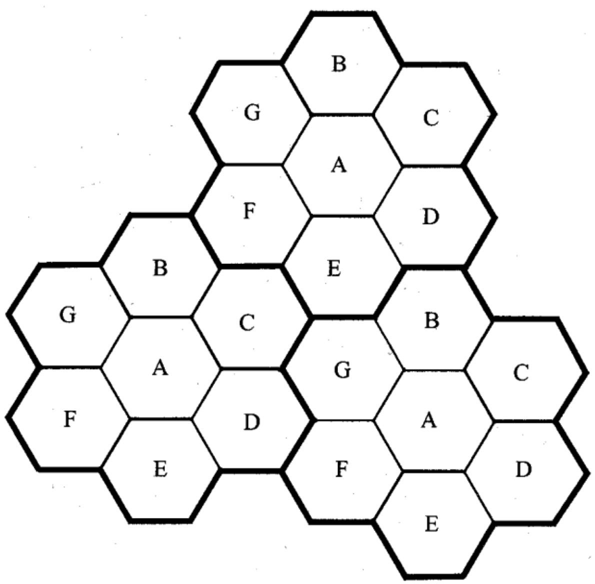
Chapter: Cellular Concept & System Design Fundamentals for further design detail (Rappaport ..Book)

Note: Numerical are attached on separate sheets

Introduction to Cellular Systems

- 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 (randomly) large number of users by reusing the channel throughout the coverage region



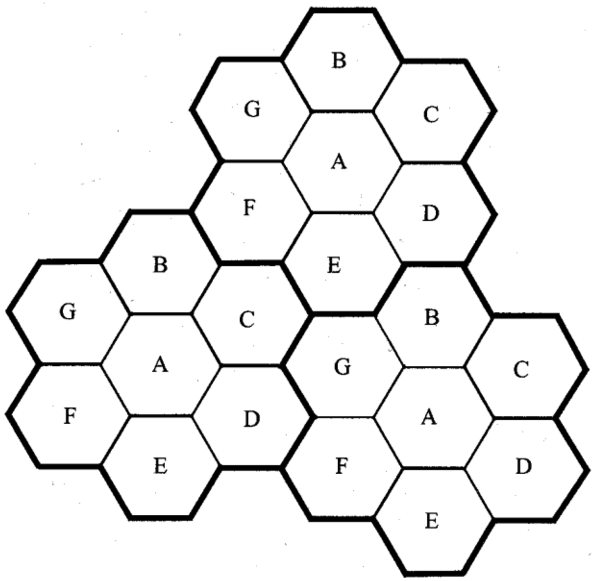
Frequency Reuse

- 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



- 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

$$C = MkN = MS$$

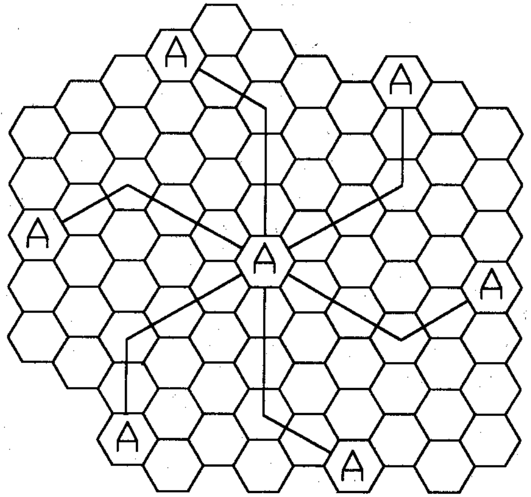
- The capacity is directly proportional to the number of replication M.
- The cluster size, N, is typically equal to 4, 7, or 12.
- The frequency reuse factor is given by

$$1/N$$

- 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

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

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



- To find the nearest co-channel neighbors of a particular cell
  - (1) Move i cells along any chain of hexagons, then (2) turn 60 degrees and move j cells.

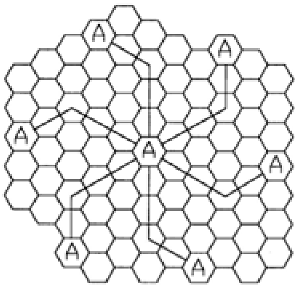


Figure 3.2 Method of locating co-channel cells in a cellular system. In this example, N = 19 (i.e., i = 3, j = 2). (Adapted from [Oet83] © IEEE.)

Frequency Reuse

- The geometry of hexagons is such that the number of cells per cluster, *N*, can only have values which satisfy Eqn-3.3

$$N = i^2 + ij + j^2 \qquad (3.3)$$

where i and j are non-negative integers.

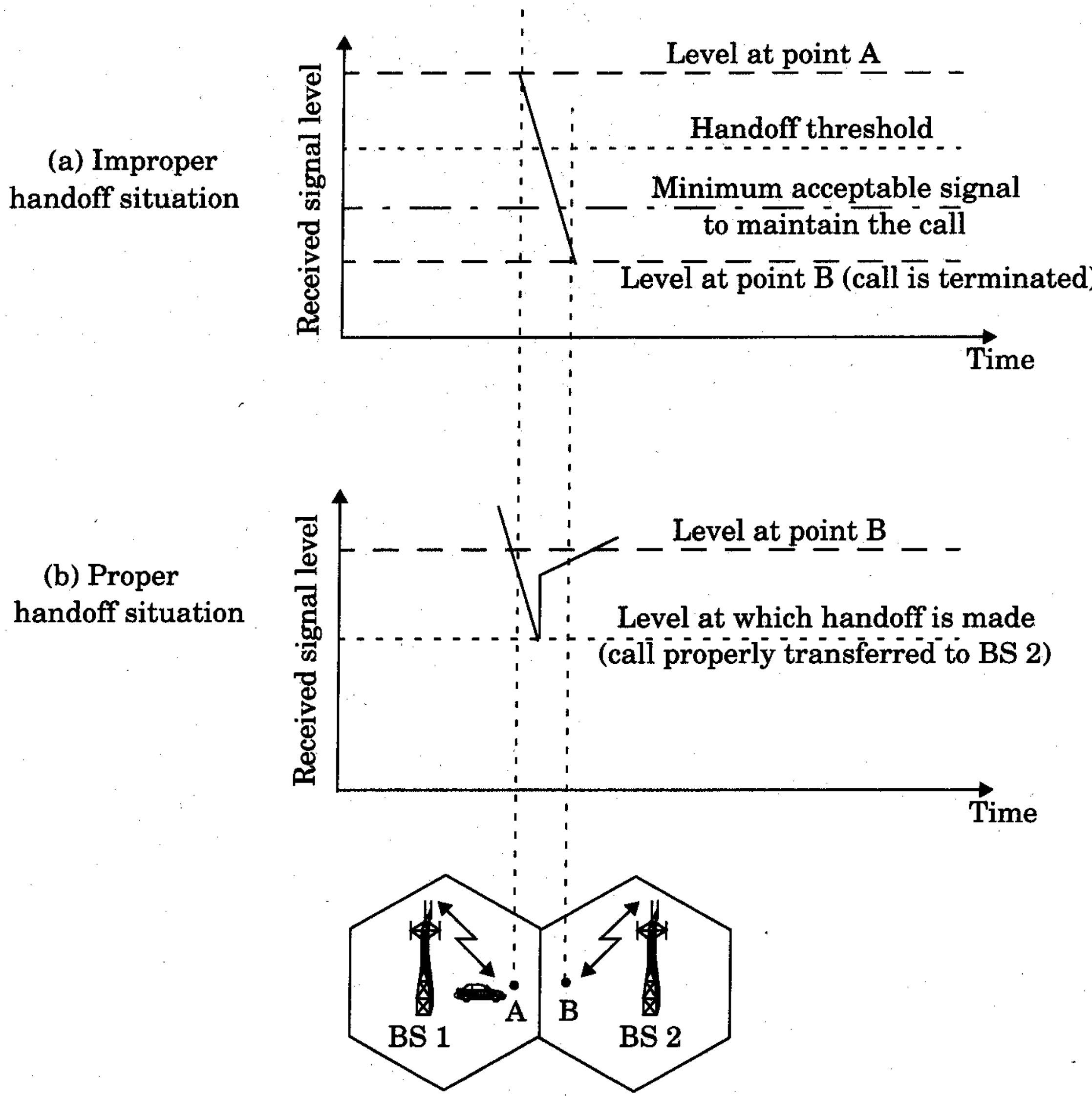
- To find the nearest co-channel neighbours of a particular cell, one must do the following:
  1. Move i cells along any chain of hexagon
  2. Turn 60 degrees counter-clockwise and move j cells.
     (see Fig-3.2)

Channel Assignment Strategies

- Frequency reuse scheme
  - increases capacity
  - minimize interference
- Channel assignment strategy
  - fixed channel assignment
  - dynamic channel assignment
- 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
- Dynamic channel assignment
  - channels are not allocated to cells permanently.
  - allocate channels based on request.
  - reduce the likelihood of blocking, increase capacity.

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.



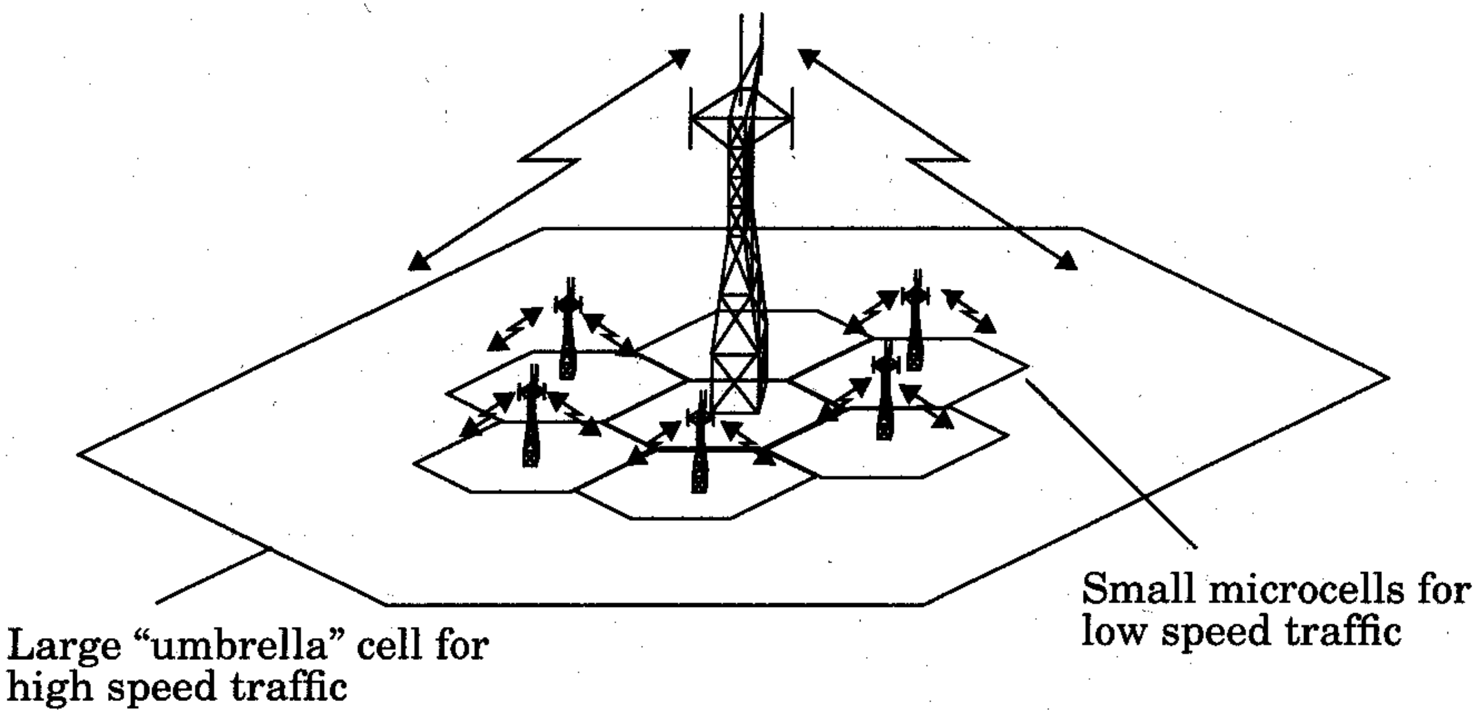
(a) Improper handoff situation
Received signal level
Level at point A
Handoff threshold
Minimum acceptable signal to maintain the call
Level at point B (call is terminated)
Time
(b) Proper handoff situation
Received signal level
Level at point B
Level at which handoff is made (call properly transferred to BS 2)
Time
A
B
BS 1
BS 2

- 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.
- Running average measurement of signal strength should be optimized so that unnecessary handoffs are avoided.
  - Depends on the speed at which the vehicle is moving.
  - Steep short term average -> the hand off should be made quickly
  - The speed can be estimated from the statistics of the received short-term fading signal at the 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

- Handoff measurement
  - In first generation analog cellular systems, signal strength measurements are made by the base station and supervised by the MSC.
  - In second generation systems (TDMA), handoff decisions are mobile assisted, called mobile assisted handoff (MAHO)
- Intersystem handoff: If a mobile moves from one cellular system to a different cellular system controlled by a different MSC.
- Handoff requests is much important than handling a new call.

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

- Handoff for first generation analog cellular systems
  - 10 secs handoff time
  - Δ is in the order of 6 dB to 12 dB
- Handoff for second generation cellular systems, e.g., GSM
  - 1 to 2 seconds handoff time
  - mobile assists handoff
  - Δ is in the order of 0 dB to 6 dB
  - Handoff decisions based on signal strength, co-channel interference, and adjacent channel interference.
- IS-95 CDMA spread spectrum cellular system
  - Mobiles share the channel in every cell.
  - No physical change of channel during handoff
  - MSC decides the base station with the best receiving signal as the service station
-

Interference and System Capacity

- Sources of interference
  - another mobile in the same cell
  - a call in progress in the neighboring cell
  - other base stations operating in the same frequency band
  - noncellular system leaks energy into the cellular frequency band
- Two major cellular interference
  - co-channel interference
  - adjacent channel interference

2.5.1 Co-channel Interference and System Capacity

- Frequency reuse - there are several cells that use the same set of frequencies
  - co-channel cells
  - co-channel interference
- To reduce co-channel interference, co-channel cell must be separated by a minimum distance.
- When the size of the cell is approximately the same
  - co-channel interference is independent of the transmitted power
  - co-channel interference is a function of
    - R: Radius of the cell
    - D: distance to the center of the nearest co-channel cell
- Increasing the ratio $Q=D/R$, the interference is reduced.
- Q is called the co-channel reuse ratio

- For a hexagonal geometry

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

- A small value of Q provides large capacity
- A large value of Q improves the transmission quality - smaller level of co-channel interference
- A tradeoff must be made between these two objectives

Table 2.1 Co-channel Reuse Ratio for Some Values of N

	Cluster Size (N)	Co-channel Reuse Ratio(Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

- Let i_0 be the number of co-channel interfering cells. The signal-to-interference ratio (SIR) for a mobile receiver can be expressed as

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

S: the desired signal power

I_i: interference power caused by the ith interfering co-channel cell base station

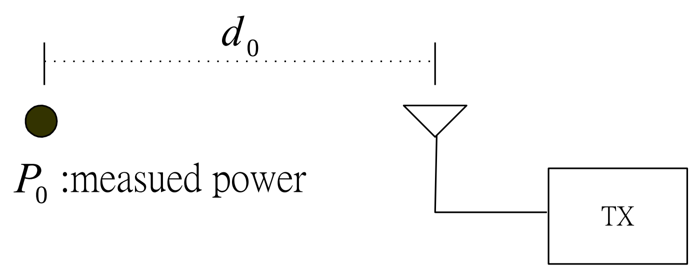
- The average received power at a distance d from the transmitting antenna is approximated by

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

or

$$P_r(\text{dBm}) = P_0(\text{dBm}) - 10n \log\left(\frac{d}{d_0} \right)$$

close-in reference point



n is the path loss exponent which ranges between 2 and 4.

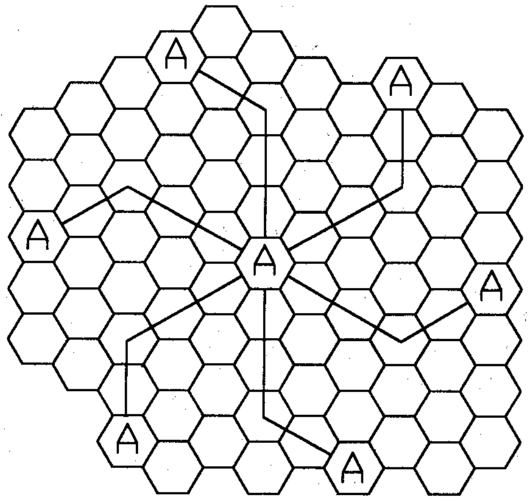
- When the transmission power of each base station is equal, SIR for a mobile can be approximated as

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

- Consider only the first layer of interfering cells

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{i_0}$$

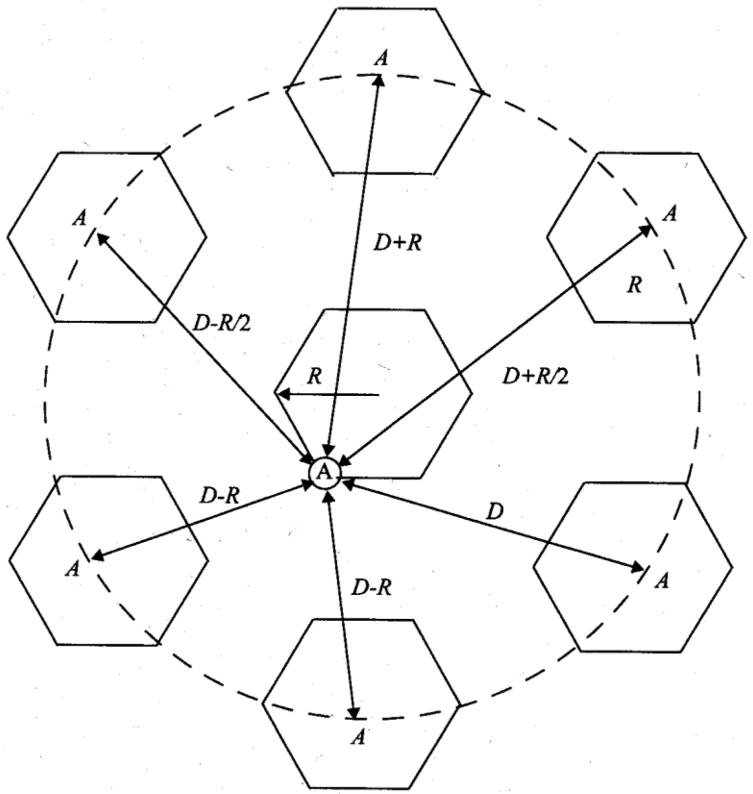
$i_0 = 6$



- Example: AMPS requires that SIR be greater than 18dB
  - *N* should be at least 6.49 for *n=4*.
  - Minimum cluster size is 7

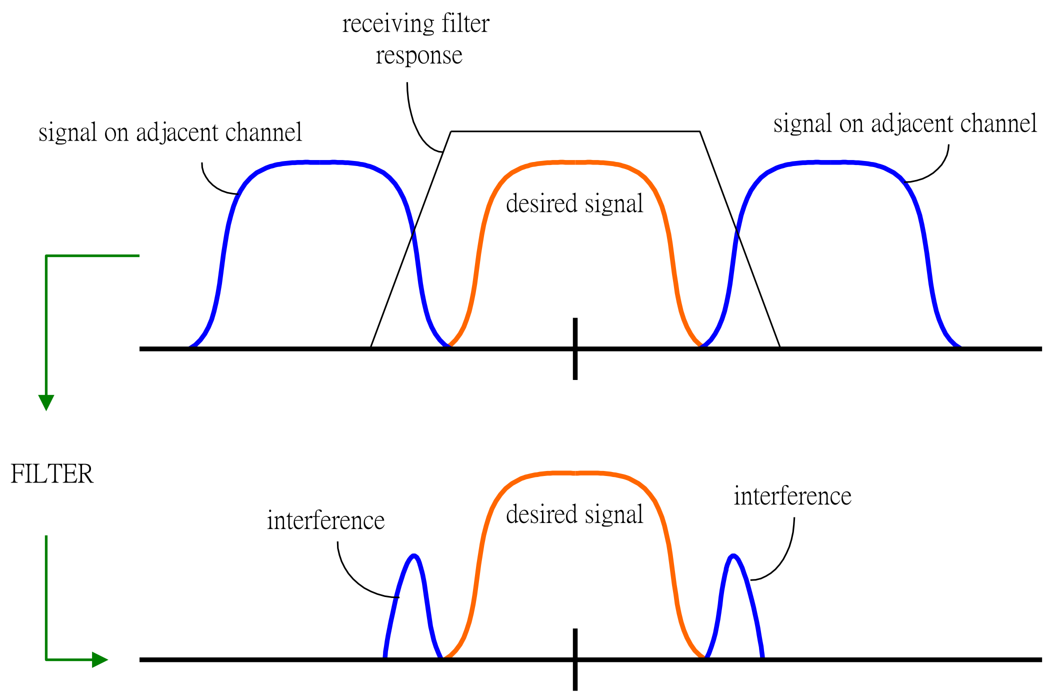
- For hexagonal geometry with 7-cell cluster, with the mobile unit being at the cell boundary, the signal-to-interference ratio for the worst case can be approximated as

$$\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4} + (D-R/2)^{-4} + (D+R/2)^{-4} + (D+R)^{-4} + D^{-4}}$$



Adjacent Channel Interference

- Adjacent channel interference: interference from adjacent in frequency to the desired signal.
  - Imperfect receiver filters allow nearby frequencies to leak into the passband
  - Performance degrade seriously due to *near-far* effect.



- Adjacent channel interference can be minimized through careful filtering and *channel assignment*.
- Keep the frequency separation between each 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.

Power Control for Reducing Interference

- Ensure each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel
  - long battery life
  - increase SIR
  - solve the near-far problem

Trunking and Grade of Service

- Erlangs: One Erlangs represents the amount of traffic density carried by a channel that is completely occupied.
  - Ex: A radio channel that is occupied for 30 minutes during an hour carries 0.5 Erlangs of traffic.
- Grade of Service (GOS): The likelihood that a call is blocked.
- Each user generates a traffic intensity of A_u Erlangs given by

$$A_u = \mu H$$

H: average duration of a call.

μ : average number of call requests per unit time

- For a system containing *U* users and an unspecified number of channels, the total offered traffic intensity *A*, is given by

$$A = UA_u$$

- For *C* channel trunking system, the traffic intensity, A_c is given as

$$A_c = UA_u / C$$

Performance Metrics

- **Call blocking probability** – probability of a new call being blocked
- **Call dropping probability** – probability that a call is terminated due to a handoff
- **Call completion probability** – probability that an admitted call is not dropped before it terminates
- **Handoff blocking probability** – probability that a handoff cannot be successfully completed
- **Handoff probability** – probability that a handoff occurs before call termination
- **Rate of handoff** – number of handoffs per unit time

Improving Capacity in Cellular Systems

- Methods for improving capacity in cellular systems
  - Cell Splitting: subdividing a congested cell into smaller cells.
  - Sectoring: directional antennas to control the interference and frequency reuse.
  - Coverage zone : Distributing the coverage of a cell and extends the cell boundary to hard-to-reach place.

Cell Splitting

- Split congested cell into smaller cells.
  - Preserve frequency reuse plan.
  - Reduce transmission power.

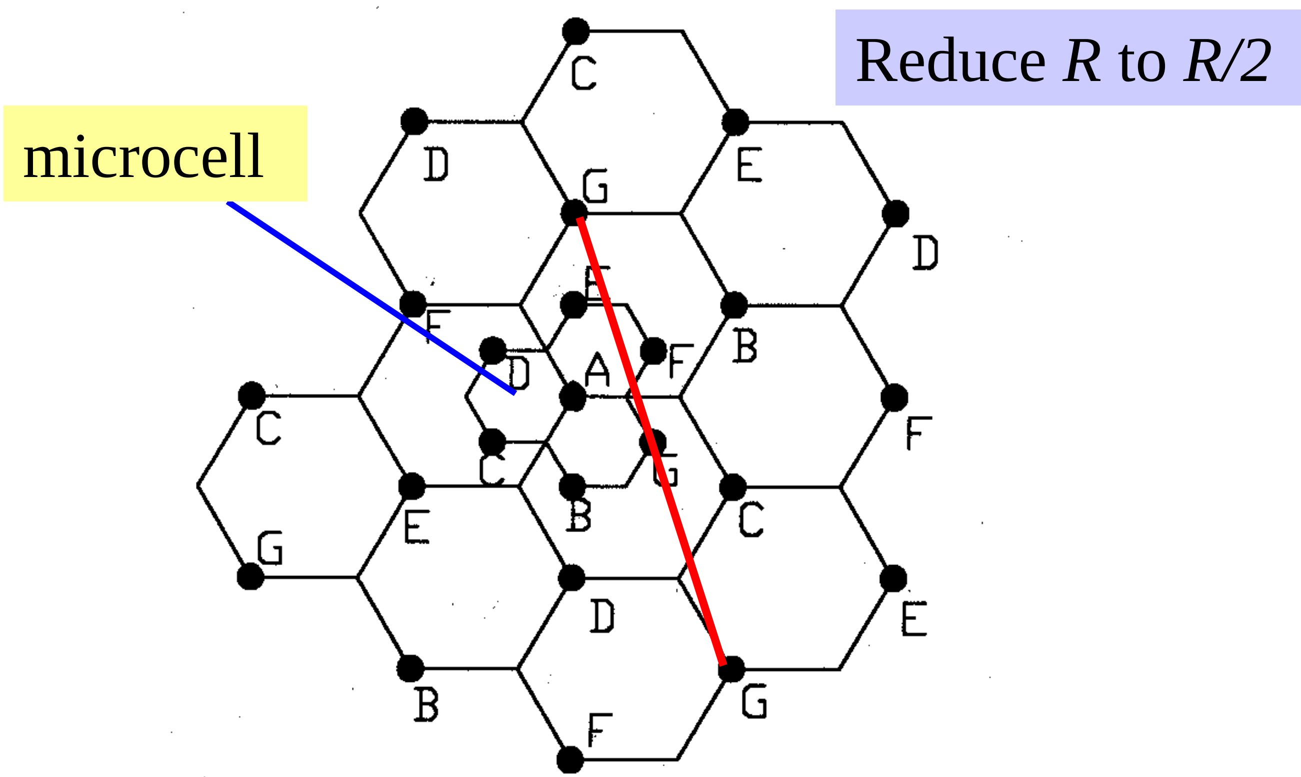
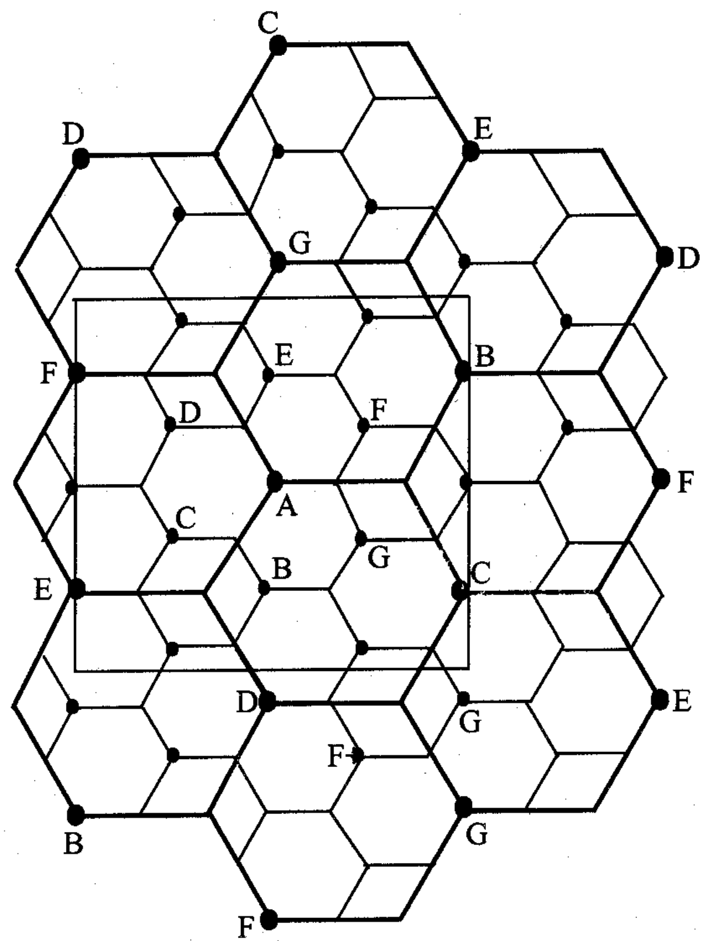


Illustration of cell splitting within a 3 km by 3 km square



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

$$P_r[\text{at old cell boundary}] \propto P_{t1} R^{-n}$$
$$P_r[\text{at new cell boundary}] \propto P_{t2} (R/2)^{-n}$$

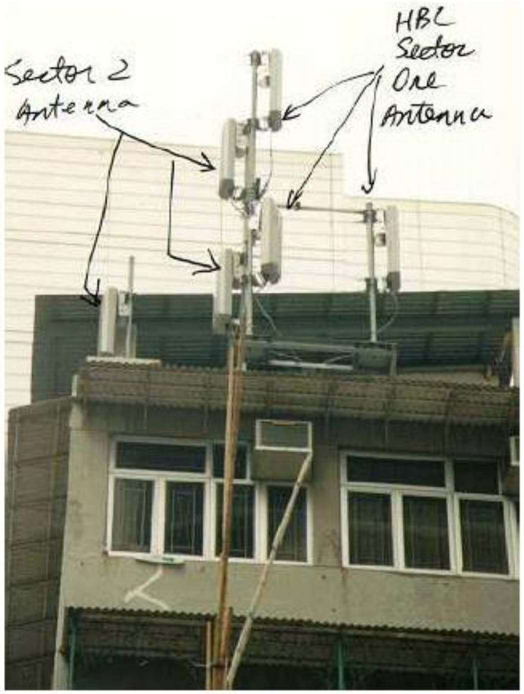
- If we take *n = 4* and set the received power equal to each other

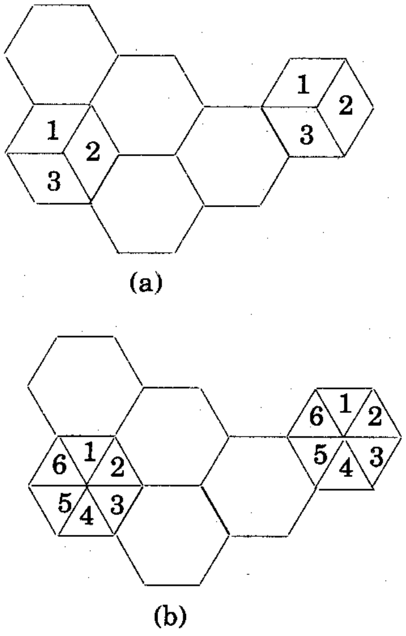
$$P_{t2} = \frac{P_{t1}}{16}$$

- The transmit power must be reduced by 12 dB in order to fill in the original coverage area.
- Problem: if only part of the cells are splited
  - Different cell sizes will exist simultaneously
- Handoff issues - high speed and low speed traffic can be simultaneously accommodated

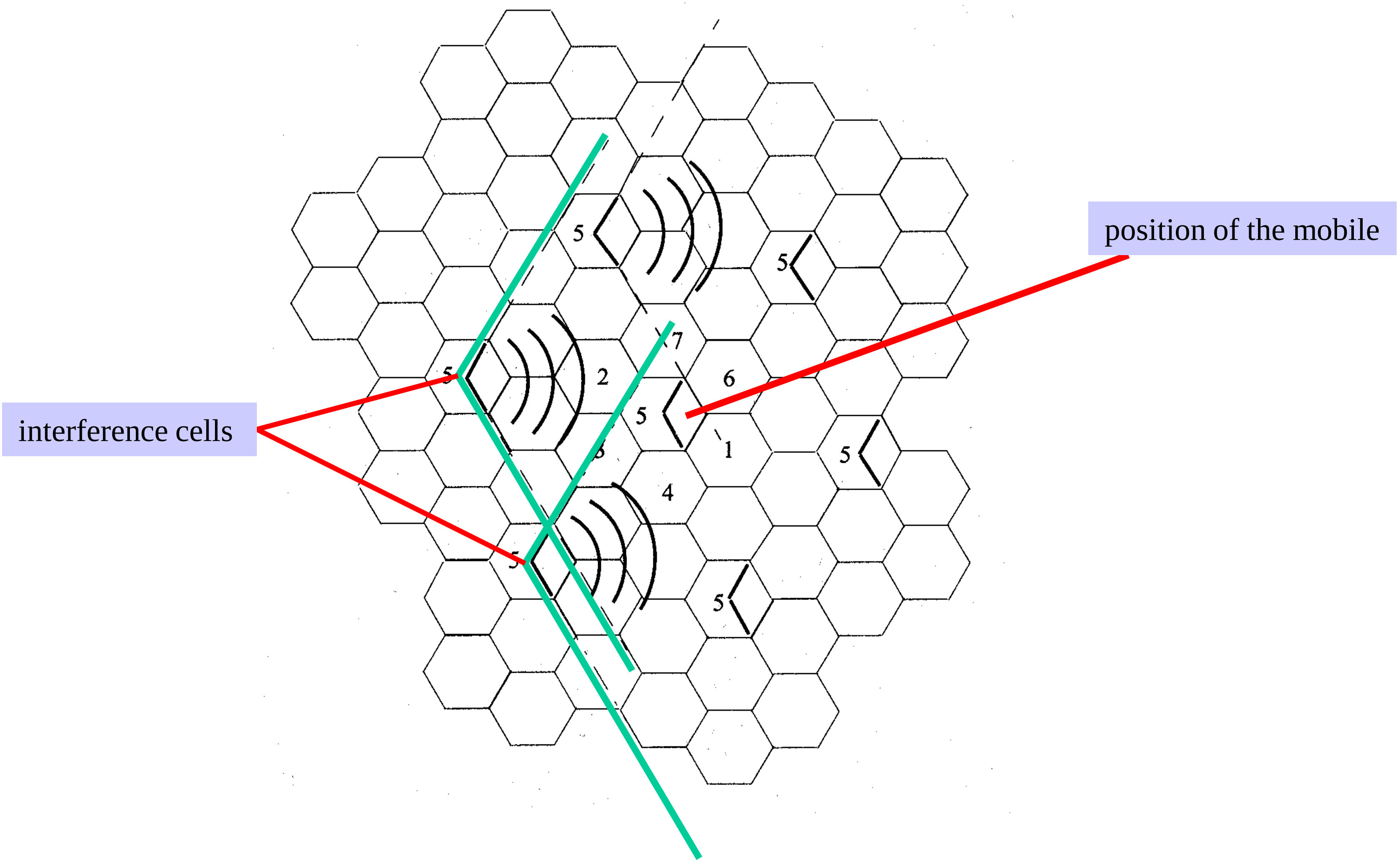
Sectoring

- 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





- Interference Reduction



Microcell Zone Concept

- Antennas are placed at the outer edges of the cell
- Any channel may be assigned to any zone by the base station
- Mobile is served by the zone with the strongest signal.

- Handoff within a cell
  - No channel re-assignment
  - Switch the channel to a different zone site
- Reduce interference
  - Low power transmitters are employed