ETI2511-WIRELESS COMMUNICATION II
HANDOUT I
1.0 PRINCIPLES OF CELLULAR COMMUNICATION

1.0 Introduction

The substitution of a single high power Base Transmitter Stations (BTS) by several low BTSs to support many users is the backbone of the cellular concept. The following four parameters are most important while considering the cellular issues: (i) system capacity, (ii) quality of service, (iii) spectrum efficiency and (iv) power management. Starting from the basic notion of a cell, this handout discusses these parameters in detail.

1.1 Cells in Mobile Communication

The power of the radio signals transmitted by the Base Station (BS) decay as the signals travel away from it. A minimum amount of signal strength (let us say, x dB) is needed in order to be detected by the Mobile Station(MS) which may the hand-held personal units or those installed in the vehicles. The region over which the signal strength lies above this threshold value x dB is known as a cell. It is the coverage area of a BS and is circular for an isotropic BS . Such a circle, which gives this actual radio coverage, is called the foot print of BS. When cells in a coverage areaare represented by circles, there can be an overlap between any two such side by side circles or a gap between the coverage areas of two adjacent circles as shown in Figure 1.1.

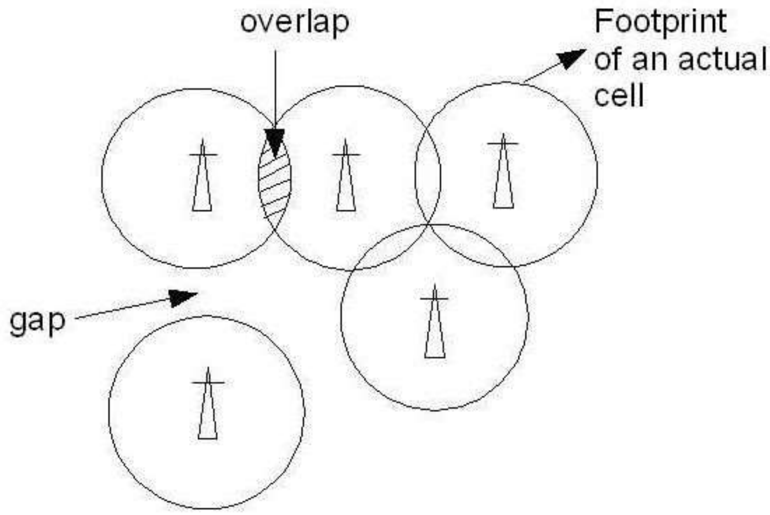


Figure 1.1: Footprint of cells showing the overlaps and gaps.

The ideal cell shape should be able to:
(a) cover the whole coverage area without leaving overlaps and gaps;
(b) Support the weakest signal which occurs at the cell boundaries; and
(c) Cover the maximum area within the mobile territory.

The circular geometry fails to satisfy these conditions. Regular polygons, namely, (i) equilateral triangle, (ii) square and (iii) hexagon can cover the entire area without any overlap and gaps.
Further, for any distance between the center and the farthest point in the cell from it, a regular hexagon covers the maximum area. Hence regular hexagonal geometry is the most commonly used cell-shape in mobile communication.

1.2. Frequency Reuse

Frequency reuse (sometimes called frequency planning), is a technique of reusing frequencies and channels within a communication system to improve capacity and spectral efficiency. Frequency reuse is one of the fundamental concepts on which commercial wireless systems are based that involve the partitioning of a coverage area into cells. The increased capacity in the cellular network, compared with a network with a single transmitter, comes from the fact that the same radio frequency can be reused in a different area. Usually, the frequencies allocated to one service are reused in a regular pattern of cells.

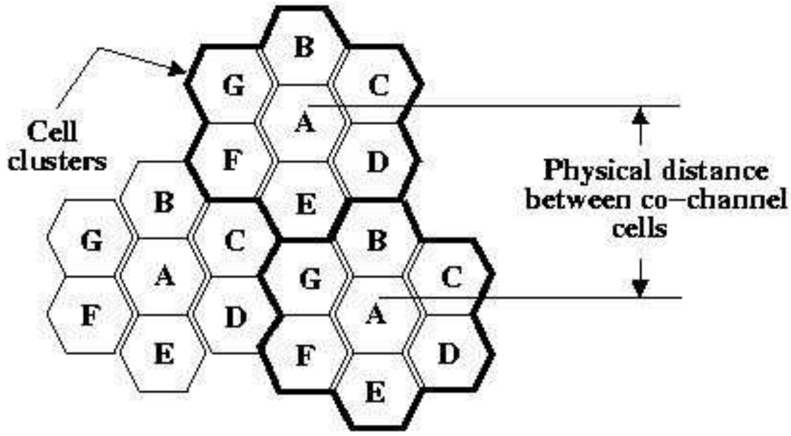


Figure 1.2: Frequency reuse technique of a cellular system.

The repeating regular pattern of cells and associated frequencies is called cluster. Since each cell is designed to use radio frequencies only within its boundaries, the same frequencies can be reused in other cells not far away without interference, in another cluster. Such cells are called 'co-channel' cells. The reuse of frequencies enables a cellular system to handle a huge number of calls with a limited number of channels. Figure 1.2 shows a frequency reuse with cluster size of 7, showing the co-channels cells in different clusters by the same letter. The closest distance between the co-channel cells (in different clusters) is determined by the choice of the cluster size and the layout of the cell cluster.

Consider a cellular system with S duplex channels available for use with N cells in a cluster. If each cell is allotted K duplex channels with all being allotted unique and disjoint channel groups we have $S = KN$ under normal circumstances. Now, if the cluster are repeated M times within the total area, the total number of duplex channels, or, the total number of users in the system would be $T = MS = KMN$. Clearly, if K and N remain constant, then

$$T \propto M \qquad (1.1)$$

If T and K are held constant, then

$$N \propto \frac{1}{M} \qquad (1.2)$$

Hence the capacity gain achieved is directly proportional to the number of times a cluster is repeated, as shown in (1.1). For a fixed neighbourhood, small N decreases the size of the cluster which results in the increase of the number of frequencies and capacity. Increasing the value of N means that co-channel cells are located much closer which can cause more interference. In practice, N is determined by calculating the amount of interference that can be tolerated to sustain quality communication.

In practice, the cluster size N cannot take on any value and is given only by the following equation

$$N = i^2 + ij + j^2, \qquad i \geq 0, j \geq 0, \qquad (1.3)$$

where i and j are integer numbers. This means that N can be 1, 3, 4, 7, 9, 12, …

Worked Example. 1:

Find the relationship between any two nearest co-channel cell distance D and the cluster size N using hexagonal pattern shown below.

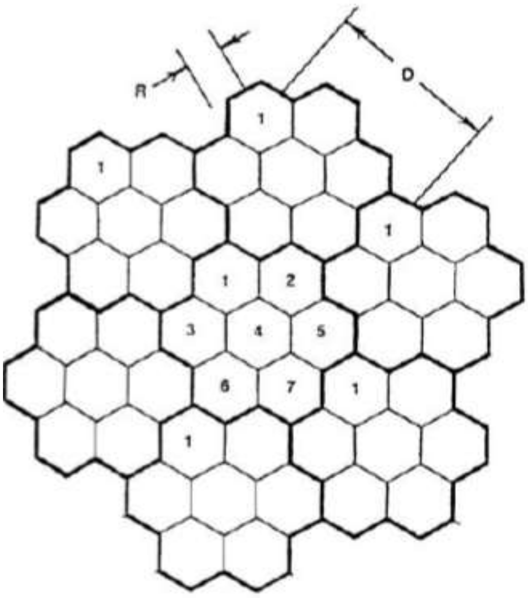
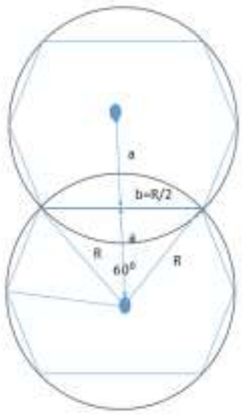


Figure 1.3. Coverage area with number of cells in a cluster, N=7, cell radius, r and frequency reuse distance, D.

Solution:

For hexagonal cells, it can be shown that the distance between two adjacent is d = 2a = $\sqrt{3}R$ as shown below.



$$a^2 + b^2 = R^2$$

$$a = \sqrt{R^2 - \left(\frac{R}{2}\right)^2}$$

$$a = R\sqrt{\frac{3}{4}}$$

$$a = \frac{R}{2}\sqrt{3}$$

$$2a = R\sqrt{3}$$

Figure 1.4: Distance between two cells each of radius R is 2a = R$\sqrt{3}$

The normalized co-channel cell distance D_n can be calculated by traveling 'i' cells in one direction and then traveling 'j' cells in anticlockwise 120^o of the primary direction. Using law of vector addition,

$$D_n^2 = j^2 \cos^2(30^o) + (i + j \sin(30^o))^2 \qquad (1.4)$$

which turns out to be

$$D_n = \sqrt{i^2 + ij + j^2} = \sqrt{N}. \qquad (1.5)$$

Multiplying the actual distance Multiplying the actual distance between two cells $\sqrt{3}$R, we get

$$D = \sqrt{3N}R \qquad (1.6)$$

1.4 Channel Assignment Strategies

With the rapid increase in number of mobile users, the mobile service providers had to follow strategies which ensure the effective utilization of the limited radio spectrum. With increased capacity and low interference being the prime objectives, a frequency reuse scheme was helpful in achieving this objective. A common problem in frequency palling is that of allocation frequencies/channels to the various cells. Several channels allocation schemes have been developed and this area still continues which can be classified as (i) Fixed Channel Allocation (FCA), Dynamic Channel Allocation (DCA), and (iii) Hybrid Channel Allocation. All channel allocation methods operate under the following principles.

1. Channel allocation schemes must not violate minimum frequency reuse conditions.
2. Channel allocation schemes efficiently utilize available transmission resources.
3. Channel allocation schemes should adapt to changing traffic conditions.

From a frequency reuse standpoint, a fixed channel allocation system distributes frequency (or other transmission) resources to the cells in an optimum manner; i.e., common channels are separated by the minimum frequency reuse distance. Thus, a fixed channel allocation scheme perfectly satisfies condition 2 as well. However, a fixed allocation scheme does not satisfy condition 3.

Generally, a dynamic channel allocation scheme will meet the requirements of all of the above three conditions to some degree.

1.4.1 Fixed Channel Assignment (FCA)

In fixed channel assignment strategy each cell is allocated a fixed number of voice channels. Any communication within the cell can only be made with the designated unused channels of that particular cell. If all the channels are occupied, then the call is blocked and subscriber has to wait.

This is simplest of the channel assignment strategies as it requires very simple implementation but provides worst channel utilization. Later there was another approach in which the channels were borrowed from adjacent cell if all of its own designated channels were occupied. This was named as *borrowing strategy*. In such cases the MSC supervises the borrowing process and ensures that none of the calls in progress are interrupted.

Simple (CB) Schemes

In Simple borrowing (CB) schemes, cell (acceptor cell) that has used all its nominal channels borrows free channels from its neighboring cell (donor cell) to accommodate new calls. Borrowing can be done from an adjacent cell which has largest number of free channels (borrowing from the richest). A search algorithm is used to select the first free channel found. The borrowed channel is returned when channel becomes free in the basic algorithm with reassignment. To be available for borrowing, the channel must not interfere with existing calls, as shown in Figure 1.4

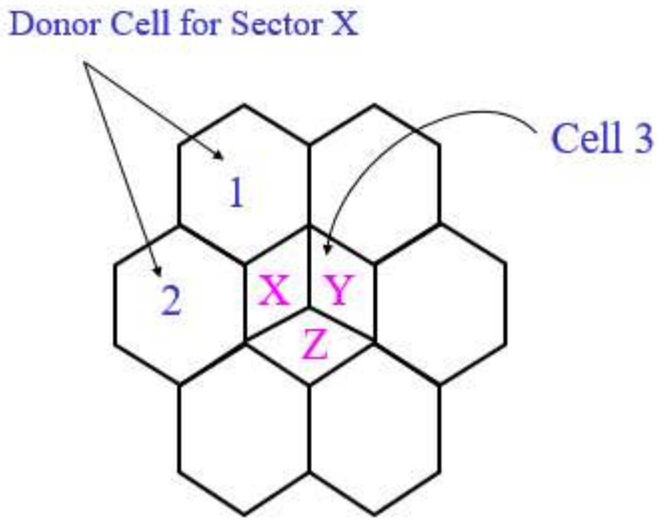


Figure 1.4: Simple Channel Borrowing Scheme - A call initiated in the sector X of cell 3 can borrow a channel from adjacent cells 1 or 2.

1.4.2 Dynamic Channel Assignment (DCA)

In DCA schemes, all channels are kept in a central pool and are assigned dynamically to new calls as they arrive in the system by the MSC. After each call is completed, the channel is returned to the central pool. It is fairly straightforward to select the most appropriate channel for any call based simply on current allocation and current traffic, with the aim of minimizing the interference. DCA scheme can overcome the problem of FCA scheme. However, variations in DCA schemes center around the different cost functions used for selecting one of the candidate channels for assignment.

DCA schemes can be centralized or distributed. The centralized DCA scheme involves a single controller selecting a channel for each cell. The distributed DCA scheme involves a number of controllers scattered across the network (MSCs).

Centralized DCA

In this channel assignment, channels are NOT pre - allocated to any cells meaning that any channel can be allocated to any desired cell during the operation of the system. The channel allocation process is as follows:

The MSC monitors all cells and all channels. Each time a call is initiated, serving BS requests a channel from the MSC. The MSC runs an algorithm that takes into account

a) Possibility of future blocking in cells

b) Frequency being used for channel

c) There used is trance of the channel

The MSC assigns a channel only if it is not used and if it will not cause co-channel interference with any cell in range.

Centralized DCA provides higher capacity(less blocking) but requires higher computational power since the MSC collects real time data of channel occupancy, traffic distribution, and radio signal strengths and uses the data for channel allocation.

Worked Example 3:

A total of 33 MHz bandwidth is allocated to a Frequency Division Duplex (FDD) cellular system with two 25 KHz simplex channels to provide full duplex voice and control channels. Compute the number of channels available per cell if the system uses (i) 4 cell, (ii) 7 cell, and (iii) 8 cell reuse technique. Assume 1 MHz of spectrum is allocated to control channels. Give a distribution of voice and control channels.

Solution:

One duplex channel = 2 x 25 = 50 kHz of spectrum. Hence the total available duplex channels are = 33 MHz / 50 kHz = 660 in number. Among these channels, 1 MHz / 50 kHz = 20 channels are kept as control channels.

(a) For N = 4, total channels per cell = 660/4 = 165. Among these, voice channels are 640/4 = 160 and control channels are 20/4 = 5 in number.

(b) For N = 7, total channels per cell are 660/7 ≈ 94. Therefore, we have to make assumptions to get the solution. From the results in (a), a total of 20 control channels and a total of 640 voice channels are kept. Here, 6 cells can use 3 control channels and the rest (one) can use 2 control channels each. On the other hand, 5 cells can use 92 voice channels and the rest two can use 90 voice channels each. Thus the total solution for this case is:

6 x 3 + 1 x 2 = 20 control channels, and, 5 x 92 + 2 x 90 = 640 voice channels.

This is one solution, there might exist other solutions too.

(c) The option N = 8 is not a valid number of cells in a cluster since it cannot satisfy equation (1.3) by two integers i and j.

1.4.3 Comparison between FCA and DCA

Fixed Channel Assignment (FCA)	**Dynamic Channel Assignment (DCA)**
■ Radio equipment covers all channels assigned to the cell ■ Independent channel control ■ Low computational effort ■ Low call set up delay ■ Low implementation complexity ■ Complex, labor intensive frequency planning ■ Low signaling load ■ Centralized control	■ Radio equipment covers the temporary channel assigned to the cell ■ Fully centralized to fully distributed control dependent on the scheme ■ High computational effort ■ Moderate to high call set up delay ■ Moderate to high implementation complexity ■ No frequency planning ■ Moderate to high signaling load ■ Centralized, distributed control depending on the scheme

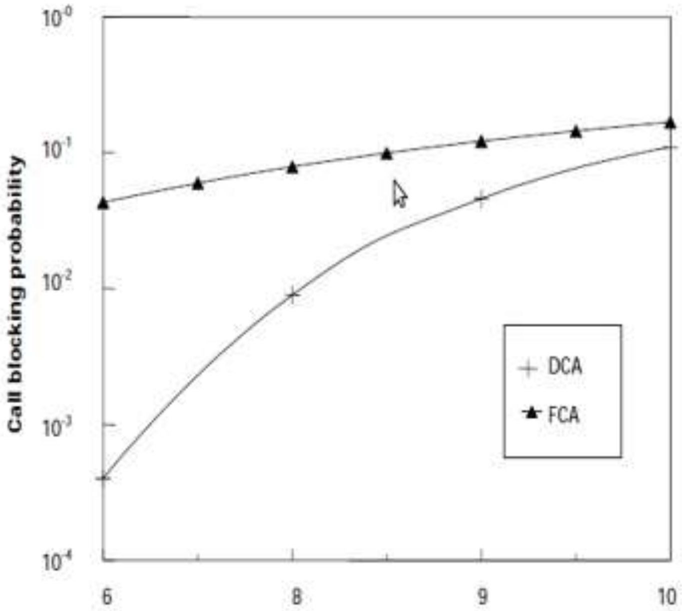


Figure 1.5. Comparison between FCA and DCA performance

1.4.3 Hybrid Channel Allocation(HCA)

In HCA schemes, the total number of channels available for service is divided into fixed and dynamic sets. The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes and, in all cases, are to be preferred for use in their respective cells. The dynamic set is shared by all users in the system to increase flexibility. Request for a channel from the dynamic set is initiated only when the cell has exhausted using all its channels from the fixed set.