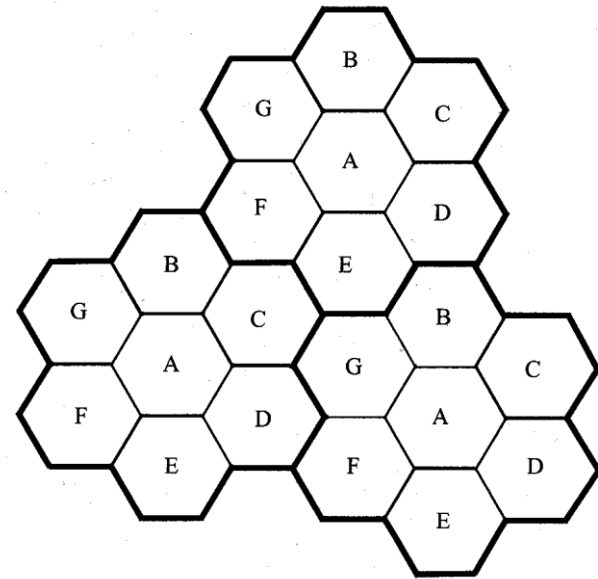




# Frequency Reuse

- 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

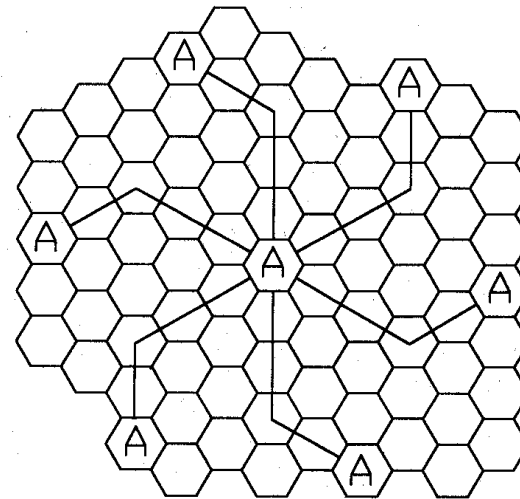
- seven groups of channel from A to G
- footprint of a cell - actual radio coverage
- omni-directional antenna v.s. directional an



- 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  $j=2$ .



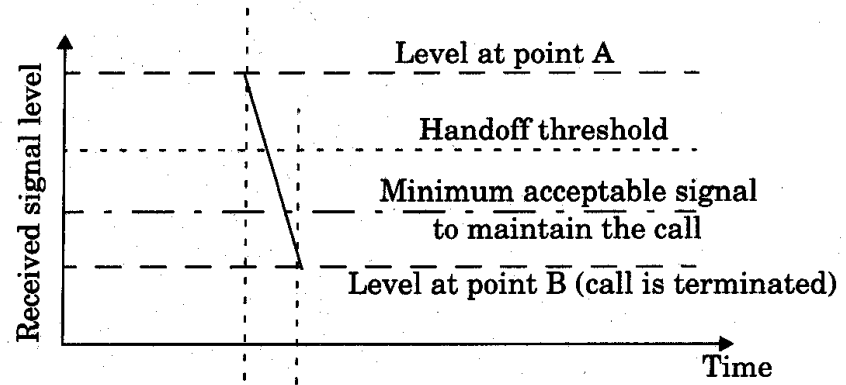
# Channel Assignment Strategies

- 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.

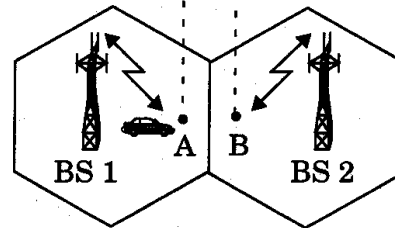
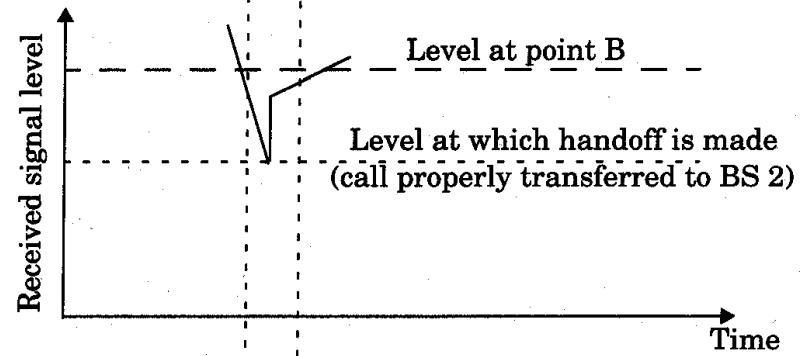
# Handoff Strategies

- 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  $\Delta$  is too large, unnecessary handoffs burden the MSC
  - If  $\Delta$  is too small, there may be insufficient time to complete handoff before a call is lost.

(a) Improper handoff situation



(b) Proper handoff situation



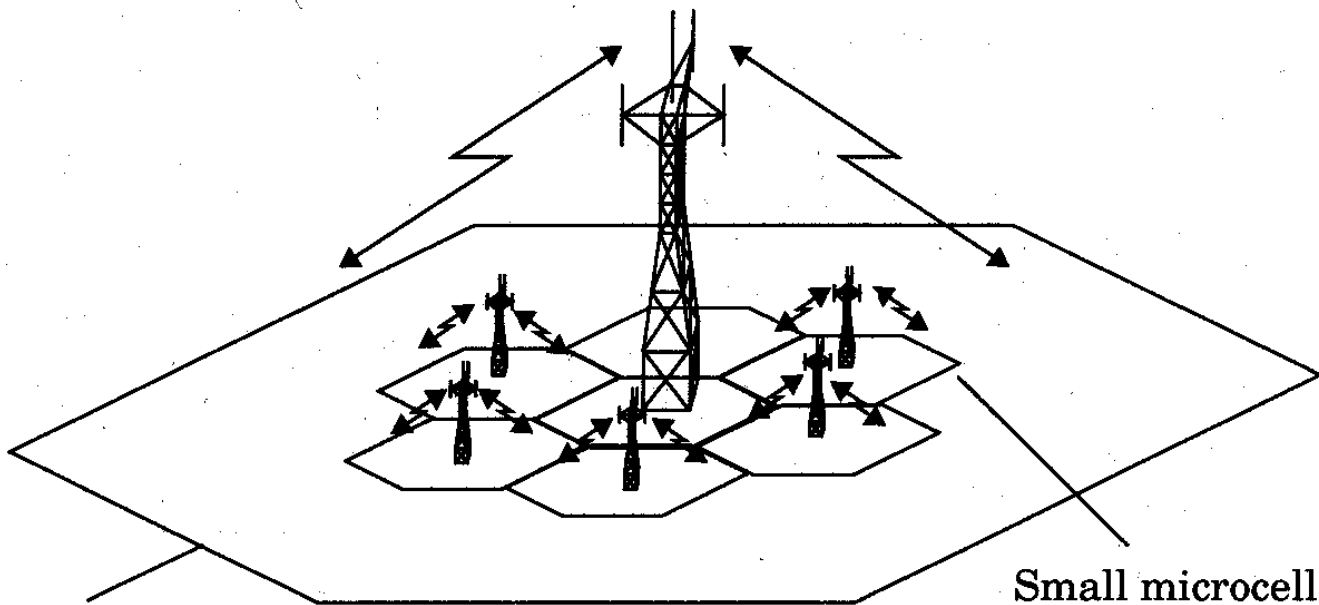
- Handoff must ensure that the drop in the measured signal is not due to momentary fading and that the mobile is actually moving away from the serving base station.
- Running average measurement of signal strength should be optimized so that unnecessary handoffs are avoided.
  - Depends on the speed 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

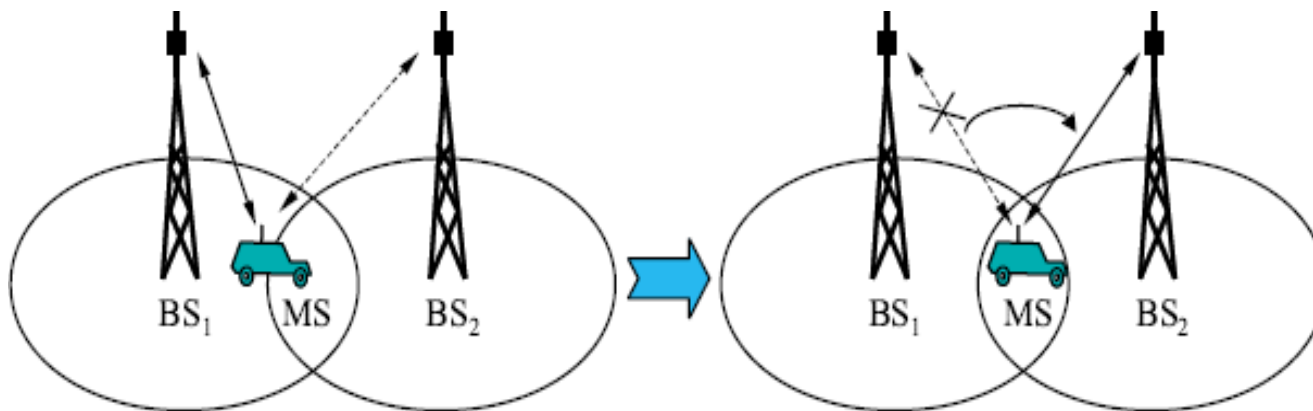
Small microcells for low speed traffic

- Handoff for first generation analog cellular systems
  - 10 secs handoff time
  - $\Delta$  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
  - $\Delta$  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

-

# Types of Handoffs:

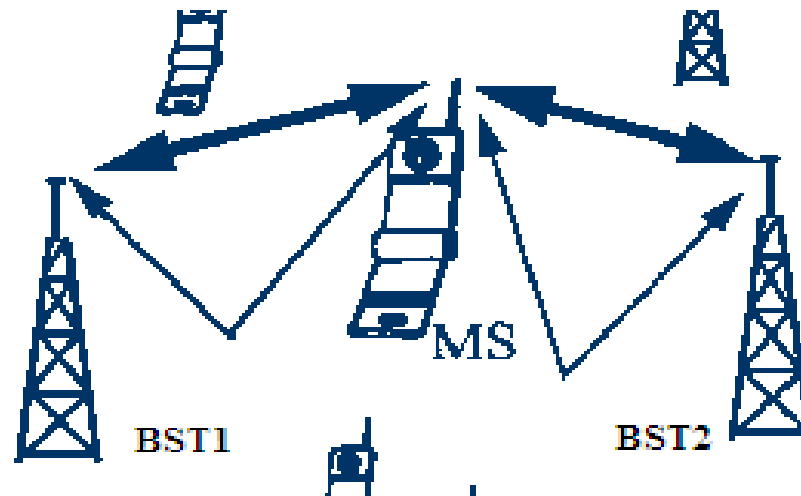
- ❖ Hard handoff: “break before make” connection
- ❖ Intra and inter-cell handoffs



Hard Handoff between the MS and BSs

# Cont.

- ❖ Soft handoff: “make-before-break” connection.
- ❖ Mobile directed handoff.
- ❖ Multiways and softer handoffs



Soft Handoff between MS and BSTs

# Handoff Prioritization:

Two basic methods of handoff prioritization are :

- ❖ Guard Channels
- ❖ Queuing of Handoff

# 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  $i$ th interfering co-channel cell base station

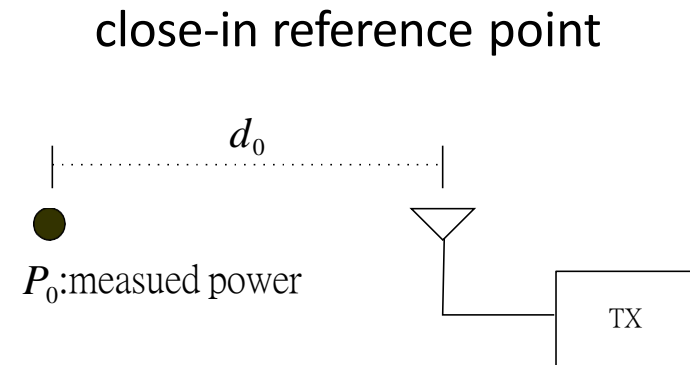
- The average received power at a distance  $d$  from the transmitting antenna is approximated by

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

or

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

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



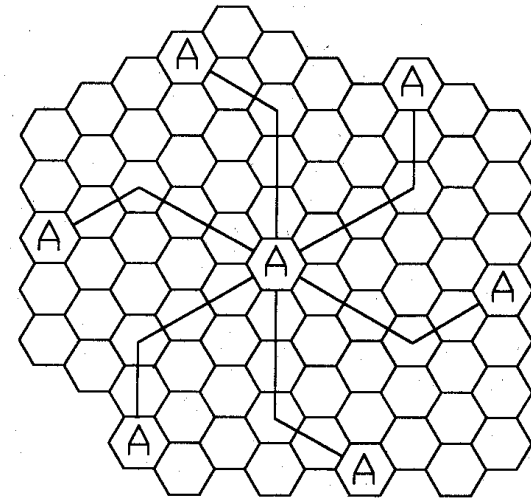
- When the transmission power of each base station is equal, SIR for a mobile can be approximated as

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

- Consider only the first layer of interfering cells

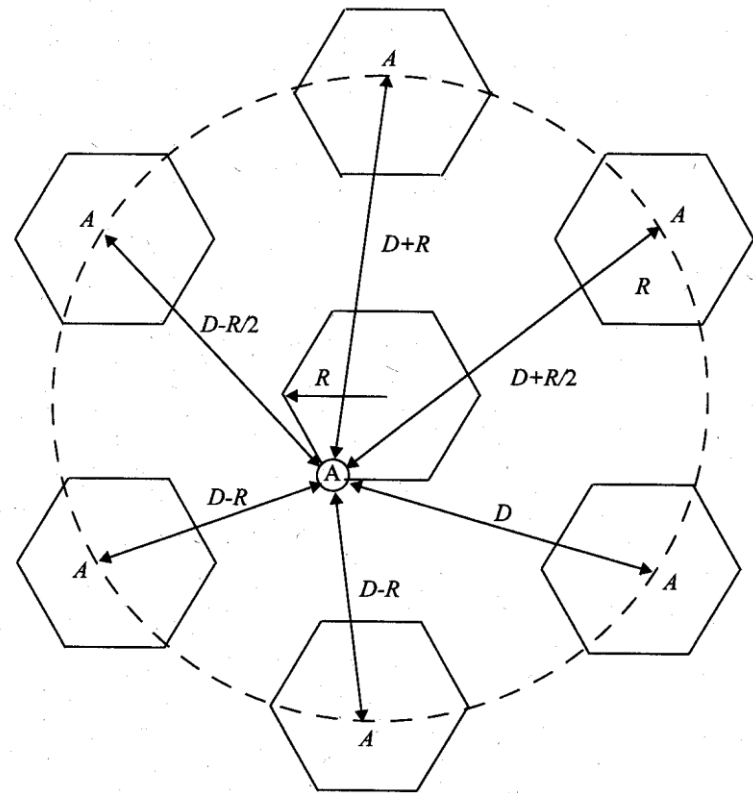
$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0} \quad i_0 = 6$$

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



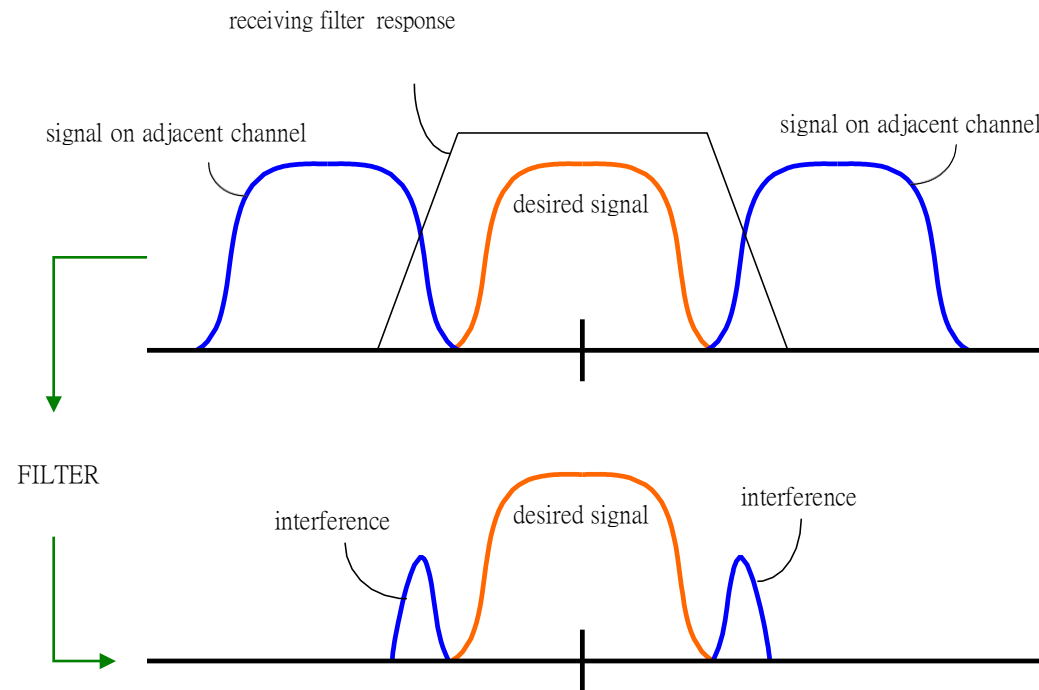
- For hexagonal geometry with 7-cell cluster, with the mobile unit being at the cell boundary, the signal-to-interference ratio for the worst case can be approximated as

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



# 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.
- 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