Wireless Communications

Lecture 2

The Cellular Concept

Introduction

- **Early mobile radio systems:** Achieve a large coverage area
  - High powered transmitter with an antenna mounted on a tall tower.
  - This approach achieved very good coverage.
  - It was impossible to reuse those same frequencies throughout the system.
  - Bell mobile system in New York City in the 1970s could only support a maximum of twelve simultaneous calls over a thousand square miles.
  - The government regulatory agencies could not make spectrum allocations in proportion to the increasing demand for mobile services.
  - The **cellular concept** was a major breakthrough in solving the problem of spectral congestion and user capacity.

Introduction

- Goals of a Cellular System
  - High capacity (Number of users)
  - Large coverage area (Geographical area)
  - Efficient use of limited spectrum
- Components of Cellular Systems
  - Mobile station (MS): Users
  - Base station (BS): Bridge between the MS and the MSC
  - Mobile Switching Center (MSC): Bridge between the cellular system and the PSTN

The Basic Concept of Cellularity

- Replace a single, high power transmitter (large cell) with many low power transmitters (small cells),
- Each cell provides a coverage to only a small portion of the service area.
- 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 so that all the available channels are assigned to a relatively small number of neighboring base stations.
- The available channels may be reused as many times as necessary so long as the interference between cochannel stations is kept below acceptable levels.

Frequency Reuse I

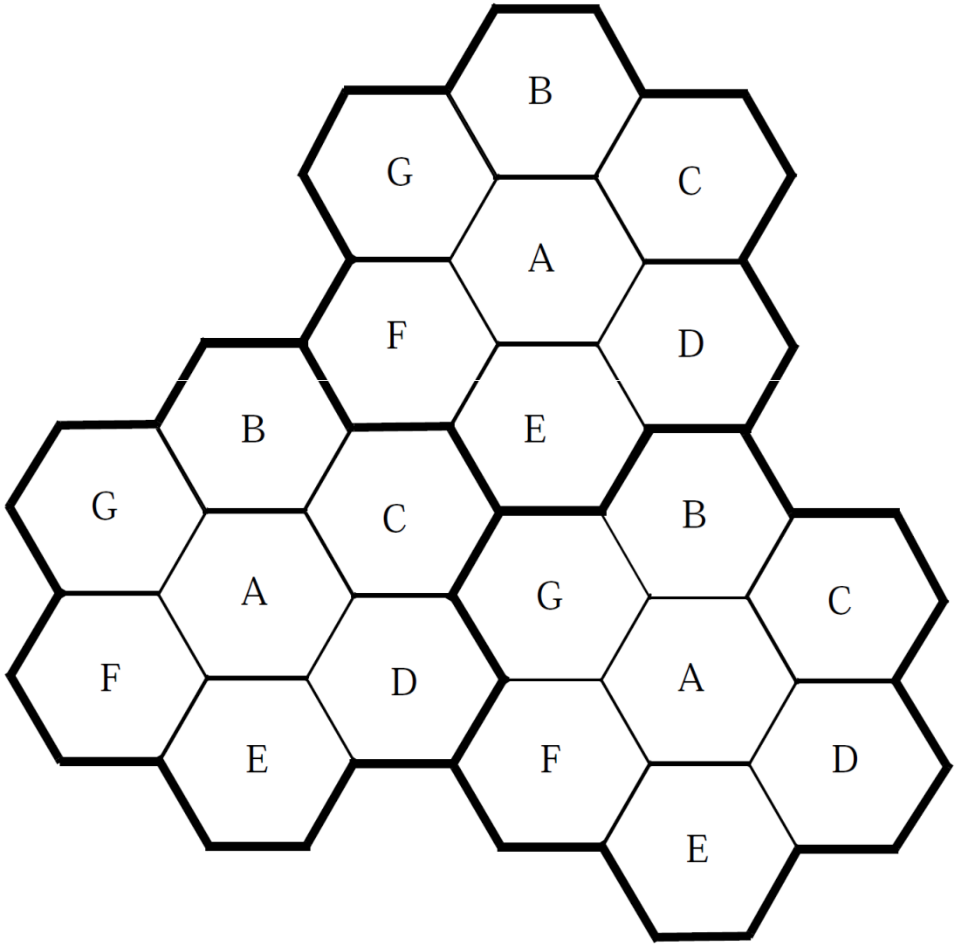


Illustration of the cellular frequency reuse concept.

Cells with the same letter use the same set of frequencies.

A cell cluster is outlined in bold and replicated over the coverage area.

In this example, the cluster size, N, is equal to seven, and the frequency reuse factor is 1/7 since each cell contains one-seventh of the total number of available channels

Frequency Reuse II

- Small coverage areas called “cells”
- Many base stations, lower power, and shorter towers
- **Cell Cluster:** group of N cells using complete set of available channels
- Each cell is allocated a percentage of the total number of available channels
- Nearby (adjacent) cells assigned different channel groups to prevent interference between neighboring base stations and mobile users
- Same frequency channels may be reused by cells a “reasonable” distance away
- Reused many times as long as interference between same channel (co-channel) cells is < acceptable level

Cellular Definitions and Notations

- **Cluster:** set of neighboring cells that use the available channels distinctively and exhaustively.
- **Co-channel cells:** cells in different clusters that use the same group of frequencies.
- ***N*** = the cluster size (in cells)
- **1/N** = frequency re-use factor (Fraction of channels used by each cell).
- **R** = cell radius (distance from hexagon center to corner).
- **D** = distance between centers of nearest co-channel cells.

Cell Design I

- Base station antennas are designed to cover a specific cell area.
- The actual radio coverage of a cell is known as the footprint and is determined from field measurements or propagation prediction models.
- Actual cell "footprint" is amorphous (no specific shape)
- It might seem natural to choose a circle to represent the coverage area of a base station.
- Adjacent circles cannot be overlaid upon a map without leaving gaps or creating overlapping regions.
- Square, an equilateral triangle, and a hexagon can cover the entire region without overlap.

Cell Design II

- A cell must be designed to serve the weakest mobiles within the footprint, and these are typically located at the edge of the cell.
- For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area of the three.
- Hexagonal shape advantages:
  - The fewest number of cells can cover a geographic region.
  - Simple model for easy analysis

Cell Design III

- Location of base station transmitters
  - In the center of the cell (center-excited cells): Omnidirectional antennas
  - On three of the six cell vertices (edge-excited cells): Sectored directional antennas

- Practical considerations usually do not allow base stations to be placed exactly as they appear in the hexagonal layout.

- Most system designs permit a base station to be positioned up to one-fourth the cell radius away from the ideal location.

Communication Modes I

Sending and Receiving Types

- Simplex:
  - Radio network transmits in one direction only, or uni-directionally.
  - Single transmitter can communicate to one or more receivers.
  - Example: broadcast radio or TV, where the network is designed with a powerful transmitter providing wide area coverage for many receiving devices.
- Half Duplex:
  - The network is capable of both transmitting and receiving radio signals, **BUT** that radio signals can flow only in one direction at a time.
  - Example: 'push to talk' walkie-talkies

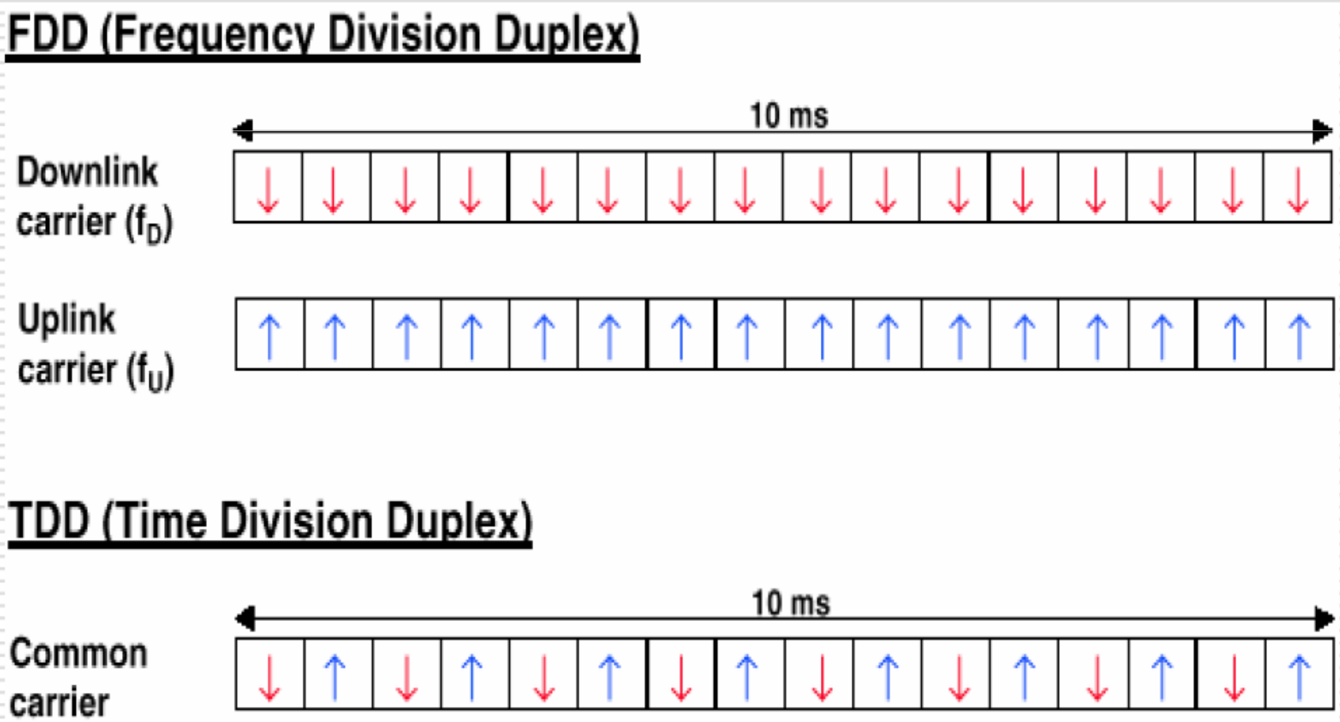
Communication Modes II

- Full Duplex:
  - A radio network is capable of **simultaneous** bi-directional communications. (send and receive at the same time)
  - Example :Telephone, Mobile Phone.

- Implementation :
  - Frequency Division Duplex (FDD)
  - Time Division Duplex (TDD)

Communication Modes III

FDD vs. TDD



Forward vs. Reverse Links

- Forward Link (Downlink):
  - The transmission path from the BS to the MS.
- Reverse Link (Uplink):
  - The transmission path from the MS to the BS.

Channel Categories

- Voice channels:
  - Carry voice traffic (~ 95%)
- Control channels:
  - Carry data about call setup, handoff, power control and other management data (~ 5%)

Cellular System Capacity I

- **System Capacity:** The possible number of simultaneous calls
- S : total number of duplex channels available for use in a given area which is determined by:
  - Amount of allocated spectrum
  - Channel BW → modulation format and/or standard specs. (e.g. AMPS)
- k: Number of channels per cell ($k<S$)
- N: cluster size
- $k = S/N$ or $S = kN$
- M: The number of clusters in the service area.
- C: System Capacity = Total Number Duplex Channels

$$C = M S = M k N$$

Cellular System Capacity II

- If cluster size (N) is reduced and the geographic area for each cell is kept constant:
  - The geographic area covered by each cluster is smaller, so M must ↑ to cover the entire coverage area (more clusters needed).
  - S remains constant (same number of channels per cluster).
  - So C ↑.
  - The smallest possible value of N is desirable to maximize system capacity.

  - What is smallest value of N?
  - Why don’t we choose it?

Cellular System Capacity III

- Cluster size N determines:
  - distance between co-channel cells (D)
  - level of co-channel interference
- A mobile or base station can only tolerate so much interference from other cells using the same frequency and maintain sufficient quality.
- large N → large D → low interference → but small M and low C !
- Tradeoff in quality and Capacity.
  - The **larger** the capacity for a given geographic area, the **poorer** the quality

Cluster Size I

- For hexagon cells, to have a uniform co-channel distance D for all cells in the system, N must obey the relation

$$N = i^2 + i\,j + j^2 \quad \text{where } i, j \geq 1$$

- Regardless of the cluster size,

  each cell has 6 first tier co-channel cells.

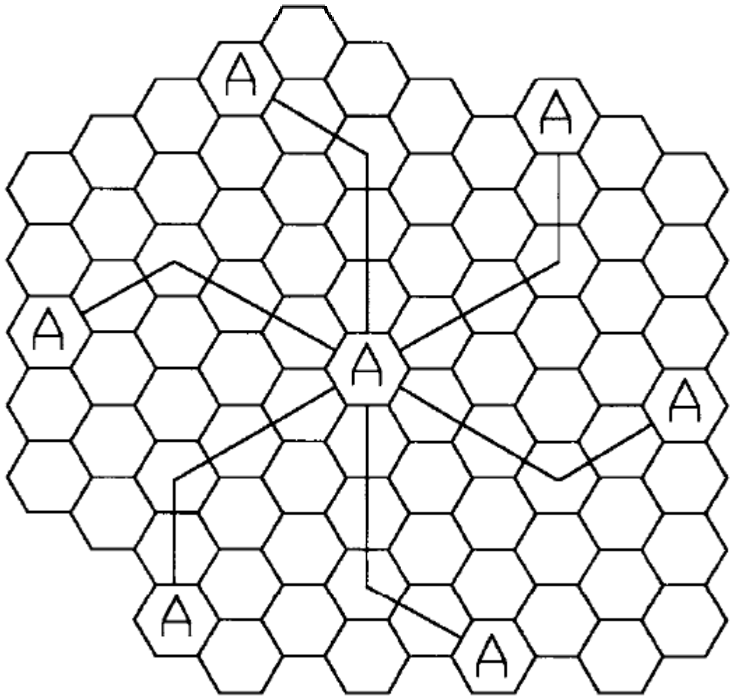
- Co-channel cells are identified from (i,j)

i	*j*	*N*
1	0	1
1	1	3
2	0	4
2	1	7
2	2	12

Cluster Size II

- To find the nearest co-channel neighbors of a particular cell, one must do the following:
  - Move ***i*** cells along any chain of hexagons and then
  - Turn **60** degrees counter-clockwise and move **j** cells

Method of locating co-channel cells in a cellular system.
In this example, N = 19
(i.e., i = 3, j = 2).



Example

- **Determine the number of channels per cell for the following cellular system for N = 4 and N=7:**
  - A total of 33 MHz bandwidth is allocated to the system.
  - It is divided into 50-kHz (voice/control) channels.
  - One control channel per cell.
  - **Solution:**
- Total number of channels = 33000/50 = 660
- N = 4:
  - 4 channels reserved for control.
  - Every cell has 656/4 = 164 voice channels and one control channel
- N = 7
  - 7 channels reserved for control
  - 653/7 = 93.3. Two cells have 94 + control, five have 93 + control

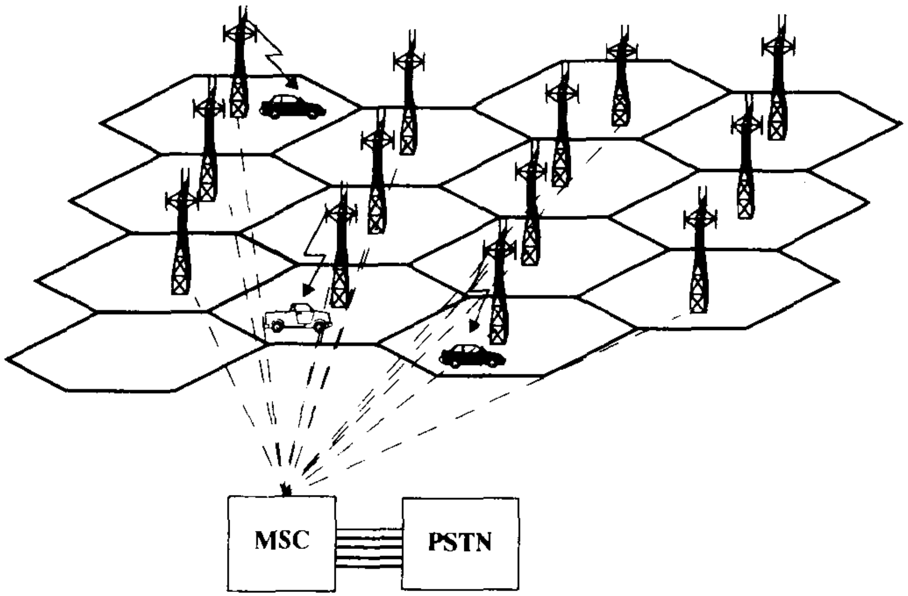
Example

- **Determine the number of channels per cell for the following cellular system for N = 4 and N=7:**
  - A total of 33 MHz bandwidth is allocated to the system.
  - It is divided into 50-kHz (voice/control) channels.
  - One control channel per cell.
  - Frequency re-use factor of control channels is 3 times less than voice channels.
- **Solution:**
- Total number of channels = 33000/50 = 660
- N = 4:
  - 12 channels reserved for control.
  - Every cell has 648/4 = 162 voice channels and one control channel
- N = 7
  - 21 channels reserved for control
  - 639/7 = 91.3. Two cells have 92 + control, five have 91 + control

Components of Cellular Systems I

A cellular system consists mainly of:

- Mobile station (MS)
- Base station (BS)
- Mobile Switching Center (MSC)



Components of Cellular Systems II

- **Base station (BS)**
  - A transmitter and receiver that relays signals (control and information - voice or data) from the mobile station (MS) to the MSC and vice versa.
  - The BS is the bridge between the MS and the MSC

- **Mobile Switching Center (MSC)**
  - Controls a cluster of cells.
  - Base stations are connected to the MSC via wireline or microwave links.
  - The MSC is the bridge between the cellular system and the PSTN.

Channel Assignment Strategies

- Objective: Efficient utilization of the radio spectrum
  - Increasing capacity.
  - Minimizing interference.

- Two main strategies:
  - **Fixed** channel assignment strategy
  - **Dynamic** channel assignment strategy

- The choice of channel assignment strategy impacts the performance of the system, particularly as to how calls are managed when a mobile user is handed off from one cell to another

Fixed channel assignment strategy

- Each cell is allocated a **predetermined** set of voice channels.
- Any call attempt within the cell can only be served by the unused channels in that particular cell.
- If all the channels in that cell are **occupied**, the call is **blocked** and the subscriber does not receive service.
- Simple but Less efficient (higher blocking probability)
- Can be improved by implementing a **borrowing strategy**

Dynamic channel assignment strategy I

- 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 cell considering:
  - The likelihood of future blocking within the cell
  - The frequency of use of the candidate channel
  - The reuse distance of the channel
  - Other cost function

Dynamic channel assignment strategy II

Advantages:

- Reduce the likelihood of blocking, which increases the trunking capacity of the system, since all the available channels in a market are accessible to all of the cells.

Disadvantages:

- Require the MSC to collect real-time data
  - Channel occupancy
  - Traffic distribution
  - Radio signal strength indications (RSSI)
- This increases the storage and computational load on the system

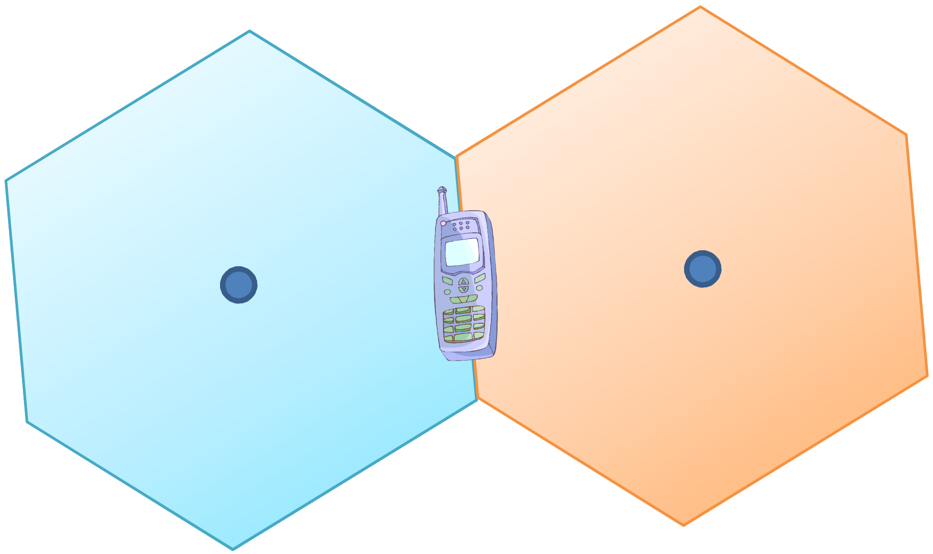
Quick review: Decibels

- S = Signal power in Watts
- Power of a signal in decibels (dBW) is $P_{signal} = 10 \log_{10}(S)$
- Remember dB by itself is used for ratios (like S/N)
- dBW is used for Watts
- dBm = dB for power in milliwatts = $10 \log_{10}(S \times 10^3)$
- dBm = $10 \log_{10}(S) + 10 \log_{10}(10^3)$ = dBW + 30
- -90 dBm = $10 \log_{10}(S \times 10^3)$
- $10^{-9} = S \times 103$
- $S = 10^{-12}$ Watts = 10^{-9} milliwatts
- -90 dBm = -120 dBW
- Signal-to-noise ratio:
- N = Noise power in Watts
- S/N = 10 log10(S/N) dB (unitless ratio)

Handoff Strategies I

- **Handoff:** Passing an active call from one BS to another without disconnection

- 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 Strategies II

- Handoff operation involves:
  - Identifying a new base station,
  - The voice and control signals has to be allocated to channels associated with the new base station.

- Many handoff strategies prioritize handoff requests over call initiation requests when allocating unused channels in a cell site.

- The criterion for handoff is based primarily on the Received Signal Strength Information (RSSI) (inferred from the reverse channel measurement).

Handoff Strategies III

- Minimum useable signal level:
  - The lowest acceptable voice quality
  - Call is dropped if below this level
  - Specified by system designers
  - Typical values → −90 to −100 dBm

- Handoff Threshold: The signal strength at which handoff occurs

- Choose a (handoff threshold) **>** (minimum useable signal level)
  - **Why?** There is time to switch channels before level becomes too low as mobile moves away from base station and toward another base station

Handoff Strategies IV

Handoff margin

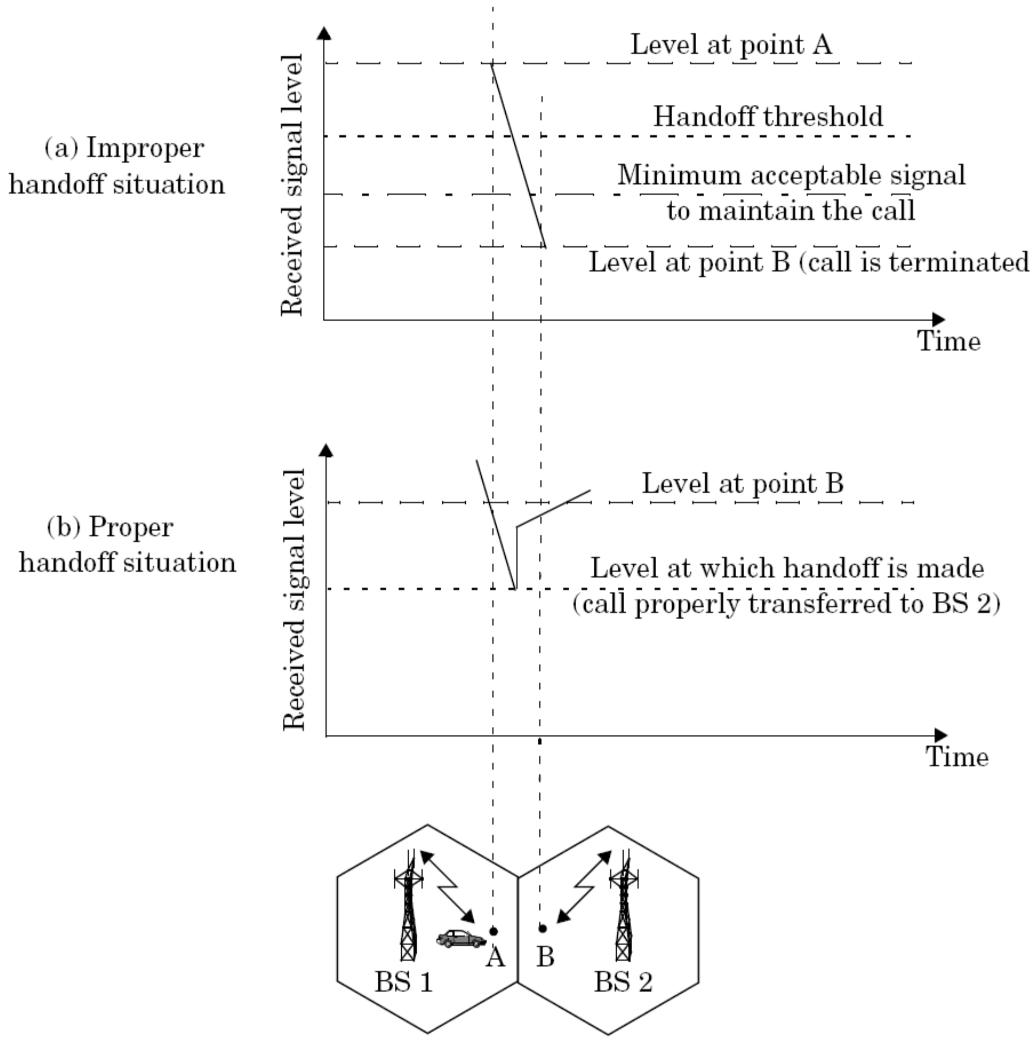
$$\Delta = P_{r\ handoff} - P_{r\ minimum\ usable}$$

- Carefully selected
- Δ too large → unnecessary handoff → MSC loaded down
- Δ too small → not enough time to transfer → call dropped!

A dropped handoff can be caused by two factors:

- Not enough time to perform handoff (Δ too small)
- Excessive delay by MSC in assigning handoff
  - High traffic conditions and high computational load on MSC
  - No channels available in new cell

Illustration of a handoff scenario at cell boundary.



Soft and Hard Handoffs

- Hard Handoff:
  - Handoff involves moving a call to another channel and another BS. (FDMA/TDMA systems)
  - MS switches to a new channel after leaving the old one (The old BS drops the MS before the new one acquires it).
- Soft Handoff:
  - A call is moved to a different BS (CDMA).
  - MS communicates with two BSs until handover is made.

Prioritizing Handoffs

- A fraction of total channels is reserved for handoff requests. (More efficient with dynamic channel assignment).

- Queuing, with handoff requests given priority over new calls.

Practical Issues: False Handoffs

Problem:

- Sometimes the drop in signal level is momentary (fading) and does not require handoff.

- **Solution:**

- Monitor the signal level for some time to detect moving-away pattern.
- Averaging the measurements over some period may be useful as well.

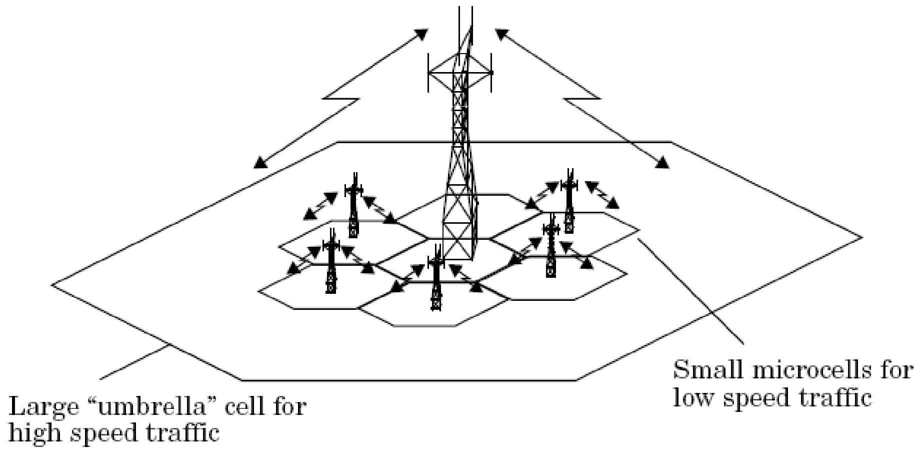
Practical Issues: High Speed Users

Problem:

- Frequent handoffs.

Solution: Umbrella cell

- Large and Small cells co-located.
- High-speed users are served by umbrella cell, while slow users are served by the microcells.
- Sophisticated algorithms are used to evaluate and partition users according to their speeds



The umbrella cell approach.

Practical Issues: Cell Dragging

Problem:

- The signal stays strong even outside cell boarders.
- Creates potential interference and management problems.

Solution:

- Handoff thresholds and coverage parameters must be adjusted.
- Note: Handoff is not required to rescue calls only. It is also required for proper overall system operation.

Intra-system and Inter-system Handoffs

- **Intra-system:** A handoff between BS's that are controlled by the same MSC.

- **Inter-system:** A handoff between BS's controlled by different MSCs.

- While Intra-system handoff are essential in any cellular system, Inter-system are not because they are not very frequent. It is acceptable that the call be disconnected while trans-crossing systems (or operators).

Typical handoff parameters

- Analog cellular (1st generation)
  - threshold margin $\Delta \approx 6$ to 12 dB
  - total time to complete handoff ≈ 8 to 10 sec
- Digital cellular (2nd generation)
  - total time to complete handoff ≈ 1 to 2 sec
  - lower necessary threshold margin $\Delta \approx 0$ to 6 dB
  - enabled by mobile assisted handoff
- Benefits of small handoff time
  - greater flexibility in handling high/low speed users
  - queuing handoffs & prioritizing
  - fewer dropped calls
- Decisions based on a wide range of metrics other than just signal strength
  - Measure interference levels

Interference

- Interference is the major limiting factor in the performance of cellular radio systems.

- **Sources of interference:**

  - Another mobile in the same cell
  - A call in progress in a neighboring cell
  - Other base stations operating in the same frequency band
  - Any noncellular system which inadvertently leaks energy into the cellular frequency band.

Effects of the interference

- **Voice channel:** causes cross talk
  - The subscriber hears interference in the background due to an undesired transmission.

- **Control channels:** leads to missed and blocked calls
  - Due to errors in the digital signaling.

- Interference is more severe in urban areas
  - Due to the greater RF noise floor and the large number of base stations and mobiles.
- Interference has been recognized as a major bottleneck in increasing capacity and is often responsible for dropped calls.

Types of system-generated cellular interference

- **Co-channel interference:** from users in other cells operating at the same frequency.

- **Adjacent-channel interference:** from users within cell

- Even though interfering signals are often generated within the cellular system, they are difficult to control in practice due to the random propagation effects.

Co-channel Interference

- Frequency reuse implies that in a given coverage area there are several cells that use the same set of frequencies.

- These cells are called co-channel cells

- The interference between signals from these cells is called co-channel interference.

Co-Channel Interference

- Possible solution :

  A) Increase base station Tx power to improve radio signal reception?

NO!!

Why ??

→ increases interference from co-channel cells by the same amount!

→ no net improvement

Co-Channel Interference

- Possible solution :

  B) Separate co-channel cells by some minimum distance to provide sufficient isolation from propagation of radio signals?

YES!!

Why ??

→ if all cell sizes ≈ same then co-channel interference is **<u>independent</u>** of Tx power

Co-Channel Interference

- CCI depends on :
  - R : cell radius
  - D : distance from BS to **<u>center</u>** of nearest co-channel cell
- $D/R\uparrow$ then spatial separation relative to cell coverage area $\uparrow$
  - Improved isolation from co-channel RF energy
- $Q = D/R$: co-channel reuse ratio
  - For hexagonal cells $\rightarrow$ $Q = D/R = \sqrt{3N}$

Fundamental Tradeoff

- Tradeoff in cellular system design:
  - Small Q → small cluster size → more frequency reuse → larger system capacity → great!!
  - But also → small cell separation → increased CCI → reduced voice quality → not so great!

Tradeoff: Capacity vs. Voice Quality

Co-Channel Interference

- Signal to Interference ratio → S/I (not S/N or SNR!!)
  - Equation (1) $$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_o} I_i}$$ where
    - S : Rx power from desired signal
    - I_i : Interference power from i^{th} co-channel cell
    - i_o : # of co-channel interfering cells
  - **Average** Rx power at distance d

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

P_0 : Rx power at close-in reference point

d_0 : close-in reference distance

n : path loss exponent

➢ Rx signal decays as power law relationship with distance between Tx and Rx

Co-Channel Interference

- If base stations have **equal Tx power** and propagation constant (n) **is the same** throughout coverage area (not always true!) then

  - Equation (2) $$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_o} (D_i)^{-n}}$$ where

D_i : Distance from i^{th} interferer to mobile Rx power @ mobile $\propto (D_i)^{-n}$

n : Path loss exponent **or** propagation constant

- Free space or LOS (no obstruction) $\rightarrow n = 2$
- Urban cellular $\rightarrow n = 2$ to 5

Co-Channel Interference

- If all interfering base stations are equidistant ($\approx D$) from mobile unit and considering only first layer (or tier) of co-channel cells then

  - Equation (3)

$$\frac{S}{I} = \left(\frac{D}{R}\right)^n \frac{1}{i_o} = \frac{Q^n}{i_o} = \frac{(3N)^{n/2}}{i_o} \qquad \left(\frac{W}{W}\right)$$

Co-Channel Interference

- What determines acceptable S/I?
  - Voice quality → **Subjective** testing
  - 1G AMPS → $S/I \geq 18$ dB (assumes $n = 4$)
    - » Solving Eq. (3) for N using $S/I = 18$ dB $= 10^{1.8} = 63.1$, $n = 4$, and $i_o = 6$ interfering co-channel cells
    - » $N = 1/3\,[\,(S/I)\,i_o\,]^{2/n} = 1/3\,[\,(63.1)\,6\,]^{2/n} = 6.5 \approx 7$
    - » $N = 7$ is **very** common choice for 1G AMPS
  - 2G GSM → $S/I \geq 10$ dB
  - 2G IS-95 (CDMA) → $S/I \approx 7$ dB (7 ± 1 dB)

Co-Channel Interference

- Many assumptions involved in Eq. (3)
  - Same Tx power for all cell BSs
  - Hexagonal geometry
  - Propagation constant, n, same throughout area
  - $D_i \approx D$ (not true for $N = 4 \rightarrow$ non-hexagonal)
  - Optimistic result in many cases
  - Computer propagation tools used to calculate S/I when assumptions are not valid
  - S/I is usually the **worst** when mobile is at cell edge
    - » Fig. 3.5, pg. 71 $\rightarrow$ $N = 7$ and $S/I \approx 17$ dB

Co-Channel Interference

Worst-case S/I on **forward** channel

→ mobile is at cell edge
→ low signal power
→ high interference power

1st Tier of Co-Channel Cells

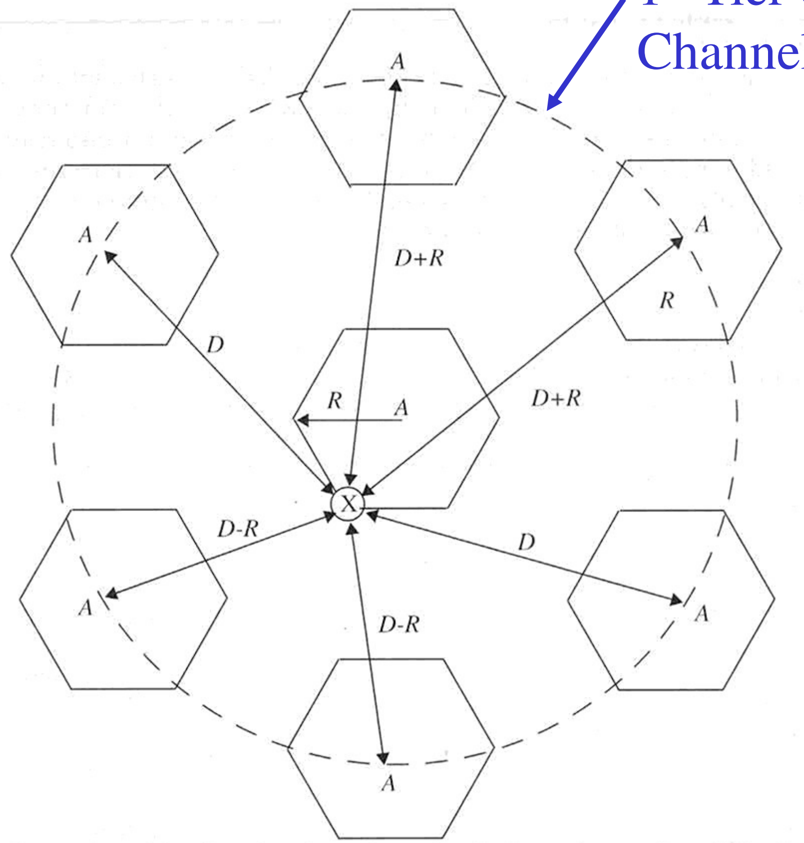


Figure 3.5 Illustration of the first tier of co-channel cells for a cluster size of $N = 7$. An approximation of the exact geometry is shown here, whereas the exact geometry is given in [Lee86]. When the mobile is at the cell boundary (point X), it experiences worst case co-channel interference on the forward channel. The marked distances between the mobile and different co-channel cells are based on approximations made for easy analysis.

Co-Channel Interference

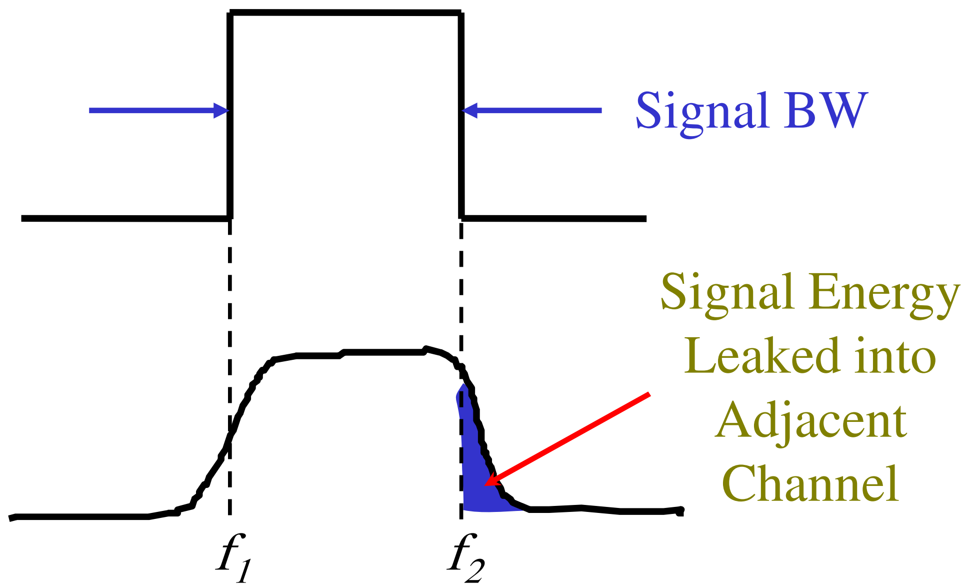
- Equations (1)-(3) are (S/I) for **forward** link only
  - Co-channel base Tx interfering with desired base station transmission to **mobile** unit
    - » Interference occurs @ mobile unit
- What about **reverse** link co-channel interference?
  - Less important b/c signals from mobile antennas (near ground!) don't propagate as well as those from **tall** base station antennas
  - Obstructions near ground level significantly attenuate mobile energy in direction of base station Rx
  - Also weaker b/c mobile Tx power is variable → power control

Adjacent Channel Interference

- Adjacent Channel Interference (ACI)
  - Caused by imperfect Rx filters that allow energy from adjacent channels to leak into passband of desired signal

Desired **Ideal** Filter Response

Actual Filter Response

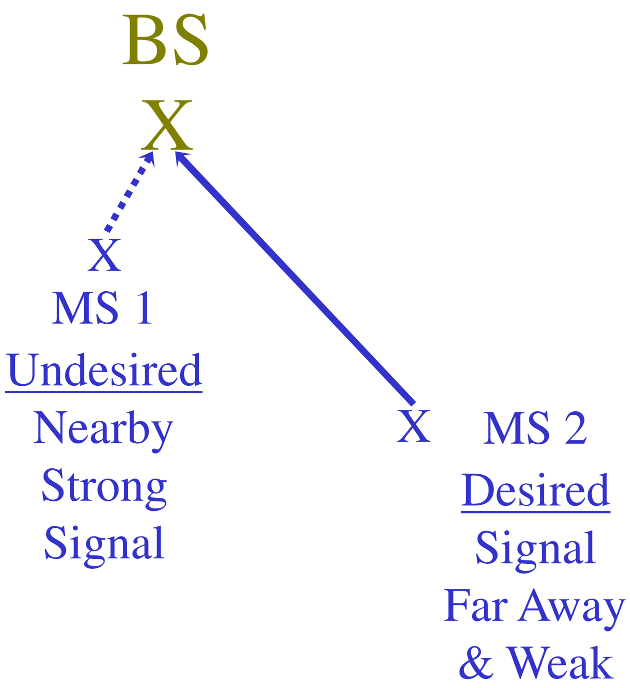


Adjacent Channel Interference

- ACI affects both forward & reverse channel links
- Forward Link → base-to-mobile
  - Interference @ primary mobile Rx from **nearby** base Tx when secondary mobile Rx is **far** away from base station
- Reverse Link → mobile-to-base
  - Interference @ base station Rx from **nearby** mobile Tx when desired mobile Tx is **far** away from base station
- Near/Far Effect
  - Interfering source is **near** some Rx when desired source is **far** away
- ACI is **primarily** from mobiles in same cell
  - Some cell-to-cell ACI does occur as well → secondary source

Adjacent Channel Interference

Reverse Link ACI



Minimizing ACI

- Don't allocate channels within a given cell from contiguous band of frequencies
- Maximize channel separation
  - Typical separation of 6 passband bandwidths
  - Many channel allocation schemes separate by N bandwidths
  - Some schemes seek to minimize ACI from neighboring cells
- Use high Q filters (sharp rolloff) in base stations
  - Better filters possible since not constrained by physical size as much as in mobile Rx
  - Makes reverse link ACI **less** of a concern than forward link ACI
    - » Also true b/c of power control (discussed next)

Minimizing ACI

- 1G AMPS Channel Allocation
  - Example 3.3 – Page 75
  - 395 VC and 21 CC per service provider (A & B)
  - 21 VC sector groups with ≈ 19 channels/group
  - 21 channel separation for each **sector group**
  - For $N = 7 \rightarrow$ 3 VC groups/cell (antenna sectorization!)
  - ≈ 57 channels/cell
  - 7 channel separation for each **cell group**

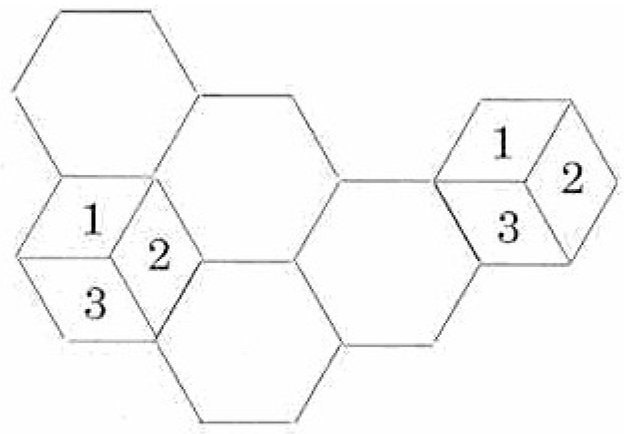
Minimizing ACI

- Mobile Unit Power Control
  - Effective technique to minimize ACI
  - Base station & MSC constantly monitor mobile RSS
  - Mobile Tx power varied (controlled) so that only the **smallest** Tx power is used to produced quality reverse link signal
  - Dramatically improves adjacent channel S/I ratio
  - Most beneficial for ACI on **reverse** link

Improving Cellular System Capacity

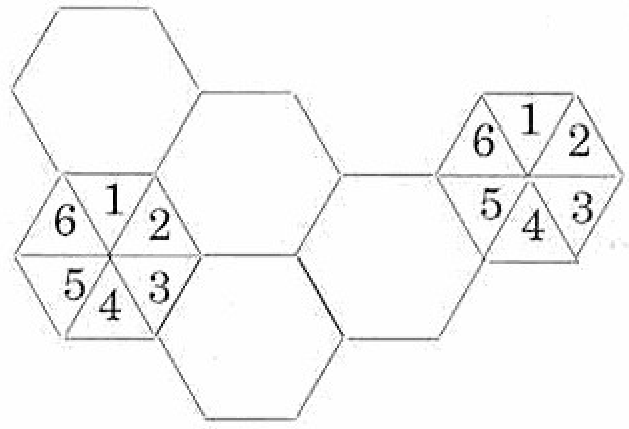
- Cell Sectoring
  - Cell splitting keeps D/R unchanged (same CCI) but increases frequency reuse/area
  - Alternate way to ↑ capacity is to **reduce** CCI
  - Replace omni-directional antennas at base station with several directional antennas
    - » 3 sectors → 3 @ 120° antennas
    - » 6 sectors → 6 @ 60° antennas
  - Cell channels broken down into **sectored** groups
  - CCI reduced b/c only **some** of neighboring co-channel cells radiate energy in direction of main cell

Cell Sectoring



(a)

3 sectors → 3 @ 120° antennas



(b)

6 sectors → 6 @ 60° antennas

Cell Sectoring

N = 7 cell cluster

6 CCI cells in first tier

120° Sectoring

i_o = 2 interfering cells

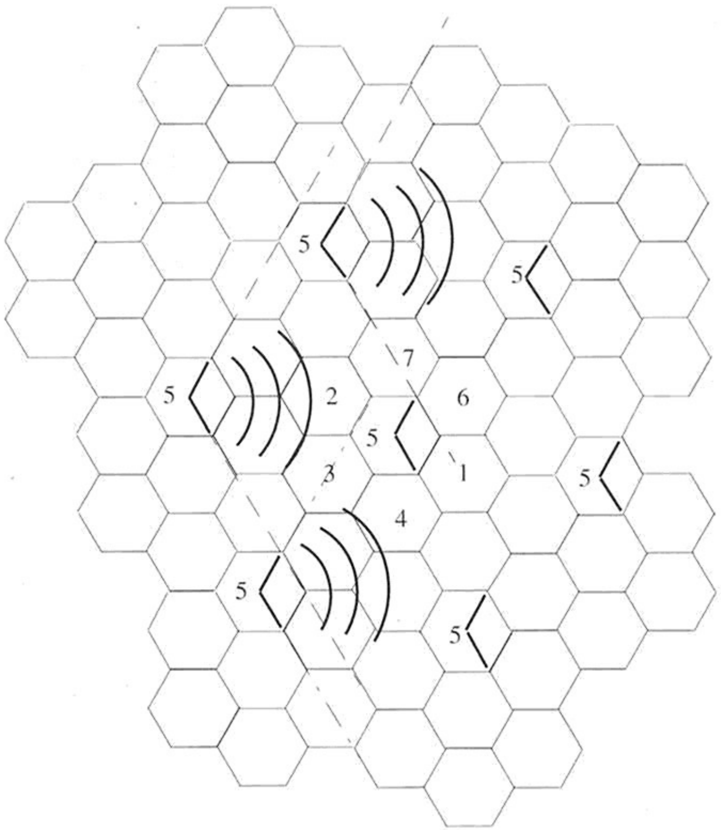


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center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

Cell Sectoring

- How is capacity increased?
  - By reducing CCI the cell system designer can choose smaller cluster size (N ↓)
  - Smaller $N \rightarrow$ greater frequency reuse $\rightarrow$ larger system capacity
- Much less costly than cell splitting
  - Only requires more antennas @ base station vs. multiple new base stations for cell splitting
- Primary disadvantage is available channels in a cell subdivided into sectored groups
  - Trunked channel pool ↓ $\therefore$ trunking efficiency ↓
- *** Overall **system** capacity **increased** at the expense of **reducing** capacity of **individual** cells ***

Cell Sectoring

- Other Advantages :
  - More antenna gain → sector antenna focuses signal energy
    - » Forward/reverse link budgets improved
    - » More Tx power delivered to coverage area
    - » Better building penetration
  - Flexibility in controlling CCI
    - » Downtilt antennas in certain sectors to reduce CCI in specific cells

Cell Sectoring

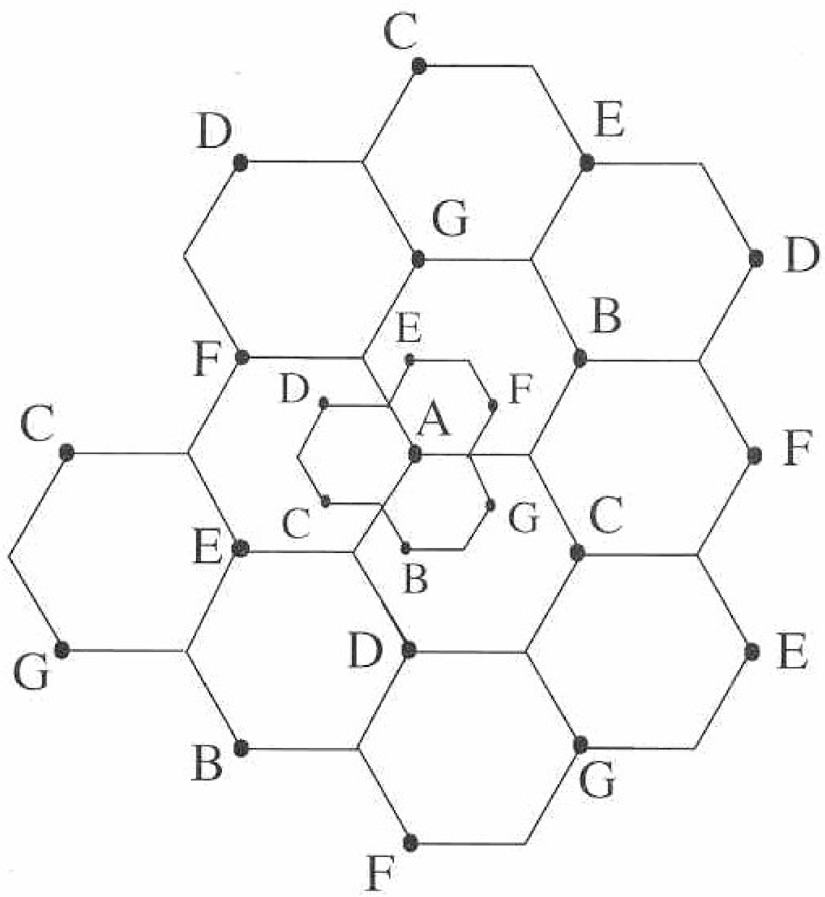
- Other Disadvantages :
  - Must design network coverage with sectoring decided **in advance**
  - Can't effectively use sectoring to increase capacity **after** setting cluster size N
  - Can't be used to **gradually** expand capacity as traffic ↑ like cell splitting

Improving Cellular System Capacity

- Cell Splitting
  - Subdivide congested cell into several smaller cells
  - Must decrease antenna height & Tx power so smaller coverage results and CCI level is held **constant**
  - Each smaller cell keeps ≈ same # of channels as the larger cell!!
  - Capacity ↑ b/c channel reuse ↑ per unit area
  - Smaller cells → "micro-cells"

Cell Splitting

Base stations placed
at cell corner
for illustration
purposes



Cell Splitting

- Advantages :
  - Only needed for cells that reach max. capacity → not **all** cells
  - Implement when Pr [blocked call] > acceptable *GOS*
  - System capacity can **gradually** expand as demand ↑
- Disadvantages :
  - # handoffs/unit area ↑
  - Umbrella cell for high velocity traffic may be needed
  - **More base stations → cost increases