Wireless Communications

EENG 5820

Lecture 2

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Today

- Introduction and Motivation
- Cellular Concept
- Frequency Reuse
- Handoff
- Interference and System Capacity

Introduction and Motivation

Early Mobile Systems

- Design objectives
  - Using a single high-power transmitter with an antenna on a tall tower
- Bell mobile system in New York in the 1970s
  - Maximum of 12 simultaneous calls
  - 1000 sq miles
- Government regulatory agencies could not make spectrum allocation in proportion to the increasing demand of mobile systems
  - Need to restructure radio telephone system
  - How?

Introduction and Motivation

Single Transmitter, Large Area, Few Users

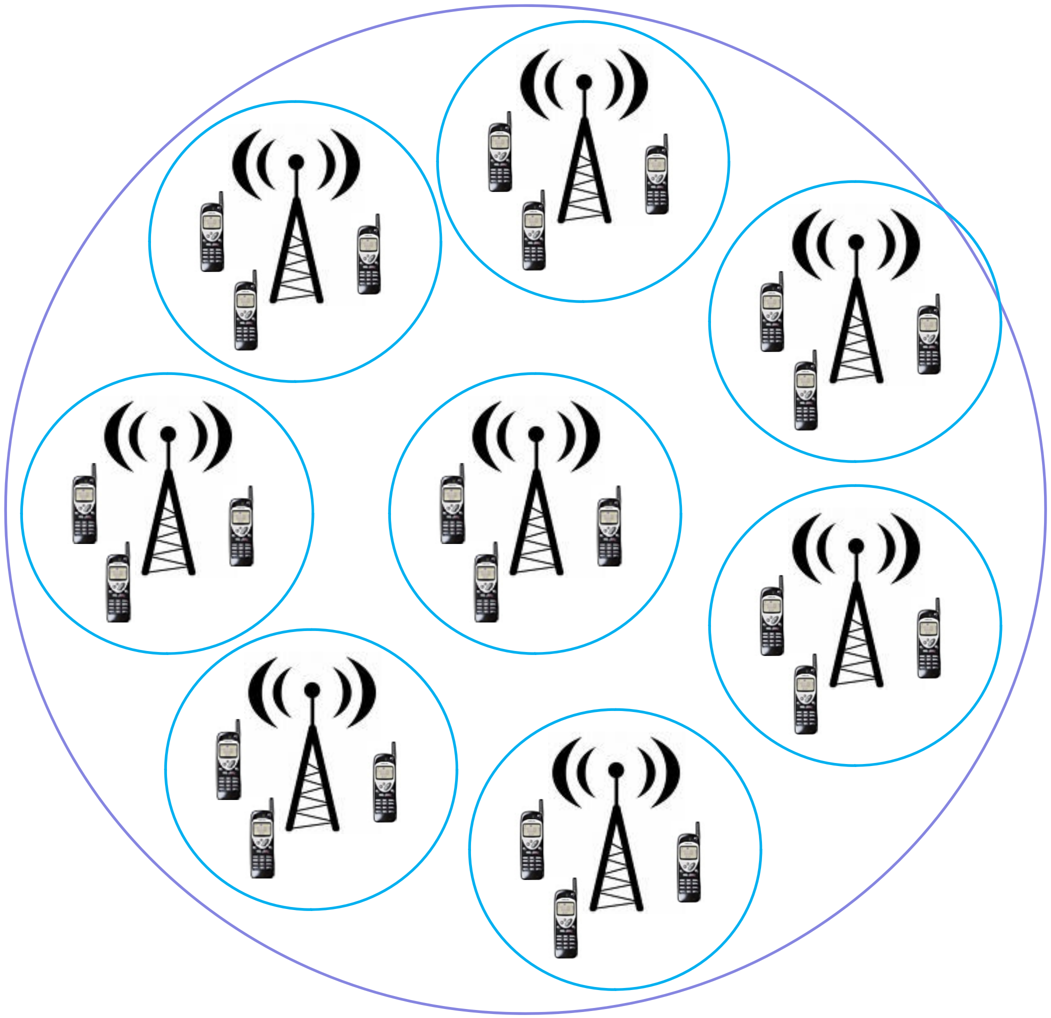
The Cellular Concept

The concept

Replace the single high power transmitter (large cell) with many low power transmitters (small cells), each providing coverage only to a small portion of the service area

The Cellular Concept

Multiple Transmitters, Smaller Areas, Many Users



The Cellular Concept

How it works?

- Each base station is allocated only a portion of the total number of available channels (frequencies)
- Nearby base station are assigned different frequencies
- The same frequencies are reused by cells that are far away, so interference is minimized

The Cellular Concept

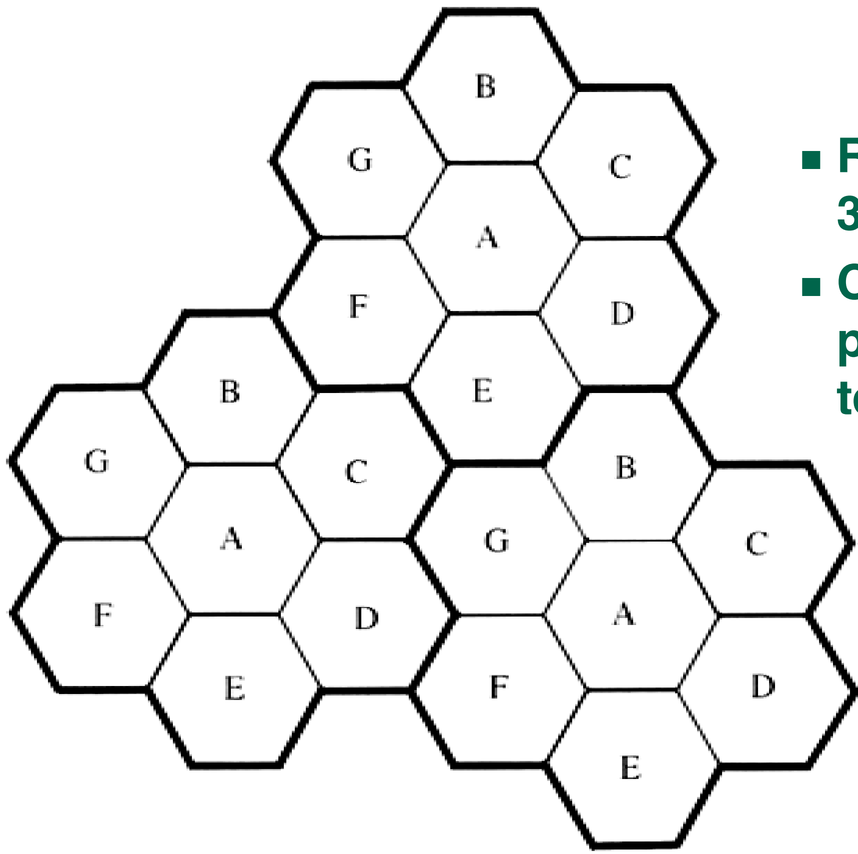
Advantages

- Enables fixed number of channels to serve an arbitrary large number of users
- Allows any mobile to be used anywhere with the same set of channels

Cell Types

- Macrocell: Diameter $\geq$ 2000 feet
- Microcell: Diameter $\in$ (400 feet ~ 2000 feet)
- Picocell: Diameter $\leq$ 400 feet (Bluetooth 10~100 ft)

Frequency Reuse



- Radius 1-25 mile, typically 3-5 miles
- Controlled by base station power, height of antenna, terrain

Figure 3.1 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

Why hexagon?

- Regular cell shape is needed for systematic design: *footprint* (map of usable area of cell)
- Circle: overlap and/or leaving gaps
- Square, Equilateral triangle, Hexagon

For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area.

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Frequency Reuse

Goals

- System-level analysis of number of required subscribers in an area, how many frequencies will be needed (when and where) and how to meet the need with the most cost-effective solution?

System Parameters

- S: Total # of available duplex (2-way) channels
- *K*: # of channels (K < S) for each cell
- N: cluster size, or # of disjoint channel groups
- M: A cluster is replicated M times within the system

$$S = k\,N$$

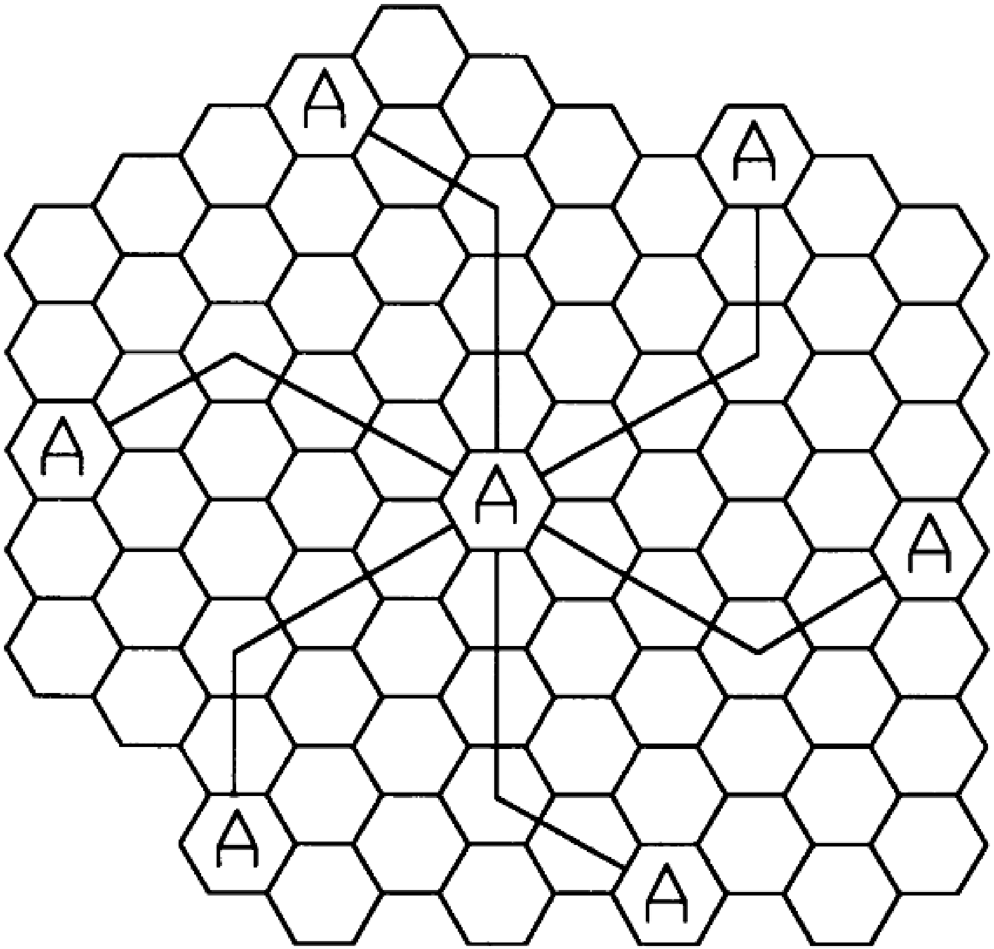
$$C = Mk\,N = MS$$

Frequency Reuse

Cluster Size N:

- When N is reduced and cell size is kept constant, more clusters are required to cover a given area $\Rightarrow$ C is increaseded
- N $\uparrow$ $\Rightarrow$ the ratio between the cell radius and the distance between co-channel cells to decrease $\Rightarrow$ weaker co-channel interference
- N $\downarrow$ $\Rightarrow$ the distance between co-channel cells increases $\Rightarrow$ more co-channel interference
- Typical N: **4, 7, 12**

Frequency Reuse



- Move i cells along any chain of hexagon
- Turn 60 degree counter-clockwise
- Move j cells

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

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.)

Channel Assignments

- **Fixed assignment (each base station has a fixed set of channels to use)**
  - Pros: Simple
  - Cons: If one cell has lots of users, it will run out of channels before a neighboring cell with fewer users. System performance will be limited by the most crowded cell. *Blocked call happens when you are out of voice channels*
- **Dynamic allocation (each base station can change the channels it uses. Channels in neighboring cells must still be different)**
  - Pros: System performance is limited by total number of available channels, better than fixed assignment
  - Cons: More complicated. *Dynamic allocation generally handled by the MSC (Borrowing strategy from neighboring cells).*

Handoff Strategies

- **When a user moves from one cell to another, the call is transferred to the new cell**
  - Between base stations AND between MSCs (Dropped call)
  - All is based on the received power level (below a given level, a handover procedure is initiated)

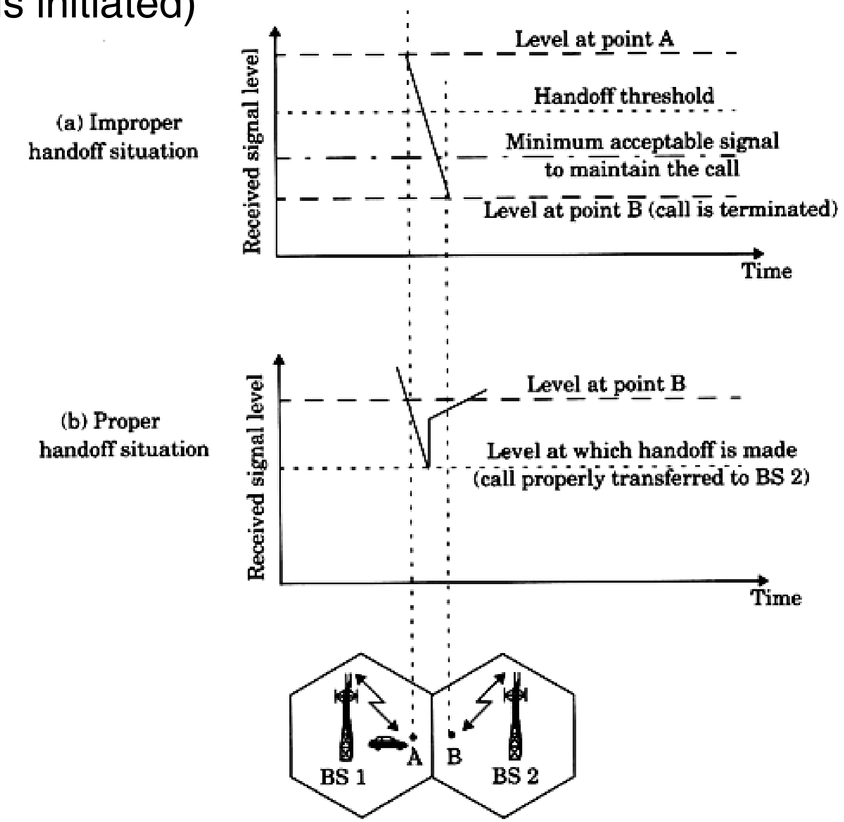


Figure 3.3 Illustration of a handoff scenario at cell boundary.

Handoff Strategies

- **RSSI: Received signal strength indicator used to determine relative strength of call at different base stations. Typically -90 dBm to -100 dBm needed for good voice reception**
- **Typical**
  - AMPS: handoff if power too low for 10 seconds
    - Handoff when RSSI is 10 to 12 dB above threshold
    - Hard handoff – must change frequency
  - GSM: handoff if power too low for 1-2 seconds
    - Handoff when RSSI is 0 to 6 dB above the threshold
  - CDMA: soft handoff – CDMA systems keep same frequency range. Multiple signals are received at different base stations, and the mobile or MSC can decide which is the best copy of the signal
  - Dwell Time: length of time call stays at a particular base station

Handoff Strategies

- **Practical Scenarios**
  - Quick fluctuation in signal strength caused by nearby car/building/multipath/etc. getting in the way
  - User moving too quickly, and call is lost before handed off
  - New cell is too busy
  - Cell dragging: slow moving mobiles (pedestrians) may have very slow decay in RSSI (LOS), and may stay with one BS until it has moved deep within another cell. This can result in Channel interference, and is certainly non-opitimal
- **This can be controlled by MSC or mobile (MAHO)**
  - MSC: Monitors all RSSI measurements that base station takes of mobiles, including neighbors (larger area, less often)
  - MAHO: Mobile contains an RSSI chip, and reports its strength to MSC (faster, less load for MSC, smaller area, more often)

Handoff Strategies

- **Solutions**
  - Guard channel: Hold a few channels free just for handoff requests
  - Umbrella cell: Use one cell tower with high antennas (for large umbrella cells) and lower antennas (for smaller cells under this umbrella). Use the umbrella cells for fast moving mobiles and smaller cells for slow moving mobiles.

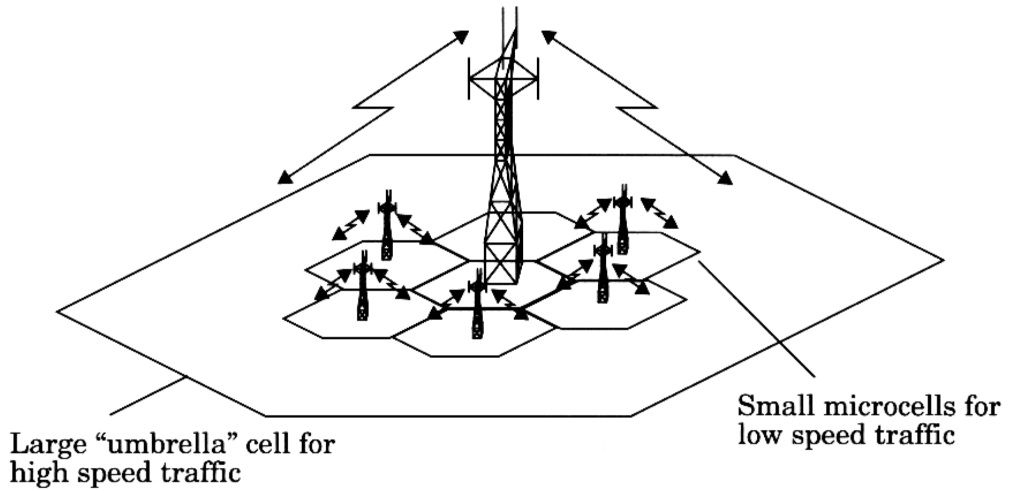


Figure 3.4 The umbrella cell approach.

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Co-Channel Interference

- Co-channels are nearby channels with the same frequency
- Co-channel interference causes
  - Voice channel: loss of quality
  - Control channel: dropped calls
- Increasing SNR does NOT solve co-channel interference (in fact, it can make it worse)
- Reduce co-channel interference by increasing distance between co-channels
  - R (Radius of each cell), D (Distance between center of cells)
  - Q = co-channel reuse ratio = D/R = $\sqrt{3N}$
    - Small Q increases system capacity
    - Small Q increases co-channel interference

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Co-Channel Interference

▪ Signal-to-interference ratio

- S = signal strength (power)
- I = co-channel interference strength (power)
- I_i = power of co-channel interference from i^{th} cell

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

Typical S/I must be 15 – 18 dB for good reception

Co-Channel Interference

Propagation decays

- Pr = Power received
- P_0 = Power at a nearby point (d_0) in the far field of the transmitter
- d_0 = near distance in the far field of the transmitter
- d= far away distance (also in the far field of the transmitter)

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

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

Co-Channel Interference

- n: path loss exponent, depends on environment

Environment	n
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban area	3 to 5
In building line of sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Co-Channel Interference

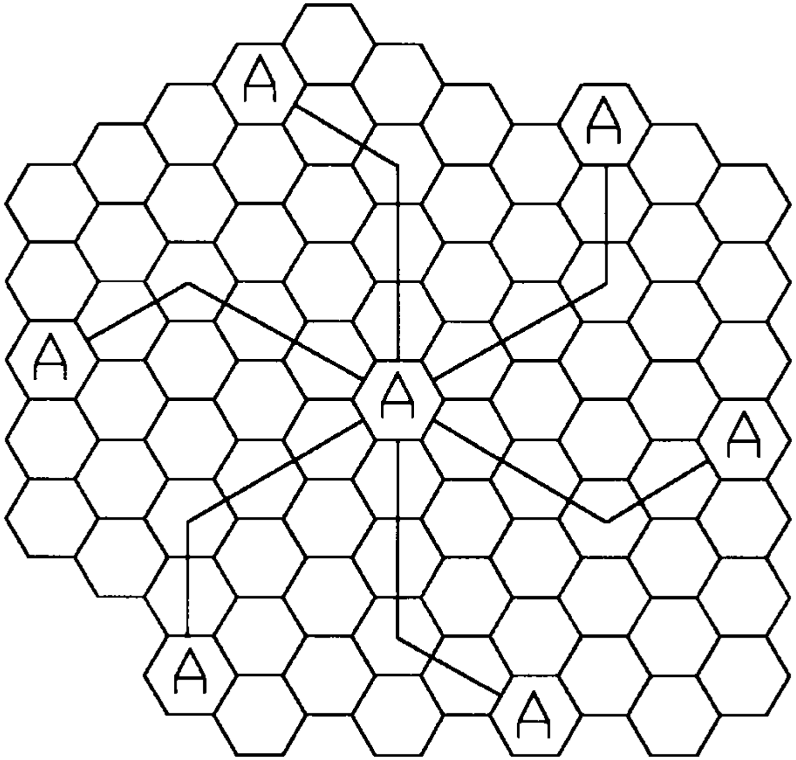
In the case of Hexagonal cells

- $S = P_0$ = worst-case signal is measured at the outer edge of the cell
- d_0 = distance to where S is measured = R
- $I_i = P_r$ = power of interference from the i^{th} cell
- d = distance to the i^{th} cell D_i

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} \left(D_i\right)^{-n}} \xrightarrow{\text{First layer}} \frac{S}{I} = \frac{\left(D/R\right)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{i_0}$$

Co-Channel Interference

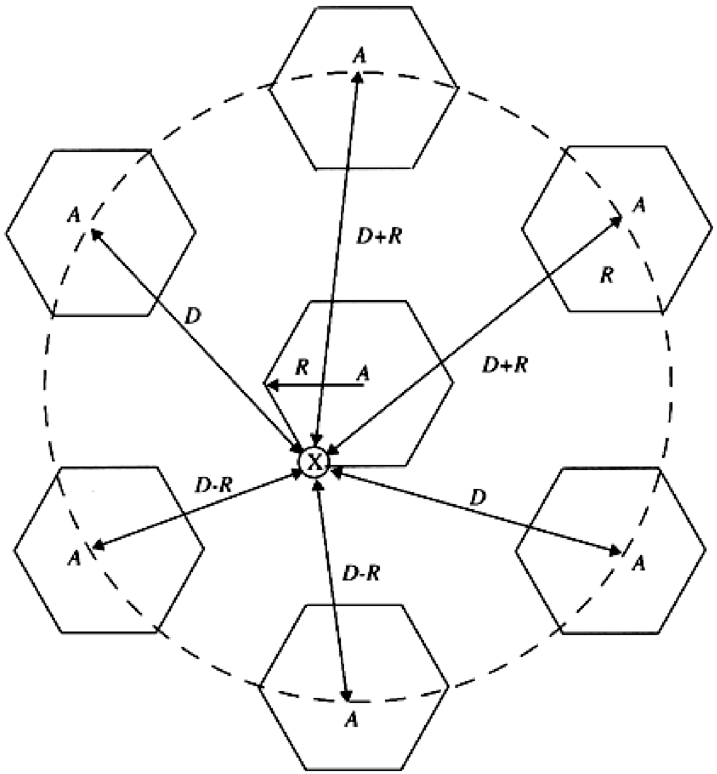
- **Example: AMPS requires that SIR be greater than18dB**
  - N should be at least 6.49 for n = 4 (i_0 = 6)
  - Minimum cluster size is 7



Co-Channel Interference

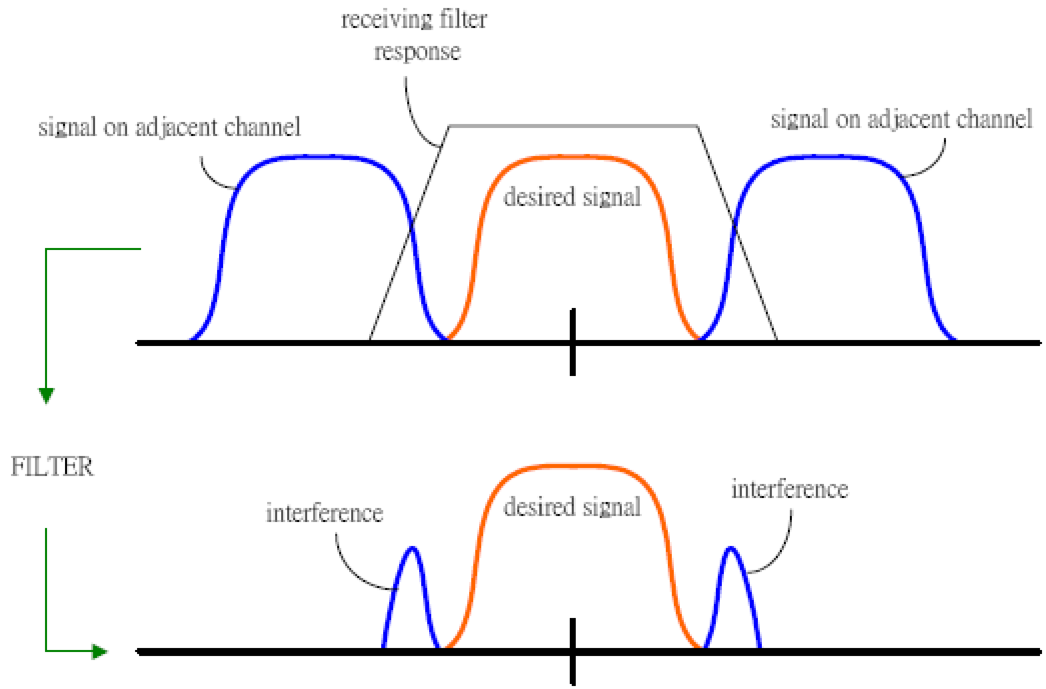
- For hexagonal geometry with 7-cell cluster, with the mobile unit being at the cell boundary, the SIR for the worst case can be approximated as

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



Adjacent Channel Interference

- **Adjacent channel 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



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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

Homework 2 (Due on Feb. 6)

Turn in:

3.1, 3.4, 3.7(v = 22.22m/s), 3.10, 3.15, 3.26

Review:

3.5, 3.8, 3.9, 3.11, 3.13, 3.14, 3.16, 3.29