CELLULAR & MOBILE COMMUNICATION

LECTURE NOTES

B.TECH (IV-I SEM-R20)

(2023-24)

PREPARED BY

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JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech (ECE)– IV-I Sem

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(20A04703c) CELLUAR & MOBILE COMMUNICATIONS
(Professional Elective Course –V)

Course Objectives:

- To explain cell coverage for signal and traffic, diversity techniques and mobile antennas by the use ofEngineering Mathematics.
- To present impairments due to multipath fading channel, fundamental techniques to overcome different fading effects, frequency management, Channel assignment and types of handoffs.
- To teach concepts and solve problems on mobile antennas and cellular systems.

Course Outcomes:

- Know about cell coverage for signal and traffic, diversity techniques and mobile antennas by the use ofEngineering Mathematics
- Explain impairments due to multipath fading channel, fundamental techniques to overcome differentfading effects, frequency management, Channel assignment and types of handoff
- Apply concepts to solve problems on mobile antennas and cellular systems
- Analyze Co-channel and Non Co-channel interferences, different Hand-offs and dropped call rates
- Evaluate performance of dropped call rate and false alarm rate
- Compare different handoffs

UNIT I

Introduction to Cellular Mobile Radio Systems: Limitations of Conventional Mobile Telephone Systems, Basic Cellular Mobile System, Uniqueness of Mobile Radio Environment, Mobile Fading Characteristics, Operations of Cellular Systems, Evolution of Cellular Systems.

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 an Omni Directional Antenna System, System Capacity, Trunking and Grade of Service, Improving Coverage and Capacity in Cellular Systems- CellSplitting, Sectoring, Microcell Zone Concept.

UNIT II

Cell Coverage for Signal and Traffic: Signal Reflections in Flat and Hilly Terrain, Effect of Human Made Structures, Phase Difference between Direct and Reflected Paths, Constant Standard Deviation, Straight Line Path Loss Slope, General Formula for Mobile Propagation Over Water and Flat Open Area, Near and Long Distance Propagation, Path Loss from a Point to Point Prediction Model in Different Conditions, Merits of Lee Model.

Cell Site and Mobile Antennas: Space Diversity Antennas, Umbrella Pattern Antennas, Minimum Separation of Cell Site Antennas, Mobile Antennas.

UNIT III

Co-Channel Interference Reduction: Measurement of Real Time Co-Channel Interference, Design of Omnidirectional and directional Antenna System, Antenna Parameters and Their Effects, Diversity Techniques- Space Diversity, Polarization Diversity, Frequency Diversity, Time Diversity.

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.

UNIT IV

Frequency Management and Channel Assignment: Numbering and Grouping, Setup Access and Paging Channels, Channel Assignments to Cell Site and Mobile Units, Channel Sharing and Borrowing, Sectorization, Overlaid Cells, Non Fixed Channel Assignment.

UNIT V

Handoffs and Dropped Calls: Handoff Initiation, Types of Handoff, Delaying Handoff, Advantages of Handoff, Power difference Handoff, Forced Handoff, Mobile Assisted and Soft Handoffs, Intersystem Handoff, Introduction to Dropped Call Rates and their Evaluation.

System Evaluation: Performance Evaluation, Blockage, Dropped-call rate, Signaling Evaluation- False Alarm Rate, Word error rate consideration and calculations, Measurement of averaged received signal level and level crossings.

Textbooks:

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

References:

1. W.C.Y Lee, Mobile Communications Engineering-Theory and Applications, McGraw Hill, SecondEdition, ,2014.
2. Gordon L. Stuber, Principles of Mobile Communications, Springer International, 2nd Edn., 2001.
3. Simon Haykin, Michael Moher, Modern Wireless Communications, Pearson Education, 2005.

UNIT-I(A)

INTRODUCTION TO CELLULAR MOBILE RADIO SYSTEMS

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.

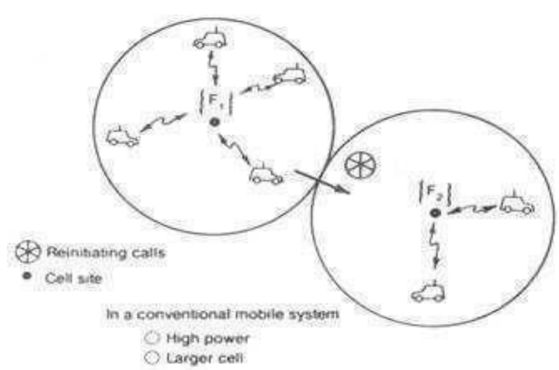

Fig.1 Conventional Mobile System

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 large number 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.

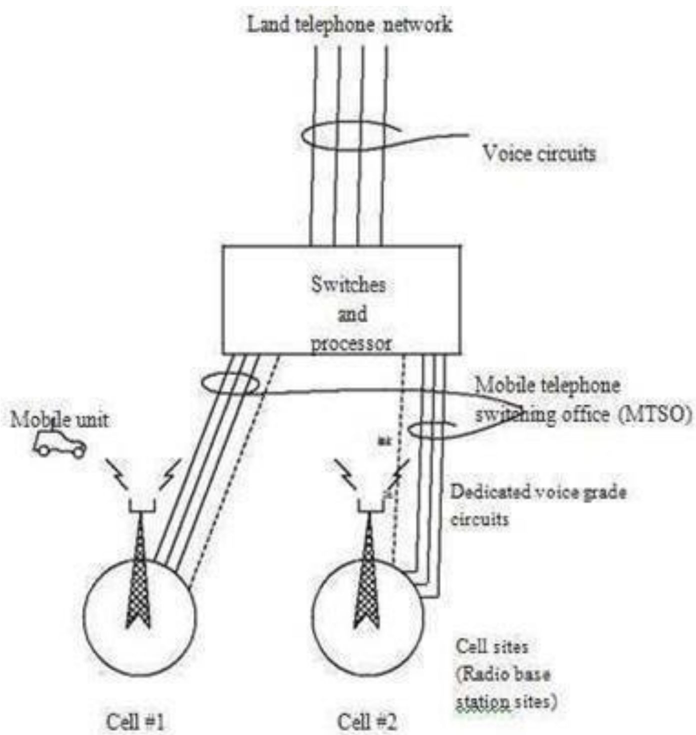

Fig: Basic cellular system

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 incident angle 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

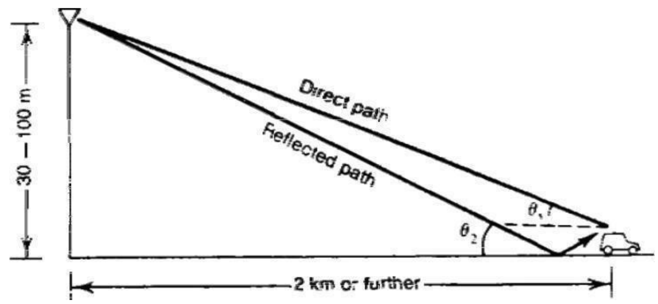

FIGURE 2.4 mobile radio transmission models.

The difference in power reception at two different distances *R*1 and *R*2 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

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

and

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

are

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 (15mi/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]

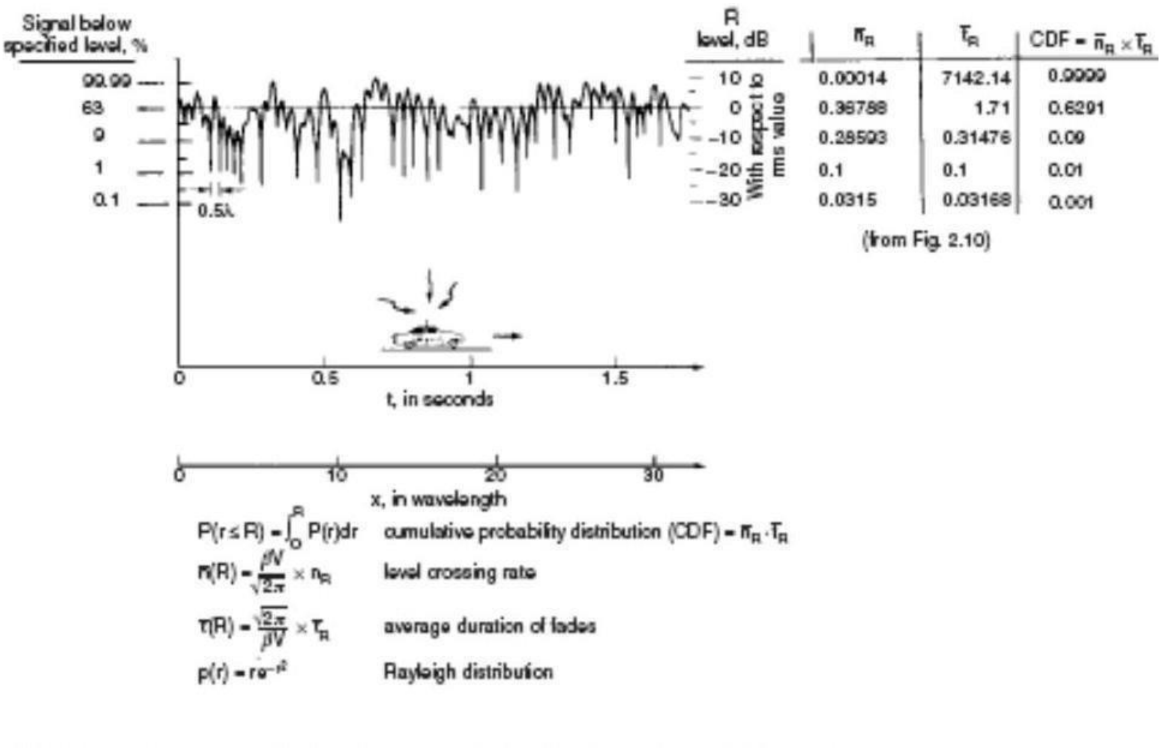

Fig: A typical fading signal while the mobile unit is moving

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 $2T$ 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 $2L$ 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.

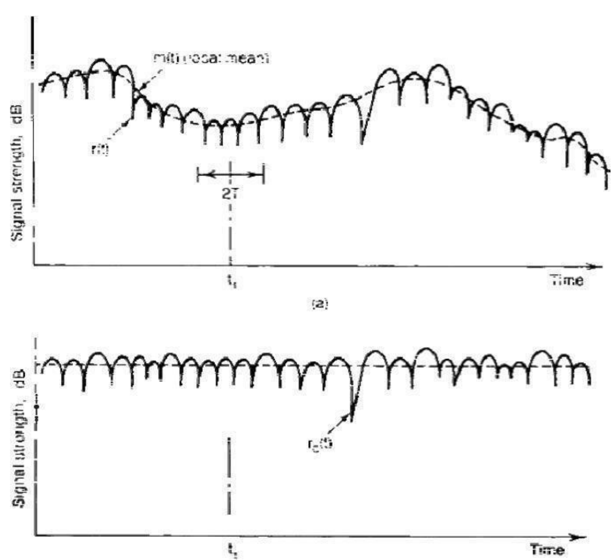

FIGURE 2.6 A mobile radio signal fading representation. (A) A mobile signal fading. (B)short-term signal fading.

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 $r0$ 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.

OPERATION OF CELLULAR SYSTEMS

Operation Procedures

This section briefly describes the operation of the cellular mobile system from a customer's perception without touching on the design parameters.[13,14] The operation can be divided into four parts and a handoff procedure.

Mobile unit initialization. When a user activates the receiver of the mobile unit, the receiver scans the set-up channels. It then selects the strongest and locks on for a certain time. Because each site is assigned a different set-up channel, locking onto the strongestset-up channel usually means selecting the nearest cell site. This self-location scheme is used in the idle stage and is user-independent. It has a great advantage because it eliminates the load on the transmission at the cell site for locating the mobile unit. The disadvantage of the self-location scheme is that no location information of idle mobile units appears at each cell site. Therefore, when the call initiates from the land line to a mobile unit, the paging process is longer. For a large percentage of calls originates at the mobile unit, the use of self-location schemes is justified. After a given period, the self-location procedure is repeated. When land-line originated calls occur, a featurecalled "registration" is used.

Mobile originated call. The user places the called number into an originating register in the mobile unit, and pushes the "send" button. A request for service is sent on a selectedset-up channel obtained from a self-location scheme. The cell site receives it, and in directional cell sites (or sectors), selects the best directive antenna for the voice channelto use. At the same time, the cell site sends a request to the mobile telephone switching office (MTSO) via a high-speed data link. The MTSO selects an appropriate voice channel for the call, and the cell site acts on it through the best directive antenna to link the mobile unit. The MTSO also connects the wire-line party through the telephone company zone office.

Network originated call. A land-line party dials a mobile unit number. The tele- phone company zone office recognizes that the number is mobile and forwards the call to the MTSO. The MTSO sends a paging message to certain cell sitesbased on the mobile unit number and the search algorithm. Each cell site transmits the page on its own set-up channel. If the mobile unit is registered, the registered site pages the mobile. The mobile unit recognizes its own identification on a strong set-up channel, locks onto it, and responds to the cell site. The mobile unitalso follows the instruction to tune to an assigned voice channel and initiate useralert.

Call termination. When the mobile user turns off the transmitter, a particular signal (signaling tone) transmits to the cell site, and both sides free the voice channel. The mobile unit resumes monitoring pages through the strongest set-up channel.

Handoff procedure. During the call, two parties are on a traffic channel. When the mobile unit moves out of the coverage area of a particular cell site, the reception becomes weak. The current cell site requests a handoff. The system switches the call to a new frequency channel in a new cell site without either interrupting the call or alerting the user. The call continues as long as the user is talking.

Evolution of 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

UNIT-I (B)

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.

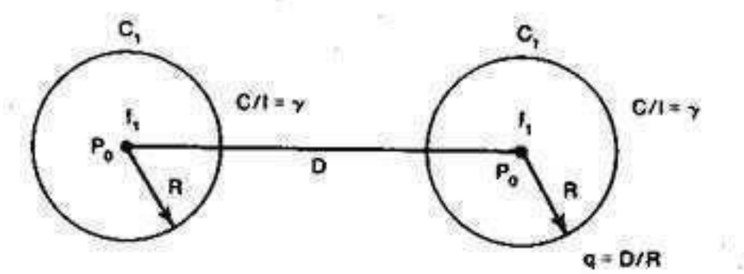

Fig.1 The ratio of D/R

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.

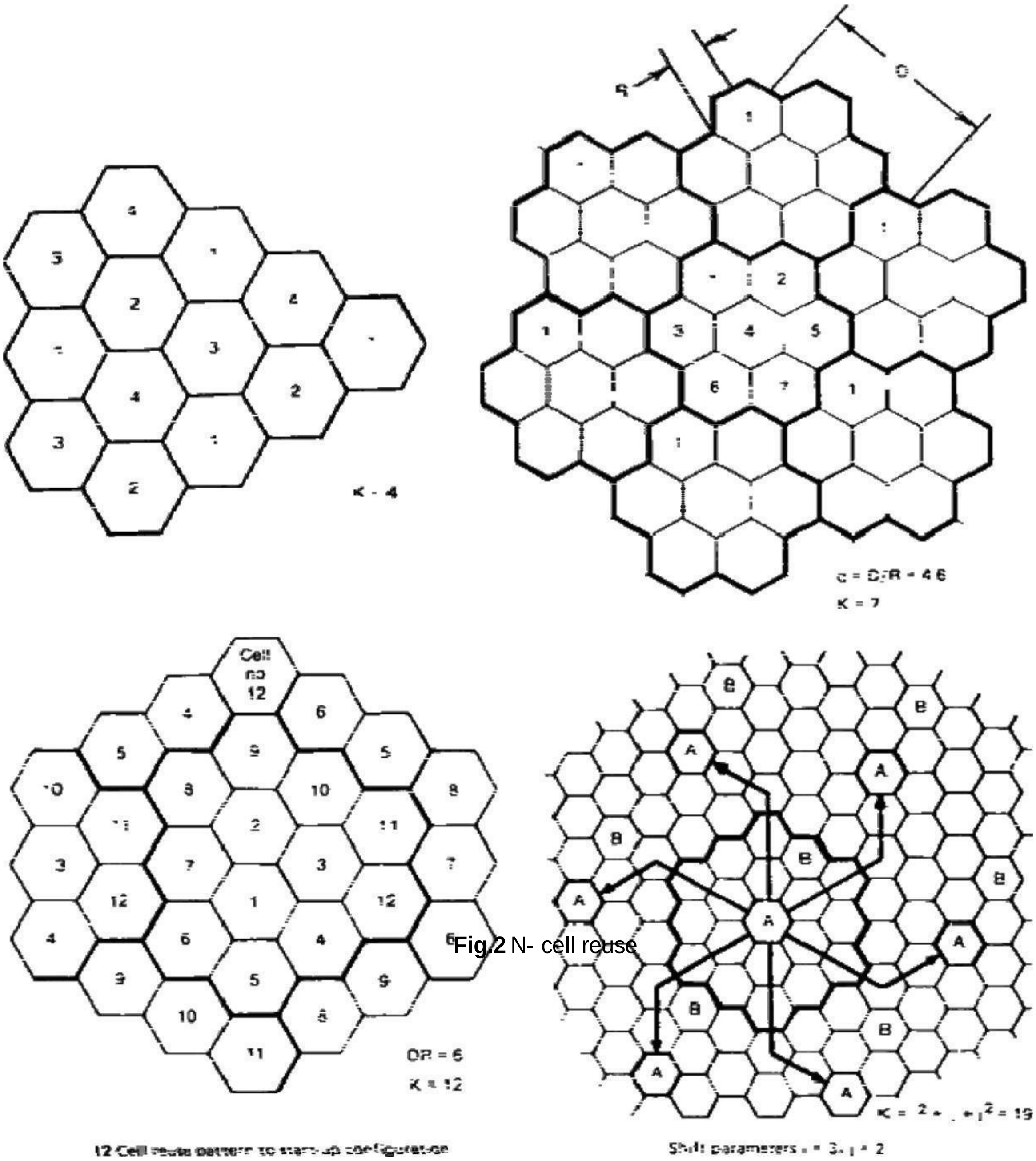

Fig.2 N- cell reuse

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

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

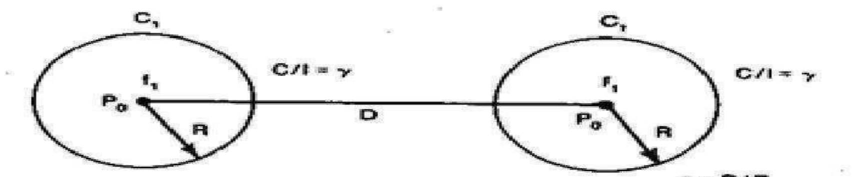

Fig.3.The ratio ofD/R

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

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

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

$$q_k = \frac{D_k}{R}$$

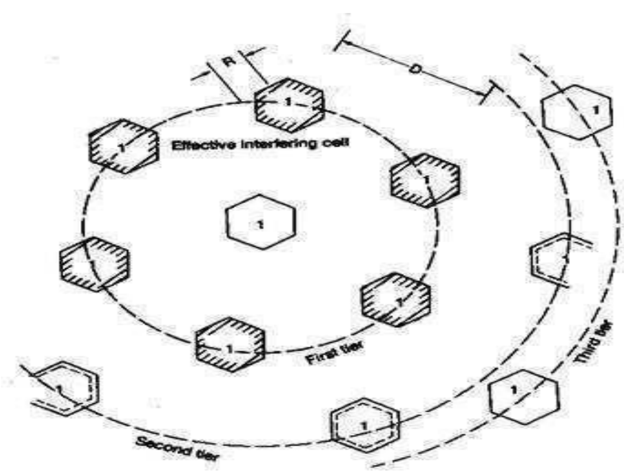

Fig 5: Six effective interfering cells of cell 1

Desired 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.

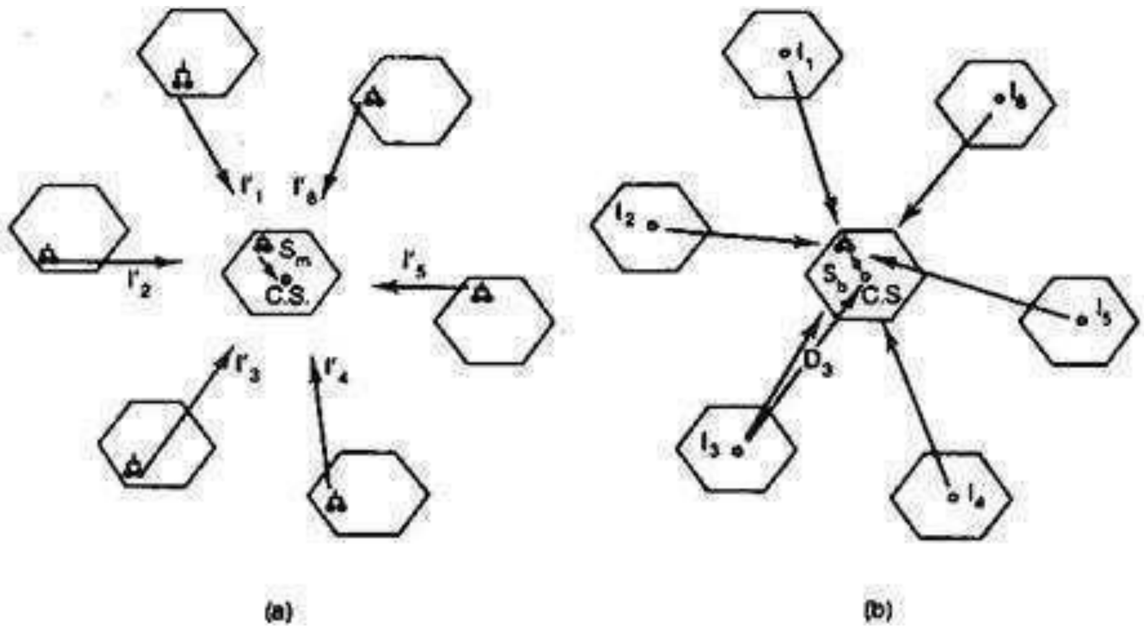

Fig 6 Cochannel interference from six interferers. (a).receiving at the cell site; (b) receiving at the mobile unit.

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. 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 principle is used in designing cellular radio systems.

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. The fundamentals of trunking theory were developed by Erlang, a Danish mathematician, in the late 19th century.

One Erlang represents the amount of traffic intensity carried by a channel that is completely occupied (i.e. 1 call-hour per hour or 1 call-miiiute 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 gradeof service is 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 numberof channels available in the system.

GOS is given as the likelihood that a call is blocked, or the likelihood of a call experiencing a delay greater than a certain queuing time. The traffic. intensity offered by each user is equal to the call request rate multiplied by the holding time. That is, eachuser generates a traffic intensity of Au Erlangs given by

$$A_u = \lambda H$$

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

$$A = UA_u$$

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 a 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. Gradeof Service (005): 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. Denoted by A seconds1. In a C channel trunked system, if the traffic is equally distributed among the channels, then the traffic intensity per channel Ac , is given as

$$A_c = UA_u/C$$

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.

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.

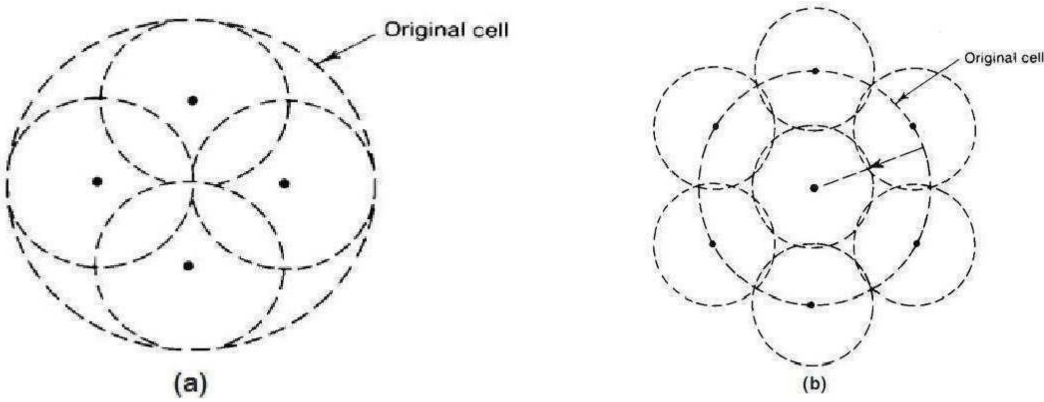

Fig.8 Cell splitting

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° sectorsorsix60°sectorsasshowninbelowfigure.

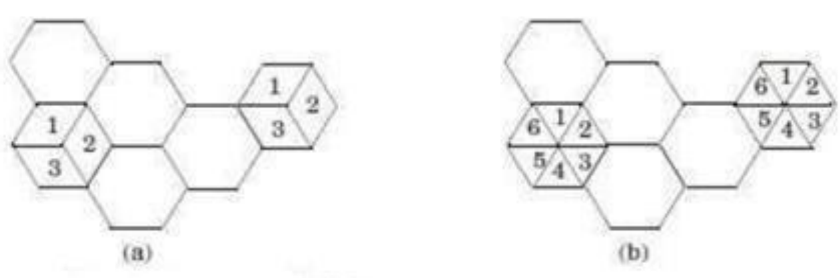

Fig: (a) 120°sectoring (b) 60° sectoring

3.7.4 A 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 [Lee91b]. This proposal is based on a microcell concept for seven cell reuse, as illustrated in Figure 3.13. 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

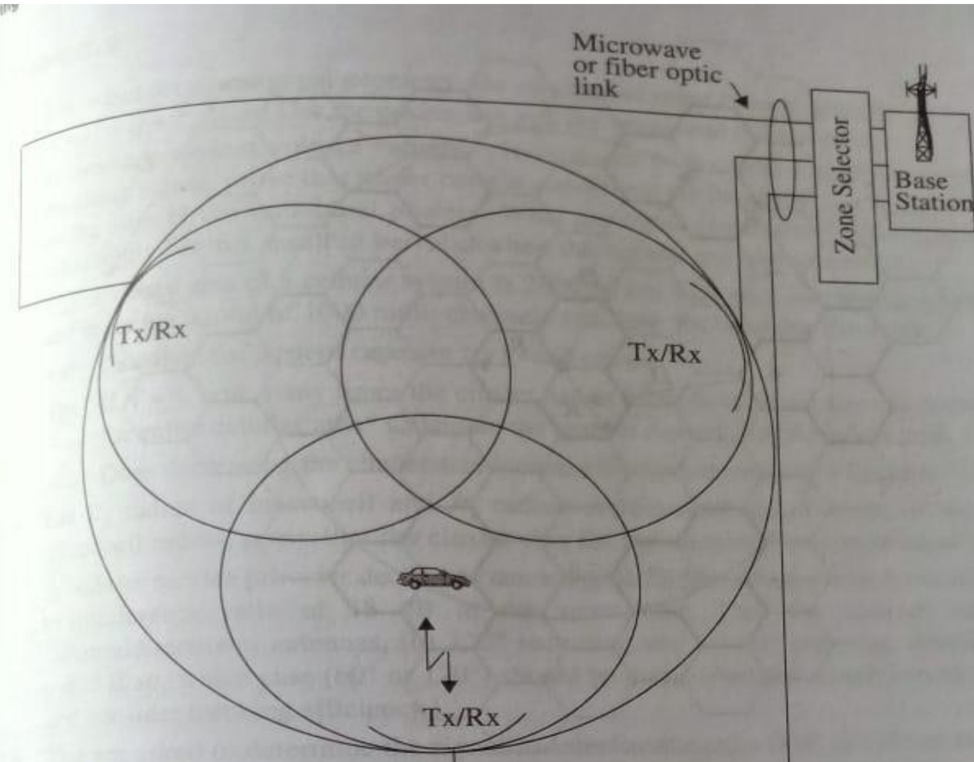

Figure 3.13 The microcell concept [adapted from [Lee91b] © IEEE].

the 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.