Wireless Communications

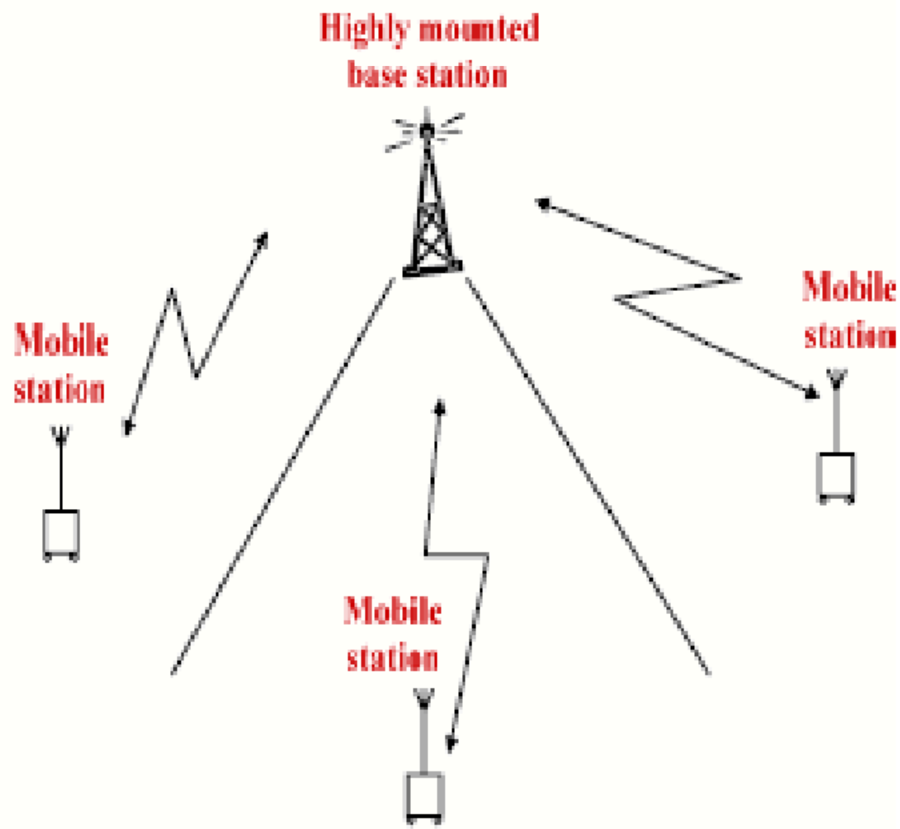
(Unit -4)

Outline

- Introduction
  - Cellular System Engineering.
  - Cellular System Concepts.
  - Frequency Reuse.
  - Channel Assignment Strategies

Cellular System Engineering

- Early-day mobile radio communications:
  - **Objective:** achieve a large coverage by using a single, high powered transmitter
  - **Macro-cell system:** one central base station served all mobiles
  - **Advantage:**
    large coverage:
    a thousand square miles
  - **Disadvantages:**
    small number of supported users (capacity)
    impossible to reuse frequency
    high transmit power



Cellular System Engineering

Cellular Concept

- Challenge: limited spectrum allocation (government regulation)
- A single high-powered transmitter
  - good coverage
  - interference: impossible to reuse the same frequency

One Tower System in New York City-1970

Maximum 12 simultaneous calls/1000 square miles

Cellular System Engineering

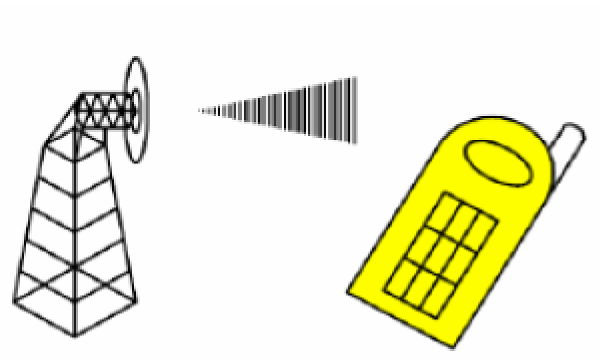
Wireless

The first commercially available radio and telephone system, known as improved mobile telephone service (IMTS), was put into service in 1946.

- unsophisticated—there was no solid state electronics available.

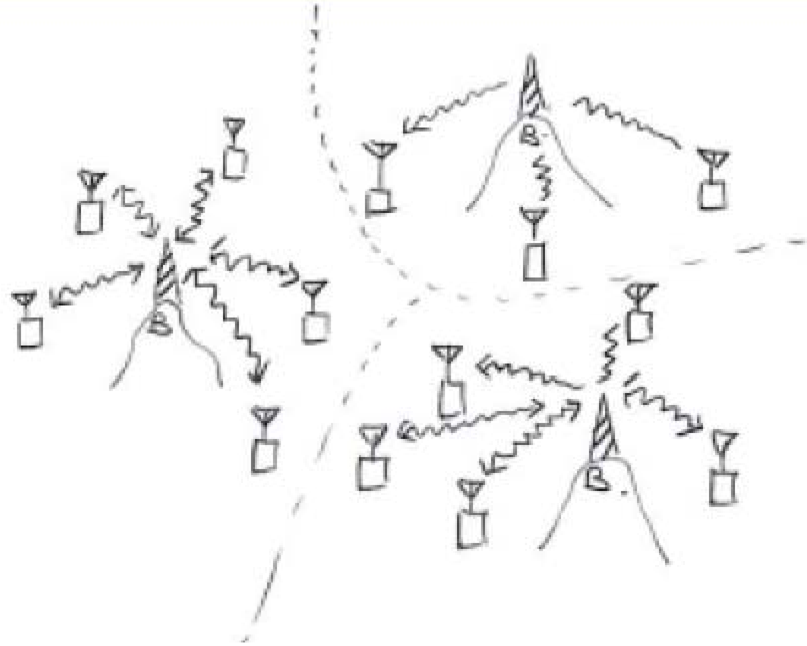
With IMTS, a tall transmitter tower was erected near the center of a metropolitan area with several assigned channels. Any vehicle within range could attempt to seize one of those channels and complete a call. Unfortunately, the number of channels did not come even close to satisfying the need.

Worse, as the metropolitan area grew, higher power were applied at the transceivers, the reach was made greater, but more subscribers were unable to get dial tone.



Cellular System Engineering

- Cellular Mobile Systems: Introduced by AT&T during 1960's.
- Made use of signal attenuation after traveling a certain distance; so that the same carrier frequency can be reused after a certain distance.
- Capacity is greatly increased.



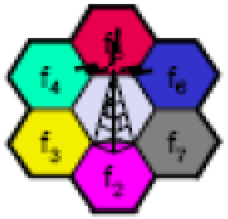
Cellular Systems

The Cellular Concept – System Design Fundamentals

- The cellular concept was a major breakthrough in solving the problem of *spectral congestion* and *user capacity*.
- Replaces single high power transmitter (large cell) with many low power transmitters (small cells), each providing coverage to only a small portion of the service area.

Cellular Systems

Cellular Concept



- areas divided into cells
- developed by Bell Labs 1960's-70's
- a system approach, no major technological changes
- few hundred meters in some cities, 10s km at country side
- each served by base station with lower power transmitter
- each gets portion of total number of channels
- neighboring cells assigned different groups of channels, interference minimized

Cellular Systems

Cellular Concept

The solution was cellular radio. Metropolitan areas were divided into cells of no more than a few miles in diameter, each cell operating on a set of frequencies (send and receive) that differed from the frequencies of the adjacent cells. Because the power of the transmitter in a particular cell was kept at a level just high enough to serve that cell, these same sets of frequencies could be used at several places within the metropolitan area.

An analogy ......

CELLULAR CONCEPT

- It is an implementation of Space Division Multiplexing.
- To divide the coverage area into a no. of contiguous smaller areas (called CELL) which are each served by its own base station

Cellular Concepts

- Each Base Station is allocated a portion of total no. of channels available to the entire system.
- Neighboring base stations are assigned different groups of channels so as to reduce interference.
- A Cluster is a group of cells. No channels are reused within a cluster.

CELL AND A CLUSTER

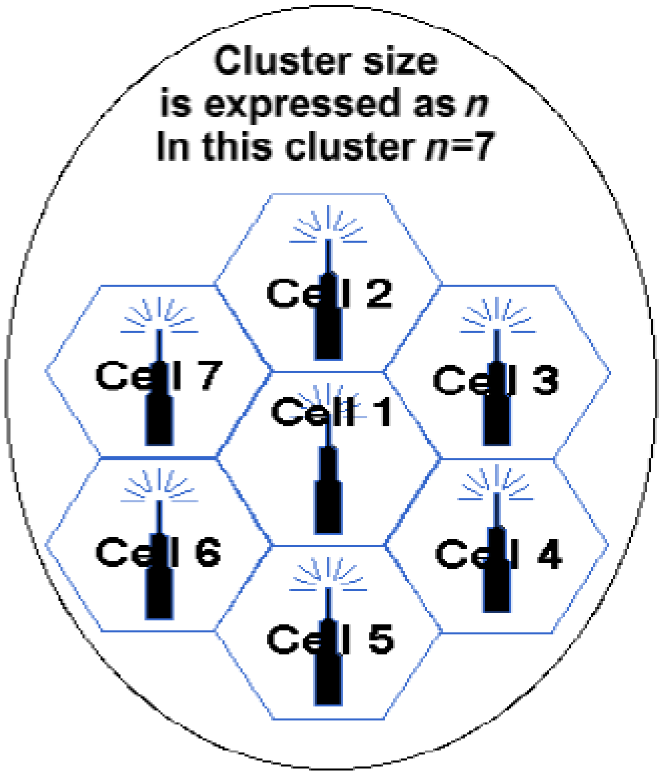
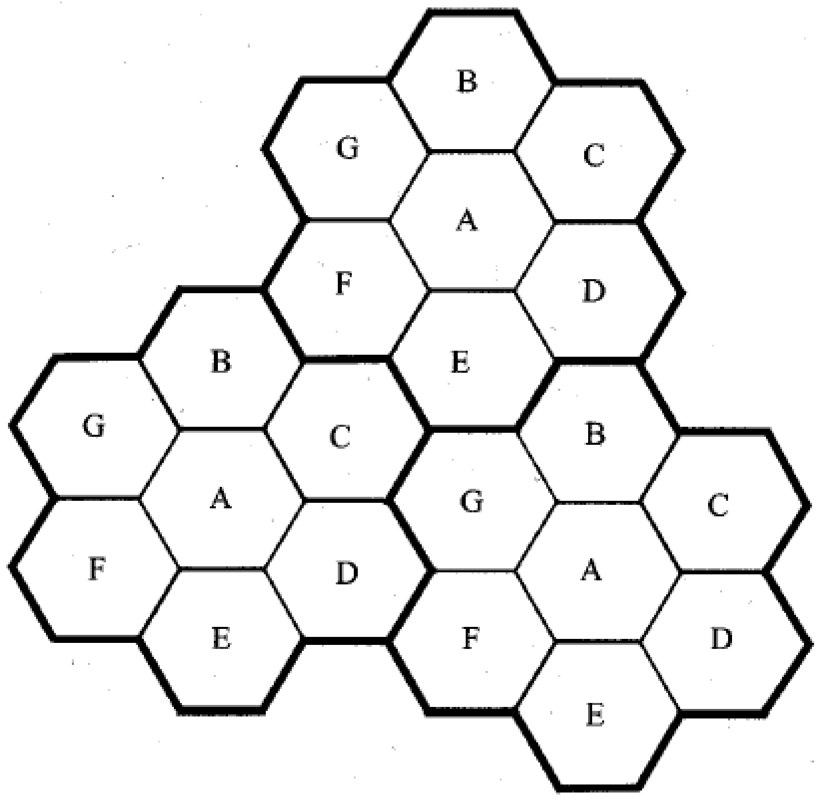


DIAGRAM VIEW OF CELLULAR CONCEPT



Cellular Systems(Advantages)

- Solves the problem of spectral congestion and user capacity.
- Offer very high capacity in a limited spectrum without major technological changes.
- Reuse of radio channel in different cells.
- Enable a fix number of channels to serve an arbitrarily large number of users by reusing the channel throughout the coverage region.

- **Cellular concept:**
  - Each base station is allocated a portion of the total number of frequency channels available to the entire system, and nearby base stations are assigned different groups of channels.
  - Neighboring base stations are assigned different groups of channels so that the interference between base stations (and the mobile users under their control) is minimized.
  - The available channels may be reused as many times as necessary, so long as the interference is kept below acceptable levels

    → provide higher capacity
- **Cell:**
  - Is a small geographic area in which a group of radio channels is allocated to be used.
- **Footprint:**
  - Is the actual radio coverage of a cell and is determined from field measurements or propagation prediction models.

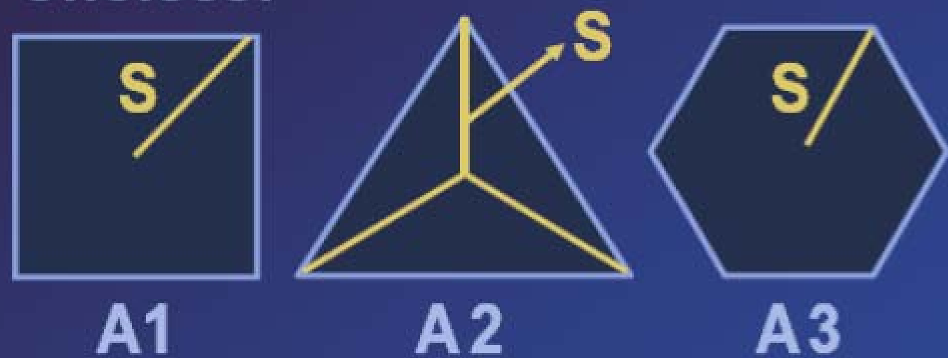
- **Hexagonal cells:** for convenience in handling performance analysis and system modeling.
  - **centre-excited cell**: the cell having the base station at the cell centre
  - **edge-excited cell**: the cell having base stations on the three of the six cell vertices
- **Cluster:**
  - Is the number of cells that collectively use the complete set of available frequency channels.
  - Cluster size N usually equal to 4, 7, 9 or 12.
  - For a given area (constant cell size), *smaller cluster size, higher capacity*
  - N is a function of how much interference a mobile or base station can tolerate while maintaining a sufficient quality of communications
- **Frequency reuse factor:**
  - Is the reciprocal of the cluster size
  - A higher frequency reuse factor implies a higher number of frequency channels is available for each cell.

Choices of Hexagonal Cell

Factors:

- Equal area
- No overlap between cells

Choices:



CHOICE OF CELL SHAPE

- CELL SHAPE should be chosen as a **regular polygon** shape so as to obtain an easier insight to the system.
- Three Possible Choices are:
- 1.Equilateral Triangle
- 2.Square
- 3.Regular Hexagon

For a given S

A3 > A1

A3 > A2

Here, A3 provides maximum coverage area for a given value of S.

Actual cellular footprint is determined by the contour of a given transmitting antenna.

By using hexagon geometry, the fewest number of cells covers a given geographic region.

Choice of Hexagonal Shape

- REASON : For a given radius i.e. largest possible distance b/w the polygon centre and its edge Hexagon has the largest area.
- CIRCLE CAN'T BE A CHOICE BECAUSE OF THE PROBLEM OF NON OVERLAPPING OF ADJACENT AREAS.(Although it is best approximation concerned with radiation pattern of antenna at Base Station)

Frequency Reuse

Each cellular base station is allocated a group of radio channels.
Base stations in adjacent cells are assigned channel groups which contain different channels than neighboring cells.

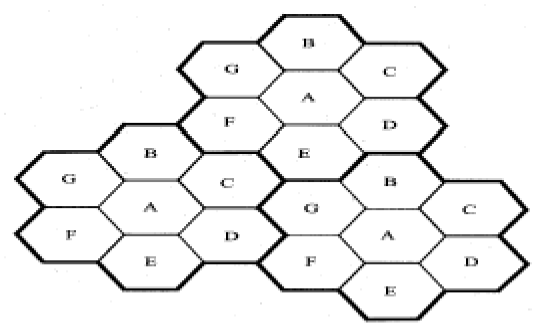
Frequency Reuse

- Each cellular base station is allocated a group of radio channels within a small geographic area called a *cell*.
- Neighboring cells are assigned different channel groups.
- By limiting the coverage area to within the boundary of the cell, the channel groups may be reused to cover different cells.
- Keep interference levels within tolerable limits.
- Frequency reuse or frequency planning

•seven groups of channel from A to G

•footprint of a cell - actual radio coverage

•omni-directional antenna v.s. directional antenna



Frequency Reuse

Frequency reuse is the process in which same set of frequencies (channels)Can be provided to more than one cells provided that cells are separated by sufficient distance.

Frequency Reuse

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 7; and the frequency reuse factor is 1/7, since each cell contains 1/7 of the total number of available channels.

Example

- FREQUENCY REUSE increases the capacity of the system.
- EXAMPLE:

Consider following parameters with a single high power Transmitter:

COVERAGE AREA: 50 Square Km

NO OF VOICE CHANNELS: 40

EXAMPLE (CONTD.)

- REPLACING IT WITH 9 LOW POWER TRANSMITTERS (supporting 40% of channels)
- Parameters are:

COVERAGE AREA:=50/9=5.5 Square Km each

NO OF VOICE CHANNELS: (40% of 40)* 9=144

CONCLUSIONS DRAWN FROM EXAMPLE

- **IMPROVEMENT OVER NO. OF CHANNELS**
- **MORE NO. OF CUSTOMERS CAN BE SERVED.**
- **INCREASED CELLULAR SYSTEM CAPACITY.**

Channel Capacity

- Consider a cellular system which has a total of *S* duplex channels.
- Each cell is allocated a group of *k* channels, $k < S$.
- The *S* channels are divided among *N* cells.
- The total number of available radio channels

$$S = kN$$

- The *N* cells which use the complete set of channels is called *cluster*
- The cluster can be repeated *M* times within the system. The total number of channels, *C*, is used as a measure of capacity

$$C = MkN = MS$$

- The capacity is directly proportional to the number of replication *M*.
- The cluster size, *N*, is typically equal to 4, 7, or 12.
- Small *N* is desirable to maximize capacity.
- The frequency reuse factor is given by $1/N$

CHOICE OF 'N'

- If **Cluster Size N is reduced** while cell size remains constant, more clusters are required to cover a given area & hence **more capacity** is achieved.
- So From design point of view smallest possible value of N is desirable to maximize capacity over a given coverage area.
- Also small N causes distance b/w co-channel cells to decrease hence **increased co-channel interference.**

CHOICE OF 'N'

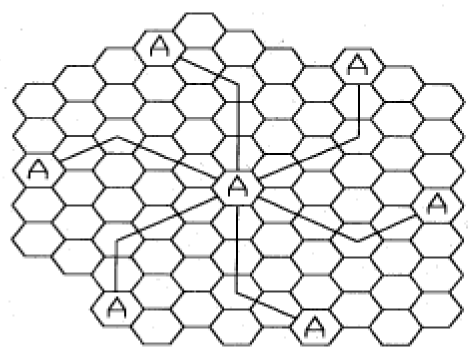
- If **Cluster size N is large**, distance between co-channel cells increases so **weaker co-channel interference.**
- THE VALUE OF N IS A FUNCTION OF HOW MUCH INTERFERENCE A MOBILE OR BASE STATION CAN TOLERATE WHILE MAINTAINING A SUFFICIENT QUALITY OF COMMUNICATION

Design of Cluster Size N

- Hexagonal geometry has
  - exactly six equidistance neighbors
  - the lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees.
- Only certain cluster sizes and cell layout are possible.
- The number of cells per cluster, *N*, can only have values which satisfy

$$N = {}^2 + j + i^2$$

- Co-channel neighbors of a particular cell, ex, ***i=3*** and ***j=2***.

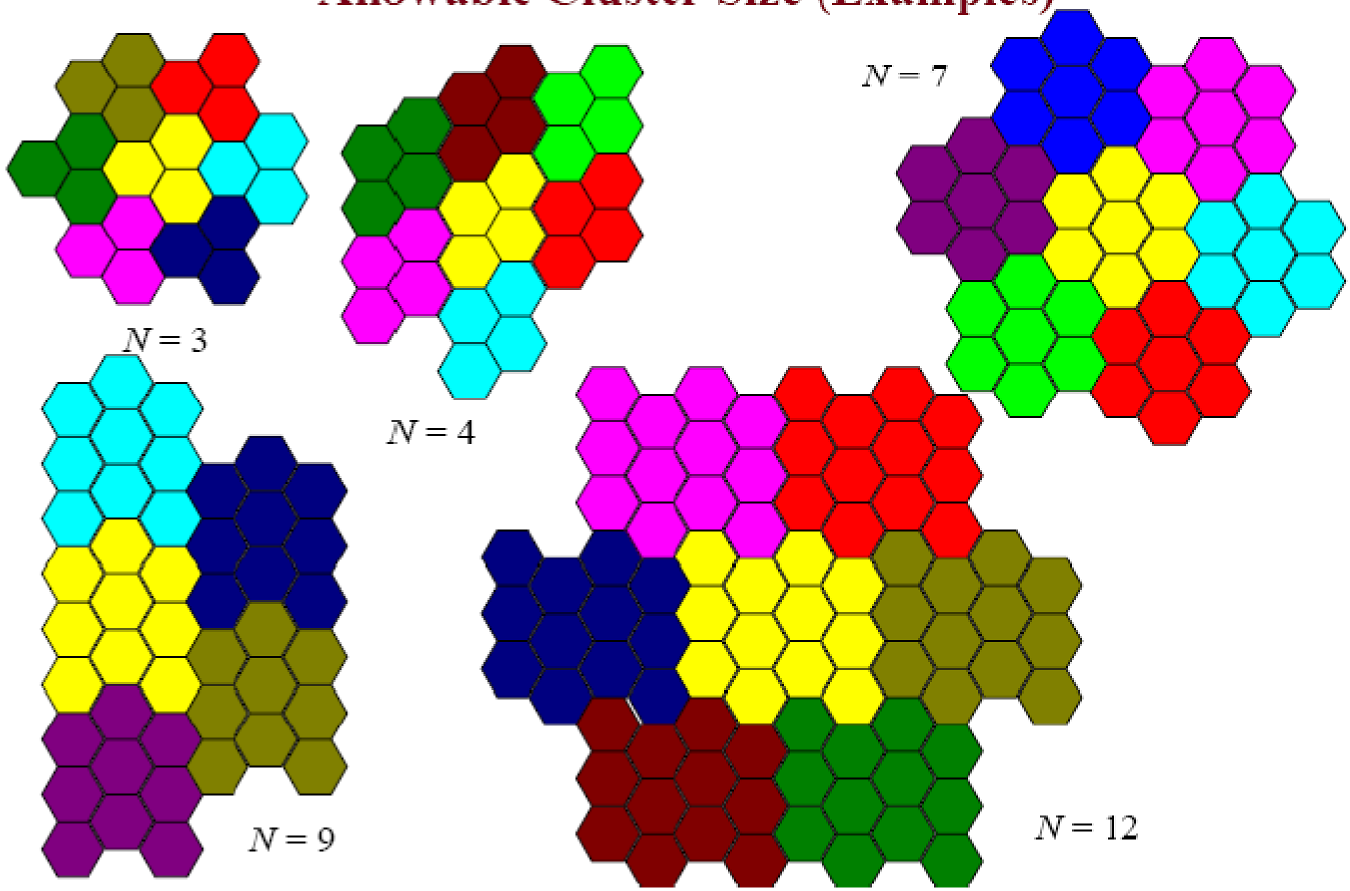


STEPS TO FIND NEAREST CO-CHANNEL NEIGHBORS OF A PARTICULAR CELL

- (1)Move i cells along any chain of hexagons and then
- (2)Turn 60 degrees counter clockwise and move j cells

Design of Cluster Size N

Allowable Cluster Size (Examples)



Design of Cluster Size N

Allowable Cluster Size

- Because the hexagonal cells are required to be connected without gaps between adjacent cells in a cellular system, the geometry of hexagons is such that the allowable cluster size N is not arbitrary and is given by

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

- where i and j are non-negative numbers. Some values of N are:

	$j = 0$	$j = 1$	$j = 2$	$j = 3$
$i = 0$	0	1	4	9
$i = 1$	1	3	7	13
$i = 2$	4	7	12	19
$i = 3$	9	13	19	27

Channel Assignment Strategies

- **Frequency reuse scheme**
  - **Objectives: increases capacity while minimizing interference**

    The design process of selecting and allocating channel groups for all of the cellular base stations within a system --**Channel assignment scheme**
- **Channel assignment strategy**
  - **Fixed channel assignment**
  - **Dynamic channel assignment**

Channel Assignment Strategies

- **Fixed channel assignment**
  - each cell is allocated a predetermined set of voice channel.
  - any new call attempt can only be served by the unused channels.
  - the call will be *blocked* if all channels in that cell are occupied.
  - **Variations: borrowing strategy, etc.**
  - MSC supervises the borrowing.

Channel Assignment Strategies

BORROWING STRATEGY: A variation of fixed assignment strategy :

- A cell is allowed to borrow channels from a neighboring cell if all its own channels are occupied.
- MSC supervises such borrowing procedures

  & ensures that borrowing does not disrupt or interfere with any of the calls in progress in the donor cell.

Channel Assignment Strategies

- **Dynamic channel assignment**
  - No pre-determined assignment of frequency channels(Voice Channels) is made.
  – When a call arrives, the base station ask the mobile switching centre (MSC) to allocate a channel.
  – MSC must take into account the co-channel interference ,reuse distance, cost function in channel allocation to requested call based on algorithm.

Channel Assignment Strategies

-H*eavy storage and computational load, lower blocking probability and increased channel utilization.*

-Dynamic Channel allocation is complex (In Real environment)

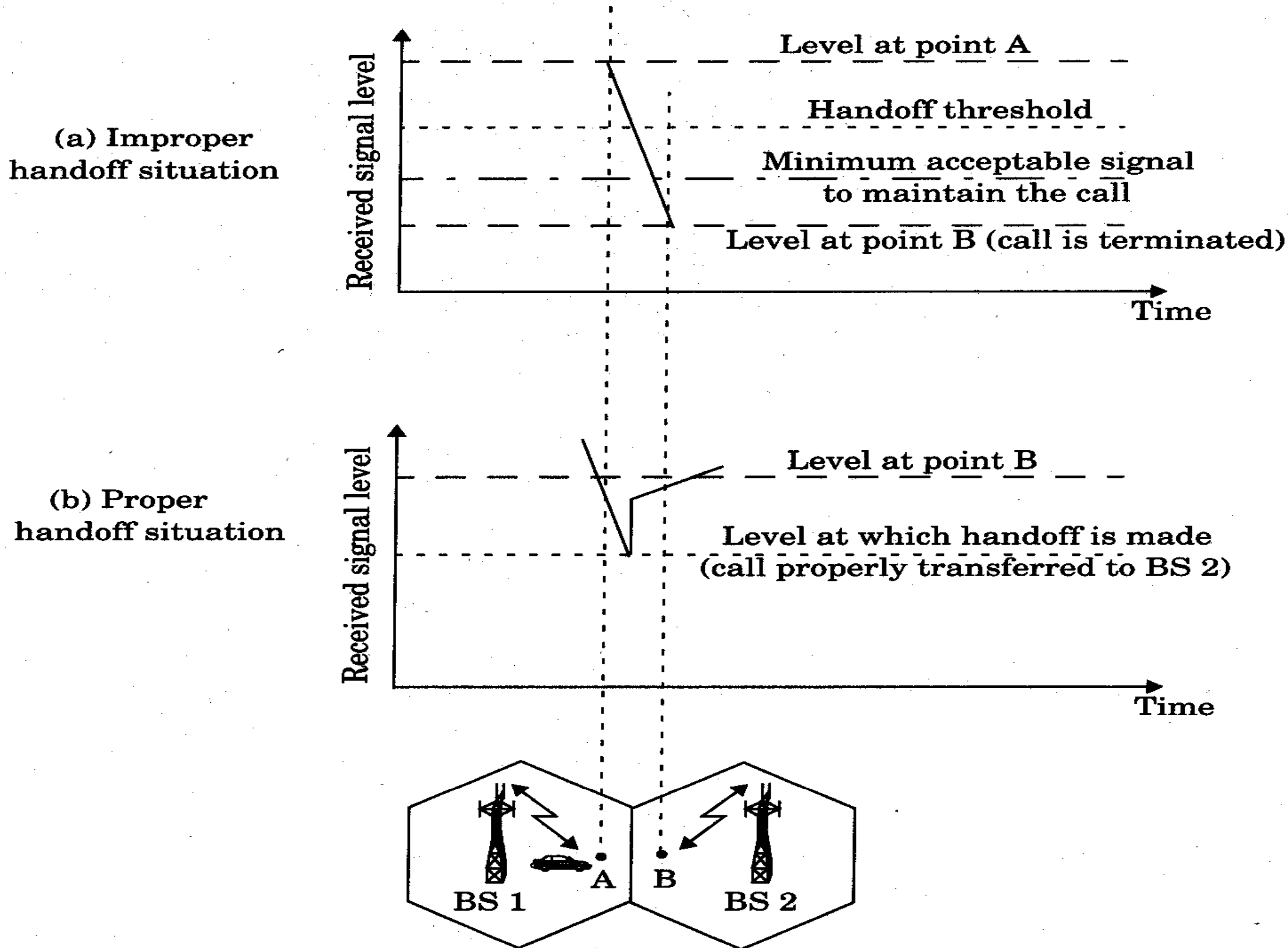
Advantages of Dynamic Channel Assignment Strategy

- Reduces likelihood of blocking
- Increases Trunking Capacity of System

Handoff Strategies

- When a mobile moves into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station.
- Handoff operation
  - identifying a new base station
  - re-allocating the voice and control channels with the new base station.
- Handoff Threshold
  - Minimum usable signal for acceptable voice quality (-90dBm to -100dBm)
  - Handoff margin $\Delta = P_{r,handoff} - P_{r,minimum\ usable}$ cannot be too large or too small.
  - If Δ is too large, unnecessary handoffs burden the MSC
  - If Δ is too small, there may be insufficient time to complete handoff before a call is lost.

Handoff Strategies



Handoff Strategies

- Handoff must ensure that the drop in the measured signal is not due to momentary fading and that the mobile is actually moving away from the serving base station.

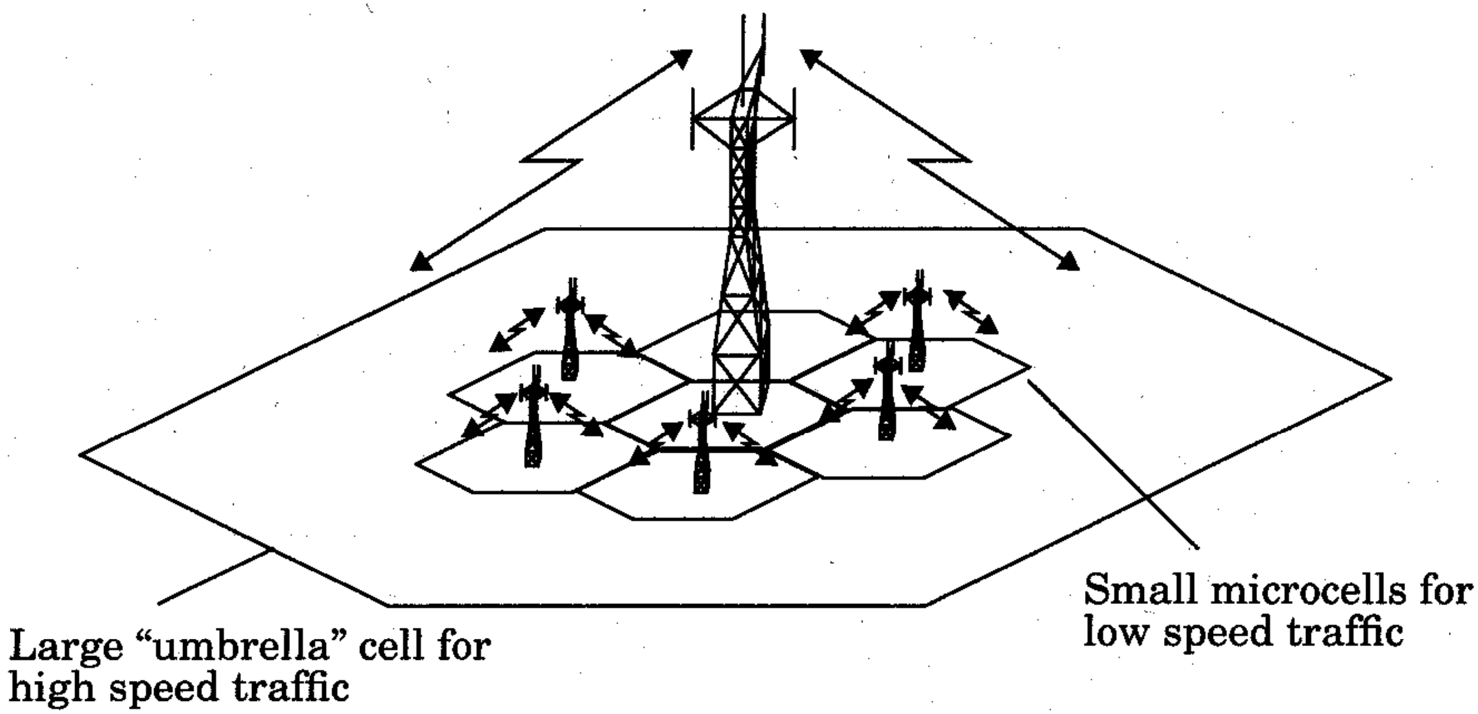
- Dwell time: the time over which a call may be maintained within a cell without handoff.

- Dwell time depends on
  - propagation
  - interference
  - distance
  - speed

Practical Handoff Consideration

- Different type of users
  - High speed users need frequent handoff during a call.
  - Low speed users may never need a handoff during a call.
- Microcells to provide capacity, the MSC can become burdened if high speed users are constantly being passed between very small cells.
- Minimize handoff intervention
  - handle the simultaneous traffic of high speed and low speed users.
- Large and small cells can be located at a single location (umbrella cell)
  - different antenna height
  - different power level

- Cell dragging problem: pedestrian users provide a very strong signal to the base station
  - The user may travel deep within a neighboring cell


Large “umbrella” cell for
high speed traffic
Small microcells for
low speed traffic

COVERAGE &CAPACITY EXPANSION TECHNIQUES

1. To obtain additional spectrum for new subscribers but this is expensive approach.
2. Change the cellular architecture.
3. Change the frequency allocation methodology.
4. Change the Modem and Access technology.

Cell splitting

- **<u>Need of Cell Splitting:</u>**

As no. of subscribers increase within a given area, the no. of channels allocated to a cell is no longer sufficient for supporting the subscriber demand. It becomes necessary to allocate more channels to the area that is being covered by this cell. This can be done by **CELL SPLITTING.**

MAXIMUM TRAFFIC LOAD

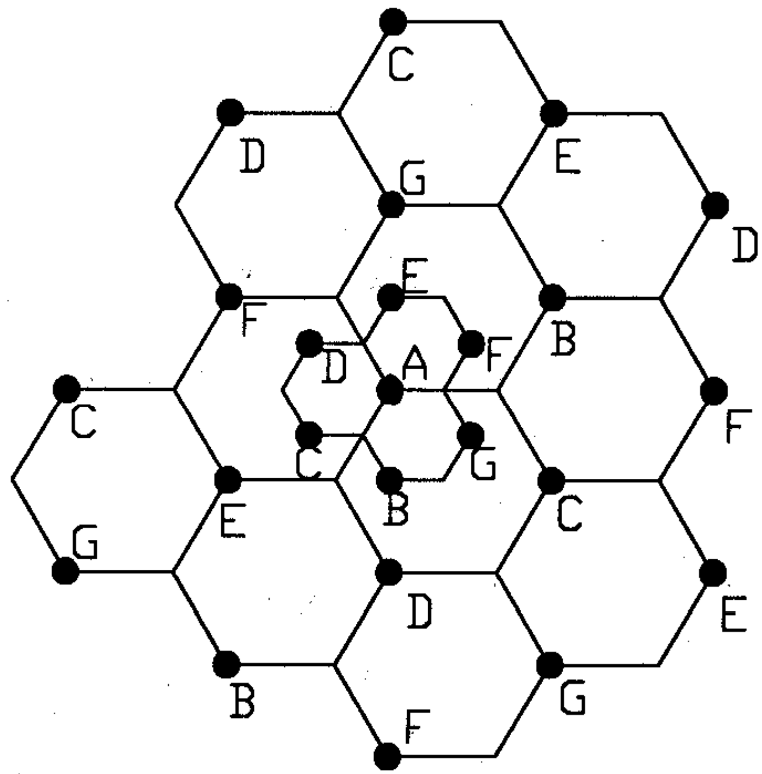
- **MAXIMUM TRAFFIC LOAD:**

  The point when a cell reaches maximum capacity occurs when the no. of subscribers wishing to place a call at any given time equals no. of channels in the cell.

CELL SPLITTING

- Cell Splitting is the process of subdividing a congested cell into smaller cells each with its own base station and corresponding reduction antenna height and transmitter power.
- It increases the capacity of the system since it increases the no. of times the channels are reused

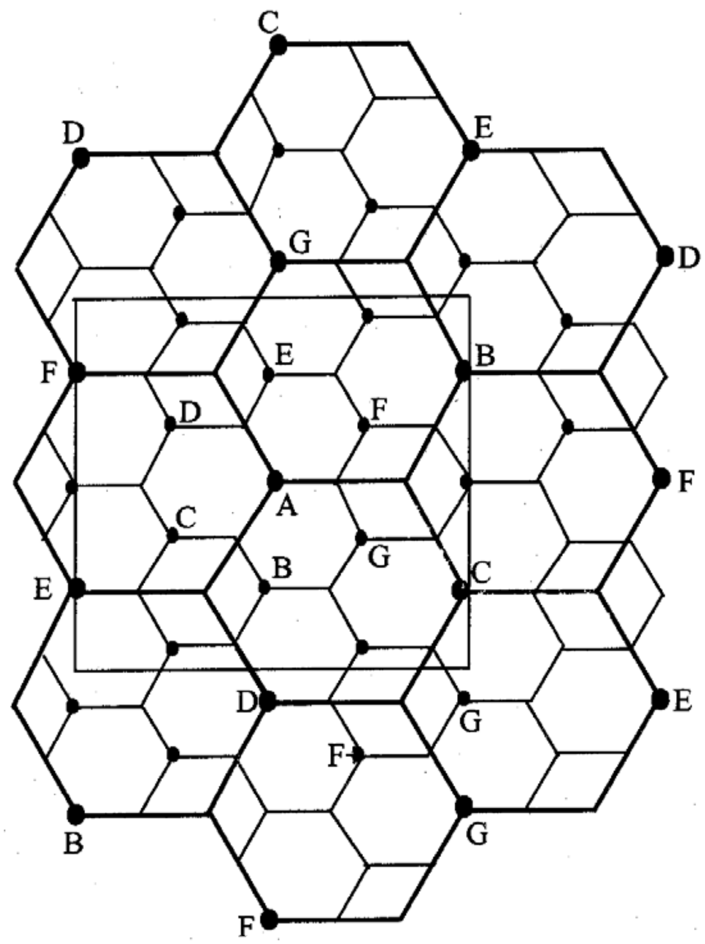
Cell splitting



Cell splitting

- Smaller cells are added in such a way to preserve the frequency reuse plan of the system for e.g Microcell base station labeled G is placed exactly half way b/w two large stations using the same channel set G

Illustration of cell splitting within a 3 km by 3 km square



Cell splitting

- New cell radius=Old cell radius/2
- New cell area=Old cell radius/4
- If each new cell carries the same maximum traffic load of the old cell then
- New Traffic Load /Unit Area=4(Old Traffic Load /Unit Area)

Problems Arising

- Let transmit power of BS of smaller cell is same as that of larger cells.
- Radius of new cell=R/2.
- Maximum distance the mobile can be from BS of this cell is R/2.
- FOR SMALLER CELL:Although the distance b/w this cell and any co-channel larger cell is reduced by half the value of Signal to Noise ratio remains the same.

Cell splitting

- FOR LARGER CELL: Signal to Noise ratio is not maintained because co-channel reuse ratio for these cells is now D/2R with respect to smaller cell.
- In order to maintain the same level of interferences the transmit power of the BS in the smaller cell should be reduced but these will increase the interference observed by the mobiles in the smaller cell.

- Transmission power reduction from P_{t1} to P_{t2}
- Examining the receiving power at the new and old cell boundary

$$P_r[\text{at old cell boundary}] \propto P_{t1} R^{-n}$$

$$P_r[\text{at new cell boundary}] \propto P_{t2} (R/2)^{-n}$$

- If we take *n = 4* and set the received power equal to each other

$$P_{t2} = \frac{P_{t1}}{16}$$

- The transmit power must be reduced by 12 dB in order to fill in the original coverage area.

- The other method is to divide the channel allocated to cells labeled A into two parts those used by ‘a’ and those not used by ‘a’.
- The channels used by ‘a’ will be used in the larger cells only within the radius of R/2 from the centre of the cell so that cochannel reuse ratio is maintained as far as these channels are concerned. This is called OVERLAID CELL CONCEPT where a larger macrocell coexists with a smaller microcell

SECTORING

We know For a hexagonal geometry

- $D/R=(3N)^{1/2}$ & S/N is inversely proportional to D/R
- In Cell Splitting capacity or no. of channels per unit area is increased by decreasing the cell radius & keeping cochannel reuse ratio D/R unchanged

SECTORING

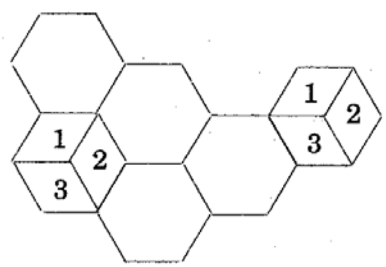
- Another way to increase the capacity is to keep cell radius unchanged and decrease D/R ratio.
- So Sectoring is the means to increase the channel capacity of a cellular telephone system by decreasing the D/R ratio while maintaining the same cell radius
- Channels allocated to a cell are further divided into three parts(120 degree sectors) each used in one sector of a cell.

SECTORING

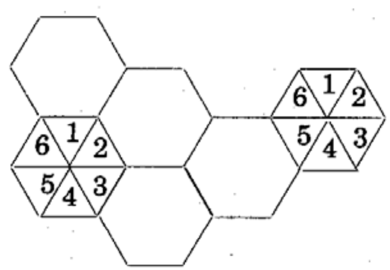
- In this approach first the S/I is improved by using directional antennas, then capacity improvement is achieved by reducing the no. of cells in a cluster.
- However Relative Interference is reduced without decreasing the transmit power.

Sectoring

- Decrease the *co-channel interference* and keep the cell radius *R* unchanged
  - Replacing single omni-directional antenna by several directional antennas
  - Radiating within a specified sector

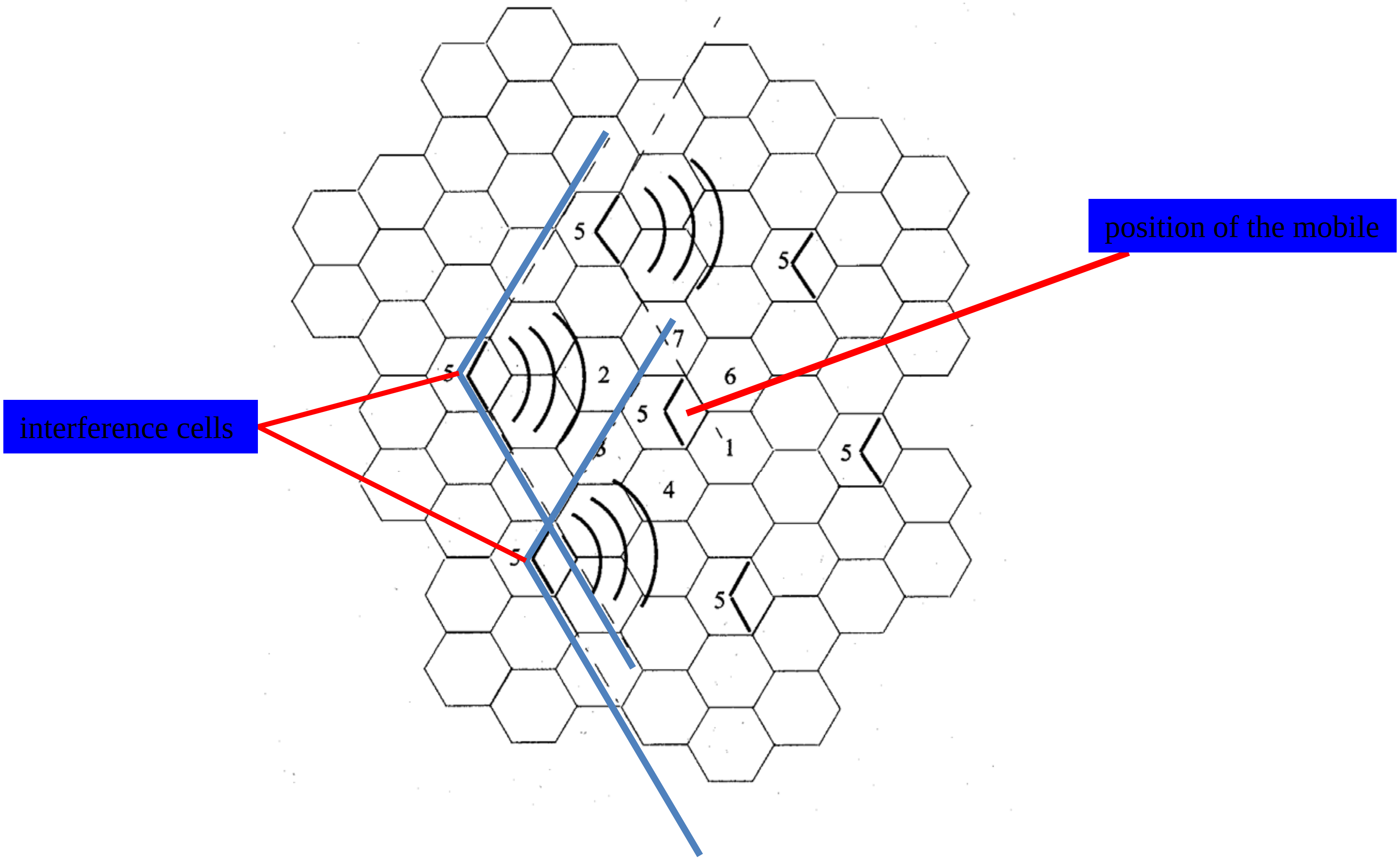


(a)



(b)

- Interference Reduction



Sectoring

- By using directional antennas a given cell will receive and transmit with only a fraction of available co-channel cells.
- In the example shown Consider the interference experienced by a mobile located in the rightmost sector in the center cell labeled '5'

.

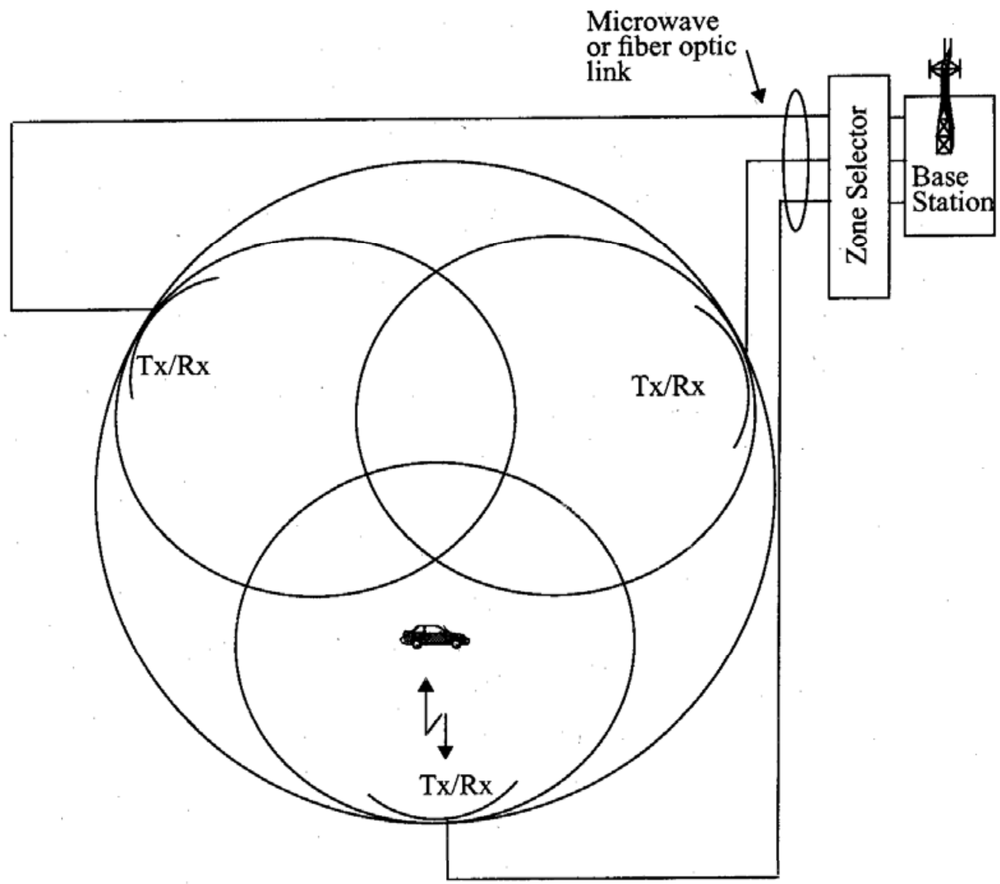
Sectoring

- There are six co-channel cell sectors labeled ‘5’ three to its right & three to its left. Out of these six only two cells have sectors with antenna patterns which radiate into the centre cell.Hence a mobile will experience interference on the forward link from these two sectors only.
- Hence Signal to Interference ratio is improved.
- By using 60 degree directional antennas no. of interfering cochannel cells reduces to one

LEE's MICROCELL ZONE CONCEPT

- In sectoring concept, Handoff is increased which increases the load on the switching &control link elements of the mobile system.
- In this concept there is only one BS per cell but there are three zone-sites located at the corners of a cell.
- All the three zone sites act as receivers for signal transmitted by mobile terminal and connected to a single BS and share the same radio equipment.

LEE’s MICROCELL ZONE CONCEPT



LEE's MICROCELL ZONE CONCEPT

- The BS determines which of the zone-sites has the best reception from the mobile and uses that zone-site to transmit the signal on the downlink.
- As the mobile user travels within the cell it is served by the zone with the strongest signal retaining the same channel.
- Thus like in sectoring, a handoff is not required at MSC when mobile travels b/w zones within the cell. The BS simply switches the channel to a different zone site.