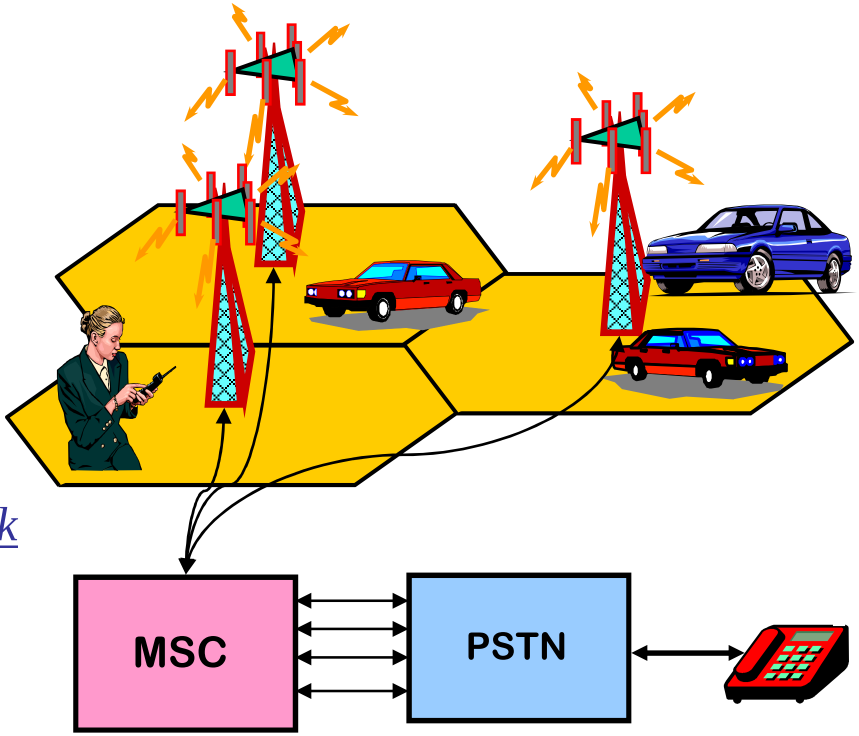
Cellular Concept and Trunking

Lecturer: Prof. Dr Noor M Khan
Department of Electronic Engineering,
Muhammad Ali Jinnah University,
Islamabad Campus, Islamabad, PAKISTAN
Ph: +92 (51) 111-878787
Ext. 129 (Office), Ext. 186 (ARWiC Lab)
email: noor@ieee.org, noormkhan@jinnah.edu.pk



Cellular Concept

- Simple Solution
  - Single high powered transmitter on a tall tower
  - Good coverage but very low capacity
  - No frequency reuse
- High Capacity Solution
  - Cellular concept solves problem of low capacity
  - Replaces a single high power transmitter (large cell) with many low power transmitters (small cells)
  - Much smaller and more efficient mobile units

Operation

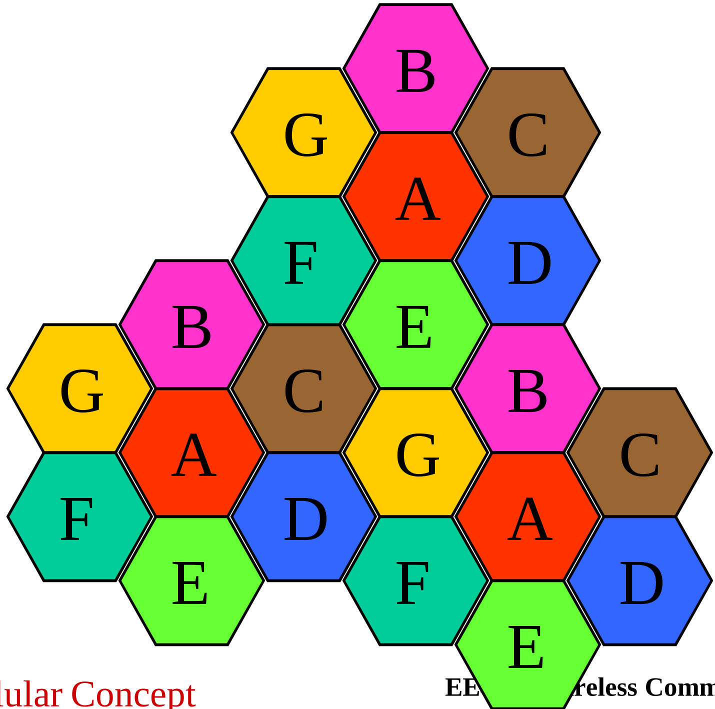
- The Cellular Concept is a system level idea:
  - Each base station is allocated a portion of the total number of channels available to the entire system
  - Nearby base stations are assigned different groups of channels
  - All channels are assigned to a relatively small number of neighboring base stations
- The level of interference between base stations (and the mobile users) is controlled

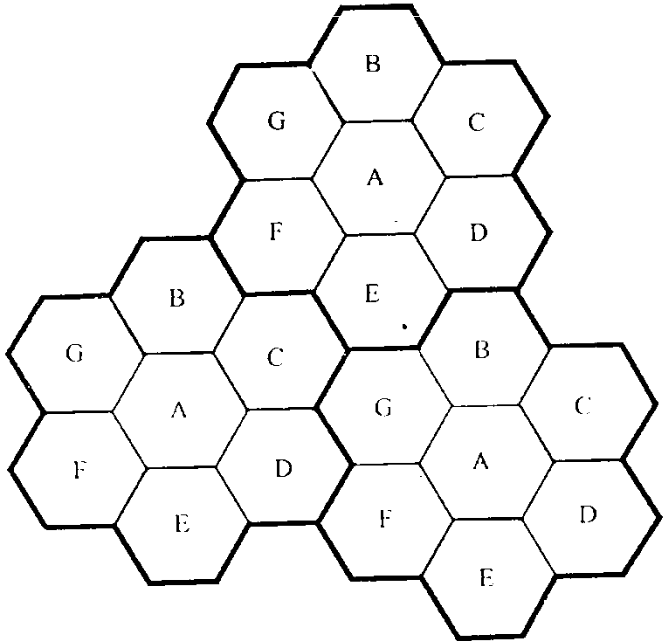
Scalability

- Frequency can be re-used as many times as necessary as long as interference between co-channel stations can be kept within acceptable limits.
- As the demand increases, the number of base stations can be increased (with a corresponding decrease in transmitter power)
- This fundamental principal is the foundation of all modern wireless communication systems.

Frequency Re-use

- The process of selecting and allocating channel groups for all base stations within a system is known as frequency re-use or frequency planning





Comments on Hexagonal Cells

- Hexagon geometry approximates omni-directional base station with free space propagation
- When hexagons are used base stations can either be
  - in the center (center excited) - omni directional antennas or
  - on 3 of the six cell vertices (edge excited) - sectored directional antennas

Simple Calculation

- Let *S* be the total number of duplex channels
- Let *k* be the number of channels in each cell
- *N* cells collectively use the complete set of *S* available channels.
- *N* is the *cluster size* (*N*=4,7 or 12), then $S = kN$
- If a cluster is replicated *M* times
- Total number of duplex channels $= MS = MkN$
- 1/N is called the *frequency re-use factor*

More About Cellular Structure

- Each cell has exactly six equidistant neighbors
- Thus there is only certain cluster sizes and cell layouts possible
- It can be shown that the number of hexagonal cells per cluster is given by

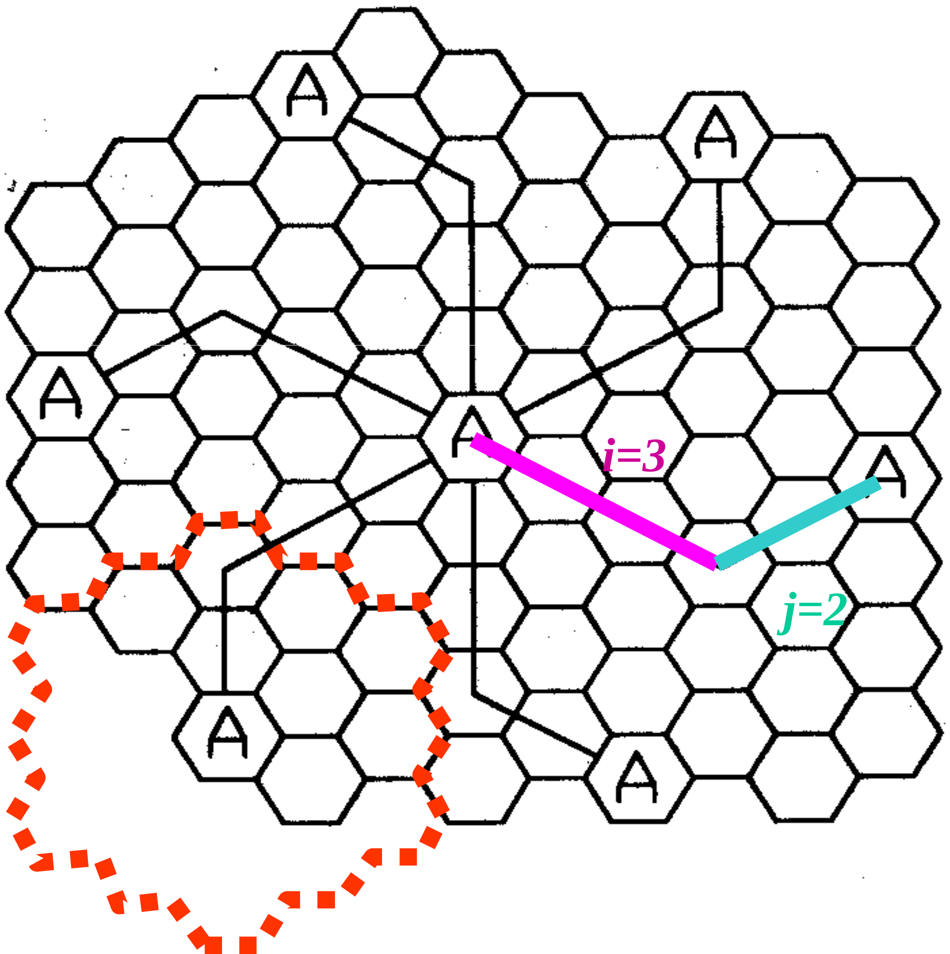
$$N = i^2 + ij + j^2$$

- i & j are non negative integers

i & j, Co-Channel Neighbors

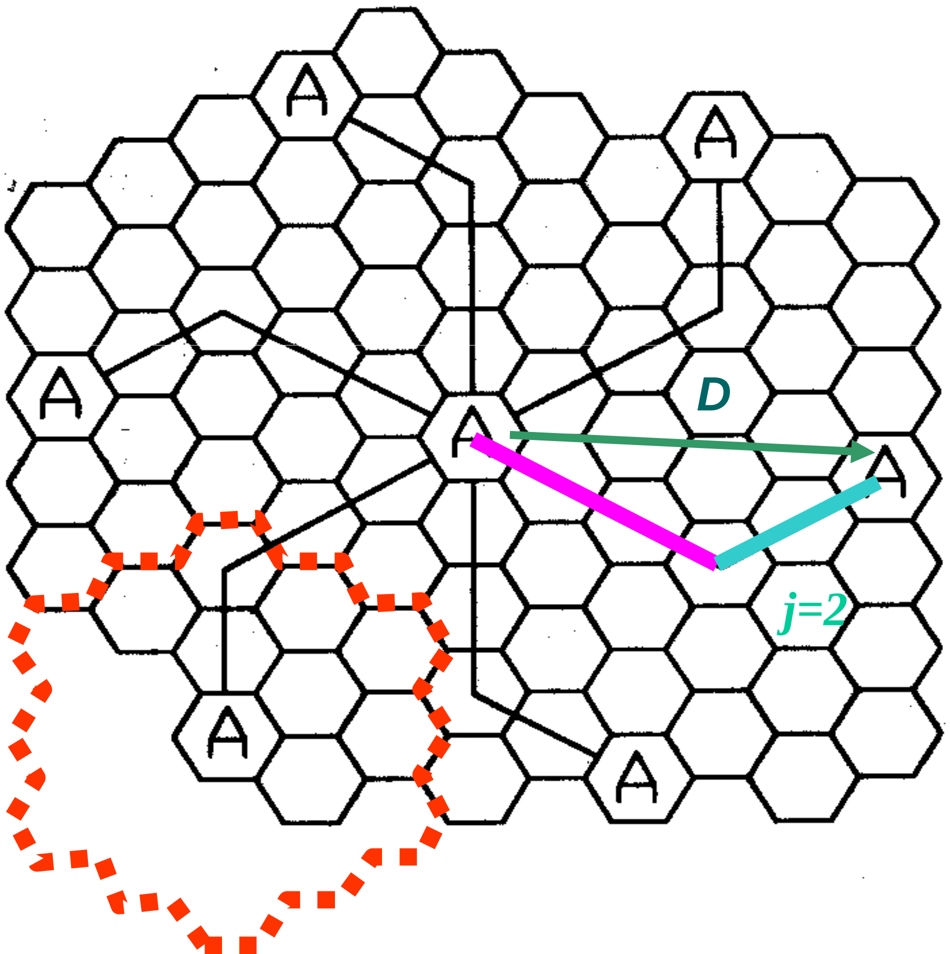
- To find the nearest co-channel neighbors
- Move *i* cells along any chain of hexagons and then
- Turn 60 degrees counter clockwise, and move *j* cells

Example



- *i=3,* (move 3 cells along any chain of hexagons)
- *j=2* (turn 60 degrees counter clockwise and move 2 cells);
- This is the way to find the central cell of the new cluster
- Number of cells in the cluster; $N=9+3*2+4=19$.

Distance



$$D = \sqrt{3}R\sqrt{j^2 + i^2 + j \cdot i} = R\sqrt{3N}$$

Channel Assignment

- Channel assignment (Frequency reuse)
  - efficient utilization of radio spectrum
  - increased capacity
  - minimized interference
- Channel assignment can be
  - *fixed*
  - *dynamic*
- Affects performance especially *handover* (*handoff*)

Fixed Channel Assignment

- Each cell is allocated a predetermined set of channels
- Any call attempt within the cell can only be served by the unused channels in that cell
- Variations that allow channel borrowing exist
  - A cell is allowed to borrow from its neighbor
  - MSC supervises the borrowing procedure

Dynamic Channel Assignment

- Each time a call is attempted, the serving BS request a channel from the MSC
- The lending algorithm take into account
  - likelihood of future blocking
  - frequency re-use of candidate channel
  - other cost functions
- Dynamic schemes reduces the call blocking probability and increases system capacity

Implications

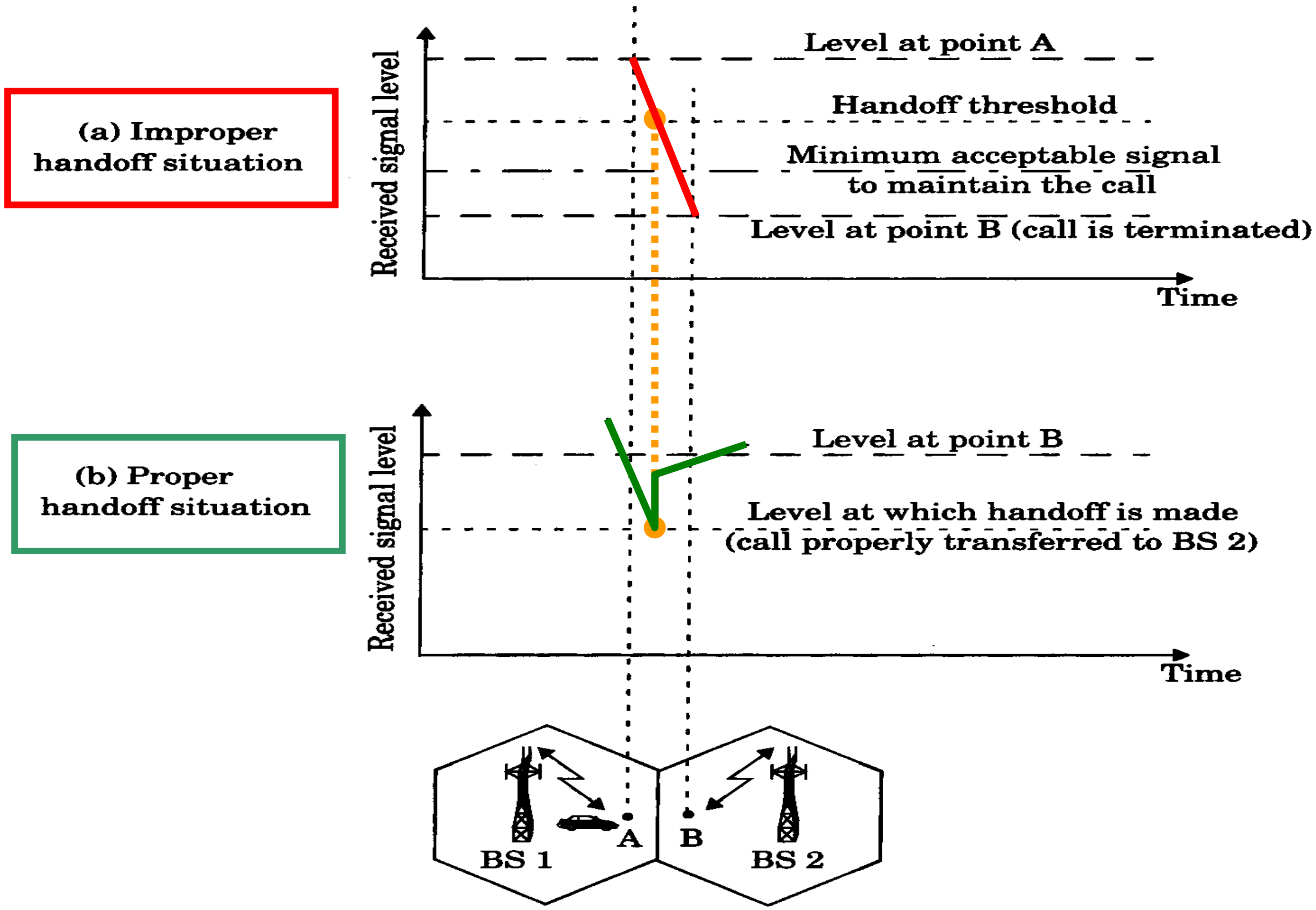
- Dynamic schemes require the MSC to collect real time data on all channels
  - Channel occupancy
  - Traffic distribution
  - Radio signal strength indications (RSSI)
- Makes the MSC more complex, and increases its storage and computational load

Handover (Handoff)

- Need to be performed successfully and infrequently as possible and be transparent to users
- Need to decide the optimum signal level to perform handover
- Generally the level is decided the handover level is set slightly above it

$$\Delta = P_{r\ \text{handover}} - P_{r\ \text{minimum usable}}$$

Example


(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

Dwell Time

- The time a call may be maintained within a cell, without handover, is called the *dwell time*.
- Dwell time is dependent on a number of factors
  - propagation
  - interference
  - distance from BS etc.
- Therefore even a stationary subscriber may have a random and finite dwell time

Mobile Assisted Handover (MAHO)

- In analog systems the signal strength was measured by the base station and supervised by the MSC,
- The MSC decides if a handover is necessary or not
- Digital systems handover decisions are mobile assisted
  - Mobile measures signal strength and reports to the serving BS
  - Handover is initiated when power received from the BS of a neighboring cell begins to exceed the power received from the current BS - certain level & duration

Handover 2

- MAHO is faster and more suited for micro cellular environments
- It is also possible to have intersystem handover,
  - Handover from a cell of one MSC to a cell of another MSC
- Numerous issues
  - A local call (initially) may become a long distance call
  - Need to deal with incompatibility of the MSC

Handover Policy

- Ways of handling handover requests
  - Same as all initial call requests
  - Give it higher priority
  - Queue requests
- Generally it is more annoying to have a call cut off in mid conversation than being blocked on a new call attempt
- Fraction of the total available channels in a cell is reserved for handover requests from ongoing calls - *guard channel*

Practical Handover Considerations

- *Cell dragging* - pedestrian users that provide a very strong signal to the BS (LOS), but moved to a close range of another base station causing interference
- Difficulty in obtaining physical cell sites
  - Zoning laws (no high rise structures)
  - Public protest (radiation concerns) e.t.c
- Too many handoffs for high speed mobiles (on a vehicle)

Handoff Improvements

- First generation mobile 10s to make handoff

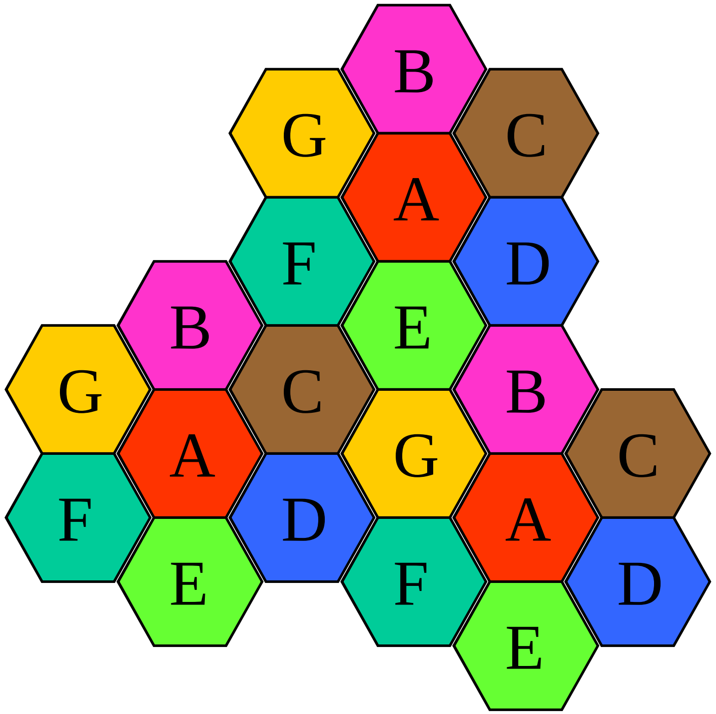
  and Δ = 6-12 dB. ($\Delta = P_{r\ handover} - P_{r\ minimum\ usable}$)
- GSM (II generation) 1-2s to make handoff with

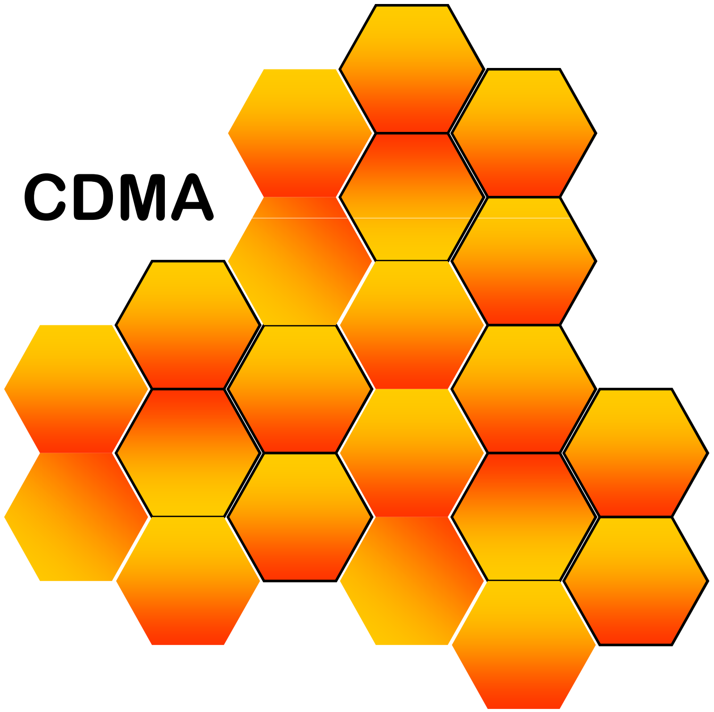
  Δ = 0-6 dB.
- Better system efficiency and handling high speed vehicles

Soft Handoff

- Channelized wireless systems (such as GSM) have to switch channels in the process of handoff
- There is always risk of losing the connection
- IS-95, Code Division Multiple Access (CDMA) system provides ***Soft Handoff***.
- ***Soft Handoff*** does not mean changing the channel but rather deciding which base station will handle the connection
- This is a unique property of CDMA concept.

CDMA Frequency Reuse Pattern





Co-channel Interference

- There are several cells that use the same set frequencies
  - co-channel cells
- Interference between signals from these cells is called co-channel interference
- Unlike thermal noise, this cannot be overcome by increasing the signal power
- The co-channel cells must be physically separated

Co-channel Interference

– Because the cell size is same, co-channel interference is independent of transmitted power

– It is a function of the radius of the cell (*R*), and the distance to the center of the nearest co-channel cell (*D*)

– For hexagonal geometry, co-channel reuse ratio *Q* is given by

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

Carrier to Interference Ratio

- Carrier to Interference ratio (SIR or S/I) is also independent of transmitted power
- It is a function of the radius of the cell (*R*), and the distance to the center of the nearest co-channel cell (*D*)
- For the first tier in hexagonal geometry, Carrier to Interference ratio is usually taken as

$$\frac{S}{I} \approx \frac{1}{6}\left(\frac{D}{R}\right)^4 = \frac{1}{6}(3N)^2$$

Some Arithmetic Again

- Let i_0 be the number of co channel interfering cells
- then carrier signal to interference ratio (SIR)

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

- S - desired signal power from desired BS; I_i - interference power caused by the i^{th} interfering co-channel cell BS

Received Power

- Ave. received signal strength at any point decays as a power law of the distance of separation (d) and is given by

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

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

- P_0 - Power received at a close-in reference point in the far field region of the antenna at a small distance; n - path loss component (2-4)

SIR

– If D_i is the distance of the i^{th} interferer, the received power at a given mobile due to the i^{th} interfering cell will be proportional to $(D_i)^{-n}$

– When the transmit power of each BS is equal and the path loss exponent is the same

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

Simpler SIR

– Considering only the first layer of interfering cells & if all these BS are equidistant

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

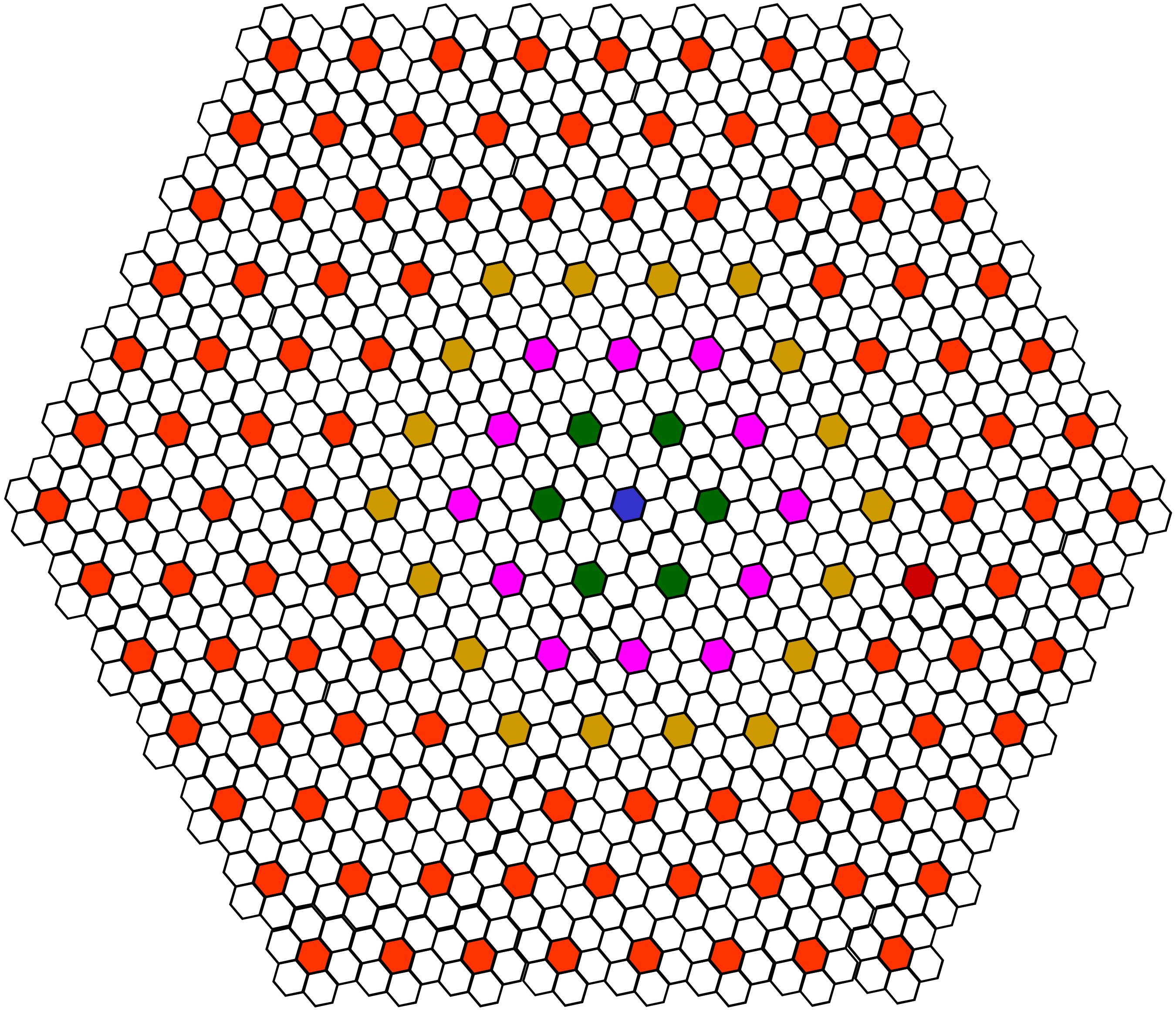
– i_0 - number of neighboring/interfering co-channel cells

Interference Limitation Example

- $i_0 = 6$ number of co-channel cells
- $N=7$
- $n = 2$

$$\frac{S}{I} = \frac{3N}{6} = \frac{N}{2}$$

- Considering only the first layer of interfering cells & if all these BS are equidistant



$1 \rightarrow 6$

$2 \rightarrow 12$

$3 \rightarrow 18$

$\cdots$

$k \rightarrow 6k$

Interference Limitation

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

$$D_K < kR\sqrt{3N}$$

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{k=0}^{K} 6 \cdot k(kR\sqrt{3N})^{-n}}$$

$$\frac{S}{I} = \frac{(\sqrt{3N})^{n}}{6 \cdot \sum_{k=0}^{K} k^{1-n}}$$

Interference Limitation

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{6 \cdot \sum_{k=0}^{K} k^{1-n}}$$

– Considering *K* layers of interfering cells

– For *N* fixed, *n=2* and the number of layers $K \rightarrow \infty$; $S/I \rightarrow 0$

$$I = \lim_{K \rightarrow \infty} O\left(\sum_{k=0}^{K} \frac{1}{k}\right) = \infty$$

Adjacent Channel Interference 1

- Interference resulting from signals which are adjacent in frequency
- Results from imperfect receiver filters which allow nearby frequencies to leak
  - Particularly serious if an adjacent channel user is transmitting very close to the a receiver
- Referred to as the *near-far* effect
  - Nearby transmitter captures the receiver

Adjacent Channel Interference 2

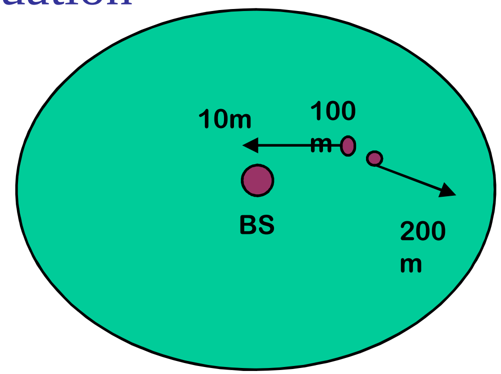
- Can be minimized by careful filtering & channel assignment
- If the frequency re-use factor is small, the separation between adjacent channels may not be sufficient to keep the adjacent channel interference level within tolerable limits

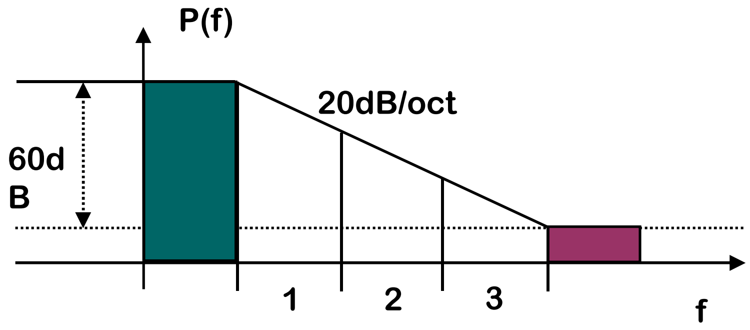
Adjacent Channel Interference 3

- If a mobile is 20 times closer to the BS than another mobile

$$SIR = (20)^{-n}$$

- For n= 4, this is equal to -52 dB
- If the intermediate filter has a slope of 20 dB/octave in the stop-band
- Adjacent channel must be displaced 3 times the pass-bandwidth from the center of the receiver frequency band-pass to achieve the 52 dB attenuation





Power Control

- The power level transmitted by every mobile is controlled by the BS
- Enables to use the smallest power to maintain good link quality and reduces interference to other cells
- Increases battery lifetime before recharging (talk time and stand-by time)
- CDMA requires very strict power control (1dB)

Trunking

- Trunking is a statistical concept which allows a large number of users to share relatively small number of channels providing access on demand from a pool of available channels.
- Relatively small number of channels can serve a large number of users since all users are not demanding access and utilization of the system at the same time

Grade of Service

- ***Grade of Service*** is a measure of the ability of a trunked system to give access to a user requiring service during the busiest hour (4-6pm, Thu, Fri)
- Grade of Service is usually measured in two ways
  1. Probability that a call is blocked
  2. Probability that a call will be delayed more than specified queuing time (some tolerable delay)

Some Traffic Quantities

- A_u - Traffic intensity

$$\boxed{A_u = \lambda \ H}$$

- H - average duration of a call
- λ - average number of calls per unit time
- For system with U, users total offered traffic intensity A, is

$$\boxed{A = UA_u}$$

Blocked Calls Cleared

- Calls arrive as Poisson distributed
- All users may request service at any time
- A - generated traffic
- C - number of channels
- Grade of Service (Erlang B formula):

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

Capacity of Erlang B System

	Capacity in Erlangs for GOS			
No.of Channels	Pr=0.01	0.005	0.002	0.001
2	0.153	0.105	0.065	0.046
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
40	29.0	27.3	25.7	24.5
100	84.1	80.9	77.4	75.2

Blocked Calls Delayed

- If a channel is not available immediately the call request may be put in a queue and delayed until a channel becomes available
- Erlang C formula:

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

Grade of Service for Delayed Calls

$$GOS = \Pr[delay > t]$$

$$= \Pr[delay > 0]\Pr[delay > t \mid delay > 0]$$

$$= \Pr[delay > 0]\; e^{-\frac{(C-A)t}{H}}$$

Average Delay in a Queued System

- The average delay D for all calls in a queued system is:

$$D = \Pr[\, delay > 0\,] \frac{H}{C - A}$$

  - Where the average delay in the queue is H/(C-A)
    - H – average duration of a call
    - C – number of channels
    - A – total offered traffic