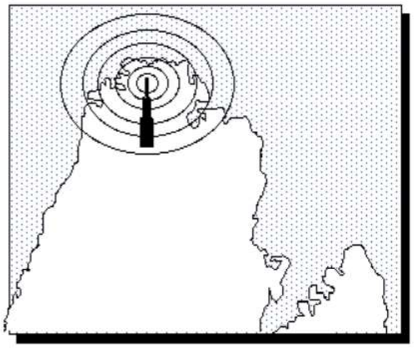
Chapter 3
The Cellular Concept
- System Design Fundamentals

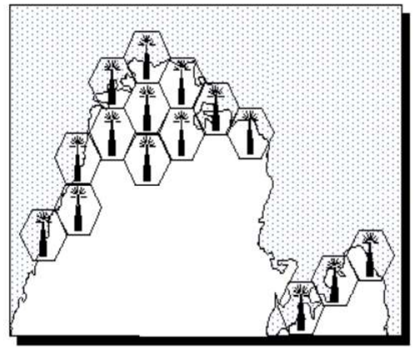
Mini Madav Khanal
BCIS 8th Semester
Boston College, Bharatpur, Chitwan

Outlines

- Frequency Reusing
- Design of Cluster
- Channel Assignment Strategies
- Co-Channel Interference and Adjacent Channel Interference
- Trunking and Grade of Service

Frequency Reusing





Early Mobile Telephone System

Traditional mobile service was similar to radio/TV broadcasting: One very powerful transmitter located at the highest spot in a large area.

Cellular System

In a cellular system, instead of using one powerful transmitter, many low-power transmitters were placed throughout a coverage area.

Frequency Reusing

Early Mobile Telephone System

Low Capacity: Consider that the assigned frequency band can afford 100 simultaneous conversations (channels).

Cellular System

High Capacity: Consider that the assigned frequency band is reused in 10 cells, the system may afford 1000 simultaneous conversations (channels).

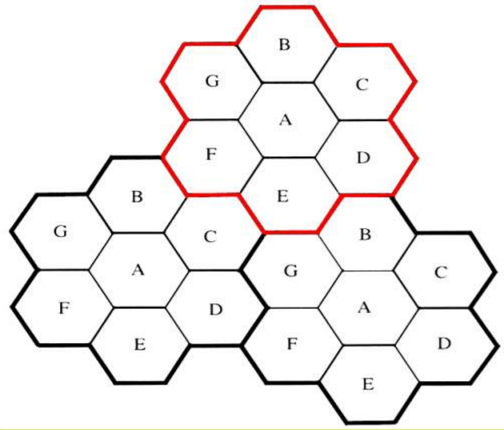
- The cellular concept was a major breakthrough in solving the problem of spectral congestion and user capacity.
- It offered very high capacity in a limited spectrum allocation without any major technological changes.

Frequency Reusing

Cellular System

However, neighboring cells will interfere to each other. Therefore, they shall use different frequency bands.

A cell cluster is outlined in bold, and replicated over the coverage area. Cells with the same letter use the same set of frequencies.



In this example, the cluster size is N=7, and the frequency reuse factor is 1/7, since each cell contains 1/7 of the total number of available channels.

Frequency Reusing

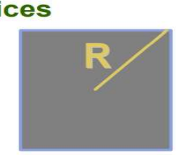
Why Choices of Hexagonal Cell Geometry/Layout?

→ **In practice, the shape of each cell depends on the transmitter radiation pattern and terrain topography.**

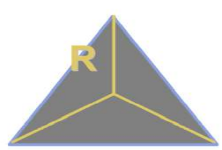
Factors

- Equal area
- No overlap between cells

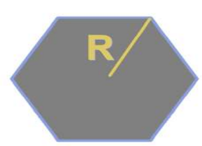
Choices



A1



A 2



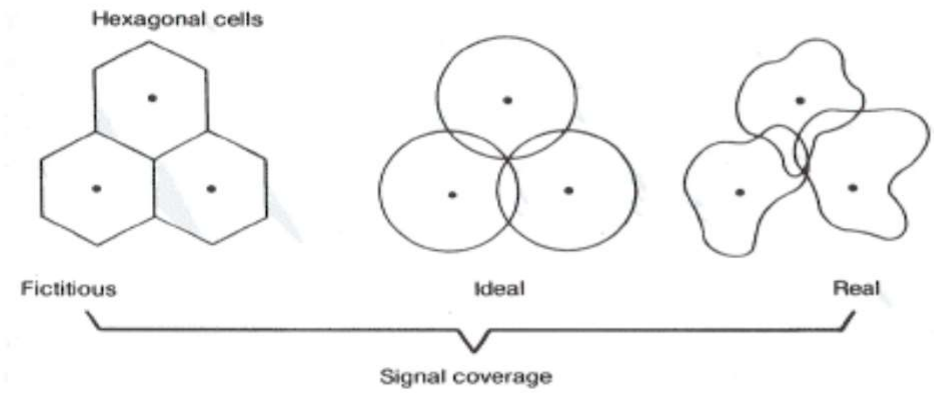
A 3

For a given R, A3 provides **maximum coverage area**.

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

Frequency Reusing

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



Frequency Reusing

Consider a cellular system

Total duplex channels : S

Cluster size : N cells

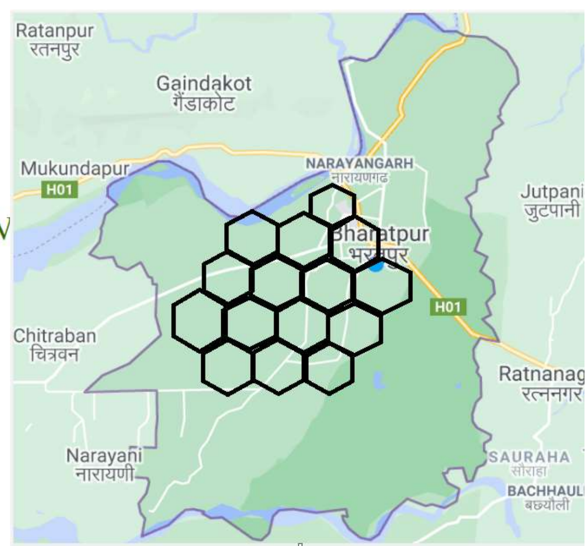
No. of channels in each cell : $k = S/N$

Capacity in a cluster : $C = kN = S$

If a cluster is replicated M times

Total capacity : $C = MkN = MS$

→ The capacity is increased by M.

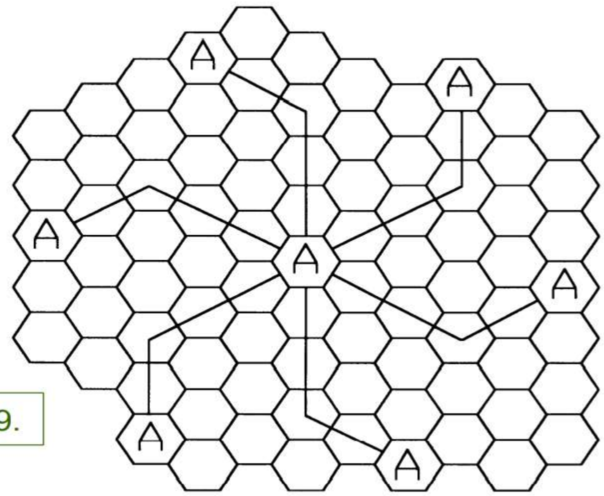


Design of Cluster Size/Co-Channel Cell Location

To Find the Nearest Co-channel Neighbor of Particular Cell:

Move i cells along any chain or hexagon.

Then turn 60 degrees counterclockwise and move j cells.



In this example, i=3, j=2, N=19.

Channel Assignment Strategies

Fixed Channel Assignment Strategy:

Each cell is allocated a predetermined set of voice channels.

If all the channels in that cell are occupied, the call is blocked, and the subscriber does not receive service.

Variation includes a borrowing strategy:

> A cell is allowed to borrow channels from a neighboring cell if all its own channels are occupied.
>
> This is supervised by the mobile switch center (MSC).

Dynamic Channel Assignment Strategy:

Voice channels are not allocated to different cells permanently.

Each time a call request is made, the serving base station requests a channel from the MSC.

The switch then allocates a channel to the requested call, based on a decision algorithm taking into account different factors - frequency re-use of candidate channel, cost factors.

Dynamic channel assignment is more complex (real time), but reduces likelihood of blocking.

Interference

Major limiting factor in performance of cellular radio systems:

- **Co-channel interference**

  - Cells that use the same set of frequencies are called co-channel cells.

  - Interference between them is called co-channel interference.

- **Adjacent channel interference**

  - Interference resulting from signals which are adjacent in frequency to the desired signal.

  - Due to imperfect receiver filters that allow nearby frequencies to leak into pass band.

Adjacent Channel Interference

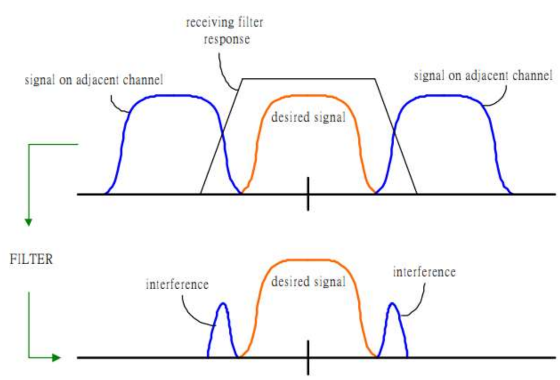
- Interference resulting from signals which are adjacent in frequency to the desired signal.

- Due to imperfect receiver filters that allow nearby frequencies to leak into pass band.

- Performance may degrade seriously due to *near-far* effect.

- Can be minimized by careful filtering and assignments; and, by keeping frequency separation between channel in a given cell as large as possible.

- A channel separation greater than six is needed to bring the adjacent channel interference to an acceptable level.



Trunking and Grade of Service

- Cellular radio systems rely on trunking to accommodate a large number of users in a limited radio spectrum. The concept of trunking allows a large population to be accommodated by a limited number of services.
- **Trunking** : each user is allocated a channel on a per-call basis; and upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels

  Trunking theory was initiated by Danish mathematician, A. K. Erlang.
- **Measure of traffic intensity**: one Erlang represents the amount of traffic intensity carried by a channel that is completely occupied. For example, a radio channel that is occupied for 30 minutes during an hour carries 0.5 Erlang of traffic.
- **Grade of Service (GOS)**: Measure of ability of the user to access a trunked system during the busiest hour during a week, month or year.

  GOS is typically given as the likelihood that a call is blocked, or the likelihood of a call experiencing a delay greater than a certain queuing time.

Trunking and Grade of Service

Some Definitions:

Set-up Time: The time required to allocate a trunked radio channel to a requesting user.

Blocked Call: Call which cannot be completed at time of request, due to congestion. Also referred to as a *lost call*.

Holding Time: Average duration of a typical call. Denoted by H (in seconds).

Traffic Intensity: Measure of channel time utilization, which is the average channel occupancy measured in Erlangs. This is a dimensionless quantity and may be used to measure the time utilization of single or multiple channels. Denoted by A.

Load: Traffic intensity across the entire trunked radio system, measured in Erlangs.

Grade of Service (GOS): A measure of congestion which is specified as the probability of a call being blocked (for Erlang B), or the probability of a call being delayed beyond a certain amount of time (for Erlang C).

Request Rate: The average number of call requests per unit time. Denoted by λ seconds^{-1}.

Trunking and Grade of Service

Traffic intensity of each user:

$$A_\mu = \lambda H \text{ (Erlang)}$$

λ : Average number of call requests per unit time

H : duration of a call

For system entering U users, the total offered traffic intensity

$$A = U A_\mu \text{(Erlangs)}$$

If there are C channels in the system, average intensity per channel is

$$A_c = A / C = U A_\mu / C$$

Trunking and Grade of Service

There are two types of trunked systems:

> **Blocked Calls Cleared System**

- No queuing for call requests
- If no channels are available, the requesting user is blocked without access and is free to try again later.

> **Blocked Calls Delayed System**

- Queue is provided to hold calls which are blocked. If a channel is not available immediately, the call request may be delayed until a channel becomes available.

Trunking and Grade of Service

Blocked Calls Cleared Formula (Erlang B Formula)

Assuming (a) There are an infinite number of users
(b) There are memoryless arrivals of requests (i.e., all users, including the blocked users, may request a channel at any time)
(c) The probability of a user occupying a channel is exponentially distributed (long calls are less likely to occur)
(d) There are a finite number of available channels C

Then (proof is given in Appendix A of the textbook)

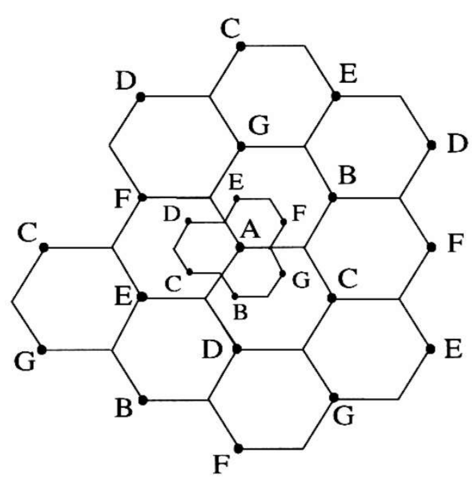
$$\text{GOS} = \Pr\,[\text{call is blocked}] = \frac{\dfrac{A^C}{C!}}{\displaystyle\sum_{k=0}^{C} \frac{A^k}{k!}}$$ **(Erlang B Formula)**

Improving Capacity in Cellular Systems

- As demand for wireless services increases, the number of channels assigned to a cell is not enough to support the required number of users.
- Solution is to increase channels per unit coverage area.

Cell Splitting :

- Subdivides a congested cell into smaller cells, each with its own base station.
- With R decreased and D/R unchanged, the capacity of a cellular system is increased.



Improving Capacity in Cellular Systems

Cell Splitting :

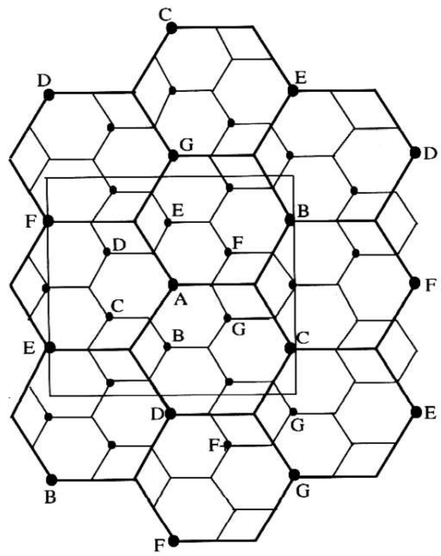
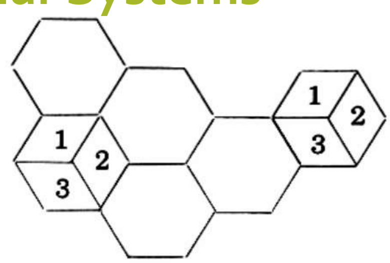


Figure 3.9 Illustration of cell splitting within a 3 km by 3 km square centered around base station A.

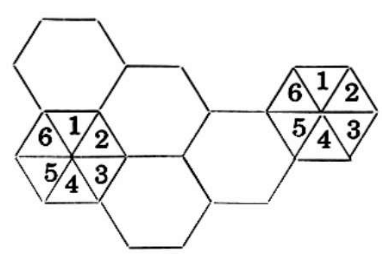
Improving Capacity in Cellular Systems

Sectoring :

- **Sectoring:** The technique for decreasing co-channel interference by using directional antennas.
- A single omni-directional antenna at the base station is replaced by several directional antennas, each radiating within a specified sector.
- A given cell will receive interference and transmit with only a fraction of the available co-channel cells.



(a) 120° sectoring

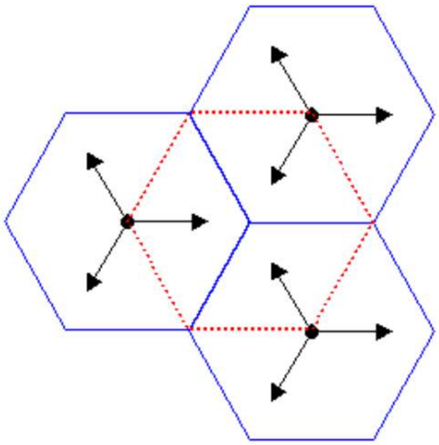


(b) 60° sectoring

Improving Capacity in Cellular Systems

Improving Capacity in Cellular Systems

Sectoring



Improving Capacity in Cellular Systems

Sectoring (con't):

- In this example (seven-cell reuse, 120° sectors), the number of interferers in the first tier is reduced from 6 to 2.
- SIR is improved from 17 dB to 24.2 dB.
- Additional SIR improvement is possible by down-tilting the sector antennas.

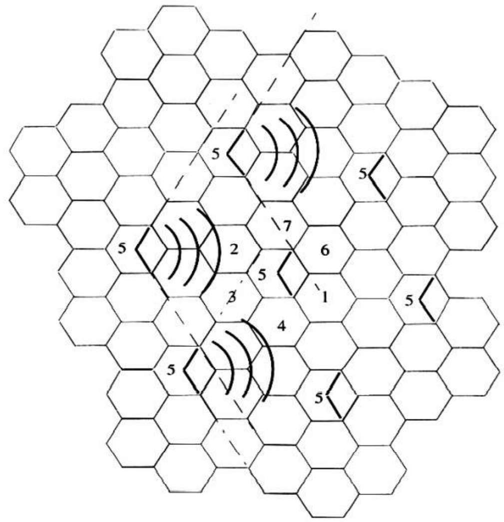


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.