EENG473 Mobile Communications
Module 2 : Week # (4)

The Cellular Concept –
System Design Fundamentals

2.2 Frequency Reuse

- Cellular radio systems rely on an **intelligent allocation and reuse of channels** throughout a coverage region.
- Base stations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells. By limiting the coverage area to within the boundaries of a cell
- **A Cell** : is a small geographic area within which each cellular base station is allocated a group of radio channels to be used.
- **Frequency reuse or frequency planning** : The design process of selecting and allocating channel groups for all of the cellular base stations within a system.

The Cellular Concept

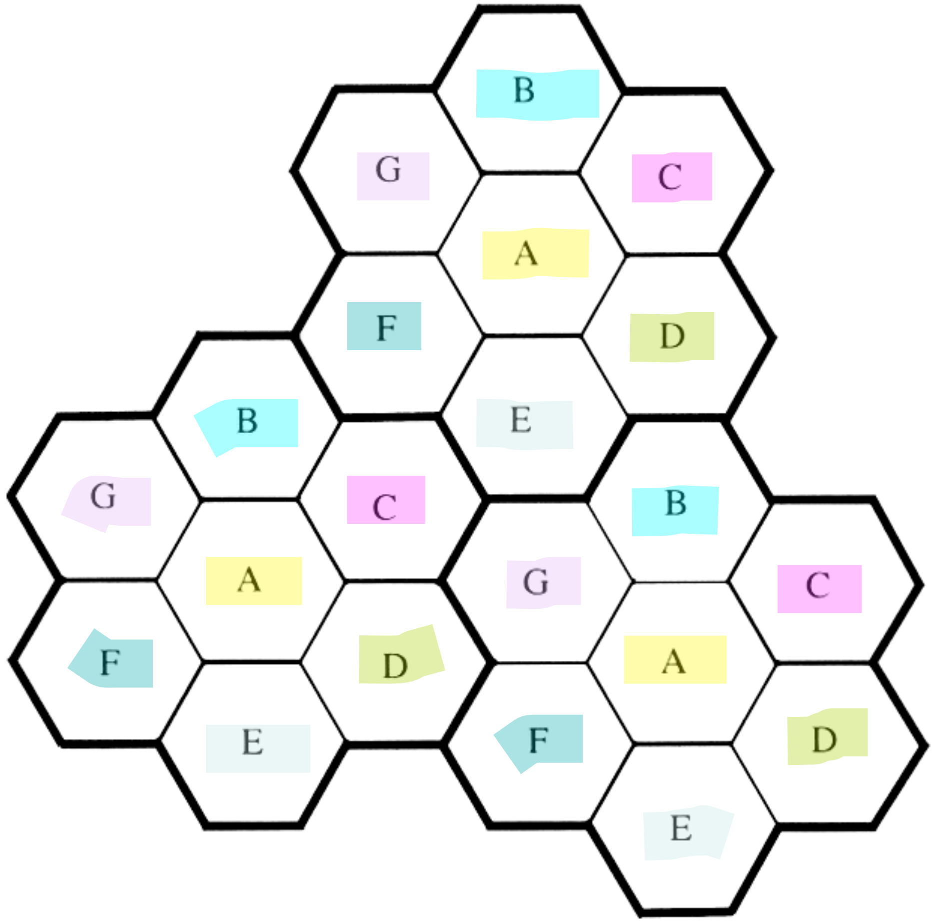
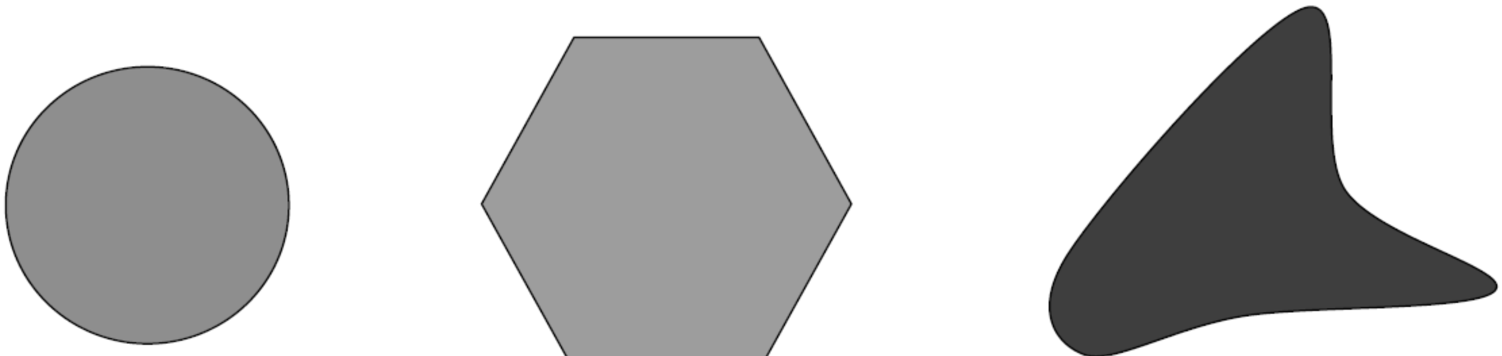


Figure 3.1 Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, N, is equal to seven, and the frequency reuse factor is 1/7 since each cell contains one-seventh of the total number of available channels.

One more look at an old viewgraph - The difference between the circular, the hexagonal cell shape, and one (of many) possible actual cell shapes is illustrated below.



Ideal (circular) cell shape.

Hexagonal cell shape.

One of many possible actual cell shapes.

As mentioned, cell shapes differ from the ideal (circular) shape, approximated by hexagons due to the fact that energy does not propagate equally in all directions.

Why Hexagonal model ?(1)

The Footprint: The actual radio coverage of a cell and is determined from field measurements or propagation prediction models. Although Real footprint is formless in nature, a regular cell shape is needed for systematic system design.

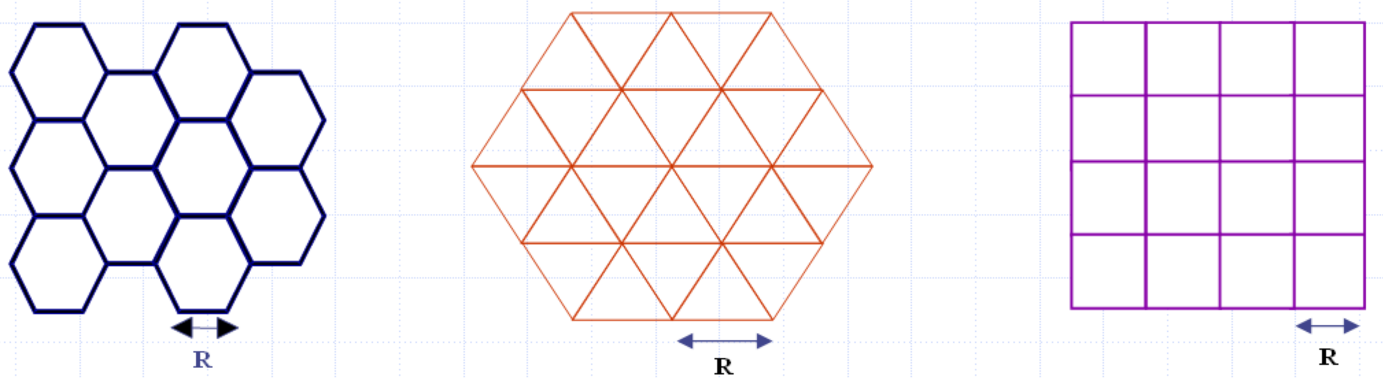
Why circle can not be used to represent the coverage area of a base station? because adjacent **circles can not be overlaid** upon a map without leaving gaps or creating overlapping regions.

Thus, when considering geometric shapes which cover an entire region without overlap and with equal area, there are three sensible choices:

a square; an equilateral triangle; and a hexagon.

Cell Geometrical Shape

To solve the dead spot problem



Tradeoffs

- The number of cells required to cover a given area.
- The cell transceiver power.

Why Hexagonal model ?(2)

(1) A cell must be designed to serve the weakest mobiles within the footprint, and these are typically located at the edge of the cell. For a given distance between the center of a polygon and its farthest perimeter points, **the hexagon has the largest area of the three.**

(2) By using the hexagon geometry, the **fewest number of cells can cover a geographic region,**

(3) The hexagon **closely approximates a circular radiation** pattern which would occur for an omni-directional base station antenna and free space propagation.

Why Hexagonal model?(3)

The hexagonal cell shape has been universally adopted since :

- conceptual and is a simplistic model of the radio coverage for each base station.
- the hexagon permits easy and manageable analysis of a cellular system.
- are attractive shapes since hexagons can be fitted together without gaps or overlap so that an area of arbitrary size is completely covered by a set of hexagons.
- In addition, a hexagon is a relatively good approximation to a circle (the locus of constant received signal power).

Cells and Clusters

- The following viewgraph illustrates an area covered by hexagons.
- sets of $N=7$ **hexagons** are grouped together.

- These groups are referred to as **clusters.**

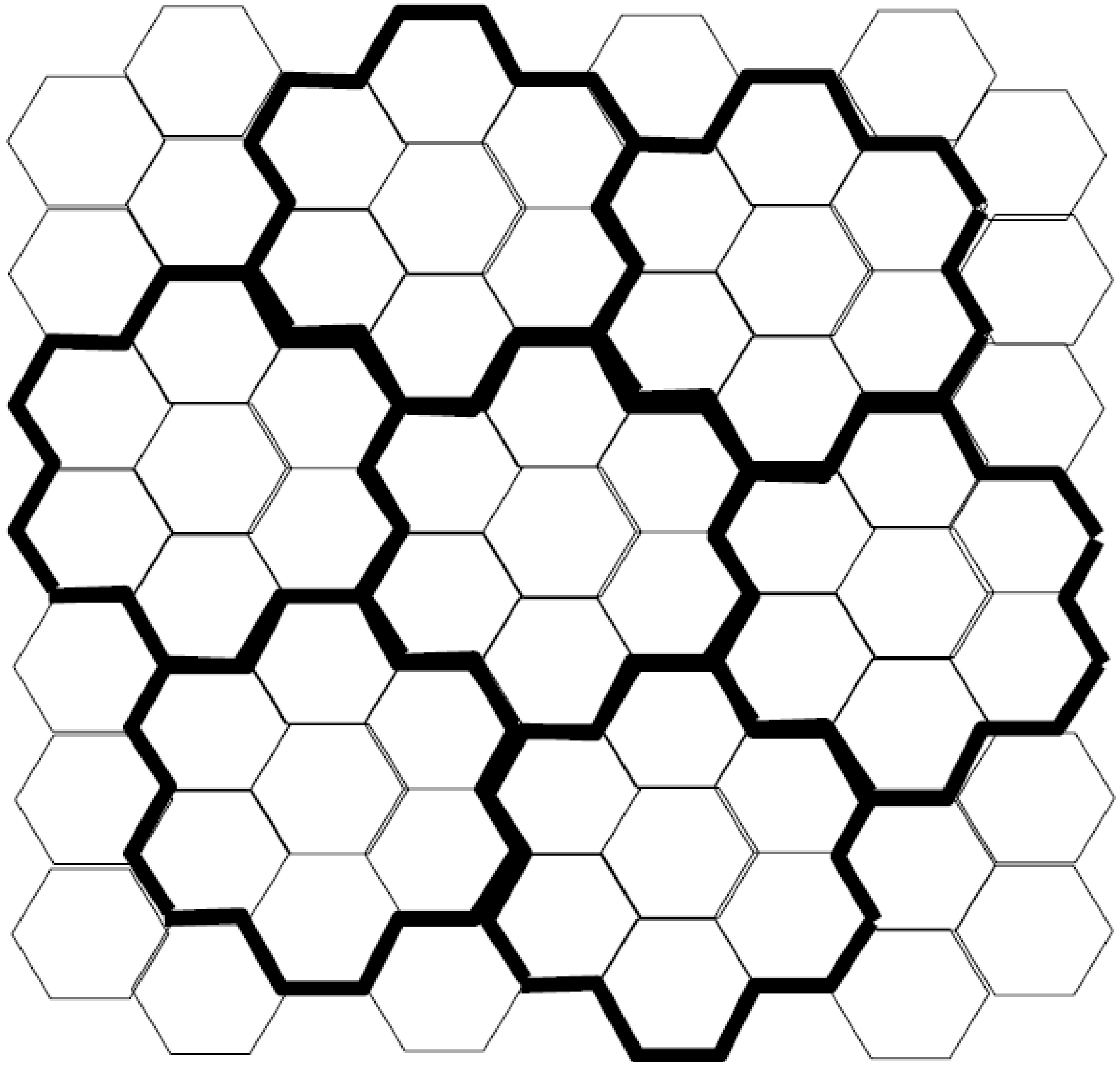
- In the following viewgraph clusters are designated by the **heavy lines**. (There are 7 complete clusters.)

- The complete “system” is composed of **multiple clusters**.

- Corresponding cells within clusters share a given system resource such as frequency slots, time slots, or code sequences.

Cells and Clusters

Cluster size
$N = 7$



Cells and Clusters

What are appropriate cluster sizes?
there are only certain cluster sizes and cell layouts which are possible.
Acceptable cluster sizes are defined by the following expression
(N, can only have values which satisfy) :

$$N = i^2 + ij + j^2$$

where i and j are integers.
In many of the examples we will assume cluster sizes defined by
$N = 7$. For the $N = 7$ case, $i = 2$ and $j = 1$.

19-cell reuse example (N=19)

i= 3 and j = 2 (example, N = 19).

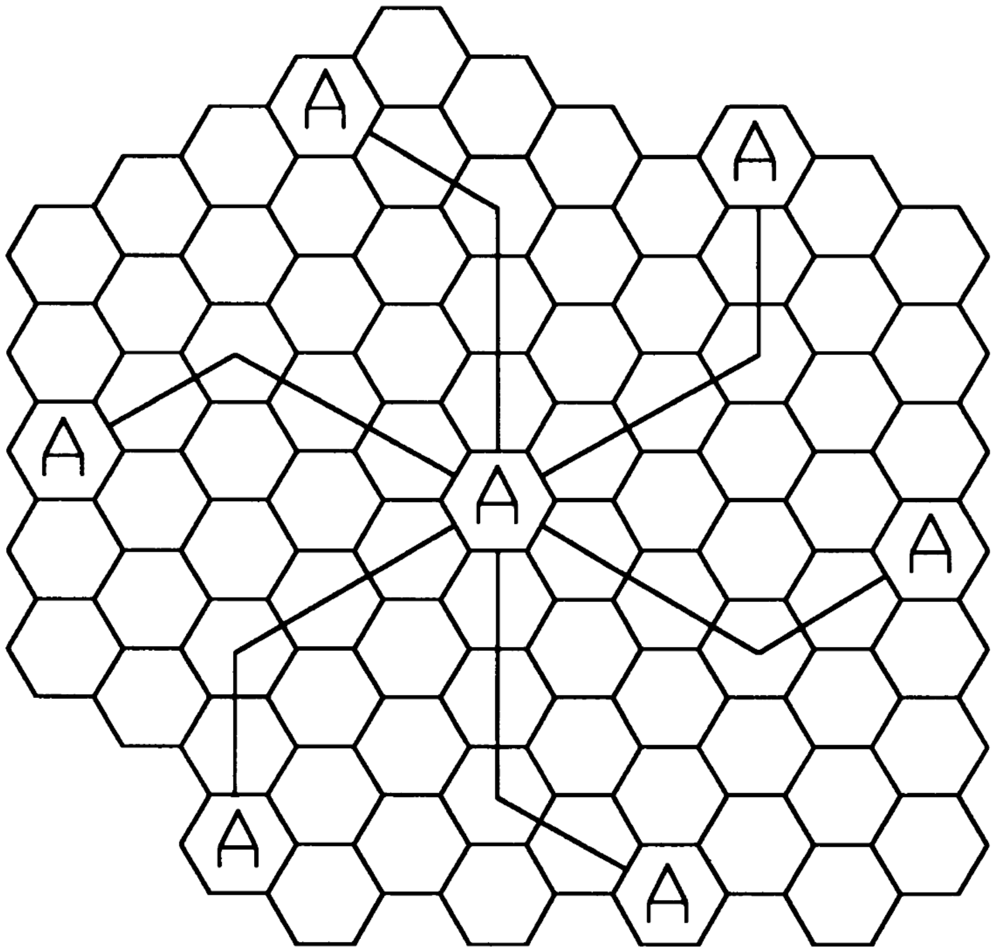
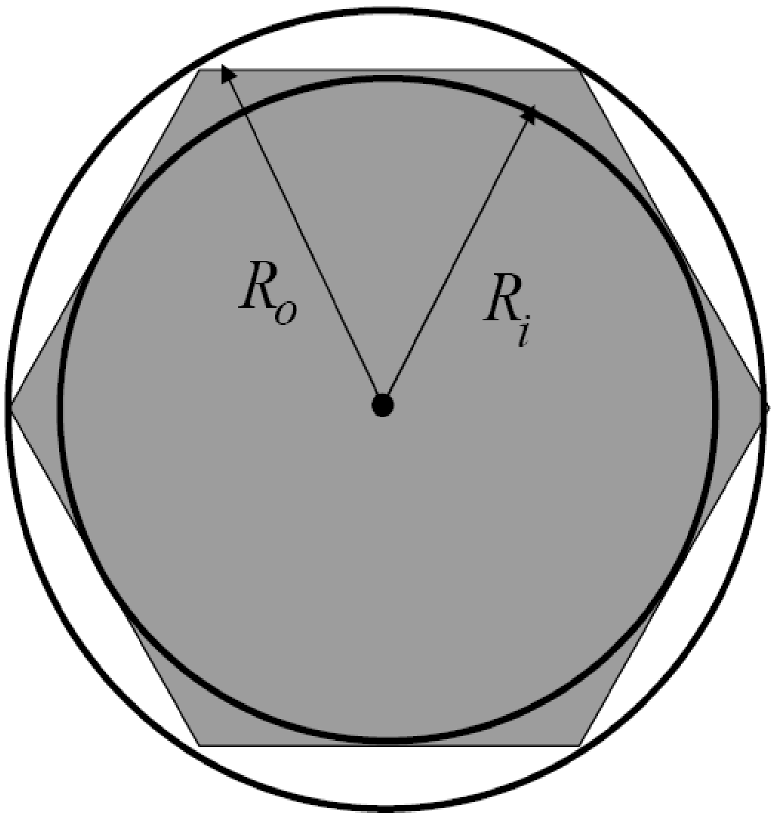
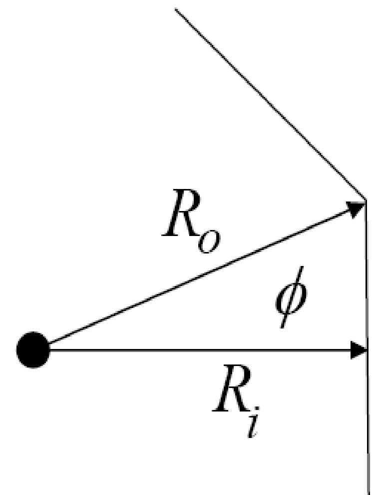


Figure 3.2 Method of locating co-channel cells in a cellular system. In this example, N = 19 (i.e., I = 3, j = 2). (Adapted from [Oet83] © IEEE.)

Cells and Clusters

For a hexagon we can define both an inner radius and an outer radius. Both are useful.

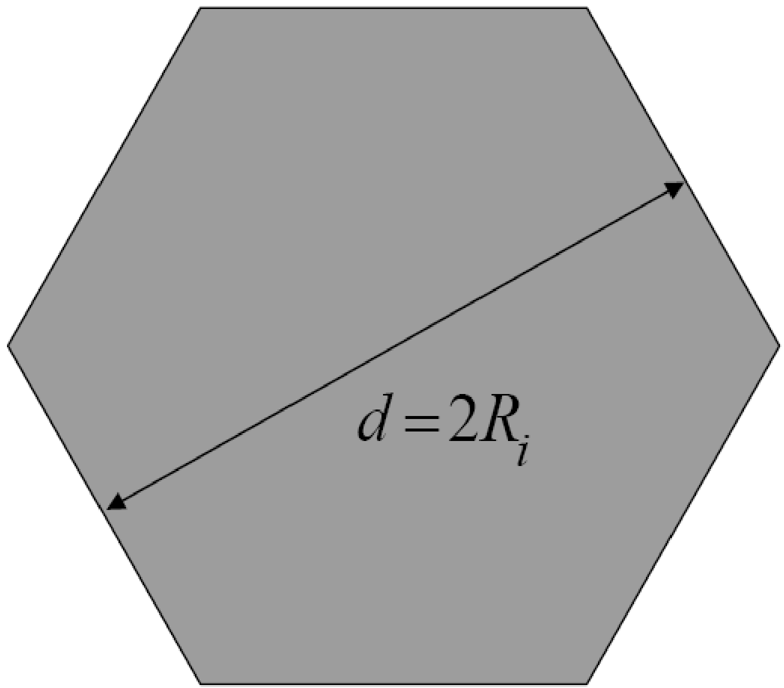




$$R_i = R_o \cos\phi = R_o \cos\frac{2\pi}{12} = R_o \frac{\sqrt{3}}{2}$$

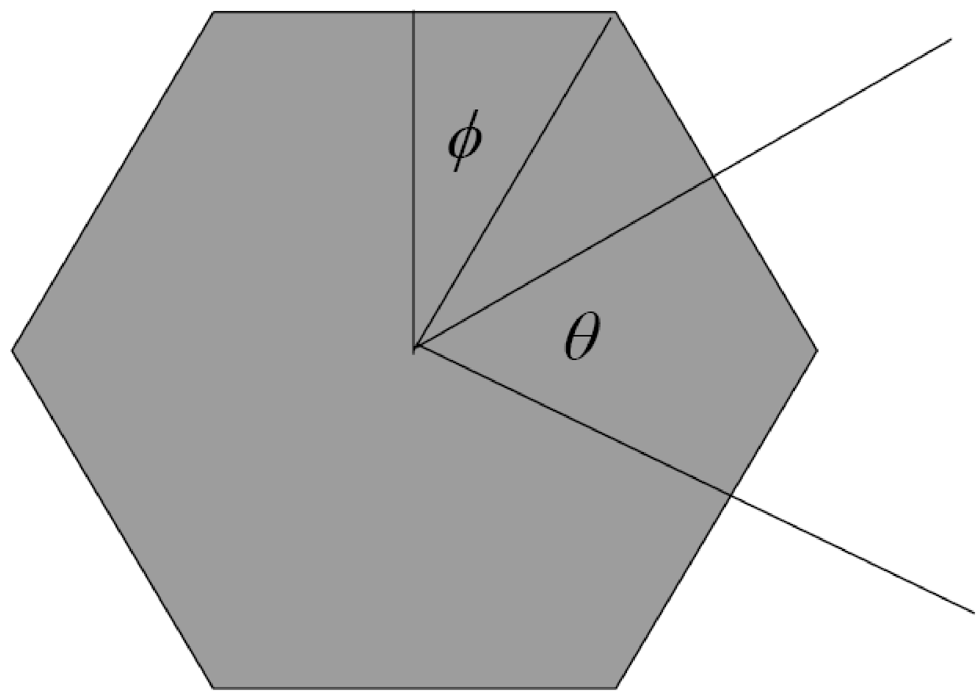
Note that a hexagon has 6 faces or, equivalently, 12 "half-faces."

The distance across a hexagon is $d = 2R_i$



This seems obvious from the definition of inner radius, and it is obvious. However, it will prove important in future work to follow. It is therefore worth pointing out.

Two angles, as defined below, are important.



We have seen that the half-face angle is $\phi = \pi/6$

Thus, the full-face angle is $\theta = \pi/3$

Capacity 1/2

In order to compute the capacity in a wireless cellular system we First make a few definitions. Let

$S =$ number of channels (frequencies) available per cluster
$k =$ number of channels per cell
$N =$ number of cells per cluster

Obviously

$$S = kN \text{ (channels per cluster)}$$

Now let

$M =$ number of clusters per entire system
$C =$ total number of channels available per system

Capacity 2/2

The number C, which is a measure of the capacity of the system, is very important to the service provider since it determines the maximum traffic capacity that can be sold by the service provider. The higher the capacity the higher the potential revenue to the service provider. It is clear that

$$C = MS = MkN$$

$$C = MS = MkN$$

- **A large cluster size** (N) indicates that the ratio between the cell radius and the distance between co-channel cells is large.

- Conversely, **a small cluster size** (N) indicates that co-channel cells are located much closer together.

- **The value for N** is a function of **how much interference** a mobile or base station can tolerate while maintaining a sufficient quality of communications.

- **From a design viewpoint, the smallest possible value of N is desirable in order to maximize "C".**

The **frequency reuse factor** of a cellular system is given by **1 /N,** since each cell within a cluster is only assigned 1/N of the total available channels in the system.

Example 2.1

If a total of **33 MHz** of bandwidth is allocated to a particular **FDD** cellular telephone system which uses **two 25 kHz simplex channels** to provide **full duplex voice and control channels**,

(1) compute the number of channels available per cell if a system uses

(a) 4-cell reuse, (b) 7-cell reuse (c) 12-cell reuse.

If 1 MHz of the allocated spectrum is dedicated to control channels,

(2) determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.

Total bandwidth 33 MHz

Channel BW=25 kHz: 2 simplex channels=50 kHz/duplex channel

Total available channels = 33,000/50 = 660 channels

(a)ForN= 4,

total number of channels available per cell 660/ 4 : 165 channels.

(b)ForN= 7,

total number of channels available per cell = 660/ 7 : 95 channels.

(c)ForN= 12,

total number of channels available per cell = 660 /12 : 55 channels.

A **1 MHz** spectrum for control channels implies that there are 1000K/50K = **20 control channels** out of the 660 channels available.

To evenly distribute the control and voice channels, **simply allocate the same number of channels in each cell wherever possible.** Here, the 660 channels must be evenly distributed each cell within the cluster.

In practice, only the **640 voice** channels would be allocated, since the control channels are allocated separately as **1 per cell**.

(a)For N = 4,

4cells : (5 control channels + 160 voice channels)

In practice, however, each cell only needs a single control channel (20 channel), **4 cells : (160 voice channels). Total = 640**

(b) For N = 7,

4 cells :(3 control channels + 92 voice channels),

+ **2 cells : (3 control channels + 90 voice channels),**

+ **1 cell :(2 control channels + 92 voice channels)**

In practice, however, each cell would have one control channel,

4 cells :(91 voice channels),

+ 3 cells : (92 voice channels). Total = 640

(c) For N = 12,

8 cells :(2 control channels + 53 voice channels),

+ **4 cells :(1 control channels + 54 voice channels),**

In practice, however, each cell would have one control channel,

8 cells :(53 voice channels),

+ 4 cells :(54 voice channels). Total = 640