Subject Name: Mobile Communication

Unit name: Cellular Concepts

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Aim and Objectives

• To make students familiar with fundamentals of mobile communication systems

• To understand the concept of frequency reuse

• To identify the limitations of 2G and 2.5G wireless mobile communication and use design of 3G and beyond mobile communication systems

• understanding the basic principles of mobile communication systems
Pre Test - MCQ type

1. The advantage of using frequency reuse is
   a. Increased capacity
   b. Limited spectrum is required
   c. Same spectrum may be allocated to other network
   d. All of the above

   ANSWER: All of the above

2. Co-channel reuse ratio depends upon
   a. Radius of the cell
   b. Distance between the centers of the co channel cells
   c. Frequency allocation of nearest cells
   d. Both a and b
   e. Both b and c

   ANSWER: Both a and b
3. Increase in Co-channel reuse ratio indicates
   a. Better transmission quality
   b. Larger capacity
   c. Low co-channel interference
   d. Both a and c
   e. Both a and b

   ANSWER: Both a and c

4. The strategies acquired for channel assignment are
   a. Fixed
   b. Dynamic
   c. Regular
   d. Both a and b
   e. Both b and c

   ANSWER: Both a and b
5. In a fixed channel assignment strategy, if all the assigned channels are occupied, the call
a. Gets transferred to another cell
b. Gets blocked
c. Is kept on waiting
d. All of the above

ANSWER: b. Gets blocked

6. In a fixed channel assignment strategy
a. Each cell is assigned a predetermined set of frequencies
b. The call is served by unused channels of the cell
c. The call gets blocked if all the channels of the cell are occupied
d. All of the above

ANSWER: All of the above
7. In a dynamic channel assignment strategy,
   a. Voice channels are not permanently assigned
   b. The serving base station requests for a channel from MSC
   c. MSC allocates the channel according to the predetermined algorithm
   d. All of the above

ANSWER: All of the above

8. Advantage of using Dynamic channel assignment is
   a. Blocking is reduced
   b. Capacity of the system is increased
   c. Both a & b
   d. None of the above

ANSWER: Both a & b
9. Disadvantage of using Dynamic channel assignment is

a. More storage required  
b. Calculations and analysis is increased  
c. Both a & b  
d. None of the above

ANSWER: Both a & b

10. In Dynamic channel assignment, any channel which is being used in one cell can be reassigned simultaneously to another cell in the system at a reasonable distance.

a. True  
b. False

ANSWER: True
Pre-Requisite:

• Basic knowledge of digital communication

• Antenna and wave propagation

• Applied random process
Subject Name: Mobile Communication

Unit – V / Cellular Concepts
Syllabus

Introduction to Cellular System
Cellular Systems-Basic Concepts

• Cellular system solves the problem of spectral congestion.
• Offers high capacity in limited spectrum.
• High capacity is achieved by limiting the coverage area of each BS to a small geographical area called cell.
• Replaces high powered transmitter with several low power transmitters.
• Each BS is allocated a portion of total channels and nearby cells are allocated completely different channels.
• All available channels are allocated to small no of neighboring BS.
• Interference between neighboring BS’s is minimized by allocating different channels.
Cellular Systems-Basic Concepts

• Same frequencies are reused by spatially separated BS’s.
• Interference between co-channels stations is kept below acceptable level.
• Additional radio capacity is achieved.
• Frequency Reuse-Fix no of channels serve an arbitrarily large no of subscribers
Topic 1

Frequency Re-use
Frequency Reuse

- Used by service providers to improve the efficiency of a cellular network and to serve millions of subscribers using a limited radio spectrum.
- After covering a certain distance a radio wave gets attenuated and the signal falls below a point where it can be no longer used.
- A transmitter transmitting in a specific frequency range will have only a limited coverage area.
- Beyond this coverage area, that frequency can be reused by another transmitter.
- The entire network coverage area is divided into cells based on the principle of frequency reuse.
Frequency Reuse

• A cell = basic geographical unit of a cellular network & the area around an antenna where a specific frequency range is used.

• When a subscriber moves to another cell, the antenna of the new cell takes over the signal transmission.

• A cluster is a group of adjacent cells, usually 7 cells; no frequency reuse is done within a cluster.

• The frequency spectrum is divided into sub-bands & each sub-band is used within one cell of the cluster.

• In heavy traffic zones cells are smaller, while in isolated zones cells are larger.
Frequency Reuse

• The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning.

• Cell labeled with same letter use the same set of frequencies.

• Cell Shapes - Circle, Square, Triangle and Hexagon.

• Hexagonal cell shape is conceptual, in reality it is irregular in shape
Frequency Reuse

Illustration of the cellular frequency reuse concept.
Frequency Reuse

• In hexagonal cell model, BS transmitter can be in centre of cell or on its 3 vertices.
• Centered excited cells use omni directional whereas edge excited cells use directional antennas.
• A cellular system having ‘S’ duplex channels, each cell is allocated ‘k’ channels (k<S).
• If S channels are allocated to N cells into unique and disjoint channels, the total no of available channel is
• S = kN.
Frequency Reuse

• N cells collectively using all the channels is called a cluster, - a group of adjacent cells.
• If cluster repeated M times, the capacity C of system is given as
  \[ C = M k N = MS \]
• Capacity of system is directly proportional to the no of times the cluster repeated.
• Reducing the cluster size N while keeping the cell size constant, more clusters are required to cover the given area and hence more capacity.
• Co-channel interference is dependent on cluster size, large cluster size less interference and vice versa.
Frequency Reuse

• The Frequency Reuse factor is given as $1/N$ & each cell is assigned $1/N$ of total channels.

• Lines joining a cell and each of its neighbor are separated by multiple of $60^0$, certain cluster sizes and cell layout possible

• Geometry of hexagon is such that no of cells per cluster i.e $N$, can only have values which satisfy the equation

\[
N = i^2 + ij + j^2
\]

- $N$, the cluster size is typically 4, 7 or 12.
- In GSM normally $N=7$ is used.

• $i$ and $j$ are integers, for $i=3$ and $j=2$ $N=19$. 
Locating co-channel Cell
Topic 2

Channel Assignment Strategies
Fixed Assignment Strategy

• A scheme for increasing capacity and minimizing interference is required for effective utilization of radio spectrum.
• CAS can be classified as either fixed or dynamic
• Choice of CAS impacts the performance of system for call management.
• In Fixed CA each cell is assigned a predetermined set of voice channels
• Any call attempt within the cell can only be served by the unused channel in that particular cell
• If all the channels in the cell are occupied, the call is blocked & the user does not get service.
• In variation of FCA – called borrowing strategy, a cell can borrow channels from its neighboring cell if its own channels are full.
Dynamic Channel Assignment

- Voice channels are not allocated to different cells permanently.
- Each time a call request is made, the BS requests a channel from the MSC.
- MSC allocates a channel to the requesting cell using an algorithm that takes into account:
  - Likelihood of future blocking
  - The reuse distance of the channel (should not cause interference)
  - Other parameters like cost
- To ensure min QoS, MSC only allocates a given frequency, not currently in use in the cell or any other cell which falls within the limiting reuse distance.
- DCA reduces the likelihood of blocking and increases capacity.
- Requires the MSC to collect realtime data on channel occupancy and traffic distribution on continuous basis.
Dynamic Channel Assignment (contd)

• This increases the storage and computational load on the system
• But provides the advantage of increased channel utilization and decreased probability of a blocked call.
Topic 3

Hand off Strategies
Introduction to Hand-off

• Mobile moves into a different cell during a conversation, MSC transfers the call to new channel belonging to new BS
• Handoff operation involves identifying the new BS and allocation of voice and control signal to channels associated with new BS
• Must be performed successfully, infrequently and imperceptible to user
• To meet these requirements an optimum signal level must be defined to initiate a handoff.
• Minimum usable signal for acceptable voice quality $\rightarrow$ 90 to -100 dBm
• A slight higher value is used as threshold
Introduction to Hand-off (contd)

By looking at the variations of signal strength from either BS it is possible to decide on the optimum area where handoff can take place.
(a) Improper handoff situation

Level at point A

Handoff threshold

Minimum acceptable signal to maintain the call

Level at point B (call is terminated)

(b) Proper handoff situation

Level at point B

Level at which handoff is made (call properly transferred to BS 2)
Hand-off strategies

- Handoff is made when received signal at the BS falls below a certain threshold.
- During handoff: to avoid call termination, safety margin should exist and should not be too large or small.

\[ \Delta = \text{Power}_{\text{handoff}} - \text{Power}_{\text{min usable}} \]

- Large \( \Delta \) results in unnecessary handoff and for small \( \Delta \) insufficient time to complete handoff, so carefully chosen to meet the requirements.
- Figure 2a, handoff not made and signal falls below min acceptable level to keep the channel active.
- Can happen due to excessive delay by MSC in assigning handoff, or when threshold \( \Delta \) is set to small.
- Excessive delay may occur during high traffic conditions due to computational loading or non availability of channels in nearby cells.
Hand-off Strategies (contd)

• In deciding when to handoff, it is important to ensure that the drop in signal level is not due to momentary fading.

• In order to ensure, the BS monitors the signal for a certain period of time before initiating a handoff.

• The length of time needed to decide if handoff is necessary depends on the speed at which the mobile is moving.
Hand-off strategies – First Generation

• In 1st generation analog cellular systems, the signal strength measurements are made by the BS and are supervised by the MSC.

• A spare Rx in base station monitors RSS of RVC's in neighboring cells
  • Tells Mobile Switching Center about these mobiles and their channels
  • Locator Rx can see if signal to this base station is significantly better than to host base station
    – MSC monitors RSS from all base stations & decides on handoff
Hand-off strategies – 2\textsuperscript{nd} Generation

• In 2\textsuperscript{nd} generation systems, Mobile Assisted Handoffs (MAHO) are used
• In MAHO, every MS measures the received power from the surrounding BS & continually reports these values to the corresponding BS.
• Handoff is initiated if the signal strength of a neighboring BS exceeds that of current BS
• MSC no longer monitors RSS of all channels
  – reduces computational load considerably
  – enables much more rapid and efficient handoffs
  – imperceptible to user
Soft Handoff Vs Inter-system Handoff

- CDMA spread spectrum cellular systems provides a unique handoff capability
- Unlike channelized wireless systems that assigns different radio channel during handoff (called hard handoff), the spread spectrum MS share the same channel in every cell
- The term handoff here implies that a different BS handles the radio communication task
- The ability to select between the instantaneous received signals from different BSs is called soft handoff.
- If a mobile moves from one cellular system to another system controlled by a different MSC, an inter-system handoff is required.
- MSC engages in intersystem handoff when signal becomes weak in a given cell.
Prioritizing Handoffs

- **Perceived Grade of Service (GOS)** – service quality as viewed by users
  - “quality” in terms of dropped or blocked calls
  - assign higher priority to handoff Vs new call request
  - a dropped call more aggravating than an occasional blocked call

- **Guard Channels**
  - % of total available **cell** channels set aside for handoff requests
  - makes fewer channels available for new call requests
  - a good strategy for dynamic channel allocation

- **Queuing of Handoff Requests**
  - use time delay between handoff threshold & minimum useable signal level
  - a handoff request during that time period, instead of having a single block/no block decision
  - prioritize requests & handoff as required
  - calls still be dropped if time period expires
Practical Handoff Considerations

• Problems occur because of a large range of mobile velocities
  – pedestrian Vs vehicle user
• Small cell sizes or micro-cells $\rightarrow$ larger # handoffs
• MSC load is heavy when high speed users are passed between very small cells
• Umbrella Cells
  – use different antenna heights & Tx power levels to provide large and small cell coverage
  – multiple antennas & Tx can be co-located at single location if required
  – large cell $\rightarrow$ high speed traffic $\rightarrow$ fewer handoffs
  – small cell $\rightarrow$ low speed traffic
  – example areas: interstate highway passing through urban center, office park, or nearby shopping mall
Umbrella Cells

Large “umbrella” cell for high speed traffic

Small microcells for low speed traffic
Topic 4

Interference & System Capacity
Interference

- Interference is the major limiting factor in the performance of cellular radio systems.
- Sources of interference include -
  - another mobile in the same cell
  - a call in progress in a neighboring cell
  - other base stations operating in same frequency band
  - any non-cellular system which leaks energy into band
- Interference on voice channels causes cross talk due to an undesired transmission.
- Interference on control channels, leads to missed & blocked calls due to errors in digital signaling.
- Interference is more severe in urban areas, due to RF noise floor & large number of base stations / mobiles.
- Interference is a major bottleneck in increasing capacity & often responsible for dropped calls
Interference (contd)

• The two major types of cellular interference are Co-channel interference (CCI) & Adjacent channel interference (ACI).
• Even though interfering signals are often generated within the cellular system, they are difficult to control due to random propagation effects.
• More difficult to control is interference due to out-of-band users due to front end overload of subscriber equipments.
• CCI is caused due to the cells that reuse the same frequency set.
• These cells using the same frequency set are called Co-channel cells.
• ACI is caused due to the signals that are adjacent in frequency.
Topic 5

Co-channel Interference
Co-channel Interference

- Frequency reuse indicates that in a given coverage area there are several cells using the same set of frequencies.
- These cells are called co-channel cells & interference between signals from these cells is called co-channel interference.
- Co-channel interference cannot be combated by simply increasing the carrier power of a transmitter.
- Because an increase in carrier transmit power increases the interference to neighboring co-channel cells.
- To reduce co-channel interference, co-channel cells must be separated by a minimum distance to provide sufficient isolation due to propagation.
- Co-channel interference is independent of the transmitted power & depends upon the radius of the cell ($R$) and the distance between centers of the nearest co-channel cells ($D$).
Co-channel Interference (contd)

• By increasing D/R ratio, the spatial separation between co-channel cells relative to the coverage distance of a cell is increased.
• Thus, interference is reduced from improved isolation of RF energy from the co-channel cell.
• The parameter $Q$ - called the co-channel reuse ratio is related to the cluster size.

$$Q = \frac{D}{R} = \sqrt[3]{N}$$

• A small value of $Q$ provides larger capacity since the cluster size $N$ is small, whereas a large value of $Q$ improves the transmission quality, due to a smaller level of co-channel interference.
Signal to Interference Ratio (S/I)

- Let $i_0$ be the number of co-channel interfering cells.
- The signal-to-interference ratio (S/I) for a mobile receiver which monitors a forward channel given by:

$$\frac{S}{I} = \frac{S}{i_0} \frac{1}{\sum_{i=1}^{i_0} I_i}$$

- where $S$ is desired signal power from the desired base station & $I_i$ is the interference power caused by the $i$th interfering co-channel cell base station.
- The average received power $P_r$ at a distance $d$ from the transmitting antenna is approximated by:

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n}$$

- where $P_0$ is the power received in far field region of the antenna at a small distance $d_0$ from the transmitting antenna & $n$ is the path loss exponent.
Signal to Interference Ratio (contd)

- When the transmit power of each base station is equal & path loss exponent is the same throughout. $S/I$ for a mobile can be approximated as-

\[
\frac{S}{I} = \frac{R^{-n}}{i_0 \sum_{i=1}^{i_n} (D_i)^{-n}}
\]

- If all the interfering base stations are equidistant from the desired base station & equal to distance $D$ between cell centers, then above simplifies to-

\[
\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3}N)^n}{i_0}
\]

- For a seven-cell cluster, with mobile unit at the cell boundary, the mobile is a distance $D - R$ from the two nearest co-channel interfering cells & exactly $D + R/2$, $D$, $D - R/2$, and $D + R$ from the other interfering cells in the first tier, as shown in figure 1.
Figure 1. First tier of co-channel cells for cluster size of $N = 7$

- Using the approximate geometry shown in Figure 1 & assuming $n = 4$, the signal-to-interference ratio for the worst case can be approximated as:

\[
\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2(D+R)^{-4} + 2D^{-4}}
\]
Topic 6

Adjacent Channel Interference
Near–Far Effect

- Interference resulting from signals adjacent in frequency to the desired signal is called adjacent channel interference.
- Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the pass-band.
- The problem can be serious if an adjacent channel user is transmitting in very close range to a subscriber’s receiver, while the receiver attempts to receive a base station on the desired channel.
- This is called as the near–far effect, where a nearby transmitter captures the receiver of the subscriber.
- It also occurs when a mobile close to a base station transmits on a channel close to one being used by a weak mobile.
Minimizing Interference

• The base station may have difficulty in discriminating the desired mobile user from the “bleed-over” caused by the close adjacent channel mobile.

• Adjacent channel interference can be minimized through careful filtering & channel assignments.

• Since each cell is given only a fraction of the available channels, a cell need not be assigned channels adjacent in frequency.

• By keeping the frequency separation between each channel in a given cell larger, the adjacent channel interference may be reduced.

• If the frequency reuse factor is large, the separation between adjacent channels at the base station not sufficient to keep the adjacent channel interference level within tolerable limits.
Minimizing Interference (contd)

• For example, if a close-in mobile is 20 times as close to the base station as another mobile & has energy spill-out of its pass-band, the signal-to-interference ratio at the base station for the weak mobile is given by -

\[ \frac{S}{I} = (20)^{-n} \]

• For a path loss exponent \( n = 4 \), this is equal to –52 dB.

• If the intermediate frequency (IF) filter of the base station receiver has a slope of 20 dB/octave, then an adjacent channel interferer must be displaced by at least six times the pass-band bandwidth to achieve -52 dB attenuation.

• This indicates more than six channel separations required to bring the adjacent channel interference to an acceptable level.

• In practice, base station receivers are preceded by a high Q cavity filter to reject adjacent channel interference.
Topic 7

Trunking & Grade of Service
Trunking

• Cellular radio systems depend on trunking to accommodate a large number of users in a limited radio spectrum.

• Trunking allows a large no of users to share a 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 (TRS) each user is allocated a channel on a per call basis, upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.
Key Definitions

• **Setup Time**: Time required to allocate a radio channel to a requesting user
• **Blocked Call**: Call which cannot be completed at the time of request, due to congestion
• **Holding Time**: Average duration of a typical call.
• **Request Rate**: The average number of calls requests per unit time ($\lambda$)
• **Traffic Intensity**: Measure of channel time utilization measured in Erlangs. Dimensionless quantity. Denoted by $A$
• **Load**: Traffic intensity across the entire TRS (Erlangs)
Erlang- Unit of Traffic

• The fundamentals of trunking theory were developed by Erlang, a Danish mathematician, the unit bears his name.
• An Erlang is a unit of telecommunications traffic measurement.
• Erlang represents the continuous use of one voice path.
• Used to describe the total traffic volume of one hour
• A channel kept busy for one hour is defined as having a load of one Erlang
• For example, a radio channel that is occupied for thirty minutes during an hour carries 0.5 Erlangs of traffic
• For 1 channel
  – Min load = 0 Erlang (0% time utilization)
  – Max load = 1 Erlang (100% time utilization)
Erlang- Unit of Traffic (contd)

- For example, if a group of 100 users made 30 calls in one hour, and each call had an average call duration (holding time) of 5 minutes, then the number of Erlangs this represents is worked out as follows:

  - Minutes of traffic in the hour = number of calls x duration
  - Minutes of traffic in the hour = 30 x 5 = 150
  - Hours of traffic in the hour = 150 / 60 = 2.5
  - Traffic Intensity= 2.5 Erlangs
Grade of Service

• In a TRS, when a particular user requests service & all the available radio channels are already in use, the user is blocked or denied access to the system.

• In some systems a queue may be used to hold the requesting users until a channel becomes available.

• Trunking systems must be designed in order to ensure that there is a low likelihood that a user will be blocked or denied access.

• The likelihood that a call is blocked, or the likelihood that a call experiences a delay greater than a certain queuing time is called “Grade of Service” (GOS)”. 
Grade of Service (GOS): Measure of ability of a user to access a trunked system during the busiest hour.

Also a Measure of the congestion which is specified as a probability.

It is a benchmark to define the desire performance of a particular trunk system.

The probability of a call being blocked -

Blocked calls cleared (BCC) or Erlang B systems.

The probability of a call being delayed beyond a certain amount of time before being granted access -

Blocked call delayed (BCD) or Erlang C systems.
Blocked Call Cleared Systems (BCC)

• When a user requests service, there is a minimal call set-up time & user is given immediate access to a channel if one is available.

• If channels are already in use and no new channels are available, call is blocked without access to the system.

• The user does not receive service, but is free to try again later.

• All blocked calls are instantly returned to the user pool.
Modeling of BCC Systems

• The Erlang B model is based on following assumptions:
  – Calls are assumed to arrive with a Poisson distribution
  – Nearly an infinite number of users
  – Call requests are memory less so that all users, including blocked users, may request a channel at any time
  – All free channels are fully available for servicing calls until all channels are occupied
  – The probability of a user occupying a channel is exponentially distributed.
  – Longer calls less likely to happen
  – Finite number of channels available in the trunking pool.
  – Inter-arrival times of call requests are independent of each other
Modeling of BCC Systems (contd)

- Erlang B formula is given by

\[
Pr \text{ [blocking]} = \frac{A^C}{C!} \sum_{k=0}^{C} \frac{A^k}{k!}
\]

- where ‘C’ is the number of trunked channels offered by a trunked radio system.
- ‘A’ is the total offered traffic.
Traffic Intensity in Erlang B (BCC)

Figure 3.6  The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.
Erlang B Trunking GOS

Table 3.4  Capacity of an Erlang B System

<table>
<thead>
<tr>
<th>Number of Channels $C$</th>
<th>Capacity (Erlangs) for GOS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>= 0.01</td>
</tr>
<tr>
<td>2</td>
<td>0.153</td>
</tr>
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<tr>
<td>70</td>
<td>56.1</td>
</tr>
<tr>
<td>100</td>
<td>84.1</td>
</tr>
</tbody>
</table>
Blocked Call Delayed Systems (BCD)

- Queues are used to hold call requests that are initially blocked.
- When a user attempts a call & a channel is not immediately available, the call request may be delayed until a channel becomes available.
- Mathematical modeling of such systems is done by Erlang C formula.
- The Erlang C model is based on following assumptions:
  - Similar to those of Erlang B
  - If offered call cannot be assigned a channel, it is placed in a queue of infinite length
  - Each call is then serviced in the order of its arrival
• Erlang C formula gives likelihood of a call not having immediate access to a channel (all channels are already in use)

\[
Pr(\text{delay} > 0) = \frac{A^C}{A^C + C! \left(1 - \frac{A}{C}\right) \sum_{k=0}^{C-1} \frac{A^k}{k!}}
\]
Modeling of BCD Systems

• Probability that any caller is delayed in queue for a wait time greater than \( t \) seconds is given as GOS of a BCD System

• The probability of a call getting delayed for any period of time greater than zero is -

\[
P[\text{delayed call is forced to wait} > t \text{ sec}] = P[\text{delayed}] \times \text{Conditional } P[\text{delay is } > t \text{ sec}]
\]

• Mathematically;

\[
Pr[\text{delay} > t] = Pr[\text{delay} > 0] \times Pr[\text{delay} > t \mid \text{delay} > 0]
\]

• Where

\[
P[\text{delay} > t \mid \text{delay} > 0] = e^{-(C-A)t/H}
\]

\[
Pr[\text{delay} > t] = Pr[\text{delay} > 0] \times e^{-(C-A)t/H}
\]

– where \( C = \) total number of channels, \( t = \) delay time of interest, \( H = \) average duration of call
Traffic Intensity in Erlang C (BCD)

Figure 3.7  The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.
Topic 8

Improving Coverage & Capacity in Cellular Systems
Introduction

• As the demand for wireless service increases, the number of channels assigned to a cell becomes insufficient to support the required number of users.
• Hence cellular design techniques are needed to provide more channels per unit coverage area.
• Techniques such as cell splitting, sectoring & coverage zone approaches are used to expand the capacity of cellular systems.
• Cell splitting allows an orderly growth of the cellular system.
• Sectoring uses directional antennas to control the interference and frequency reuse of channels.
Introduction (contd)

• The zone microcell concept distributes the coverage of a cell & extends the cell boundary to hard-to-reach places.

• While cell splitting increases the number of base stations to increase capacity, sectoring & zone microcells depend on base station antenna placements to improve capacity by reducing co-channel interference.

• Cell splitting & zone microcell techniques do not suffer trunking inefficiencies experienced by sectored cells.

• They enable base station to oversee all handoff chores related to the microcells, thus reducing the computational load at the MSC.

• These three capacity improvement techniques will be explained in detail.
Topic 9

Cell Splitting
Introduction to Cell Splitting

- Cell splitting is the process of subdividing a congested cell into smaller cells with
  - their own BS
  - a corresponding reduction in antenna height
  - a corresponding reduction in transmit power

- Splitting the cell reduces the cell size & thus more number of cells to be used
- For the new cells to be smaller in size the transmit power of these cells must be reduced.
- Idea is to keep $Q = D/R$ constant while decreasing $R$
- More number of cells ► more number of clusters ► more channels ► high capacity
Example for Cell Splitting

- An example of cell splitting is shown in Figure 1.
- The base stations are placed at corners of the cells & area served by base station A is assumed to be saturated with traffic.
- New base stations are needed in the region to increase the number of channels in the area & to reduce the area served by the single base station.
- In figure 1, the original base station A has been surrounded by six new microcells.
- The smaller cells were added in such a way to preserve the frequency reuse plan of the system.
- For example, the microcell base station labeled G was placed half way between two larger stations utilizing the same channel set G.
This is also the case for the other microcells in the figure. Hence cell splitting merely scales the geometry of the cluster. In this case, the radius of each new microcell is half that of the original cell.
Suppose the cell radius of new cells is reduced by half.

What is the required transmit power for these new cells?

\[
Pr \ [\text{at old cell boundary}] = Pt1 \ (R)^{-n}
\]
\[
Pr \ [\text{at new cell boundary}] = Pt2 \ (R/2)^{-n}
\]

where \( Pt1 \) and \( Pt2 \) are the transmit powers of the larger and smaller cell base stations & \( n \) is the path loss exponent.

So,

\[
Pt2 = Pt1 / 2^n
\]

If we take \( n=3 \) and the received powers equal to each other, then

\[
Pt2 = Pt1 / 8
\]

In other words, the transmit power must be reduced by 9dB in order to fill in the original coverage area while maintaining the S/I requirement.
Illustration of cell splitting in 3x3 square centered around base station A
Overcome – Handoff

• In practice not all the cells are split at the same time hence different size cells will exist simultaneously.
• In such situations, special care needs to be taken to keep the distance between co-channel cells at minimum & hence channel assignments become more complicated.
• To overcome handoff problem:
  – Channels in the old cell must be broken down into two channel groups - one for smaller cell & other for larger cell
  – The larger cell is dedicated to high speed traffic so that handoffs occur less frequently
  – Initially, small power group has less channels & large power group has large no of channels but at maturity of the system large power group does not have any channel
Topic 10

Sectoring
Introduction

• Cell splitting achieves capacity improvement by rescaling the system.

• By decreasing the cell radius $R$ & keeping the co-channel reuse ratio $D/R$ unchanged, cell splitting increases the number of channels per unit area.

• Another way to increase capacity is to keep the cell radius unchanged & to decrease the $D/R$ ratio.

• Sectoring increases SIR so that cluster size may be reduced.

• First the SIR is improved using directional antennas & then capacity improvement by reducing the number of cells in a cluster, thus increasing the frequency reuse.

• However, it is necessary to reduce the relative interference without decreasing the transmit power.
Reducing Co-channel Interference

• The co-channel interference may be decreased by replacing a single omnidirectional antenna at the base station by several directional antennas.

• By using directional antennas, a given cell will receive interference & transmit with only a fraction of the available co-channel cells.

• The technique for decreasing co-channel interference & increasing system performance by using directional antennas is called sectoring.

• The factor by which co-channel interference is reduced depends on the amount of sectoring used.

• A cell is normally partitioned into three 120° sectors or six 60° sectors as shown in Figure 1(a) and 1 (b).
Figure 1 - 120 & 60 degrees Sectoring
120 degree Sectoring reducing Interference

• In Figure 2, consider the interference experienced by a mobile located in the right-most sector in the center cell labeled “5”.

• There are three co-channel cell sectors labeled “5” to the right of the center cell & three to the left of the center cell.

• Out of these six co-channel cells, only two cells have sectors with antenna patterns which radiate into the center cell.

• Hence a mobile in the center cell will experience interference on the forward link from only these two sectors.

• This $S/I$ improvement allows to decrease the cluster size $N$ in order to improve the frequency reuse & the system capacity
Figure 2 - 120 degree Sectoring reducing Interference
Penalty for Improved S/I

• The penalty for improved S/I & the resulting capacity improvement is an increased number of antennas at each base station & decrease in trunking efficiency due to channel sectoring at the base station.

• Since sectoring reduces the coverage area of a particular group of channels, the number of handoffs also increases.

• Because sectoring uses more than one antenna per base station, the available channels in the cell must be subdivided & dedicated to a specific antenna.
Topic 11

Repeaters for Range Extension
Role of Repeaters

• A wireless operator needs to provide dedicated coverage for hard-to-reach areas, such as within buildings, or in valleys or tunnels.
• Radio re-transmitters, known as repeaters, are used to provide such range extension capabilities.
• Repeaters are bidirectional in nature & simultaneously send signals to and receive signals from a serving base station.
• Repeaters may be installed anywhere & capable of repeating an entire cellular band.
• Upon receiving signals from a base station, the repeater amplifies and reradiates the base station signals to the specific coverage region.
• Unfortunately, the received noise & interference is also reradiated by the repeater on both forward and reverse link.
Repeaters Vs System Capacity

• Care must be taken to properly place the repeaters & to adjust the various forward and reverse link amplifier levels and antenna patterns.

• In practice, directional antennas or distributed antenna systems (DAS) are connected to the inputs or outputs of repeaters for spot coverage, particularly in tunnels or buildings.

• By modifying the coverage of a serving cell, an operator can dedicate a certain amount of the base station’s traffic for the areas covered by the repeater.

• However, the repeater does not add capacity to the system.

• Repeaters are being used to provide coverage into and around buildings, where coverage is weak.
Location of Repeaters

- Determining the proper location for repeaters & distributed antenna systems within buildings requires careful planning, to avoid re-radiation of interference into the building from the base station.
- Also, repeaters must be provisioned to match the available capacity from the serving base station.
- Software products, such as Site-Planner allow engineers to determine the best placements for repeaters & required DAS network while simultaneously computing the traffic and installation cost.
Topic 12

Microcell Zone Concept
Introduction

- The increased number of handoffs required during sectoring results in an increased load on the switching and control link elements of the mobile system.
- A solution to this problem is based on a microcell concept for seven cell reuse, as illustrated in Figure 1.
- In this scheme, each of the three zone sites represented as Tx/Rx in Figure 1 are connected to a single base station & share the same radio equipment.
- The zones are connected by coaxial cable, fiber-optic cable, or microwave link to the base station.
- Multiple zones & 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.
Time & Space Distribution

• As a mobile travels from one zone to another within the cell, it retains the same channel.
• 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.
• Thus a given channel is active only in the particular zone in which the mobile traveling & hence the base station radiation is localized & interference is reduced.
• The channels are distributed in time & space by all three zones & reused in co-channel cells in the normal fashion.
• This technique is particularly useful along highways or along urban traffic corridors.
Advantage of Zone Cell Technique

• The advantage of this zone cell technique - while the cell maintains a particular coverage radius, the co-channel interference is reduced.

• And a large central base station is replaced by several lower powered transmitters.

• Decreased co-channel interference improves the signal quality & increase in capacity without degradation in trunking efficiency caused by sectoring.
Figure 1 – The Micro-cell Concept
Figure 2 – Microcell Architecture with N = 7
Reduction in Cluster size

• In Figure 2, 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.
• The capacity of the zone microcell system is related to the distance between co-channel cells & not zones. This distance is represented as $D$.
• For a $D_z / R_z$ value = 4.6, the value of co-channel ratio - $D/R$, is equal to three, where $R$ is the radius of the cell & equal to twice the length of the hexagon radius.
• $D/R = 3$ 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 based on the zone microcell concept.
Applications

• 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 omni-directional antennas.

• No loss in trunking efficiency is experienced.

• Zone cell architectures are being adopted in many cellular & personal communication systems.
SHORT QUESTION ANSWER
• 1) What is frequency re-use?

The design process of selecting & allocating channel groups for all the cellular base stations within a system is called frequency reuse or frequency planning.

2) Define cell in a wireless network.

A cell is a basic geographical unit of a cellular network & the area around an antenna where a specific frequency range is used. When a subscriber moves to another cell, the antenna of the new cell takes over the signal transmission.
3) Mention the factors which influence the co-channel interference in cellular networks.
Co-channel interference is dependent on cluster size, large cluster size less interference and vice versa.

4) What is channel assignment strategy?
A scheme for increasing capacity and minimizing interference is required for effective utilization of radio spectrum. CAS can be classified as either fixed or dynamic. Choice of CAS impacts the performance of system for call management.
• 5) What is called fixed channel assignment strategy?
   In Fixed CA each cell is assigned a predetermined set of voice channels. Any call attempt within the cell can only be served by the unused channel in that particular cell.

6) What is called dynamic channel assignment strategy?
   Voice channels are not allocated to different cells permanently. MSC only allocates a given frequency, not currently in use in the cell or any other cell which falls within the limiting reuse distance.
7) Mention the advantages & disadvantages of dynamic channel assignment strategy.

Advantage: Increased channel utilization and decreased probability of a blocked call.
Disadvantage: Increases the storage and computational load on the system.

8) What is hand-off operation?

Handoff operation involves identifying the new BS and allocation of voice and control signal to channels associated with new BS. It must be performed successfully, infrequently and imperceptible to user.
9) What is the safety margin required for hand-off operation?

During handoff: to avoid call termination, safety margin should exist and should not be too large or small

$$\Delta = \text{Power}_{\text{handoff}} - \text{Power}_{\text{min usable}}$$

- Large $\Delta$ results in unnecessary handoff and for small $\Delta$ insufficient time to complete handoff, so carefully chosen to meet the requirements.
• 10) What is the role of a MSC in a cellular network?

MSC no longer monitors RSS of all channels
– reduces computational load considerably
– enables much more rapid and efficient handoffs
– imperceptible to user

• 11) What is soft-handoff operation?

The ability to select between the instantaneous received signals from different Base Stations is called soft handoff.
• 12) What is intersystem hand-off?
If a mobile moves from one cellular system to another system controlled by a different MSC, an inter-system handoff is required. MSC engages in intersystem handoff when signal becomes weak in a given cell.

13) Mention the practical considerations for hand-off operation.
- Problems occur because of a large range of mobile velocities
- Small cell sizes or micro-cells → larger handoffs
- MSC load is heavy when high speed users are passed between very small cells
- Umbrella Cells
• 14) What are called Umbrella Cells?

Cells which are meant to use different antenna heights & Transmitter power levels to provide large and small area coverage are called Umbrella cells.

• 15) Mention the sources of interference in a cellular network.

Sources of interference include -

- another mobile in the same cell
- a call in progress in a neighboring cell
- other base stations operating in same frequency band
- any non-cellular system which leaks energy into band
• 16) Mention the major types of cellular interferences.
• The two major types of cellular interference are Co-channel interference (CCI) & Adjacent channel interference (ACI).

• 17) Differentiate between CCI and ACI.
• CCI is caused due to the cells that reuse the same frequency set. These cells using the same frequency set are called Co-channel cells.
• ACI is caused due to the signals that are adjacent in frequency.
• 18) What are co-channel cells?
• Frequency reuse indicates that in a given coverage area there are several cells using the same set of frequencies. These cells are called co-channel cells.

• 19) What is called near-far effect?
• If an adjacent channel user is transmitting in very close range to a subscriber’s receiver, while the receiver attempts to receive a base station on the desired channel, then its is called as the near–far effect.
20) What is trunking?
A technique which allows a large no of users to share a small number of channels in a cell by providing access to each user, on demand, from a pool of available channels.

21) Define Erlang.
An Erlang is a unit of telecommunications traffic measurement. Erlang represents the continuous use of one voice path. It is used to describe the total traffic volume of one hour.
• 22) What is grade of service (GOS)?
• The likelihood that a call is blocked, or the likelihood that a call experiences a delay greater than a certain queuing time is called “Grade of Service” (GOS).”

• 23) What is Cell splitting?
• Cell splitting is the process of subdividing a congested cell into smaller cells with -
  • their own BS
  • a corresponding reduction in antenna height
  • a corresponding reduction in transmit power
• 24) What is called Sectoring?
• The technique for decreasing co-channel interference & increasing system performance by using directional antennas in a cellular network is called sectoring.

• 25) What is microcell concept?
• Base stations are decomposed into three or more zones connected by coaxial cable or fiber-optic cable to the base station.
• Multiple zones & a single base station make up a cell.
• The mobile is served by the zone with the strongest signal within the cell.
Applications:

Vehicles - Applications

• Transmission of music, news, road conditions, weather reports, and other broadcast information are received via digital audio broadcasting (DAB) with 1.5Mbit/s.

• For personal communication, a universal mobile telecommunications system (UMTS) phone might be available offering voice and data connectivity with 384kbit/s.

• For remote areas, satellite communication can be used, while the current position of the car is determined via the GPS (Global Positioning System).

• A local ad-hoc network for the fast exchange of information (information such as distance between two vehicles, traffic information, road conditions) in emergency situations or to help each other keep a safe distance. Local ad-hoc network with vehicles close by to prevent guidance system, accidents, redundancy.
Applications:

- Vehicle data from buses, trucks, trains and high speed train can be transmitted in advance for **maintenance**.

- In ad-hoc network, car can comprise personal digital assistants (PDA), laptops, or mobile phones connected with each other using the Bluetooth technology.

*Fig: A Typical Application of Mobile Communication in Road Traffic*
Applications:

Emergency- Applications

• **Video communication:** Responders often need to share vital information. The transmission of real time situations of video could be necessary. A typical scenario includes the transmission of live video footage from a disaster area to the nearest fire department, to the police station or to the near NGOs etc.

• **Push To Talk (PTT):** PTT is a technology which allows half duplex communication between two users where switching from voice reception mode to the transmit mode takes place with the use of a dedicated momentary button. It is similar to walkie-talkie.

• **Audio/Voice Communication:** This communication service provides full duplex audio channels unlike PTT. Public safety communication requires novel full duplex speech transmission services for emergency response.

• **Real Time Text Messaging (RTT):** Text messaging (RTT) is an effective and quick solution for sending alerts in case of emergencies. Types of text messaging can be email, SMS and instant message.
Applications:

Business-Applications:

Travelling Salesman
• Directly access to customer files stored in a central location.
• Consistent databases for all agents
• Mobile office
• To enable the company to keep track of all the activities of their travelling employees.

In Office
Wi-Fi wireless technology saves businesses or companies a considerable amount of money on installations costs.
There is no need to physically setup wires throughout an office building, warehouse or store.
Bluetooth is also a wireless technology especially used for short range that acts as a complement to Wi-Fi. It is used to transfer data between computers or cellphones.

Transportation Industries
In transportation industries, GPS technology is used to find efficient routes and tracking vehicles.
MCQ- post-test

1. The process of transferring a mobile station from one base station to another is
   a. MSC
   b. Roamer
   c. Hand off
   d. Forward channel
   ANSWER: Hand off

2. Interference in cellular systems is caused by
   a. Two base stations operating in same frequency band
   b. Two calls in progress in nearby mobile stations
   c. Leakage of energy signals by non cellular systems into cellular frequency band
   d. All of the above
   ANSWER: All of the above
3. Interference in frequency bands may lead to
   a. Cross talk
   b. Missed calls
   c. Blocked calls
   d. All of the above

   ANSWER: All of the above

4. Advantage of using Spread Spectrum modulation is/are

   1. Interference rejection capability
   2. Frequency planning is not required
   3. Resistance to multipath fading
   4. ISI is lesser
   a. 1 and 2 are correct
   b. 1, 2 and 3 are correct
   c. 2 and 3 are correct
   d. All the four are correct

   ANSWER: All the four are correct
MCQ- post-test

5. Guard band is

a. The small unused bandwidth between the frequency channels to avoid interference
b. The bandwidth allotted to the signal
c. The channel spectrum
d. The spectrum acquired by the noise between the Signal

ANSWER: The small unused bandwidth between the frequency channels to avoid interference

6. Radio capacity may be increased in cellular concept by

a. Increase in radio spectrum
b. Increasing the number of base stations & reusing the channels
c. Both a & b
d. None of the above

ANSWER: Increasing the number of base stations & reusing the channels
MCQ- post-test

7. The techniques used to improve the capacity of cellular systems are
   a. Splitting
   b. Sectoring
   c. Coverage zone approach
   d. All of the above

   ANSWER: All of the above

8. Trunking in a cellular network refers to
   a. Termination of a call
   b. Spectrum unavailability
   c. Accommodating large number of users in limited spectrum
   d. All of the above

   ANSWER: Accommodating large number of users in limited spectrum
9. When all of the radio channels are in use in a trunking system
   a. The user is blocked
   b. The access to the system is denied
   c. The queue may be provided
   d. All of the above

   ANSWER: All of the above

10. Grade of service refers to
    a. Accommodating large number of users in limited spectrum
    b. Ability of a user to access trunked system during busy hour
    c. Two calls in progress in nearby mobile stations
    d. High speed users with large coverage area

   ANSWER: Ability of a user to access trunked system during busy hour
Conclusion

• To make students familiar with various generations of mobile communications

• To understand the concept of cellular communication

• To understand the basics of wireless communication
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Assignment:

1) Explain the concept of frequency re-use and the channel assignment strategies in detail.

2) Discuss in detail, the hand-off strategies implemented in a cellular network.

3) Explain the co-channel interference and adjacent channel interference in detail.

4) Describe about trunking and grade of service in a cellular network.

5) Write short notes on – (i) Cell Splitting (ii) Sectoring.

6) What is the concept of microcell zone? Explain it with an illustration in detail.