UNIT II
ELEMENTS OF CELLULAR RADIO SYSTEM DESIGN

General Description of the Problem

Based on the concept of efficient spectrum utilization, Elements of Cellular Mobile Radio System Design are

(1) the concept of frequency reuse channels

(2) the co-channel interference reduction factor

(3) the desired carrier-to-interference ratio

(4) the handoff mechanism

(5) cell splitting.

Challenge **-** to serve the greatest number of customers with a specified system quality.

1. How many customers can be served in a busy hour?
2. How many subscribers can we take into the system?
3. How many frequency channels are needed?

Maximum Number of Calls per Hour per Cell

To calculate the predicted number of calls per hour per cell Q in each cell, the following parameters are required

- The size of the cell
- The traffic conditions in the cell

Maximum number of frequency channels per cell

The maximum number of frequency channels per cell N is closely related to an average calling time in the system. The standard user's calling habits may change as a result of the charging rate of the system and the general income profile of the users If an average calling time T is 1.76 min and the maximum calls per hour per cell is Qi, then the offered load can be derived as

$$A = Qi*T/60 \text{ (Erlangs)}$$

If the blocking probability is given, then it is easy to find the required number of radios in each cell. If a large area is covered by 28 cells, Kt = 28; the total number of customers in the system increases. Therefore, we may assume that the number of subscribers per cell Mi is somehow related to the percentage of car phones used in the busy hours and the number of calls per hour per cell Qi as $M_i = f(Q_i, \eta_c)$

Where the value Qi is a function of the blocking probability B, the average calling time T, and the number of channels N.

$$Qi = f(B, T, N)$$

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.2.1). 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.

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

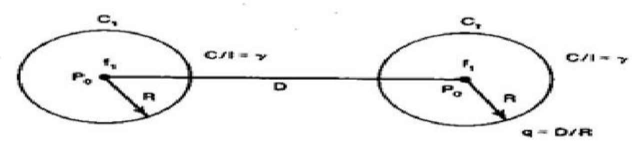


Fig.2.1 The ratio of D/R

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. 2.2 for K — 4, 7, 12, and 19.

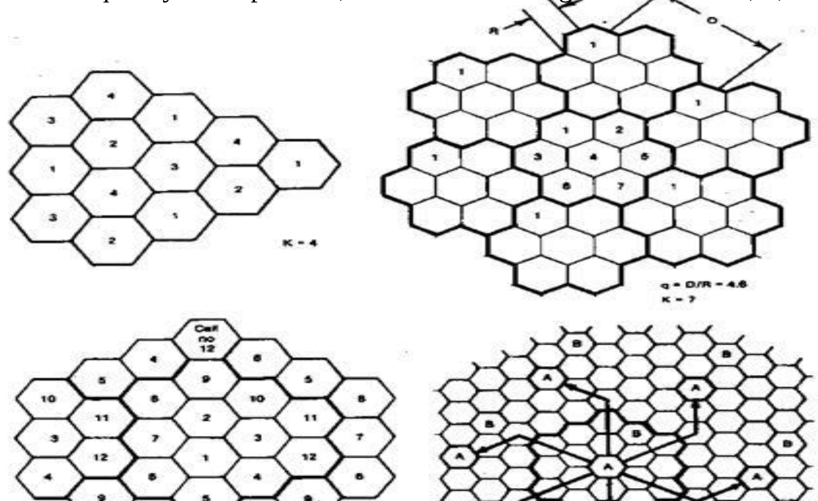


Fig.2.2 N- cell reuse pattern

Frequency reuse 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.2.1, then

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

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.

Cochannel 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.2.3 ; 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 cochannel interfering cells and is equal to 6 in a fully developed system, as shown in Fig. 5.

The six cochannel interfering cells in the second tier cause weaker interference than those in the first tier. Therefore, the cochannel 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* cochannel interfering cell

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

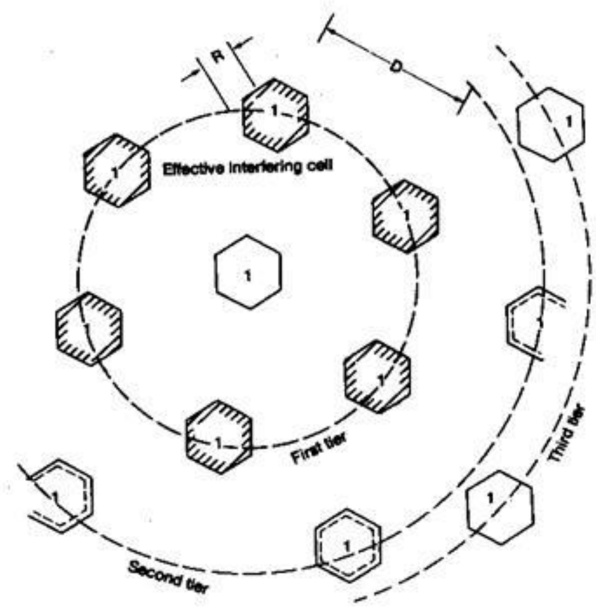


Fig 2.3: Six effective interfering cells of cell 1

C/I for normal case in an omnidirectional antenna system:

There are two cases to be considered: (1) the signal and cochannel interference received by the mobile unit and (2) the signal and cochannel interference received by the cell site. Both cases are shown in Fig.2.4. 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,

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

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

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 cochannel 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 cochannel 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

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

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

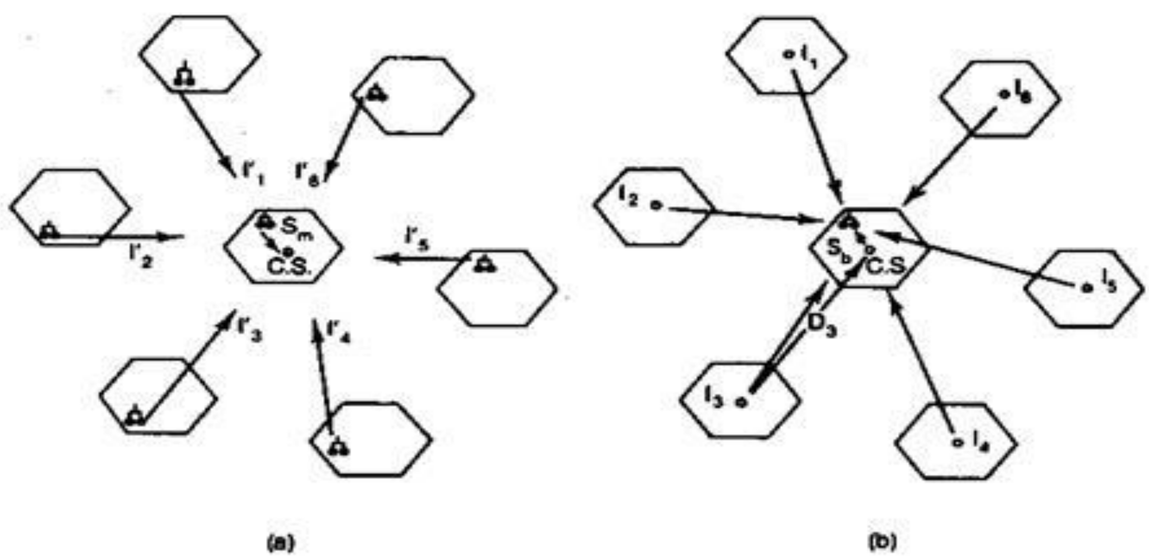


Fig 2.4 Cochannel interference from six interferers. (a).receiving at the cell site; (b) receiving at the mobile unit.

Hand-off Mechanism: Hand-off is the process of automatically changing the frequencies. When the mobile unit moves out of the coverage areas of a particular cell site, the reception becomes weak. At this instant the present cell site requests Hand-off, then system switches the call to a new frequency channel in a new cell site without interrupting either call or user. This phenomenon is known as “hand -off” or ‘handover’. Hand -off processing scheme is an important task for any successful mobile system. This concept can he applied to one dimensional as well as two dimensional cellular configurations.

By the reception of weak signals from the mobile unit by the cell site, the Hand-off is required in the following two situations. They are

The level for requesting a Hand-off in a noise limited environment is at the cell boundary say-l00 dBm.

In a particular cell site, when the mobile unit is reaching the signal strength holes (gaps).

Figure 2.5 shows the usage of frequency F1 in two cochannel cells which arc separated by a distance D. Now, we have to provide a communication system in the whole area by filling other frequency channels F2,F3 and F4 between two co-channel cells. Depending on the same value of q the cells C2 ,C3 and C4 to which the above fill-in frequencies F2, F3 and F4 are assigned respectively as shown in figure.

Initially a mobile unit is starting a call in cell with fill-in frequency F1 and then moves to a cell with fill-in frequency F2. The mobile unit moves from cell C1 to cell C2, meanwhile however the call being dropped and reinitiated in the frequency channel from F1 to F2. This process of changing frequencies can be done automatically by the system without the user's intervention. In the cellular system the above mentioned Hand-off process is used.

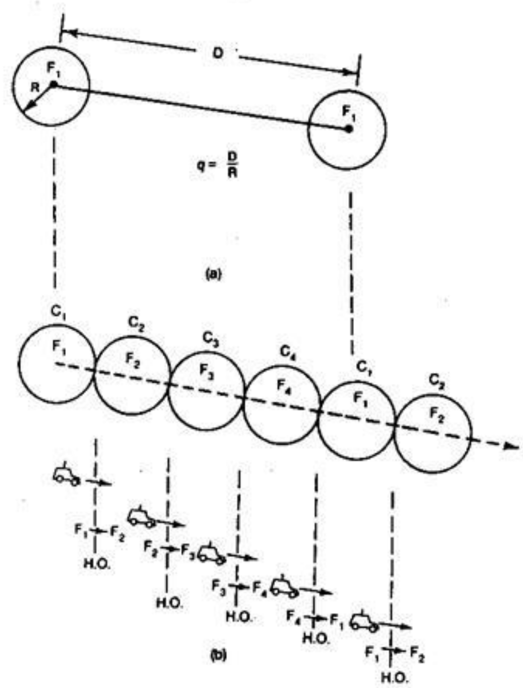


Fig.2.5: (a). cochannel interference reduction ratio 2, (b) fill in frequency

need of 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.

Splitting

There are two kinds of cell-splitting techniques:

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 2 h.

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.

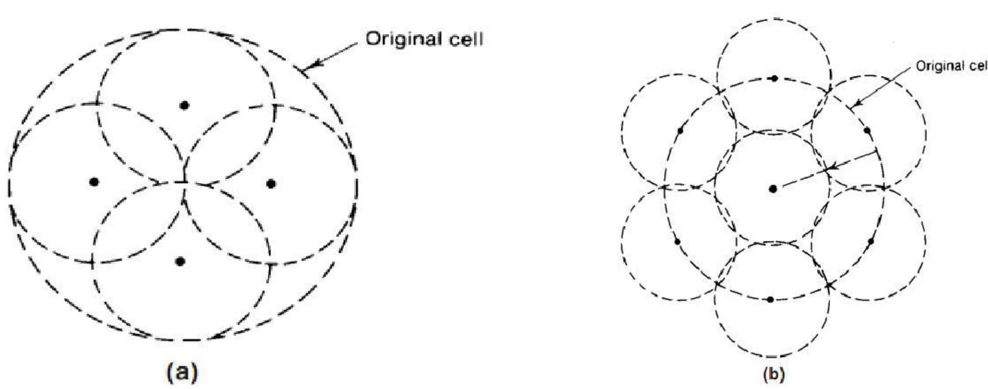


Fig.2.6: Cell splitting

the importance of $K = i^2 + ij + j^2$

For hexagonal cells i.e. with "honeycomb" cell layouts commonly used in mobile radio with possible cluster sizes are $K = i^2 + ij + j^2$

Where i, j — Non negative integers

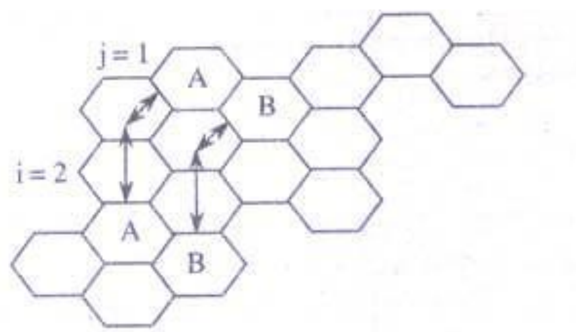
The integers i, j determine the relative location of co channels. The main reason for obtaining the above expression is to calculate the smallest number K which can still meet our system performance requirements. This process involves estimating co-channel interference and selecting the minimum frequency reuse distance D to reduce cochannel interference. Thus, the smallest possible value for K is 3, obtained by putting i=1,j=1 in above eq.

The nearest co-channel neighbors of a particular cell can be obtained by the following two steps

(i) Moving i cells along any chain of hexagons.

(ii) Turn 60 degrees counter-clockwise and move j cells.

The method of locating cochannel cells in a 7-cell reuse pattern with i=2 and j=1 is shown figure



The equation for frequency reuse pattern $K = i^2 + ij + j^2$ can also be used to measure the following.

I. The distance between co-channel cells in adjacent clusters is given by $D = \sqrt{i^2 + ij + j^2}$.

The number of cells in a cluster, K is obtained by $N = D^2 = i^2 + ij + j^2$.

The frequency reuse factor, Q is obtained by

$$Q = \frac{D}{R} = \sqrt{3N} = \sqrt{3(i^2 + ij + j^2)}$$