip antenna (2 dB above isotropic)	2	1.58:1	39
High-gain antenna	6	4:1	16
Low-gain antenna	4	2.5:1	24



FREQUENCY MANAGEMENT AND CHANNEL ASSIGNMENT

The function of frequency management is to divide the total number of available channels into subsets which can be assigned to each cell either in a fixed fashion or dynamically (i.e., in response to any channel among the available channels). The terms ―frequency management‖ and ―channel assignment‖ often create some confusion. Frequency management refers to designating setup channels and voice channels (done by the FCC), numbering the channels (done by the FCC), and grouping the voice channels into subsets (done by each system according to its preference).

Channel assignment refers to the allocation of specific channels to cell sites and mobile units. A fixed channel set consisting of one more subsets is assigned to a cell site on a long-term basis. During a call, a particular channel is assigned to a mobile unit on a short- term basis. For a short-term assignment, one channel assignment per call is handled by the mobile telephone switching office (MTSO). Ideally channel assignment should be based on causing the least interference in the system. However, most cellular systems cannot perform this way.

NUMBERING THE RADIO CHANNELS

The total number of channels at present (January 1988) is 832. But most mobile units an systems are still operating on 666 channels. Therefore we describe the 666 channel numbering first. A channel consists of two frequency channel bandwidths, one in the low band and one in the high band. Two frequencies in channel 1 are 825.030 MHz (mobile transmit) 870.030 MHz (cell-site transmit). The two frequencies in channel 666 are 844.98 MHz (mobile transmit) and 898 MHz (cell-site transmit). The 666 channels are divided into two groups: block A system and block B system. Each market (i.e., each city) has two systems for a duopoly market policy. Each block has 333 channels, as shown in Fig.1.1.

The 42 set-up channels are assigned as follows.

Channels 313-333 block A

Channels 334-354 block B

The voice channels are assigned as follows.

Channels 1-312 (312 voice channels) block A

Channels 355-666 (312 voice channels) block B

	1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	1C	2C	3C	4C	5C	6C	7C	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	
	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	
	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	
	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	
	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	
	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	
	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	
	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	
	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	
	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	
	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	
Block A system	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	
	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	—	—	—	
	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	Control channel sets
	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	
	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	
Block B system	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	
	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	
	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	
	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	
	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	
	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	
	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	
	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	
	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	
	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	
	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	
	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	
	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	
	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	—	—	—	

Fig.4.1. Frequency management chart

These 42 set-up channels are assigned in the middle of all the assigned channels to facilitate scanning of those channels by frequency synthesizers. In the new additional spectrum allocation of 10 MHz (sec Fig. 1.2.), an additional 166 channels are assigned. Since a 1 MHz is assigned below 825 MHz (or 870 MHz) in the future, additional channels will be numbered up to 849 MHz (or 894 MHz) and will then circle back. The last channel number is 1023. There are no Channels between channels 799 and 991.

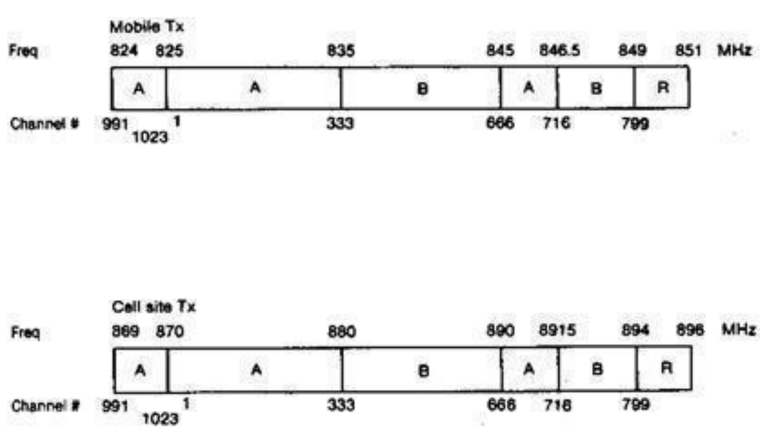


Fig.4.2. New additional spectrum allocation

GROUPING INTO SUBSETS

The number of voice channels for each system is 312. We can group these into any number of subsets. Since there are 21 set-up channels for each system, it is logical to group the 312 channels into 21 subsets. Each subset then consists of 16 channels. In each set, the closest adjacent channel is 21 channels away, as shown in Fig.1.1. The 16 channels in each subset can be mounted on a frame and connected to a channel combiner. Wide separation between adjacent channels is required for meeting the requirement of minimum isolation. Each 16-channel subset is idealized for each 16-channel combiner. In a seven- cell frequency-reuse cell system each cell contains three subsets, iA+iB+iC, where i is an integer from 1 to 7. The total number of voice channels in a cell is about 45. The minimum separation between three subsets is 7 channels. If six subsets are equipped in an omnicell site, the minimum separation between two adjacent channels can be only three (21/6> 3) physical channel bandwidths.

For example,

1A+1B+1C+4A+4B+4 C

Or

1A+1B+1C+5A+5B+5C

SET-UP CHANNELS

Set-up channels also called control channels are the channels designated to setup calls. We should not be confused by fact that a call always needs a set-up channel. A system can be operated without set-up channels. If we are choosing such a system all the 333 channels in each cellular system (block A or block B) can be voice channels; however each mobile unit must then scan 333 channels continuously and detect the signaling for its call. A customer who wants to initiate a call must scan all the channels and find an idle (unoccupied) one to use.

In a cellular system, we are implementing frequency-reuse concepts. In this case the set-up channels are acting as control channels. The 21 set-up channels are taken out from the total number of channels. The number 21 is derived from a seven-cell frequency-reuse pattern with three 120◦ sectors per cell, or a total of 21 sectors, which require 21 set-up channels. However, now only a few of the 21 setup channels are being used in each system. Theoretically, when cell size decreases the use of set-up channels should increase. Set-up channels can beclassified by usage into two types: access channels and paging channels.

An access channel is used for the mobile-originating calls and paging channels for the land originating calls. For this reason, a set-up channel is sometimes called an ‗access channel' and sometimes called a ‗paging channel.' Every two- way channel contains two 30-kHz bandwidth.. Normally one set-up channel is also specified by two operations as a forward set-up channel (using the upper band) and a reverse set-up channel (using the lower band). In the most common types of cellular systems, one set-up channel is used for both access and paging. The forward set-up channel functions as the paging channel for responding to the mobile-originating calls.The reverse set-up channel functions as the access channel for the responder to the paging call. The forward set- up channel is transmitted at the cell site, and the reverse set-up channel is transmitted at the mobile unit. All set- up channels carry data information only.

ACCESS CHANNELS:

In mobile-originating calls, the mobile unit scans its 21 set-up channels and chooses the strongest one. Because each set-up channel is associated with one cell, the strongest set-up channel indicates which cell is to serve the mobile-originating calls. Th. mobile unit detects the system information transmitted from the cell site. Also, the mobile unit monitors the Busy/Idle status bits over the desired forward setup channel. When the idle bits are received, the mobile unit can use the corresponding reverse set-up channel to initiate a call.

Frequently only one system operates in a given city; for instance, block B system might be operating and the mobile unit could be set to ―preferable A system.‖ When the mobile unit first scans the 21 set-up channels in block A, two conditions can occur.

1. If no set-up channels of block A are operational, the mobile unit automatically switches to block B.

2. If a strong set-up signal strength is received but no message can be detected, then the scanner chooses the second strongest set-up channel. If the message still cannot be detected, the mobile unit switches to block B and scans to block B set-up channels.

THE OPERATIONAL FUNCTIONS ARE DESCRIBED AS FOLLOWS:

1. POWER OF A FORWARD SET-UP CHANNEL [OR FORWARD CONTROL CHANNEL (FOCC)]: The power of the set-up channel can be varied in order to control the number of incoming calls served by the cell. The number of mobile-originating calls is limited by the number of voice channels in each cell site, when the traffic is heavy, mostvoice channels are occupied and the power of the set-up channel should be reduced in order to reduce the coverage of the cell for the incoming calls originating from the mobile unit. This will force the mobile units to originate calls from other cell sites, assuming that all cells are adequately overlapped.

2. THE SET-UP CHANNEL RECEIVED LEVEL: The setup channel threshold level is determined in order to control the reception at the reverse control channel (RECC). If the received power level is greater than the given set-up threshold level, the call request will be taken.

3. CHANGE POWER AT THE MOBILE UNIT: When the mobile unit monitors the strongest signal strength from all Set-up channels and selects that channel to receive the messages, there are three types ofmessage.

A. MOBILE STATION CONTROL MESSAGE. This message is used for paging and consists of one, two, or four words -DCC, MIN, SCC and VMAX.

B. SYSTEM PARAMETER OVERHEAD MESSAGE. This message contains two words, including DCC, SID, CMAX, or CPA.

c. CONTROL-FILLER MESSAGE. This message may be sent with a system parameter overhead message, CMAC—a control mobile attenuation code (seven levels).

4. DIRECT CALLS RETRY. When a cell site has no available voice channels, it can send a direct call-retry message through the set-up channel. The mobile unit will initiate, the call from a neighboring cell which is on the list of neighboring cells in the direct call-retry message.

PAGING CHANNELS:

Each cell site has been allocated its own setup channel (control channel). The assigned forward set-up channel (FOCC) of each cell site is used to page the mobile unit with the same mobile station control message.

Because the same message is transmitted by the different set-up channels, no simulcast interference occurs in the system. The algorithm for paging & mobile unit can be performed in different ways. The simplest way is to page from all the cell sites. This can occupy a large amount of the traffic load. The other way is to page in an area corresponding to the mobile unit phone number. If there is no answer, the system tries to page in other areas. The drawback is that response time is sometimes too long.

When the mobile unit responds to the page on the reverse set-up channel, the cell site which receives the response checks the signal reception level and makes a decision regarding the voice channel assignment based on least interference in the selected sector or underlay-overlay region.

FIXED CHANNEL ASSIGNMENT

ADJACENT-CHANNEL ASSIGNMENT:

Adjacent-channel assignment includes neighboring-channel assignment and next-channel assignment. The near-end–far-end (ratio) interference can occur among the neighboring channels (four channels on each side of the desired channel). Therefore, within a cell we have to be sure to assign neighboring channels in an Omni- directional-cell system and in a directional-antenna-cell system properly.

In an Omni-directional-cell system, if one channel is assigned to the middle cell of seven cells, next channels cannot be assigned in the same cell. Also, no next channel (preferably including neighboring channels) should be assigned in the six neighboring sites in the same cell system area (Fig. 7.3a). In a directional-antenna-cell system, if one channel is assigned to a face, next channels cannot be assigned to the same face or to the other two faces in the same cell. Also, next channels cannot be assigned to the other two faces at the same cell site (Fig. 7.3b). Sometimes the next channels are assigned in the next sector of the same cell in order to increase capacity. Then performance can still be in the tolerance range if the design is proper.

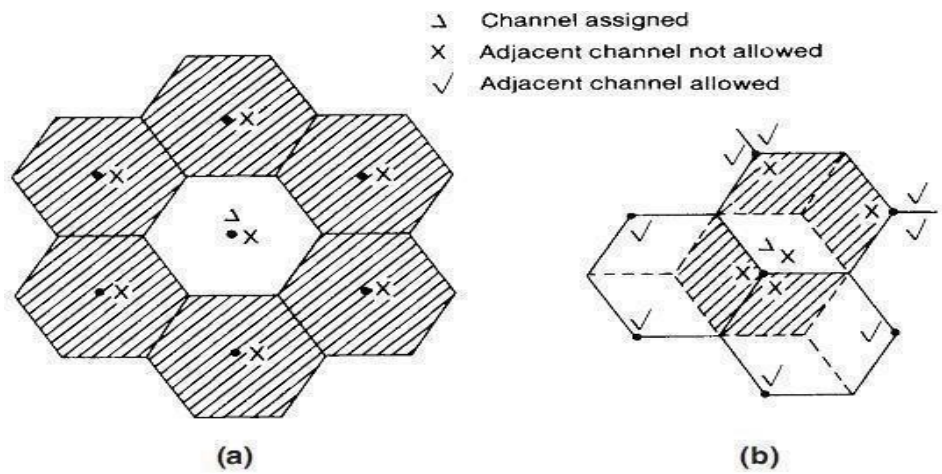


Fig.4.3 Adjacent channel assignment (a) Omni direction antenna cells; (b) Directional antenna cells

CHANNEL SHARING

Channel sharing is a short-term traffic-relief scheme. A scheme used for a seven-cell three-face system is shown in Fig. 7.2. There are 21 channel sets, with each set consisting of about 16 channels. Figure7.2 shows the channel set numbers. When a cell needs more channels, the channels of another face at the same cell site can be shared to handle the short-term overload. To obey the adjacent-channel assignment algorithm, the sharing is always cyclic. Sharing always increases the trunking efficiency of channels.

Since we cannot allow adjacent channels to share with the nominal channels in the same cell, channel sets 4 and 5 cannot both be shared with channel sets 12 and 18, a indicated by the grid mark. Many grid marks are indicated in Fig.7.2 for the same reason. However, the upper subset of set 4 can be shared with the lower subset of set 5 with no interference. In channel-sharing systems, the channel combiner should be flexible in order to combine up to 32 channels in one face in real time. An alternative method is to install a standby antenna.

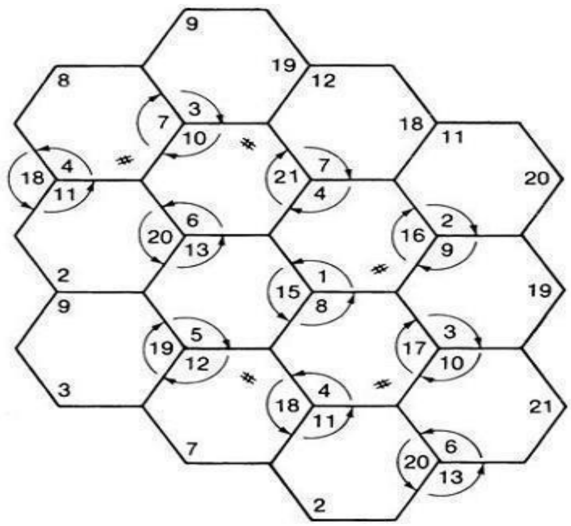


Fig.4.4. Channel sharing algorithm

CHANNEL BORROWING

Channel borrowing is usually handled on a long-term basis. The extent of borrowing more available channels from other cells depends on the traffic density in the area. Channel borrowing can be implemented from one cell-site face to another face at the same cell site. In addition, the central cell site can borrow channels from neighboring cells. The channel-borrowing scheme is used primarily for slowly-growing systems. It is often helpful in delaying cell splitting in peak traffic areas. Since cell splitting is costly, it should be implemented only as a last resort.

ADVANTAGE OF SECTORIZATION:

The total number of available channels can be divided into sets (subgroups) depending on the Sectorization of the cell configuration: the 120◦-sector system, the 60◦-sector system, and the 45◦-sector system. In certain locations and special situations, the sector angle can be reduced (narrowed) in order to assign more channels in one sector without increasing neighboring-channel interference. Sectorization serves the same purpose as the channel-borrowing scheme in delaying cell splitting. In addition, channel coordination to avoid co- channel interference is much easier in sectorization than in cell splitting. Given the same number of channels, trunking efficiency decreases in Sectorization.

SECTORIZED CELLS: There are three basic types.

1. The 120◦-sector cell is used for both transmitting and receiving Sectorization. Each sector has an assigned a number of frequencies. Changing sectors during a call requires handoffs.

2. The 60◦-sector cell is used for both transmitting and receiving Sectorization. Changing sectors during a call requires handoffs. More handoffs are expected for a 60◦ sector than a 120◦ sector in areas close to cell sites

(close-in areas).

3. The 120◦ or 60◦-sector cell is used for receiving Sectorization only. In this case, the transmitting antenna is Omni directional. The number of channels in this cell is not sub- divided for each sector. Therefore, no handoffs are required when changing sectors. This receiving-Sectorization-only configuration does not decrease interference or increase the D/R ratio; it only allows for a more accurate decision regarding handing off the calls to neighboring cells.

UNDERLAY-OVERLAY ARRANGEMENT

In actual cellular systems cell grids are seldom uniform because of varying traffic conditions in different areas and cell-site locations.

OVERLAID CELLS:

To permit the two groups to reuse the channels in two different cell-reuse patterns of the same size, an —under laid‖ small cell is sometimes established at the same cell site as the large cell (see Fig. 7.5a). The —doughnut‖ (large) and —hole‖ (small) cells are treated as two different cells. They are usually considered as —neighboring cells.‖

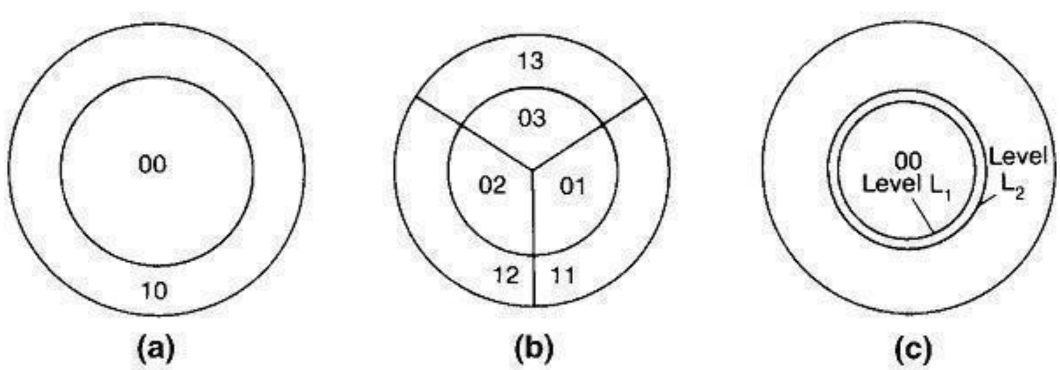


Fig.4.5.Under laid-overlaid cell arrangements. (a) Underlay-overlay in omnicell; (b) Underlay-overlay in Sectorized cell; (c) Two level handoff scheme

The use of either an Omni directional antenna at one site to create two sub ring areas or three directional antennas to create six subareas is illustrated in Fig. 4.5 b. As seen in Fig.4.5, a set of frequencies used in an overlay area will differ from a set of frequencies used in an underlay area in order to avoid adjacent-channel and co-channel interference.

The channels assigned to one combiner—say, 16 channels—can be used for overlay, and another combiner can be used for underlay.

IMPLEMENTATION:

The antenna of a set-up channel is usually Omni directional. When an incoming call is received by the set-up channel and its signal strength is higher than a level L, the under laid cell is assigned; otherwise, the overlaid cell is assigned. The handoffs are implemented between the under laid and overlaid cells. In order to avoid the unnecessary handoffs, we may choose two levels L1 and L2 and L1 > L2 as shown in Fig. 4.5 (c). When a mobile signal is higher than a level L1 the call is handed off to the under laid cell. When a signal is lower than a level L2 the call is handed off to the overlaid cell. The channels assigned in the under laid cell have more protection against co-channel interference.

NON FIXED CHANNEL ASSIGNMENT STRATEGY

1. FIXED CHANNEL ASSIGNMENT: The fixed channel assignment (FCA) algorithm is the most common algorithm adopted in many cellular systems. In this algorithm, each cell assigns its own radio channels to the vehicles within its cell.

2. DYNAMIC CHANNEL ASSIGNMENT: In dynamic channel assignment (DCA), no fixed channels are assigned to each cell. Therefore, any channel in a composite of N radio channels can be assigned to the mobile unit. This means that a channel is assigned directly to a mobile unit. On the basis of overall system performance, DCA can also be used during a call.

3. HYBRID CHANNEL ASSIGNMENT: Hybrid channel assignment (HCA) is a combination of FCA and DCA. A portion of the total frequency channels will use FCA and the rest will use DCA.

4. BORROWING CHANNEL ASSIGNMENT: Borrowing channel assignment (BCA) uses FCA as a normal assignment condition. When all the fixed channels are occupied, then the cell borrows channels from the neighboring cells.

5. FORCIBLE-BORROWING CHANNEL ASSIGNMENT: In forcible-borrowing channel assignment (FBCA), if a channel is in operation and the situation warrants it, channels must be borrowed from the neighboring cells and at the same time, another voice channel will be assigned to continue the call in the neighboring cell. There are many different ways of implementing FBCA. In a general sense, FBCA can also be applied while accounting for the forcible borrowing of the channels within a fixed channel set to reduce the chance of co-channel assignment in a reuse cell pattern. The FBCA algorithms based on assigning a channel dynamically but obeying the rule of reuse distance.

The distance between the two cells is reuse distance, which is the minimum distance at which no co-channel interference would occur. Very infrequently, no channel can be borrowed in the neighboring cells. Even those channels currently in operation can be forcibly borrowed and will be replaced by a new channel in the neighboring cell or the neighboring cell of the neighboring cell. If all the channels in the neighboring cells cannot be borrowed because of interference problems, the FBCA stops.

HANDOFFS

WHY HAND OFF IS NECESSARY?

In an analog system, once a call is established, the set-up channel is not used again during the call period. Therefore, handoff is always implemented on the voice channel. In the digital systems, the handoff is carried out through paging or common control channel. The value of implementing handoffs is dependent on the size of the cell. For example, if the radius of the cell is 32 km (20 mi), the area is 3217 km^2(1256 mi^2). After a call is initiated in this area, there is little chance that it will be dropped before the call is terminated as a result of a weak signal at the coverage boundary. Then why bother to implement the handoff feature? Even for a 16-km radius, cell handoff may not be needed. If a call is dropped in a fringe area, the customer simply redials and reconnects the call. Today the size of cells becomes smaller in order to increase capacity. Also people talk longer. The handoffs are very essential. Handoff is needed in two situations where the cell site receives weak signals from the mobile unit: (1) at the cell boundary, say, −100 dBm, which is the level for requesting a handoff in a noise-limited environment; and (2) when the mobile unit is reaching the signal-strength holes (gaps) within the cell site as shown in Fig.1.

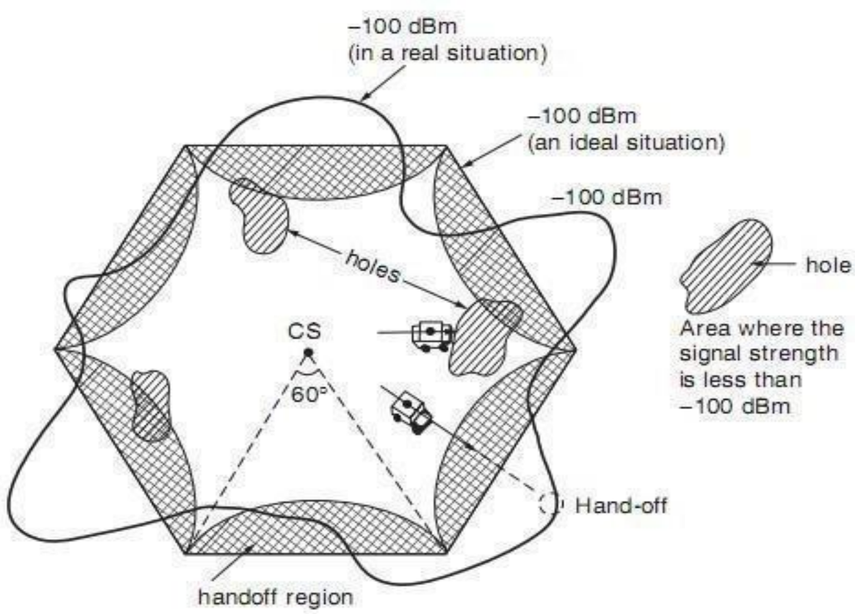


Fig.1. Occurrence of handoffs

THE TWO DECISIONS MAKING PARAMETERS OF HANDOFF

There are two decision-making parameters of handoff: (1) that based on signal strength and (2) that based on carrier-to-interference ratio. The handoff criteria are different for these two types. In type 1, the signal-strength threshold level for handoff is −100 dBm in noise-limited systems and −95 dBm in interference-limited systems. In type 2, the value of C/I at the cell boundary for handoff should be at a level, 18 dB for AMPS in order to have toll quality voice. Sometimes, a low value of C/I may be used for capacity reasons.

Type 1: It is easy to implement. The location receiver at each cell site measures all the signal strengths of all receivers at the cell site. However, the received signal strength (RSS) itself includes interference.

RSS = C + I

where C is the carrier signal power and I is the interference. Suppose that we set up a threshold level for RSS; then, because of the I , which is sometimes very strong, the RSS level is higher and far above the handoff threshold level. In this situation handoff should theoretically take place but does not. Another situation is when I is very low but RSS is also low. In this situation, the voice quality usually is good even though the RSS level is low, but since RSS is low, unnecessary handoff takes place. Therefore, it is an easy but not very accurate method of determining handoffs. Some analog systems use SAT information together with the received signal level to determine handoffs. Some CDMA systems use pilot channel information.

Type 2: Handoffs can be controlled by using the carrier-to-interference ratio C/I C+I/I = C/I

we can set a level based on C/I ,so C drops as a function of distance but I is dependent on the location. If the handoff is dependent on C/I , and if the C/I drops, it does so in response to increase in (1) propagation distance or (2) interference. In both cases, handoff should take place. In today's cellular systems, it is hard to measure C/I during a call because of analog modulation. Sometimes we measure the level I before the call is connected, and the level C + I during the call. Thus (C + I)/I can be obtained.

TYPES OF HANDOFF

There are four types of handoff:

1. **INTERSECTOR OR SOFTER HANDOFF**

   The mobile communicates with two sectors of the same cell (see Fig. 10-1). A RAKE receiver at the base station combines the best versions of the voice frame from the diversity antennas of the two sectors into a single traffic frame.

2. **INTERCELL OR SOFT HANDOFF**

   The mobile communicates with two or three sectors of different cells (see Fig. 10-2). The base station that has the direct control of call processing during handoff is referred to as the primary base station. The primary base station can initiate the forward control message. Other base stations that do not have control over call processing are called the secondary base stations. Soft handoff ends when either the primary or secondary base station is dropped. If the primary base station is dropped, the secondary base station becomes the new primary for this call. A three-way soft handoff may end by first dropping one of the base stations and becoming a two-way soft handoff. The base stations involved coordinate handoff by exchanging information via SS7 links. A soft handoff uses considerably more network resources than the softer handoff.

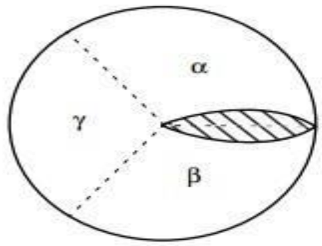
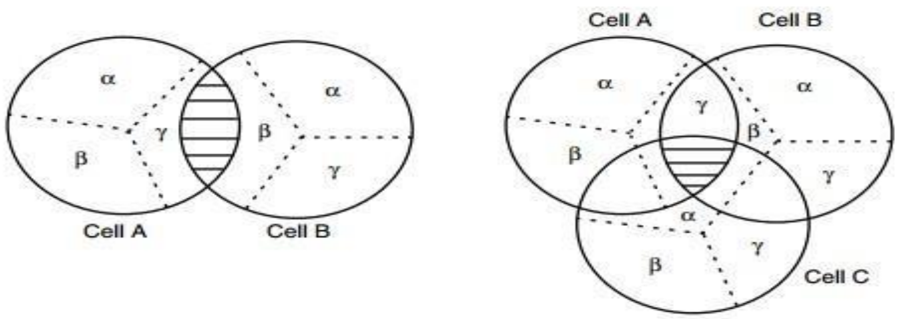


Figure 10-1 Softer Handoff



Two-Way Soft Handoff   Three-Way Soft Handoff

Figure 10-2 Soft Handoff

3. SOFT-SOFTER HANDOFF

The mobile communicates with two sectors of one cell and one sector of another cell (see Fig. 10-3). Network resources required for this type of handoff include the resources for a two-way soft handoff between cell A and B plus the resources for a softer handoff at cell B.

4. HARD HANDOFF

Hard handoffs are characterized by the break-before-make strategy. The connection with the old traffic channel is broken before the connection with the new traffic channel is established. Scenarios for hard handoff include

◆ Handoff between base stations or sectors with different CDMA carriers

◆ Change from one pilot to another pilot without first being in soft handoff with the new pilot (disjoint active sets)

◆ Handoff from CDMA to analog, and analog to CDMA

◆ Change of frame offset assignment—CDMA traffic frames are 20 ms long. The start of frames in a particular traffic channel can be at 0 time in reference to a system or it can be offset by up to 20 ms (allowed in IS- 95). This is known as the frame offset. CDMA traffic channels are assigned different frame offset to avoid congestion. The frame offset for a particular traffic channel is communicated to the mobile. Both forward and reverse links use this offset. A change in offset

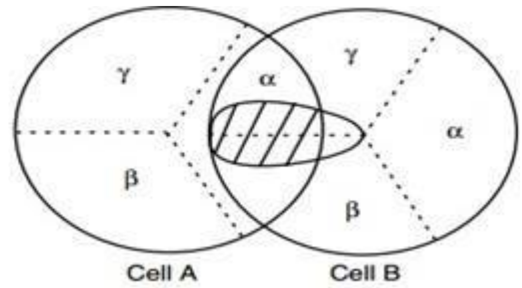


Fig 10.3 Soft-Softer Handoff

Assignment will disrupt the link. During soft handoff the new base station must allocate the same frame offset to the mobile as assigned by the primary base station. If that particular frame offset is not available, a hard handoff may be required. Frame offset is a network resource and can be used up

HANDOFF INITIATION

A hard handoff occurs when the old connection is broken before a new connection is activated. The performance evaluation of a hard handoff is based on various initiation criteria [1, 3, 13]. It is assumed that the signal is averaged over time, so that rapid fluctuations due to the multipath nature of the radio environment can be eliminated. Numerous studies have been done to determine the shape as well as the length of the averaging window and the older measurements may be unreliable. Figure 1.2 shows a MS moving from one BS (BS1) to another (BS2). The mean signal strength of BS1 decreases as the MS moves away from it. Similarly, the mean signalstrength of BS2 increases as the MS approaches it. This figure is used to explain various approaches described in the following subsection.

RELATIVE SIGNAL STRENGTH

This method selects the strongest received BS at all times. The decision is based on a mean measurement of the received signal. In Figure 1.2, the handoff would occur at position A. This method is observed to provoke too many unnecessary handoffs, even when the signal of the current BS is still at an acceptable level.

RELATIVE SIGNAL STRENGTH WITH THRESHOLD

This method allows a MS to hand off only if the current signal is sufficiently weak (less than threshold) and the other is the stronger of the two. The effect of the threshold depends on its relative value as compared to the signal strengths of the two BSs at the point at which they are equal. If the threshold is higher than this value, say T1 in Figure 1.2, this scheme performs exactly like the relative signal strength scheme, so the handoff occurs at position A. If the threshold is lower than this value, say T2 in Figure 1.2, the MS would delay handoff until the current signal level crosses the threshold at position B. In the case of T3, the delay may be so long that the MS drifts too far into the new cell.

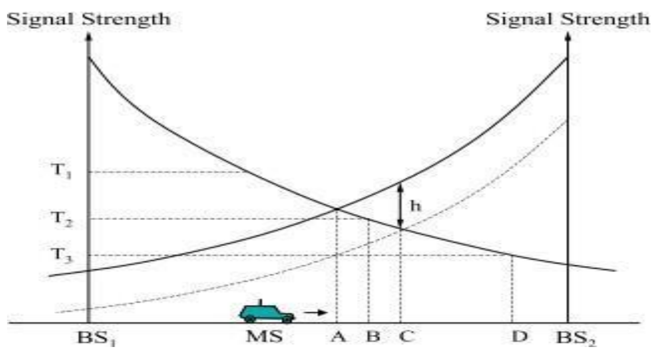


Figure 1.2 Signal strength and hysteresis between two adjacent BSs for potential handoff.

This reduces the quality of the communication link from BS1 and may result in a dropped call. In addition, this results in additional interference to cochannel users. Thus, this scheme may create overlapping cell coverage areas. A threshold is not used alone in actual practice because its effectiveness depends on prior knowledge of the crossover signal strength between the current and candidate BSs.

RELATIVE SIGNAL STRENGTH WITH HYSTERESIS

This scheme allows a user to hand off only if the new BS is sufficiently stronger (by a hysteresis margin, h in Figure 1.2) than the current one. In this case, the handoff would occur at point C. This technique prevents the so-called ping-pong effect, the repeated handoff between two BSs caused by rapid fluctuations in the received signal strengths from both BSs. The first handoff, however, may be unnecessary if the serving BS is sufficiently strong.

RELATIVE SIGNAL STRENGTH WITH HYSTERESIS AND THRESHOLD

This scheme hands a MS over to a new BS only if the current signal level drops below a threshold and the target BS is stronger than the current one by a given hysteresis margin. In Figure 1.2, the handoff would occur at point D if the threshold is T3

PREDICTION TECHNIQUES

Prediction techniques base the handoff decision on the expected future value of the received signal strength. A technique has been proposed and simulated to indicate better results, in terms of reduction in the number of unnecessary handoffs, than the relative signal strength, both without and with hysteresis, and threshold methods.

CONCEPT OF DELAYING A HANDOFF

In many cases, a two-handoff-level algorithm is used. The purpose of creating two request handoff levels is to provide more opportunity for a successful handoff. A handoff could be delayed if no available cell could take the call. A plot of signal strength with two request handoff levels and a threshold level is shown in Fig.3. The plot of average signal strength is recorded on the channel received

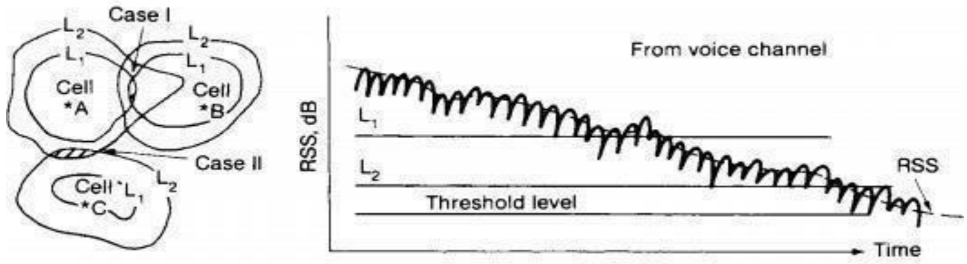


Fig.3. A two level handoff scheme

Signal strength indicator (RSSI), which is installed at each channel receiver at the cell site. When the signal strength drops below the first handoff level, a handoff request is initiated. If for some reason the mobile unit is in ahole (a weak spot in a cell) or a neighboring cell is busy, the handoff will be requested periodically every 5 s. At the first handoff level, the handoff takes place if the new signal is stronger. However, when the second handoff level is reached, the call will be handed off with no condition. The MSO always handles the handoff call first and the originating calls second. If no neighboring calls are available after the second handoff level is reached, the call continues until the signal strength drops below the threshold level; then the call is dropped. In AMPS systems if the supervisory audio tone (SAT) is not sent back to the cell site by the mobile unit within 5 s, the cell site turns off the transmitter.

ADVANTAGES OF DELAYED HANDOFF

1. Consider the following example. The mobile units are moving randomly and the terrain contour is uneven. The received signal strength at the mobile unit fluctuates up and down. If the mobile unit is in a hole for less than 5 s (a driven distance of 140 m for 5 s, assuming a vehicle speed of 100 km/h), the delay (in handoff) can even circumvent the need for a handoff. If the neighboring cells are busy, delayed handoff may take place. In principle, when call traffic is heavy, the switching processor is loaded, and thus a lower number of handoffs would help the processor handle call processing more adequately. Of course, it is very likely that after the second handoff level is reached, the call may be dropped with great probability.
2. The other advantage of having a two-handoff-level algorithm is that it makes thehandoff occur atthe proper location and eliminates possible interference in the system. Figure 3, case I, shows the area where the first-level handoff occurs between cell A and cell B. If we only use the second-level handoff boundary of cell A, the area of handoff is too close to cell B. Figure 3, case II, also shows where the second-level handoff occurs between cell A and cell C. This is because the first-level handoff cannot be implemented.

POWER DIFFERENCE HANDOFF

A better algorithm is based on the power difference (_) of a mobile signal received by two cell sites, home andhandoff. _ can be positive or negative. The handoff occurs depending on a preset value of _.

_ the mobile signal measured at the candidate handoff site

− The mobile signal measured at the

home siteFor example, the following cases can

occur.

_> 3 dB request a handoff

1dB <_< 3 dB prepare a handoff

−3dB <_< 0 dB monitoring the signal strength

_< −3 dB no handoff

Those numbers can be changed to fit the switch processor capacity. This algorithm is not based on the received signal strength level, but on a relative (power difference) measurement. Therefore, when this algorithm is used, all the call handoffs for different vehicles can occur at the same general location in spite of different mobile antenna gains or heights.

FORCED HANDOFF

A forced handoff is defined as a handoff that would normally occur but is prevented from happening, or a handoff that should not occur but is forced to happen.

MOBILE-ASSISTED HANDOFF

In a mobile-assisted handoff process, the MS makes measurements and the network makes thedecision. In the circuit switched GSM (global system mobile), the BS controller (BSC) is in charge of the radio interface management. This mainly means allocation and release of radio channels and handoff management. The handoff time between handoff decision and execution in such a circuit-switched GSM is approximately 1 second.

SOFT HANDOFF

SOFT HANDOFF (FORWARD LINK)

In this case all traffic channels assigned to the mobile are associated with pilots in the active set and carry the same traffic information with the exception of power control subchannel. When the active set contains more than one pilot, the mobile provides diversity by combining its associated forward traffic channels.

SOFT HANDOFF (REVERSE LINK)

During intercell handoff, the mobile sends the same information to both base stations. Each base station receives the signal from the mobile with appropriate propagation delay. Each base station then transmits the received signal to the vocoder/selector. In other words, two copies of the same frame are sent to the vocoder/selector. The vocoder/selector selects the better frame and discards the other.

SOFTER HANDOFF (REVERSE LINK)

During intersector handoff, the mobile sends the same information to both sectors. The channel card/element at the cell site receives the signals from both sectors. The channel card combines both inputs, and only one frame is sent to the vocoder/selector. It should be noted that extra channel cards are not required to support softer handoff as is the case for soft handoffs. The diversity gain from soft handoffs is more than the

diversity gain from softer handoffs because signals from distinct cells are less correlated than signals from sectors of the same cell.

10.2.4 BENEFIT OF SOFT HANDOFF

A key benefit of soft handoff is the path diversity on the forward and reverse traffic channels. Diversity gain is obtained because less power is required on the forward and reverse links. This implies that total system interference is reduced. As a result, the average system capacity is improved. Also less transmit power from the mobile results in longer battery life and longer talk time. In a soft handoff, if a mobile receives an up power control bit from one base station and a down control bit from the second base station, the mobile decreases its transmit power. The mobile obeys the power down command since a good communications link must have existed to warrant the command from the second base station.

INTERSYSTEM HANDOFF

Occasionally, a call may be initiated in one cellular system (controlled by one MSO) and enter another system (controlled by another MSO) before terminating. In some instances, intersystem handoff can take place; this means that a call handoff can be transferred from one system to a second system so that the call is continued while the mobile unit enters the second system. The software in the MSO must be modified to apply this situation. Consider the simple diagram shown in Fig.7. The car travels on a highway and the driver originates a call in system A. Then the car leaves cell site A of system A and enters cell site B of system B. Cell sites A and B are controlled by two different MSOs. When the mobile unit signal becomes weak in cell site A, MSO A searches for a candidate cell site in its system and cannot find one. Then MSO A sends

The handoff request to MSO B through a dedicated line between MSO A and MSO B, and MSO B makes a complete handoff during the call conversation. This is just a one-point connection case. There are many ways of implementing intersystem handoffs, depending on the actual circumstances. For instance, if two MSOs are manufactured by different companies, then compatibility must be determined before implementation of intersystem handoff

can be considered.

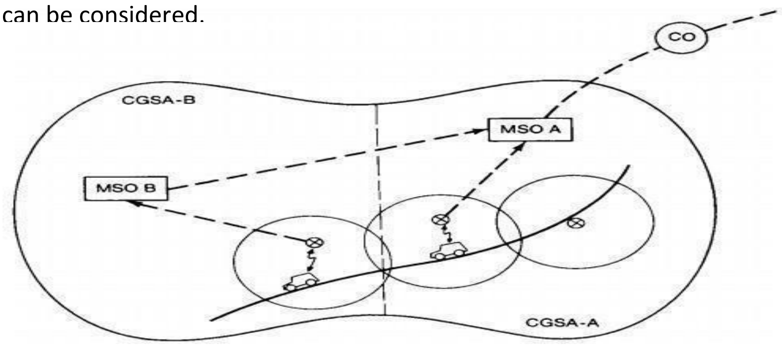


Fig.7. Intersystem handoffs

1. Why hand off is necessary?

In an analog system, once a call is established, the set-up channel is not used again during thecall period. Therefore, handoff is always implemented on the voice channel. In the digital systems, the handoff is carried out through paging or common control channel. The value of implementing handoffs is dependent on the size of the cell. For example, if the radius of the cell is 32 km (20 mi), the area is 3217 km^2(1256 mi^2). After a call is initiated in this area, there is little chance that it will be dropped before the call is terminated as a result of a weak signal at the coverage boundary. Then why bother to implement the handoff feature? Even for a 16-km radius, cell handoff may not be needed. If a call is dropped in a fringe area, the customer simply redials and reconnects the call. Today the size of cells becomes smaller in order to increase capacity. Also people talk longer. The handoffs are very essential. Handoff is needed in two situations where the cell site receives weak signals from the mobile unit: (1) at the cell boundary, say, −100 dBm, which is the level for requesting a handoff in a noise-limited environment; and
(2) when the mobile unit is reaching the signal-strength holes (gaps) within the cell site as shownin Fig.1.

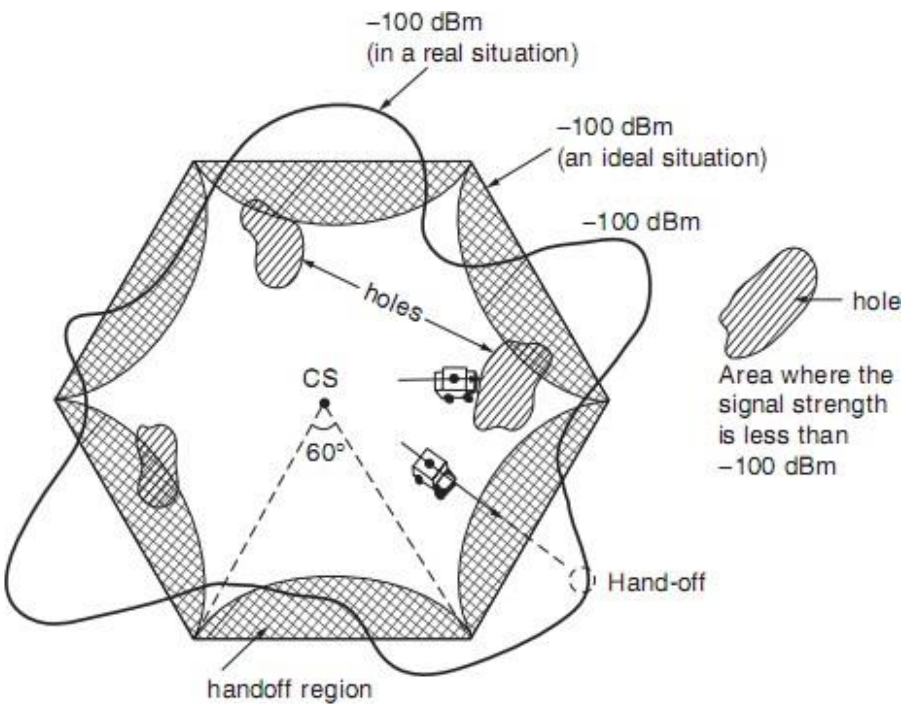


Fig.1. Occurrence of handoffs

2. What are the two decision making parameters of handoff explain.

There are two decision-making parameters of handoff: (1) that based on signal strength and (2) that based on carrier-to-interference ratio. The handoff criteria are different for these two types. In type 1, the signal-strength threshold level for handoff is −100 dBm in noise-limited systemsand −95 dBm in interference-limited systems. In type 2, the value of C/I at the cell boundary for handoff should be at a level, 18 dB for AMPS in order to have toll quality voice. Sometimes, alow value of C/I may be used for capacity reasons.

Type 1: It is easy to implement. The location receiver at each cell site measures all the signalstrengths of all receivers at the cell site. However, the received signal strength (RSS) itself includes interference.

$$RSS = C + I$$

where C is the carrier signal power and I is the interference. Suppose that we set up a threshold level for RSS; then, because of the I , which is sometimes very strong, the RSS level is higher and far above the handoff threshold level. In this situation handoff should theoretically take place but does not. Another situation is when I is very low but RSS is also low. In this situation, the voice quality usually is good even though the RSS level is low, but since RSS is low, unnecessary handoff takes place. Therefore, it is an easy but not very accurate method of determining handoffs. Some analog systems use SAT information together with the receivedsignal level to determine handoffs. Some CDMA systems use pilot channel information.

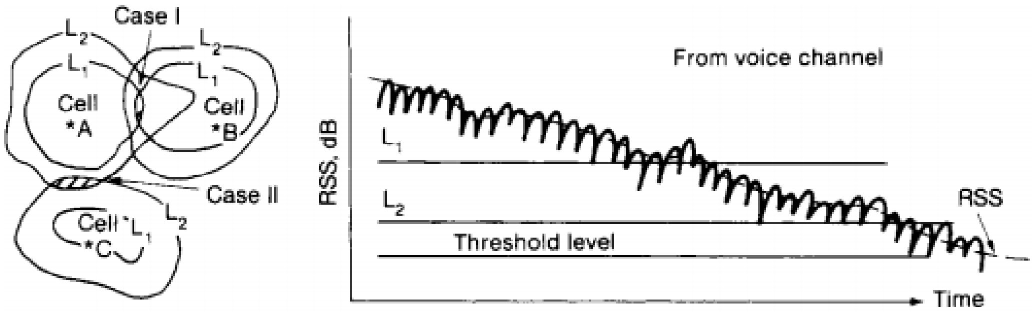
Type 2: Handoffs can be controlled by using the carrier-to-interference ratio C/I

$$C+I/I = C/I$$

we can set a level based on C/I ,so C drops as a function of distance but I is dependent on the location. If the handoff is dependent on C/I , and if the C/I drops, it does so in response to increase in (1) propagation distance or (2) interference. In both cases, handoff should take place. In today's cellular systems, it is hard to measure C/I during a call because of analog modulation. Sometimes we measure the level I before the call is connected, and the level C + I during the call. Thus (C + I)/I can be obtained. Another method of measuring C/I is described in Sec. 9.3.

3. Concept of delaying a handoff

In many cases, a two-handoff-level algorithm is used. The purpose of creating two request handoff levels is to provide more opportunity for a successful handoff. A handoff could be delayed if no available cell could take the call. A plot of signal strength with two request handoff levels and a threshold level is shown in Fig.3. The plot of average signal strength is recorded on the channel received



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Consider the following example. The mobile units are moving randomly and the terrain contour is uneven. The received signal strength at the mobile unit fluctuates up and down. If the mobile unit is in a hole for less than 5 s (a driven distance of 140 m for 5 s, assuming a vehicle speed of 100 km/h), the delay (in handoff) can even circumvent the need for a handoff. If the neighboring cells are busy, delayed handoff may take place. In principle, when call traffic is heavy, the switching processor is loaded, and thus a lower number of handoffs would help the processor handle call processing more adequately. Of course, it is very likely that after the second handoff level is reached, the call may be dropped with great probability. The other advantage of having a two-handoff-level algorithm is that it makes the handoff occur at the proper location and eliminates possible interference in the system. Figure 3, case I, shows the area where the first- level handoff occurs between cell A and cell B. If we only use the second-level handoff boundary of cell A, the area of handoff is too close to cell B. Figure 3, case II, also shows where the second-level handoff occurs between cell A and cell C. This is because the first-level handoff cannot be implemented.

5. Write about forced handoff

A forced handoff is defined as a handoff that would normally occur but is prevented fromhappening, or a handoff that should not occur but is forced to happen.

Controlling a Handoff:

The cell site can assign a low handoff threshold in a cell to keep a mobile unit in a cell longer or assign a high handoff threshold level to request a handoff earlier. The MSO also can control a handoff by making either a handoff earlier or later, after receiving a handoff request from a cell site.

Creating a Handoff:

In this case, the cell site does not request a handoff but the MSO finds that some cells are too congested while others are not. Then, the MSO can request call sites to create early handoffs for those congested cells. In other words, a cell site has to follow the MSO's order and increase the handoff threshold to push the mobile units at the new boundary and to handoff earlier.

Queuing of handoff:

Queuing of handoffs is more effective than two-threshold-level handoffs. The MSO will queue the requests of handoff calls instead of rejecting them if the new cell sites are busy. A queuing scheme becomes effective only when the requests for handoffs arrive at the MSO in batches or bundles. If handoff requests arrive at the MSO uniformly, then the queuing scheme is not needed. Before showing the equations, let us define the parameters as follows. $1/\mu$ averagecalling time in seconds, including new calls and handoff calls in each cell

$\lambda 1$	arrival rate ($\lambda 1$ calls per second) for originating calls
$\lambda 2$	arrival rate ($\lambda 2$ handoff calls per second) for handoff calls
M1	size of queue for originating calls
M2	size of queue for handoff calls
N	number of voice channels
a	$(\lambda 1 + \lambda 2)/\mu$
b1	$\lambda 1/\mu$
b2	$\lambda 2/\mu$

The following analysis can be used to see the improvement. We are analyzing three cases.

1. No queuing on either the originating calls or the handoff calls. The blocking for either an originating call or a handoff call is

$$B_o = \frac{a^N}{N!} P(0)$$

Where

$$P(0) = \left(\sum_{n=0}^{N} \frac{a^N}{n!} \right)^{-1}$$

2. Queuing the originating calls but not the handoff calls. The blocking probability for originating calls is

$$B_{oq} = \left(\frac{b_1}{N} \right)^{M_1} P_q(0)$$

Where

$$P_q(0) = \left[N! \sum_{n=0}^{N-1} \frac{a^{n-N}}{n!} + \frac{1 - (b_1/N)^{M_1+1}}{1 - (b_1/N)} \right]^{-1}$$

The blocking probability for handoff calls is

$$B_{oh} = \frac{1 - (b_1/N)^{M_1+1}}{1 - (b_1/N)} P_q(0)$$

3. Queuing the handoff calls but not the originating calls. The blocking probability for handoff calls is

$$B_{hq} = \left(\frac{b_2}{N} \right)^{M_2} P_q(0)$$

The blocking probability for originating calls is

$$B_{ho} = \frac{1 - (b_2/N)^{M_2+1}}{1 - (b_2/N)} P_q(0)$$

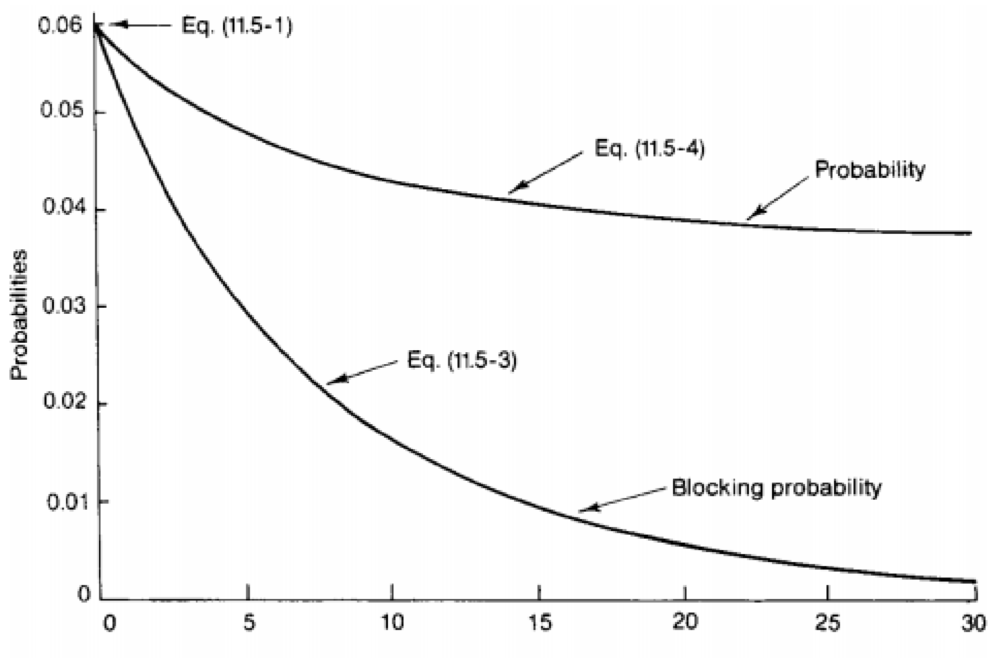

Fig.5. Originating queue size

We have seen (Fig.5.) with queuing of originating calls only, the probability of blocking is reduced. However, queuing of originating calls results in increased blocking probability on handoff calls, and this is a drawback. With queuing of handoff calls only, blocking probability is reduced from 5.9 to 0.1 percent by using one queue space. Therefore it is very worthwhile to implement a simple queue (one space) for handoff calls. Adding queues in handoff calls does not affect the blocking probability of originating calls. However, we should always be aware that queuing for the handoff is more important than queuing for those initiating calls on assignedvoice channels because call drops upset customers more than call blockings.

6. Write about Power difference handoff

A better algorithm is based on the power difference (Δ) of a mobile signal received by two cell sites, home and handoff. Δ can be positive or negative. The handoff occurs depending on a presetvalue of Δ.

Δ = the mobile signal measured at the candidate handoff site

− the mobile signal measured at the home siteFor

example, the following cases can occur.

Δ> 3 dB request a handoff1dB <Δ<

3 dB prepare a handoff

−3dB <Δ< 0 dB monitoring the signal strength

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Those numbers can be changed to fit the switch processor capacity. This algorithm is not basedon the received signal strength level, but on a relative (power difference) measurement. Therefore, when this algorithm is used, all the call handoffs for different vehicles can occur at the same general location in spite of different mobile antenna gains or heights.

7. What is Intersystem handoff?

Occasionally, a call may be initiated in one cellular system (controlled by one MSO) and enter another system (controlled by another MSO) before terminating. In some instances, intersystem handoff can take place; this means that a call handoff can be transferred from one system to a second system so that the call is continued while the mobile unit enters the second system. The software in the MSO must be modified to apply this situation. Consider the simple diagramshown in Fig.7. The car travels on a highway and the driver originates a call in system A. Then the car leaves cell site A of system A and enters cell site B of system B. Cell sites A and B are controlled by two different MSOs. When the mobile unit signal becomes weak in cell site A, MSO A searches for a candidate cell site in its system and cannot find one. Then MSO A sends the handoff request to MSO B through a dedicated line between MSO A and MSO B, and MSOB makes a complete handoff during the call conversation. This is just a one-point connection case. There are many ways of implementing intersystem handoffs, depending on the actual circumstances. For instance, if two MSOs are manufactured by different companies, then compatibility must be determined before implementation of intersystem handoff can be considered.

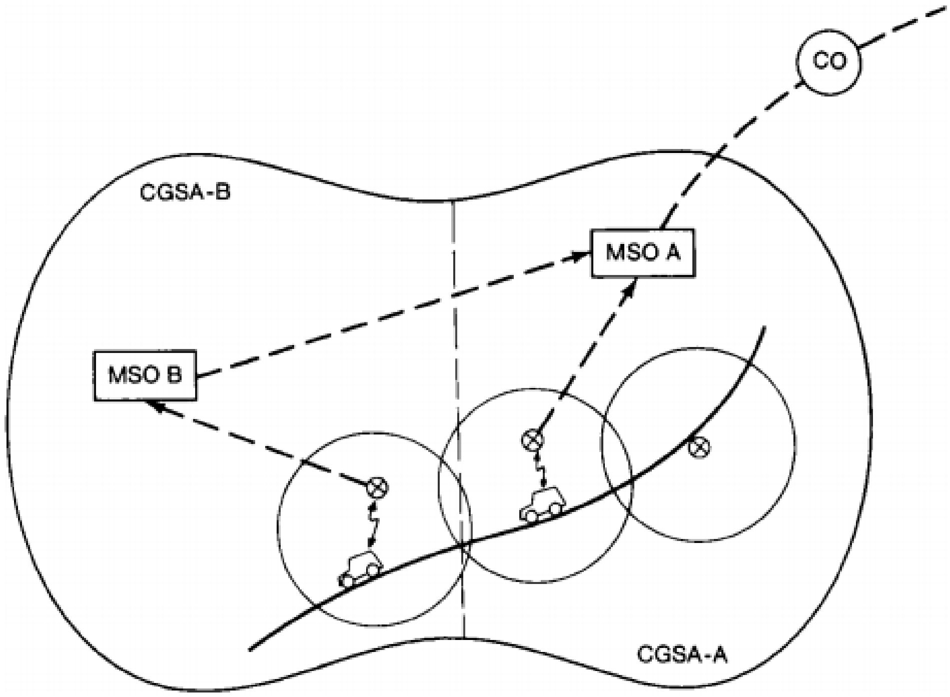

Fig.7. Intersystem handoffs

8. Definition of dropped call rate and consideration of dropped call rates

The definition of a dropped call is after the call is established but before it is properly terminated. The definition of “the call is established” means that the call is setup completely by the setup channel. If there is a possibility of a call drop due to no available voice channels, this is countedas a blocked call not a dropped call. If there is a possibility that a call will drop due to the poor signal of the assigned voice channel, this is considered a dropped call. This case can happenwhen the mobile or portable units are at a standstill and the radio carrier is changed from a strong setup channel to a weak voice channel due to the selective frequency fading phenomenon.

The perception of dropped call rate by the subscribers can be higher due to:

1. The subscriber unit not functioning properly (needs repair).

2. The user operating the portable unit in a vehicle (misused).

3. The user not knowing how to get the best reception from a portable unit (needs education).

In principle, dropped call rate can be set very low if we do not need to maintain the voice quality. The dropped call rate and the specified voice quality level are inversely proportional. In designing a commercial system, the specified voice quality level is given relating to how much C/I (or C/N) the speech coder can tolerate. By maintaining a certain voice quality level, the dropped call rate can be calculated by taking the following factors into consideration:

1. Provide signal coverage based on the percentage (say 90 percent) that the entire received signal will be above a given signal level.

2. Maintain the specified co-channel and adjacent channel interference levels in each cell during a busy hour (i.e., the worst interference case).

3. Because the performance of the call dropped rate is calculated as possible call dropping in every stage from the radio link to the PSTN connection, the response time of the handoff in the network will be a factor when the cell becomes small, the response time for a handoff request has to be shorter in order to reduce the call dropped rate.

9. Relation among capacity, voice quality, dropped call rate

Radio Capacity m is expressed as follows:

$$m = \frac{B_T / B_c}{\sqrt{\frac{2}{3}(C/I)_S}}$$

Where BT/Bc is the total number of voice channels. BT /Bc is a given number, and (C/I)s is a required C/I for designing a system. The above equation is obtained based on six cochannel interferers which occur in busy traffic (i.e., a worst case). In an interference limited system, the adjacent channel interference has only a secondary effect.

$$(C/I)_S = \frac{3}{2}\left(\frac{B_T/B_c}{m}\right)^2 = \frac{3}{2}\left(\frac{B_T}{B_c}\right)^2 \cdot \frac{1}{m^2}$$

Because the (C/I)s is a required C/I for designing a system, the voice quality is based on the (C/I)s .When the specified (C/I)S is reduced, the radio capacity is increased. When the measured (C/I) is less than the specified (C/I)S , both poor voice quality and dropped calls can occur.

10. What is the general formula of dropped call rate? Explain?

General formula of dropped call rate

The general formula of dropped call rate P in a whole system can be expressed as:

$$P = 1 - \left[\sum_{n=0}^{N} \alpha_n X^n\right] = \sum_{n=0}^{N} \alpha_n \cdot P_n$$

Where

$$P_n = 1 - X^n$$

P_n is the probability of a dropped call when the call has gone through n handoffs and

$X = (1-\delta)(1-\mu)(1-\theta\tau)(1-\beta)^2$

δ = Probability that the signal is below the specified receive threshold (in a noise-limited system).

μ = Probability that the signal is below the specified cochannel interference level (in an interference-limited system).

τ = Probability that no traffic channel is available upon handoff attempt when moving into a new cell.

θ = Probability that the call will return to the original cell.

β = Probability of blocking circuits between BSC and MSC during handoff.

α_n = The weighted value for those calls having n handoffs, and $\sum_{n=0}^{N} \alpha_n = 1$

N = N is the highest number of handoffs for those calls.

1. z1 and z2 are two events, z1 is the case of no traffic channel in the cell, z2 is the case of no-safe return to original cell. Assuming that z1 and z2 are independent events, then

$$P(z_2|z_1) \cdot P(z_1) = P(z_2) \cdot P(z_1) = \theta \cdot \tau$$

2. (1 − β) is the probability of a call successfully connecting from the old BSC to the MSC. Also,(1 − β) is the probability of a call successfully connecting from the MSC to the new BSC. Then the total probability of having a successful call connection is

$$\begin{array}{ll} \text{BSC (old)} \rightarrow \text{MSC} & (1-\beta) \\ \text{MSC} \rightarrow \text{BSC (new)} & (1-\beta) \end{array} \Bigg\} \rightarrow (1-\beta)^2$$

3. The call dropped rate P expressed in above Eq can be specified in two cases:

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1. In a noise limited system (startup system): there is no frequency reuse, the call dropped rate PA is based on the signal coverage. It can also be calculated under busy hour conditions.

In a noise-limited environment (for worst case)

$$\delta = \delta_1$$

$$\mu = \mu_1$$

$$\left.\begin{aligned} \tau &= \tau_1 \\ \theta &= \theta_1 \\ \beta &= \beta_1 \end{aligned}\right\} \text{the conditions for the noise limited case}$$

2. In an interference-limited system (mature system): frequency reuse is applied, and the dropped rate PB is based on the interference level. It can be calculated under busy hour conditions.

In an interference-limited environment (for worst case)

$$\delta = \delta_2$$

$$\mu = \mu_1$$

$$\left.\begin{aligned} \tau &= \tau_2 \\ \theta &= \theta_2 \\ \beta &= \beta_2 \end{aligned}\right\} \text{the conditions for the interference limited case}$$

In a commonly used formula of dropped call rate, the values of τ , θ, and β are assumed to bevery small and can be neglected. Then

$$X = (1 - \delta)(1 - \mu)$$

Furthermore, in a noise-limited case, $\mu \to 0$,

$$P_A = \sum_{n=0}^{N} \alpha_n P_n = \sum \alpha_n [1 - (1 - \delta)^n]$$

and in an interference-limited system, $\delta \to 0$,

$$P_B = \sum_{n=0}^{N} \alpha_n P_n = \sum \alpha_n [1 - (1 - \mu)^n]$$

11. Write about cell site handoff only scheme

Cell site handoff scheme:

This scheme can be used in a non cellular system. The mobile unit has been assigned a frequency and talks to its home cell site while it travels. When the mobile unit leaves its home cell andenters a new cell, its frequency does not change; rather, the new cell must tune into the frequency of the mobile unit (see Fig. 10.). In this case only the cell sites need the frequency information of the mobile unit. Then the aspects of mobile unit control can be greatly simplified, and there willbe no need to provide handoff capability at the mobile unit. The cost will also be lower. This scheme can be recommended only in areas of very low traffic. When the traffic is dense, frequency coordination is necessary for the cellular system. Then if a mobile unit does not change frequency on travel from cell to cell, other mobile units then must change frequency to avoid interference. Therefore, if a system handles only low volumes of traffic, that is, if the channels assigned to one cell will not reuse frequency in other cells, then it is possible toimplement the cell-site handoff feature as it is applied in military systems.

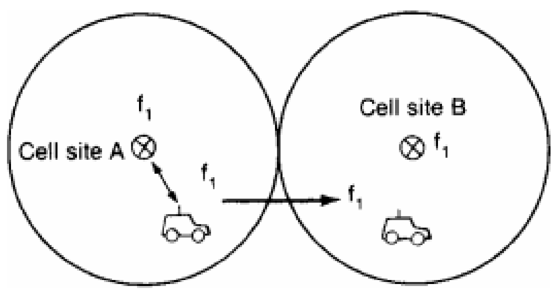


Fig.10. Cell site handoff only scheme

Multiple Access Techniques

Multiple access schemes are used to allow many mobile users to share simultaneously a finite amount of radio spectrum. The sharing of spectrum is required to achieve high capacity by simultaneously allocating the available bandwidth (or the available amount of channels) to multiple users. For high quality communications, this must be done without severe degradation in the performance of the system.

Introduction

In wireless communications systems, it is often desirable to allow the subscriber to send simultaneously information to the base station while receiving information from the base station. For example, in conventional telephone systems, it is possible to talk and listen simultaneously, and this effect, called *duplexing,* is generally required in wireless telephone systems.

Duplexing may be done using frequency or time domain techniques. *Frequency division duplexing* (FDD) provides two distinct bands of frequencies for every user. The *forward band* provides traffic from the base station to the mobile, and the *reverse band* provides traffic from the mobile to the base station. In FDD, any *duplex channel* actually consists of two simplex channels (a forward and reverse), and a device called a *duplexer* is used inside each subscriber unit and base station to allow simultaneous bidirectional radio transmission and reception for both the subscriber unit and the base station on the duplex channel pair. The frequency separation between each forward and reverse channel is constant throughout the system, regardless of the particular channel being used.

Time division duplexing (TDD) uses time instead of frequency to provide both a forward and reverse link. In TDD, multiple users share a single radio channel by taking turns in the time domain. Individual users are allowed to access the channel in assigned *time slots,* and each duplex channel has both a forward time slot and a reverse time slot to facilitate bidirectional communication. If the time separation between the forward and reverse time slot is small, then the transmission and reception of data appears simultaneous to the users at both the subscriber unit and on the base station side. Figure 1 illustrates FDD and TDD techniques. TDD allows communication on a single channel (as opposed to requiring two separate simplex or dedicated channels) and simplifies the subscriber equipment since a duplexer is not required.

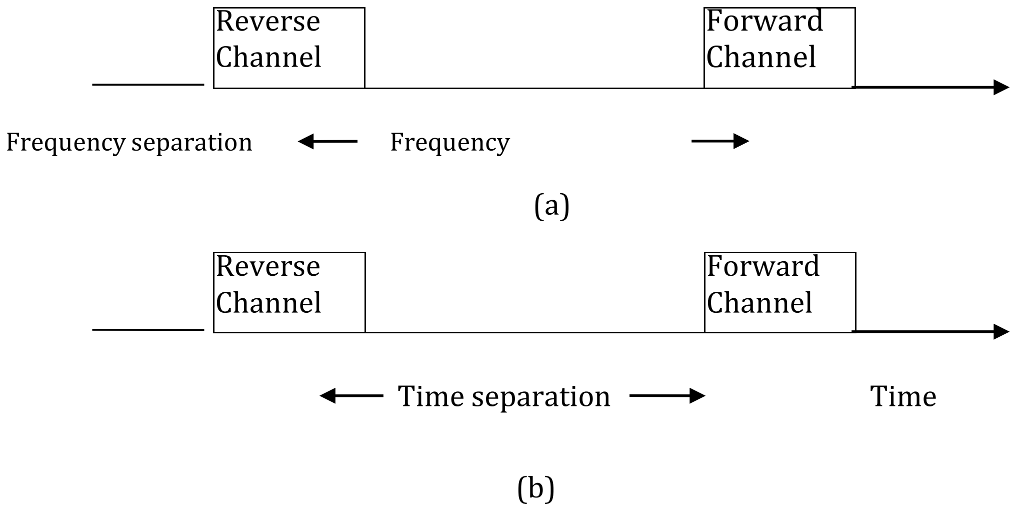


Figure 1 (a) FDD provides two simplex channels at the same time; (b) TDD provides two simplex time slots on the same frequency.

There are several tradeoffs between FDD and TDD approaches. FDD is geared toward radio communications systems that allocate individual radio frequencies for each user. Because each transceiver simultaneously transmits and receives radio signals which can vary by more than 100 dB, the frequency allocation used for the forward and reverse channels must be carefully coordinated within its own system and with out-of-band users that occupy spectrum between these two bands. Furthermore, the frequency separation must be coordinated to permit the use of inexpensive RF and oscillator technology. TDD enables each transceiver to operate as either a transmitter or receiver on the same frequency, and eliminates the need for separate forward and reverse frequency bands. However, there is a time latency created by TDD due to the fact that communications is not full duplex in the truest sense, and this latency creates inherent sensitivities to propagation delays of individual users. Because of the rigid timing required for time slotting, TDD generally is limited to cordless phone or short range portable access. TDD is effective for fixed wireless access when all users are stationary so that propagation delays do not vary in time among the users.

Introduction to Multiple Access

Frequency division multiple access (FDMA), *time division multiple access* (TDMA), and *code division multiple access* (CDMA) are the three major access techniques used to share the available bandwidth in a wireless communication system. These techniques can be grouped as *narrowband* and *wideband* systems, depending upon how the available bandwidth is allocated to the users. The duplexing technique of a multiple access system is usually described along with the particular multiple access scheme, as shown in the examples that follow.

Narrowband Systems — The term *narrowband* is used to relate the bandwidth of a singlechannel to the expected coherence bandwidth of the channel. In a narrowband multiple access system, the available radio spectrum is divided into a large number of narrowband channels. Thechannels are usually operated using FDD. To minimize interference between forward and reverse links on each channel, the frequency separation is made as great as possible within the frequency spectrum, while still allowing inexpensive duplexers and a common transceiver antenna to be used in each subscriber unit. In narrowband FDMA, a user is assigned a particular channel which is not shared by other users in the vicinity, and if FDD is used (that is, eachduplex channel has a forward and reverse simplex channel), then the system is called FDMA/FDD. Narrowband TDMA, on the other hand, allows users to share the same radio channel but allocates a unique time slot to each user in a cyclical fashion on the channel, thus separating a small number of users in time on a single channel. For narrowband TDMA systems,there generally are a large number of radio channels allocated using either FDD or TDD, and each channel is shared using TDMA. Such systems are called TDMA/FDD or TDMA/TDD access systems.

Wideband systems — In wideband systems, the transmission bandwidth of a singlechannel is much larger than the coherence bandwidth of the channel. Thus, multipath fadingdoes not greatly vary the received signal power within a wideband channel, and frequency selective fades occur in only a small fraction of the signal bandwidth at any instance of time. In wideband multiple access systems a large number of transmitters are allowed to transmit on the same channel. TDMA allocates time slots to the many transmitters on the same channel and allows only one transmitter to access the channel at any instant of time, whereas spread spectrum

CDMA allows all of the transmitters to access the channel at the same time. TDMA and CDMA systems may use either FDD or TDD multiplexing techniques.

In addition to FDMA, TDMA, and CDMA, two other multiple access schemes will be used for wireless communications. These are *packet radio* (PR) and *space division multiple access* (SDMA).

Frequency Division Multiple Access (FDMA)

Frequency division multiple access (FDMA) assigns individual channels to individual users. It can be seen from Figure 2 that each user is allocated a unique frequency band or channel. These channels are assigned on demand to users who request service. During the period of the call, no other user can share the same channel. In FDD systems, the users are assigned a channel as a pair of frequencies; one frequency is used for the forward channel, while the other frequency is used for the reverse channel. The features of FDMA are as follows:

- The FDMA channel carries only one phone circuit at a time.
- If an FDMA channel is not in use, then it sits idle and cannot be used by other usersto increase or share capacity. It is essentially a wasted resource.

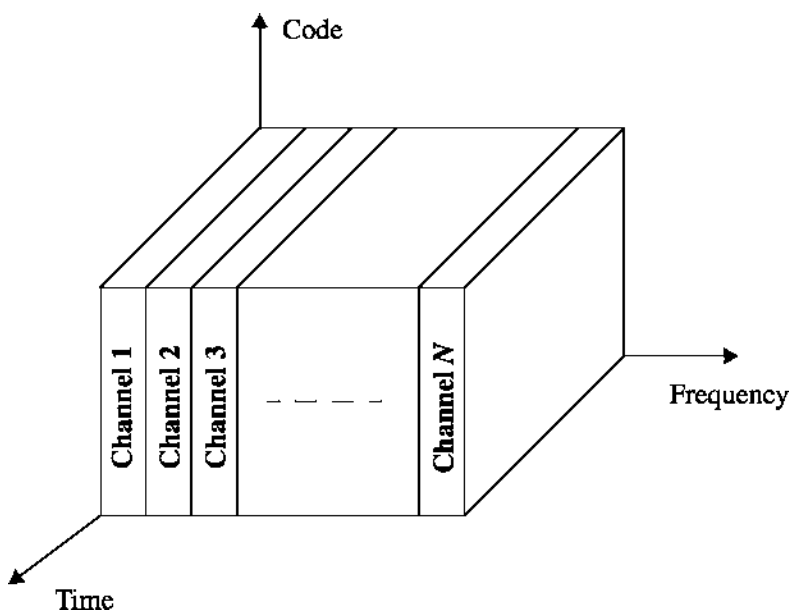


Figure 2 FDMA where different channels are assigned different frequency bands

- After the assignment of a voice channel, the base station and the mobile transmit simulta-neously and continuously.
- The bandwidths of FDMA channels are relatively narrow (30 kHz in AMPS) as each channel supports only one circuit per carrier. That is, FDMA is usually implemented in narrowband systems.
- The symbol time of a narrowband signal is large as compared to the average delay spread. This implies that the amount of intersymbol interference is low and, thus, little or no equalization is required in FDMA narrowband systems.
- The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.
- Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.
- FDMA systems have higher cell site system costs as compared to TDMA systems, because of the single channel per carrier design, and the need to use costly bandpass filters to eliminate spurious radiation at the base station.
- The FDMA mobile unit uses duplexers since both the transmitter and receiver operate at the same time. This results in an increase in the cost of FDMA subscriber units and base stations.
- FDMA requires tight RF filtering to minimize adjacent channel interference

Nonlinear Effects in FDMA — In a FDMA system, many channels share the same antenna at the base station. The power amplifiers or the power combiners, when operated at or near saturation for maximum power efficiency, are nonlinear. The nonlinearities cause signal spreading in the frequency domain and generate *intermodulation* (IM) frequencies. IM is undesired RF radiation which can interfere with other channels in the FDMA systems. Spreading of the spectrum results in adjacent-channel interference. Intermodulation is the generation of undesirable harmonics. Harmonics generated outside the mobile radio band cause interference to adjacent services, while those present inside the band cause interference to other users in the wireless system .

The first US analog cellular system, the *Advanced Mobile Phone System* (AMPS), is based on FDMA/FDD. A single user occupies a single channel while the call is in progress, and the single channel is actually two simplex channels which are frequency duplexed with a 45 MHz split. When a call is completed, or when a handoff occurs, the channel is vacated so that anothermobile subscriber may use it. Multiple or simultaneous users are accommodated in AMPS by giving each user a unique channel. Voice signals are sent on the forward channel from the base station to mobile unit, and on the reverse channel from the mobile unit to the base station. In AMPS, analog narrowband frequency modulation (NBFM) is used to modulate the carrier. The number of channels that can be simultaneously supported in a FDMA system is given by:

$$N = \frac{B_t - 2B_{guard}}{B_c}$$

where B_t is the total spectrum allocation, B_{guard} is the guard band allocated at the edge of the allocated spectrum band, and B_c is the channel bandwidth. Note that B_t and B_c may be speci- fied in terms of simplex bandwidths where it is understood that there are symmetric frequency allocations for the forward band and reverse band.

Time Division Multiple Access (TDMA)

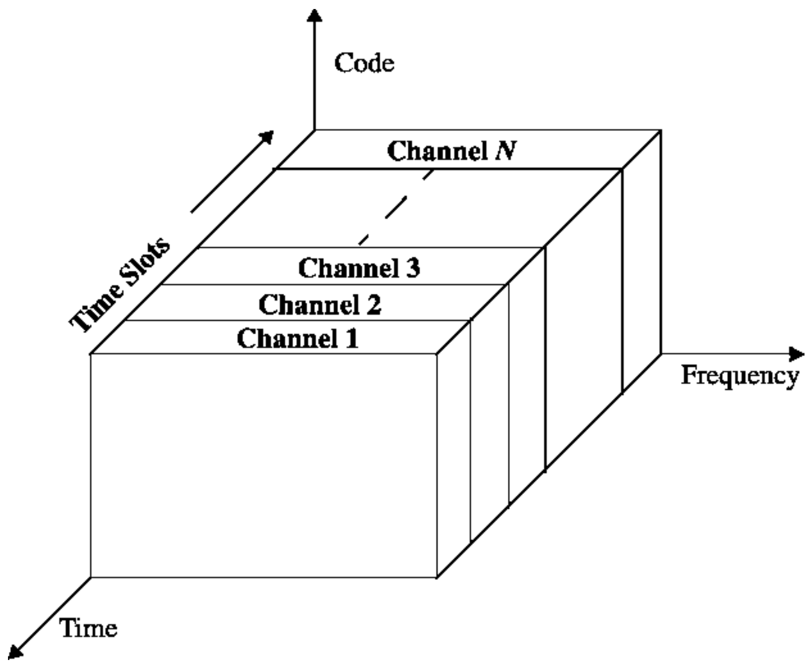


Figure 3 TDMA scheme where each channel occupies a cyclically repeating time slot.

Time division multiple access (TDMA) systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. It can be seen from Figure 3 that each user occupies a cyclically repeating time slot, so a channel may be thought of as a particular time slot that reoccurs every frame, where *N* time slots comprise a frame. TDMA systems transmit data in a *buffer-and-burst* method, thus the transmission for any user is non- continuous. This implies that, unlike in FDMA systems which accommodate analog FM, digital data and digital modulation must be used with TDMA. The transmission from various users is interlaced into a repeating frame structure as shown in Figure 4. It can be seen that a frame consists of a number of slots. Each frame is made up of a preamble, an information message, andtail bits. In TDMA/ TDD, half of the time slots in the frame information message would be used for the forward link channels and half would be used for reverse link channels. In TDMA/FDD systems, an identical or similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links. In general, TDMA/FDD systems intentionally induce several time slots of delay between the forward and reverse time slots for a particular user, so that duplexers are not required in the subscriber unit.

----------------------- One TDMA Frame --

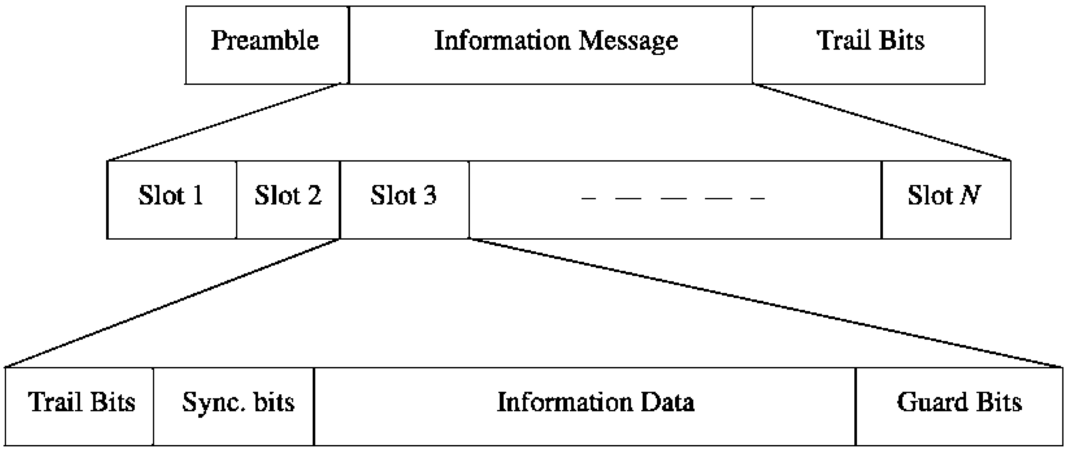


Figure 4 TDMA frame structure. The frame is cyclically repeated over time.

In a TDMA frame, the preamble contains the address and synchronization information thatboth the base station and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames. Different TDMA standards have different TDMA frame structures.

The features of TDMA include the following:

- TDMA shares a single carrier frequency with several users, where each user makes use ofnon-overlapping time slots. The number of time slots per frame depends on several factors, such as modulation technique, available bandwidth, etc.
- Data transmission for users of a TDMA system is not continuous but occurs in bursts. This results in low battery consumption, since the subscriber transmitter can be turned offwhen not in use (which is most of the time).
- Because of discontinuous transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations during idle time slots. An enhanced link control, such as that provided by *mobile assisted handoff* (MAHO) can be carried out by a subscriber by listening on an idle slot in the TDMA frame.
- TDMA uses different time slots for transmission and reception, thus duplexers are not required. Even if FDD is used, a switch rather than a duplexer inside the subscriber unit is

all that is required to switch between transmitter and receiver using TDMA.

- Adaptive equalization is usually necessary in TDMA systems, since the transmission rates are generally very high as compared to FDMA channels.
- In TDMA, the guard time should be minimized. If the transmitted signal at the edges of a time slot are suppressed sharply in order to shorten the guard time, the transmitted spec- trum will expand and cause interference to adjacent channels.
- High synchronization overhead is required in TDMA systems because of burst transmis-sions. TDMA transmissions are slotted, and this requires the receivers to be synchronizedfor each data burst. In addition, guard slots are necessary to separate users, and this results in the TDMA systems having larger overheads as compared to FDMA.
- TDMA has an advantage in that it is possible to allocate different numbers of time slots per frame to different users. Thus, bandwidth can be supplied on demand to different users by concatenating or reassigning time slots based on priority.

Efficiency of TDMA — The efficiency of a TDMA system is a measure of the percentageof transmitted data that contains information as opposed to providing overhead for the access scheme. The frame efficiency η_f, is the percentage of bits per frame which contain transmitteddata. Note that the transmitted data may include source and channel coding bits, so the raw end-user efficiency of a system is generally less than η_f. The frame efficiency can be found asfollows.

The number of overhead bits per frame is,

$$b_{OH} = N_r b_r + N_t b_p + N_t b_g + N_r b_g$$

where N_r is the number of reference bursts per frame, N_t is the number of traffic bursts per frame, b_r is the number of overhead bits per reference burst, b_p is the number of overhead bits per preamble in each slot, and b_g is the number of equivalent bits in each guard time interval.

The total number of bits per frame, b_T, is

$$b_T = T_f R$$

where T_f- is the frame duration, and R is the channel bit rate. The frame efficiency η_f is thus given as

$$\eta_f = \left(1 - \frac{b_{OH}}{b_T}\right) \times 100\%$$

Number of channels in TDMA system — The number of TDMA channel slots that can be provided in a TDMA system is found by multiplying the number of TDMA slots per channel by the number of channels available and is given by

$$N = \frac{m(B_{tot} - 2B_{guard})}{B_c}$$

where *m* is the maximum number of TDMA users supported on each radio channel. Note thattwo guard bands, one at the low end of the allocated frequency band and one at the high end, are required to ensure that users at the edge of the band do not "bleed over" into an adjacent radio service.

Spread Spectrum Multiple Access

Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth that is several orders of magnitude greater than the minimum required RF bandwidth. A pseudo-noise (PN) sequence converts a narrowband signal to a wideband noise-like signal before transmission. SSMA also provides immunity to multipath interference and robust multiple access capability. SSMA is not very bandwidth efficient when used by a single user. However, since many users can share the same spread spectrum bandwidth without interfering with one another, spread spectrum systems become bandwidth efficient in a multiple userenvironment. It is exactly this situation that is of interest to wireless system designers. There are two main types of spread spectrum multiple access techniques; *frequency hopped multipleaccess* (FH) and *direct sequence multiple access* (DS). Direct sequence multiple access is also called *code division multiple access* (CDMA).

Frequency Hopped Multiple Access (FHMA)

Frequency hopped multiple access (FHMA) is a digital multiple access system in which the car- rier frequencies of the individual users are varied in a pseudorandom fashion within a wideband channel. Figure 5 illustrates how FHMA allows multiple users to simultaneously occupy the same spectrum at the same time, where each user dwells at a specific narrowband channel at a particular instance of time, based on the particular PN code of the user. The digital data of each user is broken into uniform sized bursts which are transmitted on different channels within the allocated spectrum band. The instantaneous bandwidth of any one transmission burst is much smaller than the total spread bandwidth. The pseudorandom change of the channel frequencies ofthe user randomizes the occupancy of a specific channel at any given time, thereby allowing for multiple access over a wide range of frequencies. In the FH receiver, a locally generated PNcode is used to synchronize the receiver's instantaneous frequency with that of the transmitter.At any given point in time, a frequency hopped signal only occupies a single, relatively narrow channel since narrowband FM or FSK is used. The difference between FHMA and a traditional FDMA system is that the frequency hopped signal changes channels at rapid intervals. If the rate of change of the carrier frequency is greater than the symbol rate, then the system is referred toas *a fast frequency hopping system.* If the channel changes at a rate less than or equal to the symbol rate, it is called *slow frequency hopping.* A fast frequency hopper may thus be thought ofas an FDMA system which employs frequency diversity. FHMA systems often employ energy efficient constant envelope modulation. Inexpensive receivers may be built to provide non- coherent detection of FHMA. This implies that linearity is not an issue, and the power of multiple users at the receiver does not degrade FHMA performance.

A frequency hopped system provides a level of security, especially when a large number ofchannels are used, since an unintended (or an intercepting) receiver that does not know the pseudorandom sequence of frequency slots must retune rapidly to search for the signal it wishes to intercept. In addition, the FH signal is somewhat immune to fading, since error control coding and interleaving can be used to protect the frequency hopped signal against deep fades which may occasionally occur during the hopping sequence. Error control coding and interleaving can also be combined to guard against *erasures* which can occur when two or more users transmit onthe same channel at the same time. Bluetooth and Home RF wireless technologies have adopted FHMA for power efficiency and low cost implementation.

Code Division Multiple Access (CDMA)

In *code division multiple access* (CDMA) systems, the narrowband message signal is multiplied by a very large bandwidth signal called the *spreading signal.* The spreading signal is a pseudo- noise code sequence that has a chip rate which is orders of magnitudes greater than the data rate of the message. All users in a CDMA system, as seen from Figure 5, use the same carrier fre- quency and may transmit simultaneously. Each user has its own pseudorandom codeword which is approximately orthogonal to all other codewords. The receiver performs a time correlation operation to detect only the specific desired codeword. All other code words appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independently with no knowledge of the other users.

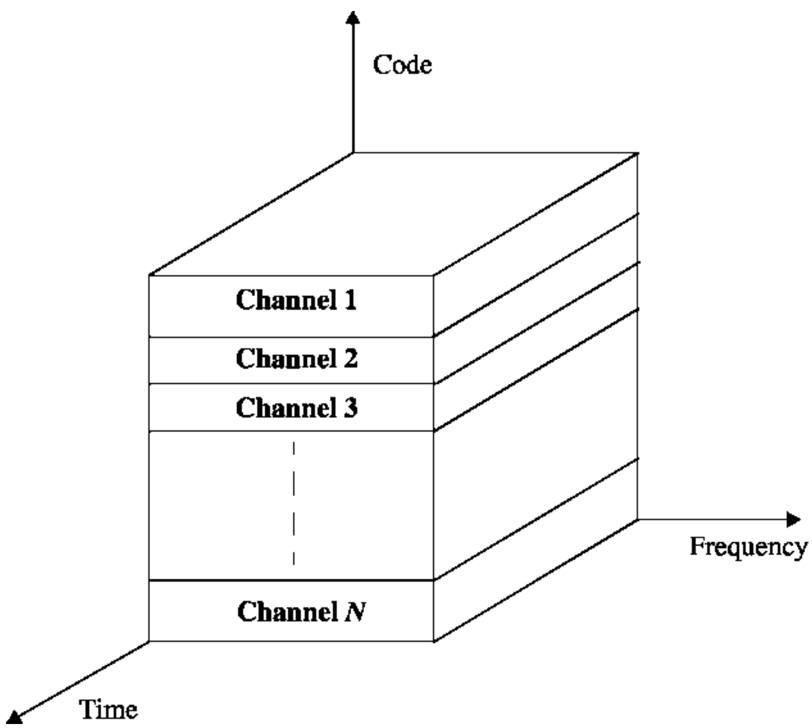


Figure 5 Spread spectrum multiple access in which each channel is assigned a unique PN codewhich is orthogonal or approximately orthogonal to PN codes used by other users.

In CDMA, the power of multiple users at a receiver determines the noise floor after de-cor-relation. If the power of each user within a cell is not controlled such that they do not appear equal at the base station receiver, then the *near-far problem* occurs.

The near-far problem occurs when many mobile users share the same channel. In general, the strongest received mobile signal will *capture* the demodulator at a base station. In CDMA, stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signals will be received. To combat the near-far problem, *power control* is used in most CDMA implementations. Power control is provided by each base station in a cellular system and assures that each mobile within the base station coverage area provides the same signal level to the base station receiver. This solves the problem of a nearby subscriber overpowering the base station receiver and drowning out the signals of far away subscribers. Power control is implemented at the base station by rapidly sampling the radio signal strength indicator (RSSI) levels of each mobile and then sending a power change command over the forward radio link. Despite the use of power control within each cell, out-of-cell mobiles provide interference which is not under the control of the receiving base station.

The features of CDMA including the following:

- Many users of a CDMA system share the same frequency. Either TDD or FDD may be used.
- Unlike TDMA or FDMA, CDMA has a soft capacity limit. Increasing the number of users in a CDMA system raises the noise floor in a linear manner. Thus, there is no absolute limit on the number of users in CDMA. Rather, the system performance gradually degrades for all users as the number of users is increased, and improves as the number of users is decreased.
- Multipath fading may be substantially reduced because the signal is spread over a large spectrum. If the spread spectrum bandwidth is greater than the coherence bandwidth of the channel, the inherent frequency diversity will mitigate the effects of small-scale fading.
- Channel data rates are very high in CDMA systems. Consequently, the symbol (chip) duration is very short and usually much less than the channel delay spread. Since PN sequences have low autocorrelation, multipath which is delayed by more than a chip willappear as noise. A RAKE receiver can be used to improve reception by collecting time delayed versions of the required signal.
- Since CDMA uses co-channel cells, it can use macroscopic spatial diversity to provide

soft handoff. Soft handoff is performed by the MSC, which can simultaneously monitora particular user from two or more base stations. The MSC may chose the best version ofthe signal at any time without switching frequencies.

- Self-jamming is a problem in CDMA system. Self-jamming arises from the fact that the spreading sequences of different users are not exactly orthogonal, hence in the de- spreading of a particular PN code, non-zero contributions to the receiver decision statistic for a desired user arise from the transmissions of other users in the system.
- The near-far problem occurs at a CDMA receiver if an undesired user has a high detected power as compared to the desired user.

Space Division Multiple Access (SDMA)

Space division multiple access (SDMA) controls the radiated energy for each user in space. It can be seen from Figure 8 that SDMA serves different users by using spot beam antennas. Thesedifferent areas covered by the antenna beam may be served by the same frequency (in a TDMA or CDMA system) or different frequencies (in an FDMA system). Sectorized antennas may be thought of as a primitive application of SDMA. In the future, adaptive antennas will likely be used to simultaneously steer energy in the direction of many users at once and appear to be best suited for TDMA and CDMA base station architectures.

The reverse link presents the most difficulty in cellular systems for several reasons. First, the base station has complete control over the power of all the transmitted signals on the forwardlink. However, because of different radio propagation paths between each user and the base station, the transmitted power from each subscriber unit must be dynamically controlled to prevent any single user from driving up the interference level for all other users. Second, transmit power is limited by battery consumption at the subscriber unit, therefore there are limitson the degree to which power may be controlled on the reverse link. If the base station antenna ismade to spatially filter each desired user so that more energy is detected from each subscriber, then the reverse link for each user is improved and less power is required.

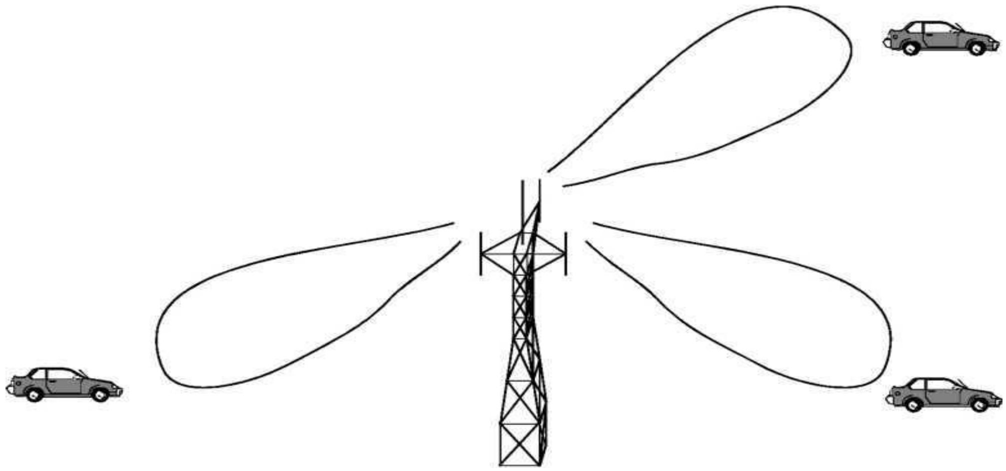


Figure 8 A spatially filtered base station antenna serving different users by using spot beams.

Adaptive antennas used at the base station (and eventually at the subscriber units) promise to mitigate some of the problems on the reverse link. In the limiting case of infinitesimal beam- width and infinitely fast tracking ability, adaptive antennas implement optimal SDMA, thereby providing a unique channel that is free from the interference of all other users in the cell. With SDMA, all users within the system would be able to communicate at the same time using the same channel. In addition, a perfect adaptive antenna system would be able to track individual multipath components for each user and combine them in an optimal manner to collect all of the available signal energy from each user. The perfect adaptive antenna system is not feasible since it requires infinitely large antennas.

OFDM (Orthogonal Frequency Division Multiplexing)

In modulations, information is mapped on to changes in frequency, phase or amplitude(or a combination of them) of a carrier signal. Multiplexing deals with allocation/accommodationof users in a given bandwidth (i.e. it deals with allocation of available resource). OFDM is a combination of modulation and multiplexing. In this technique, the given resource (bandwidth) is shared among individual modulated data sources. Normal modulation techniques (like AM, PM, FM, BPSK, QPSK, etc..,) are single carrier modulation techniques, in which the incoming information is modulated over a single carrier. OFDM is a multicarrier modulation technique, which employs several carriers, within the allocated bandwidth, to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques (BPSK, QPSK, QAM etc..,).

Why OFDM

OFDM is very effective for communication over channels with frequency selective fading (different frequency components of the signal experience different fading). It is very difficult to handle frequency selective fading in the receiver , in which case, the design of the receiver is hugely complex. Instead of trying to mitigate frequency selective fading as a whole (which occurs when a huge bandwidth is allocated for the data transmission over a frequency selective fading channel), OFDM mitigates the problem by converting the entire frequency selective fading channel into small flat fading channels (as seen by the individual subcarriers). Flat fading is easier to combat (compared to frequency selective fading) by employing simple error correction and equalization schemes.

Difference between FDM and OFDM:

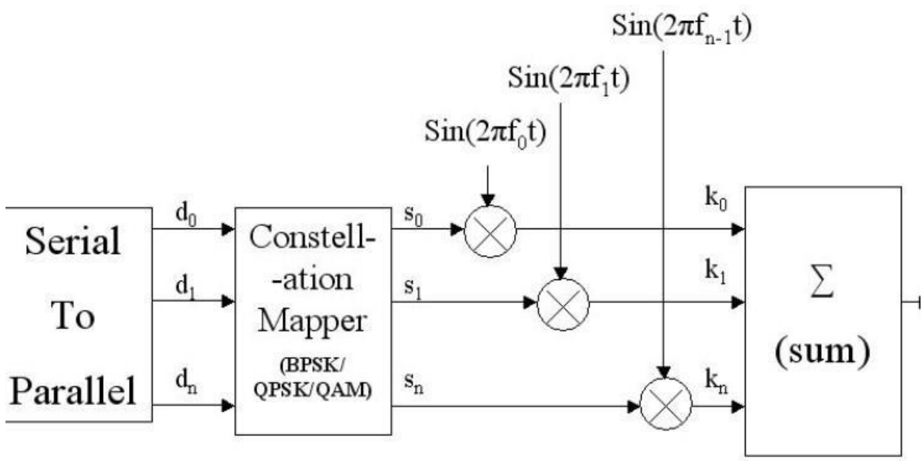
OFDM is a special case of FDM (Frequency Division Multiplexing). In FDM, the givenbandwidth is subdivided among a set of carriers. There is no relationship between the carrier frequencies in FDM. For example, consider that the given bandwidth has to be divided among 5 carriers (say a,b,c,d,e). There is no relationship between the subcarriers ;a,b,c,d and e cananything within the given bandwidth.If the carriers are harmonics, say (b=2a,c=3a,d=4a,d=5a , integral multiple of fundamental component a) then they become orthogonal. This is a special case of FDM, which is called OFDM (as implied by the word – 'orthogonal' in OFDM)

Designing OFDM Transmitter:

Consider that we want to send the following data bits using OFDM : D = {d0,d1,d2,…}. The first thing that should be considered in designing the OFDM transmitter is the number of subcarriers required to send the given data. As a generic case, lets assume that we have N subcarriers. Each subcarriers are centered at frequencies that are orthogonal to each other (usually multiples of frequencies).

The second design parameter could be the modulation format that we wish to use. An OFDM signal can be constructed using anyone of the following digital modulation techniques namely BPSK, QPSK, QAM etc.., .The data (D) has to be first converted from serial stream into parallel stream depending on the number of sub-carriers (N). Since we assumed that there are N subcarriers allowed for the OFDM transmission, we name the subcarriers from 0 to N-1. Now,the Serial to Parallel converter takes the serial stream of input bits and outputs N parallel streams (indexed from 0 to N-1). These parallel streams are individually converted into the required digital modulation format (BPSK, QPSK, QAM etc..,). Lets call this output S_0,S_1,..S_N. The conversion of parallel data (D) into the digitally modulated data (S) is usually achieved by a constellation mapper, which is essentially a look up table (LUT). Once the data bits are converted to required modulation format, they need to be superimposed on the required orthogonal subcarriers for transmission. This is achieved by a series of N parallel sinusoidal oscillators tuned to N orthogonal frequencies (f_0,f_1,...f_{N-1}). Finally, the resultant output from the N parallel arms are summed up together to produce the OFDM signal.

The following figure illustrates the basic concept of OFDM transmission (note: In orderto give a simple explanation to illustrate the underlying concept,the usual IFFT/FFT blocks that are used in actual OFDM system, are not used in the block diagram) .



DECT Radio Link (Extra to understand Packet Radio you can study this)

DECT operates in the 1880 MHz to 1900 MHz band. Within this band, the DECT standarddefines ten channels from 1881.792 MHz to 1897.344 MHz with a spacing of 1728kHz. DECT supports a Multiple Carrier / TDMN / TDD structure. Each base station provides a frame structurewhich supports 12 duplex speech channels, and each time slot may occupy any of the DECTchannels. Thus, DECT base stations support FHMA on top of the TDMA / TDD structure. If the frequency hopping option is disabled for each DECT base station, a total of 120 channels withinthe DECT spectrum are provided before frequencyreuse is required. Each time slot may beassigned to a different channel in order to exploit advantages provided by frequency hopping,and to avoid interference from other users in an asynchronous fashion.

Channel Types - DECT user data is provided in each B-field time slot (seeFigure 11.19). Three hundred twenty user bits are provided during each time slot yielding a32 kbps data stream per user. No error correction is provided although 4 parity bits are used for code error detection.

DECT control information is carried by 64 bits in every time slot of an established call (seeFigure 11.19). These bits are assigned to one of the four logical channels depending on the natureof the controlinformation. Thus, the gross control channel data rate is 6.4 kbps per user. DECTrelies on error detection and retransmission for accurate delivery of control information. Each64 bit control word contains 16 cyclic redundancy check (CRC) bits, in addition to the 48 controldata bits. The maximum information throughput of the DECT control channel is 4.8 kbps.

Speech Coding - Analog speech is digitized into PCM using a 8 kHz sampling rate.The digital speech samples are ADPCM encoded at 32 kbps.

Channel Coding - For speech signals, no channel coding is used since DECT providesfrequency hopping for each time slot. However, thecontrol channels use 16 bit cyclic redundancy check (CRC) codes in each time slot.

Modulation - DECT uses a tightly filtered GMSK modulation technique. Minimum shift keying (MSK) is a form of FSK where the phase transitionsbetween two symbols are constrained to be continuous. Before the modulation, the signal isfiltered using a Gaussian shaping filter.

Antenna Diversity - In DECT, spatial diversity at the RFP (base station) receiver isimplemented using twoantennas. The antenna which provides the best signal for each time slot
is selected. This is performed on the basis of a power measurement or alternatively by using anappropriate quality measure (such as interference or BER). Antenna diversity helps solve fadingand interference problems. No antenna diversity is used at the subscriber unit.

GENERAL PACKET RADIO SERVICE (GPRS)- (Important for Packet Radio)

General Packet Radio System is also known as **GPRS** is a third-generation step toward internet access. GPRS is also known as GSM-IP that is a Global-System Mobile Communications Internet Protocol as it keeps the users of this system online, allows to make voice calls, and access internet on-the-go. Even Time-Division Multiple Access (TDMA) users benefit from this system as it provides packet radio access. GPRS also permits the network operators to execute an Internet Protocol (IP) based core architecture for integrated voice and data applications that will continue to be used and expanded for 3G services.

GPRS supersedes the wired connections, as this system has simplified access to the packet data networks like the internet. The packet radio principle is employed by GPRS to transport user data packets in a structure way between GSM mobile stations and external packet data networks. These packets can be directly routed to the packet switched networks from the GPRS mobile stations.

In the current versions of GPRS, networks based on the Internet Protocol (IP) like the global internet or private/corporate intranets and X.25 networks are supported.

The GPRS specifications are written by the European Telecommunications Standard Institute (ETSI), the European counterpart of the American National Standard Institute (ANSI).

Key Features of

Following three key features describe wireless packet data:

1. **The always online feature -** Removes the dial-up process, making applications

only oneclick away.

2. **An upgrade to existing systems -** Operators do not have to replace their equipment;rather, GPRS is added on top of the existing infrastructure.

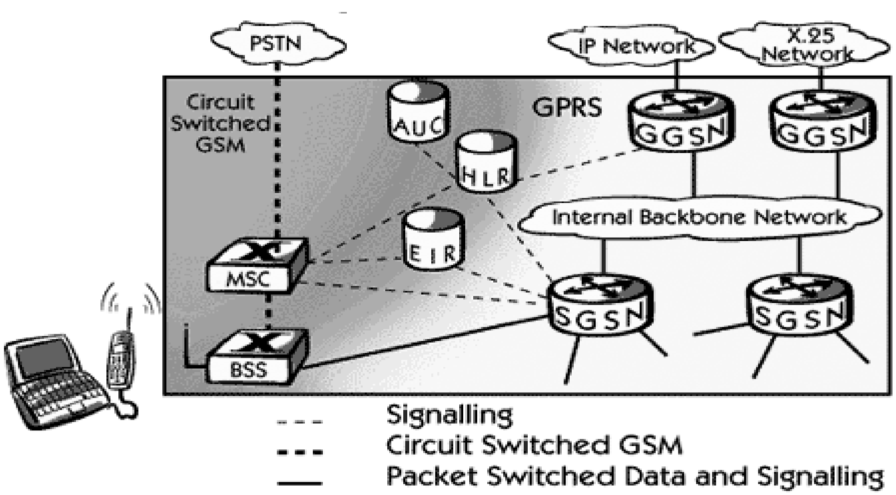
3. **An integral part of future 3G systems -** GPRS is the packet data core network for 3Gsystems EDGE and WCDMA.

Goals of GPRS

GPRS is the first step toward an end-to-end wireless infrastructure and has the following goals:

4. Open architecture
5. Consistent IP services
6. Same infrastructure for different air interfaces
7. Integrated telephony and Internet infrastructure
8. Leverage industry investment in IP
9. Service innovation independent of infrastructure

GPRS Architecture diagram:



GPRS attempts to reuse the existing GSM network elements as much as possible, but to effectively build a packet-based mobile cellular network, some new network elements, interfaces, and protocols for handling packet traffic are required.

Therefore, GPRS requires modifications to numerous GSM network elements as summarizedbelow:

GSM Network Element	**Modification or Upgrade Required for GPRS.**

Mobile Station (MS)	New Mobile Station is required to access GPRS services. These new terminals will be backward compatible with GSM for voice calls.
BTS	A software upgrade is required in the existing Base Transceiver Station(BTS).
BSC	The Base Station Controller (BSC) requires a software upgrade and the installation of new hardware called the packet control unit (PCU). The PCU directs the data traffic to the GPRS network and can be a separate hardware element associated with the BSC.
GPRS Support Nodes (GSNs)	The deployment of GPRS requires the installation of new core network elements called the serving GPRS support node (SGSN) and gateway GPRS support node (GGSN).
Databases (HLR, VLR, etc.)	All the databases involved in the network will require software upgrades to handle the new call models and functions introduced by GPRS.

GPRS Mobile Stations

New Mobile Stations (MS) are required to use GPRS services because existing GSM phones do not handle the enhanced air interface or packet data. A variety of MS can exist, including a high- speed version of current phones to support high-speed data access, a new PDA device with an embedded GSM phone, and PC cards for laptop computers. These mobile stations are backward compatible for making voice calls using GSM.

GPRS Base Station Subsystem

Each BSC requires the installation of one or more Packet Control Units (PCUs) and a software upgrade. The PCU provides a physical and logical data interface to the Base Station Subsystem (BSS) for packet data traffic. The BTS can also require a software upgrade but typically does notrequire hardware enhancements.

When either voice or data traffic is originated at the subscriber mobile, it is transported over the air interface to the BTS, and from the BTS to the BSC in the same way as a standard GSM call. However, at the output of the BSC, the traffic is separated; voice is sent to the Mobile Switching Center (MSC) per standard GSM, and data is sent to a new device called the SGSN via the PCU over a Frame Relay interface.

GPRS Support Nodes

Following two new components, called Gateway GPRS Support Nodes (GSNs) and, Serving GPRS Support Node (SGSN) are added:

Gateway GPRS Support Node (GGSN)

The Gateway GPRS Support Node acts as an interface and a router to external networks. It contains routing information for GPRS mobiles, which is used to tunnel packets through the IP based internal backbone to the correct Serving GPRS Support Node. The GGSN also collects charging information connected to the use of the external data networks and can act as a packet filter for incoming traffic.

Serving GPRS Support Node (SGSN)

The Serving GPRS Support Node is responsible for authentication of GPRS mobiles, registrationof mobiles in the network, mobility management, and collecting information on charging for the use of the air interface.

Internal Backbone

The internal backbone is an IP based network used to carry packets between different GSNs. Tunnelling is used between SGSNs and GGSNs, so the internal backbone does not need any information about domains outside the GPRS network. Signalling from a GSN to a MSC, HLRor EIR is done using SS7.

Routing Area

GPRS introduces the concept of a Routing Area. This concept is similar to Location Area in GSM, except that it generally contains fewer cells. Because routing areas are smaller than location areas, less radio resources are used While broadcasting a page message.

Digital European Cordless Telephone (DECT)

The Digital European Cordless Telephone (DECT) is a universal cordless telephone standard developed by the European Telecommunications Standards Institute. It is the first pan-European standard for cordless telephones and was finalized in July 1992.

Features and Characteristics

10. DECT provides a cordless communications framework for high traffic density, short range telecommunications, and covers a broad range of applications and environments.
11. DECT offers excellent quality and services for voice and data applications .
12. The main function of DECT is to provide local mobility to portable users in an in-building Private Branch Exchange (PBX). The DECT standard supports telepoint services, as well.
13. DECT is configured around an open standard (OSI) which makes it possible to interconnect wide area fixed or mobile networks, such as ISDN or GSM, to a portable subscriber population.
14. DECT provides low power radio access between portable parts and fixed base stations at ranges of up to a few hundred meters.

DECT Architecture

The DECT system is based on OSI (Open System Interconnection) principles in a mannersimilar to ISDN. A control plane (C-plane) and a user plane (U-plane) use the services provided by the lower layers (i.e., the physical layer and the medium access control (MAC) layer). DECT is able to page up to 6000 subscribers without the need to know in which cell they reside (no registration required), and DECT is not a total system concept. It is designed for radio local loop or metropolitan area access, but may be used in conjunction with wide area wireless systems such as GSM. DECT uses dynamic channel allocation based on signals received by the portable user and is specifically designed to only support handoffs at pedestrian speeds.

ULTRA WIDEBAND SYSTEMS (UWB)

As the name implies UWB, ultra wide band technology, is a form of transmission that occupies a very wide bandwidth. Typically this will be many Gigahertz, and it is this aspect that enables itto carry data rates of Gigabits per second. However the very high bandwidth used also allows thepower spectral density to be very low, and the power limits on UWB are being strictly limited bythe regulatory bodies.

- Ultra-Wideband (UWB) provides an interesting new technology for shortrange ultra-highspeed communications in the frequency band 3.1 GHz to 10.6 GHz.
- It supports a bit rate greater than 100 Mbps within a 10-meter radius for wireless personalarea communications.
- The advantages of UWB include low-power transmission, robustness for multi-path fading and low power dissipation.
- The low power transmission of the UWB is the key characteristic that might allow it to coexist with other wireless networking standards such as 802.11 LAN, 802.16 MAN and WAN.

1.2 What Are Ad Hoc Networks?

An ad hoc network is a collection of wireless mobile nodes (or routers) dynami-cally forming a temporary network without the use of any existing network infra- structure or centralized administration. The routers are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a stand-alonefashion, or may be connected to the Internet. Multihop, mobility, large network size combined with device heterogeneity, bandwidth, and battery power constraints make the design of adequate routing protocols a major challenge. Some form of routing protocol is in general necessary in such an environment, because two hosts that may wish to exchange packets might not be able to communicate directly, asshown in Figure 1.6.

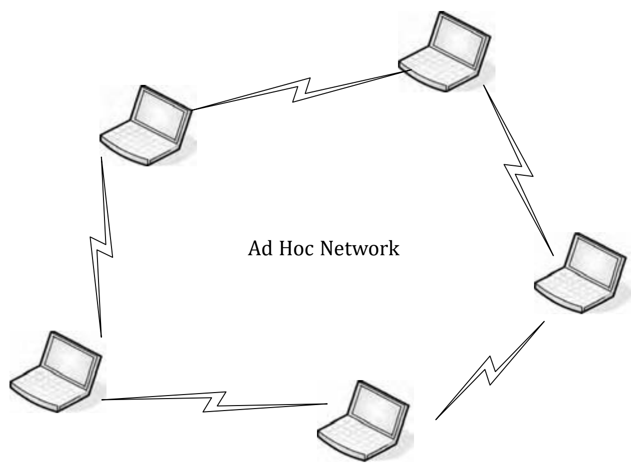


Figure 1.6 Mobile ad hoc network.

Mobile users will want to communicate in situations in which no fixed wiredinfrastructure is available. For example, a group of researchers en route to a confer- ence may meet at the airport and need to connect to the wide area network, studentsmay need to interact during a lecture, or firefighters need to connect to an ambulance en route to an emergency scene. In such situations, a collection of mobile hosts with wireless network interfaces may form a temporary network without the aid of any established infrastructure or centralized administration. Because nowadays many laptops are equipped with powerful CPUs, large hard disk drives, and good sound and image capabilities, the idea of forming a network among these researchers, students, or members of a rescue team, who can easily be equipped with the devicesmentioned above, seems possible.

Such networks received considerable attentionin recent years in both commercial and military applications, due to the attractive properties of building a network on the fly and not requiring any preplanned infra- structure such as a base station or central controller.

A mobile ad hoc network (MANET) group has been formed within IETF. The primary focus of this working group is to develop and evolve MANET specificationsand introduce them to the Internet standard track. The goal is to support mobile ad hoc networks with hundreds of routers and solve challenges in this kind of network.Some challenges that ad hoc networking faces are limited wireless transmission range, hidden terminal problems, packet losses due to transmission errors, mobility-induced route changes, and battery constraints. Mobile ad hoc networks could enhance the service area of access networks and provide wireless connectivity into areas with poor or previously no coverage (e.g., cell edges). Connectivity to wired infrastructure will be provided through multiple gateways with possibly different capabilities and uti- lization. To improve performance, the mobile host should have the ability to adapt

Table 1.2 Differences between Cellular and Ad Hoc Wireless Networks

Cellular	*Ad Hoc Wireless Networks*
Infrastructure networks	Infrastructureless networks
Fixed, prelocated cell sites andbase station	No base station, and rapid deployment
Static backbone network topology	Highly dynamic network topologieswith multihop
Relatively caring environment andstable connectivity	Hostile environment (noise, losses)and irregular connectivity
Detailed planning before base stationcan be installed	Ad hoc network automatically formsand adapts to changes
High setup costs	Cost-effective
Large setup time	Less setup time

to variation in performance and coverage and to switch gateways when beneficial. To enhance the prediction of the best overall performance, a network-layer metric has a better overview of the network. Ad hoc networking brings features like easy connection to access networks, dynamic multihop network structures, and directpeer-to-peer communication. The multihop property of an ad hoc network needs to be bridged by a gateway to the wired backbone. The gateway must have a network interface on both types of networks and be a part of both the global routing and the local ad hoc routing. Users could benefit from ubiquitous networks in several ways. User mobility enables users to switch between devices, migrate sessions, and still get the same personalized services. Host mobility enables the users' devices to movearound the networks and maintain connectivity and reachability.

1.3.1 Differences between Cellular andAd Hoc Wireless Networks

Table 1.2 gives the major differences between cellular and ad hoc networks.

1.3.2 Applications of Ad Hoc Wireless Networks

The field of wireless networking emerges from the integration of personal com- puting, cellular technology, and the Internet. This is due to the increasing inter- actions between communication and computing, which are changing information access from "anytime anywhere" into "all the time, everywhere." At present, a largevariety of networks exists, ranging from the well-known infrastructure of cellular networks to noninfrastructure wireless ad hoc networks.

The following are the applications of ad hoc wireless networks:

- Community network
- Enterprise network
- Home network
- Emergency response network
- Vehicle network
- Sensor network

Unlike a fixed wireless network, wireless ad hoc or on-the-fly networks are char- acterized by the lack of infrastructure. Nodes in a mobile ad hoc network are free to move and organize themselves in an arbitrary fashion. Each user is free to roam about while communicating with others. The path between each pair of users may have multiple links, and the radio between them can be heterogeneous. This allows an association of various links to be a part of the same network. Mobile ad hoc networks can operate in a stand-alone fashion or could possibly be connected to alarger network such as the Internet.

Ad hoc networks are suited for use in situations where an infrastructure is unavailable or to deploy one is not cost-effective. One of many possible uses ofmobile ad hoc networks is in some business environments, where the need for collaborative computing might be more important outside the office environmentthan inside, such as in a business meeting outside the office to brief clients on agiven assignment. Work has been going on to introduce the fundamental conceptsof game theory and its applications in telecommunications. Game theory originates from economics and has been applied in various fields. Game theory deals with multiperson decision making, in which each decision maker tries to maximize hisor her utility. The cooperation of the users is necessary to the operation of ad hocnetworks; therefore, game theory provides a good basis to analyze the networks.

A mobile ad hoc network can also be used to provide crisis management servicesapplications, such as in disaster recovery, where the entire communication infra-structure is destroyed and resorting communication quickly is crucial. By using amobile ad hoc network, an infrastructure could be set up in hours instead of weeks, as is required in the case of wired line communication. Another application exampleof a mobile ad hoc network is Bluetooth, which is designed to support a personalarea network (PAN) by eliminating the need for wires between various devices, suchas printers and personal digital assistants. The famous IEEE 802.11 or WiFi protocolalso supports an ad hoc network system in the absence of a wireless access point.

The idea of ad hoc networking goes back to the U.S. Defense Advanced ResearchProjects Agency (DARPA) packet radio network, which was used in the 1970s. A mobile ad hoc network is a collection of mobile devices establishing a short liveor temporary network in the absence of a supporting structure. Mobile ad hoc networks can be used in establishing efficient, dynamic communication for rescue,
emergency, and military operations. A commercial application, such as Bluetooth,is one of the recent developments utilizing the concept of ad hoc networking.

Bluetooth is named after King Harald Blat (translated as King Harold Bluetoothin English), who ruled Denmark in the tenth century a.d. Bluetooth was first intro- duced in 1998. It uses radio waves to transmit wireless data over short distances,and can support many users in any environment. Eight devices can communicatewith each other in a piconet. At one time, ten of these piconets can coexist in thesame coverage range of the Bluetooth radio. A Bluetooth device can act as both aclient and a server. A connection must be established to exchange data between anytwo Bluetooth devices. To establish a connection, a device must request a connec- tion with the other device. Bluetooth was based on the idea of advancing wireless interactions with various electronic devices. Devices like mobile phones, personal digital assistants, and laptops with the right chips could all communicate wirelessly with each other. However, later it was realized that a lot more is possible.

1.3.3 Technical and Research Challenges

Mobile ad hoc networks pose several technical and research challenges that need to be addressed. Ad hoc architecture has many benefits, such as self-reconfiguration and adaptability to highly variable mobile characteristics such as power and trans- mission conditions, traffic distributions, and load balancing. These benefits pose new challenges which mainly reside in the unpredictability of network topologydue to the mobility of nodes, which, coupled with the local broadcast capability,causes a set of concerns in designing a communication system on top of ad hoc wireless networks. To deal with this issue, many potential approaches have been proposed: distributed MAC and dynamic routing, Wireless Service Location Protocol, Wireless Dynamic Host Configuration Protocol, distributed admission call control, and quality-of-service (QoS)–based routing technique.

1.3.3.1 Security Issues and Challenges

Security has become a primary concern to provide protected communication between mobile nodes in a hostile environment. Unlike the wired line networks, the unique characteristics of mobile ad hoc networks pose a number of nontrivial challengesto security design, such as open peer-to-peer network architecture, shared wireless medium, stringent resource constraints, and highly dynamic network topology. These challenges clearly make a case for building multifence security solutions thatachieve both broad protection and desirable network performance.

One of the fundamental vulnerabilities of MANETs comes from their open peer-to-peer architecture. Unlike wired networks that have dedicated routers, each mobile node in an ad hoc network may function as a router and forward packets for other nodes. The wireless channel is accessible to both legitimate network users and malicious attackers. As a result, there is no clear line of defense in MANETs from the security design perspective. The boundary that separates the inside network from the outside world becomes blurred. There is no well-defined place or infrastructure where we may deploy a single security solution. Moreover, portable devices, as well as the system security information they store, are vulnerable to compromises or physical capture, especially low-end devices with weak protection. Attackers may sneak into the network through these subverted nodes, which pose the weakest link and incur a domino effect of security breaches in the system.

The stringent resource constraints in MANETs constitute another nontrivial challenge to security design. The wireless channel is bandwidth constrained andshared among multiple networking entities. The computation capability of a mobile node is also constrained. For example, some low-end devices, such as PDAs,can hardly perform computation-intensive tasks like asymmetric cryptographic computation. Because mobile devices are typically powered by batteries, they may have very limited energy resources. The wireless medium and node mobility pose far more dynamics in MANETs compared to the wired line networks. The network topology is highly dynamic as nodes frequently join or leave the network, and roam in the network on their own will. The wireless channel is also subject tointerferences and errors, exhibiting volatile characteristics in terms of bandwidth and delay. Despite such dynamics, mobile users may request “anytime, anywhere” security services as they move from one place to another.

The above characteristics of MANETs clearly make a case for building multi- fence security solutions that achieve both broad protection and desirable network performance. First, the security solution should spread across many individual components and rely on their collective protection power to secure the entire network. The security scheme adopted by each device has to work within its own resource limitations in terms of computation capability, memory, communication capacity, and energy supply. Second, the security solution should span different layers of the protocol stack, with each layer contributing to a line of defense. No single-layer solution is possible to thwart all potential attacks. Third, the security solution shouldthwart threats from both outsiders who launch attacks on the wireless channel and network topology, and insiders who sneak into the system through compromiseddevices and gain access to certain system knowledge. Fourth, the security solution should encompass all three components of prevention, detection, and reaction that work in concert to guard the system from collapse. Finally, the security solutionshould be practical and affordable in a highly dynamic and resource-constrained networking scenario.

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