18-452/18-750
Wireless Networks and Applications
Lecture 17:
Cellular - Principles

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http://www.cs.cmu.edu/~prs/wirelessF18/

Overview

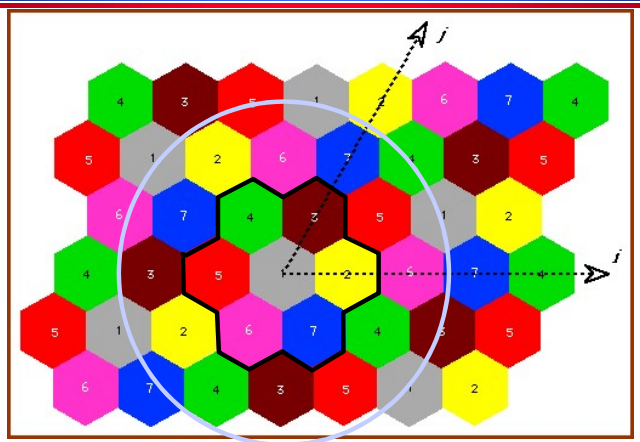
- Cellular principles – "classic" view
  - » Cellular design
  - » Elements of a (generic) cellular network
  - » How does a mobile phone call take place?
  - » Handoff
  - » Frequency Allocation, Traffic Engineering
- Early cellular generations: 1G, 2G, 3G
- Today's cellular: LTE

Some slides based on material from
"Wireless Communication Networks and Systems"

Frequency reuse

- Each cell features one base transceiver
- Through power control the tower covers the cell area while limiting the power leaking to other co-frequency cells
- The number of frequency bands assigned to a cell dependent on its traffic
  - » 10 to 50 frequencies assigned to each cell (early systems)
- How do we determine how many cells must separate two cells using the same frequency?
  - » Need to control the "power to interference" ratio

Minimum separation?



Frequency reuse characterization

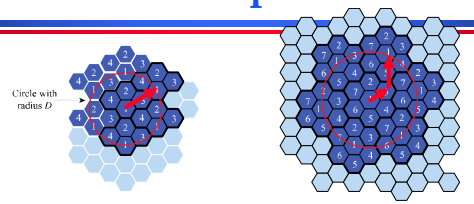
- D = minimum distance between centers of co-channel cells
- R = radius of cell
- d = distance between centers of adjacent cells
- N = number of cells in a repetitious pattern, i.e. reuse factor
- Hexagonal pattern only possible for certain N:

$$N = I^2 + J^2 + (I \times J), \quad I, J = 0, 1, 2, 3, \ldots$$

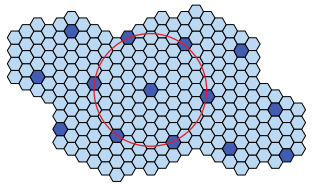
- The following relationship hold

$$\frac{D}{R} = \sqrt{3N} \quad \text{or} \quad \frac{D}{d} = \sqrt{N}$$

Frequency Reuse Pattern Examples



(a) Frequency reuse pattern for $N = 4$ (b) Frequency reuse pattern for $N = 7$



(c) Black cells indicate a frequency reuse for $N = 19$

Capacity and Interference

- S = Total # of duplex channels available for use
- k = Total # of duplex channels per cell
- N = Size of cluster, i.e., cells that collectively use the complete set of available frequencies

$$\frac{S}{k} = N \quad \Rightarrow S = kN$$

- If a cluster is replicated M times within the system, the total # of duplex channels C can be used as a measure of capacity

$$\Rightarrow \quad C = MkN = MS$$

Tradeoffs

$C = MkN = MS$

- If N ↓ ⇒ k ↑ since S is a constant
  ∴ M ↑ for a fixed geographical area if the same cell radius is maintained
  ⇒ Capacity increases as cluster size goes down
- Reuse distance: $\frac{D}{R}\downarrow$ ⇒ Co-channel interference ↑
- NOTE: To reduce co-channel interference

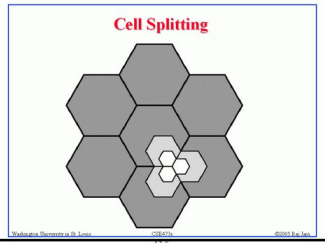
  $\frac{D}{R}\uparrow \quad \Leftrightarrow N\uparrow \quad \Rightarrow M\downarrow$ ∴ Capacity ↓ since kN = S = fixed
- There is a trade-off between capacity and interference reduction

Approaches to Cope with Increasing Capacity

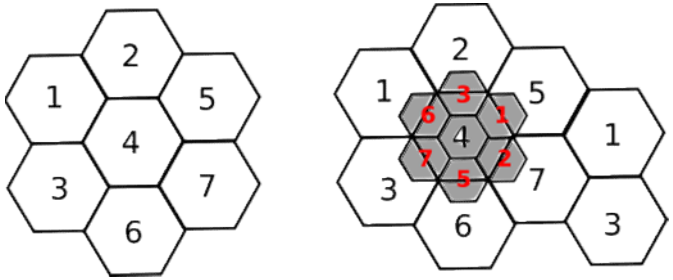
- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into wedge-shaped sectors, each with their own set of channels
- Network densification – more cells and frequency reuse
  - » Microcells – antennas move to buildings, hills, and lamp posts
  - » Femtocells – antennas to create small cells in buildings

Cell splitting

- Cell size ~ 6.5-13Km, Minimum ~ 1.5Km
  - » Again, for early systems
- Requires careful power control and possibly more frequent handoffs for mobile stations
- A radius reduction by F reduces the coverage area and increases the number of base stations by F^2



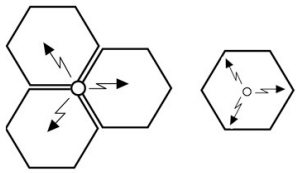
Cell splitting



Radius of small cell half that of the original

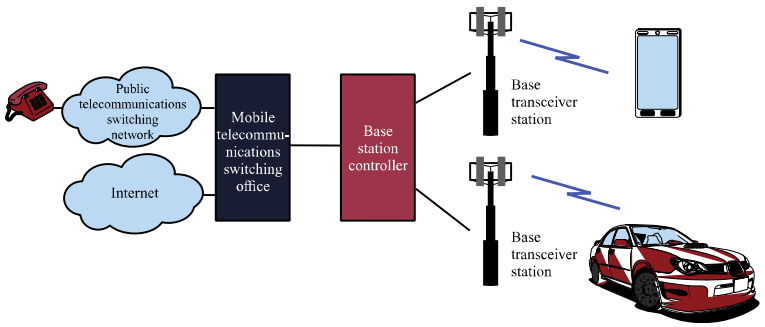
Cell sectoring

- Cell divided into wedge shaped sectors
- 3-6 sectors per cell, each with own channel set
- Subset of cell's channel, use of directional antennas



Right! ☺ Wrong! ☹

Overview of Cellular System

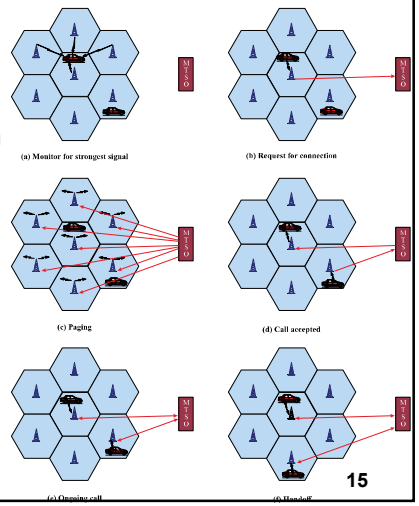


Elements of a cellular system

- Base Station (BS): includes antenna, a controller, and a number of transceivers for communicating on the channels assigned to that cell
- Controller handles the call process between the mobile unit and the rest of the network
- MTSO: Mobile Telecommunications Switching Office, serving multiple BSs. Connects calls between mobiles and to the PSTN. Assigns the voice channel, performs handoffs, billing

MTSO Sets up Call between Mobile Users

- Mobile unit initialization
- Mobile-originated call
- Paging
- Call accepted
- Ongoing call
- Handoff



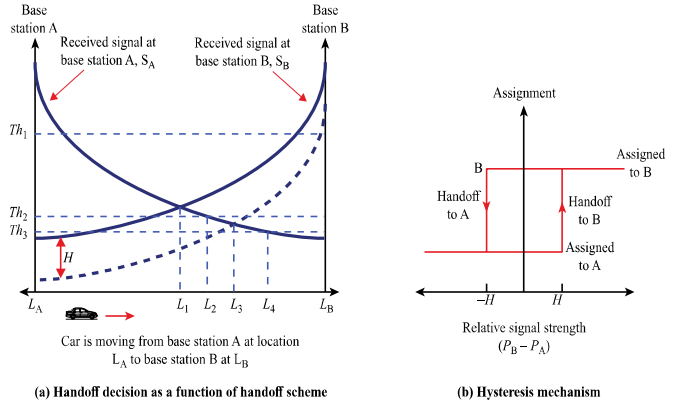
Paging

- Broadcast mechanism to locate a target mobile unit
- Normally, there is knowledge on a limited number of cells where the mobile may be (Location Area in GSM, Routing Area if data packet sessions)
- GSM: neighbor cells grouped in Location Area and subscriber only updates when moving across. Paging restricted to the Location Area itself.
  - » How do we assign cells to LAs?

Handoff Strategies Used to Determine Instant of Handoff

- **Metrics related to handoff:**
  - » Call blocking probability: probability of a new call being blocked
  - » Call dropping probability: probability that a call is terminated due to a handoff
- **Possible strategies for scheduling handoffs:**
  - » Relative signal strength – L_1
  - » Relative signal strength with threshold Th_2 – L_2
  - » Relative signal strength with hysteresis H – L_3
  - » Relative signal strength with hysteresis and threshold Th_1 or Th_2 – L_3; Th_3 – L_4
  - » Prediction techniques

Example of Handoff



Handoff implementations

- **GSM/W-CDMA**
  - » Inter-frequency handovers will measure the target channel before moving over
  - » Once the channel is confirmed OK, the network will command the mobile to move and start bi-directional communication there
- **CDMA2000/W-CDMA(same)**
  - » Both channels are used at the same time – soft handover
- **IS-95 (inter-frequency)**
  - » Impossible to measure channel directly while communicating. Need to use pilot beacons. Almost always a brief disruption.

Mobile Radio Propagation Effects

- **Signal strength**
  - » Must be strong enough to maintain signal quality at the receiver
  - » Must not be so strong as to create too much co-channel interference with channels in another cell using the same frequency band
  - » Fading may distort the signal and cause errors
- **Mobile transmission power minimized to avoid co-channel interference, alleviate health concerns and save battery power**
- **In systems using CDMA, need to equalize power from all mobiles at the BS**

Open and Closed Loop Power Control

- Open loop power control: BS sends pilot
  - » Used by mobile to acquire timing and phase reference, and to assess channel attenuation
  - » Mobile adjust power accordingly
    - – Assume up and down channels are similar
  - » Can adjust quickly but not very accurate
- Closed loop power control: power is adjust based on explicit feedback from receiver
  - » Reverse signal power level, received signal-to-noise ratio, or received bit error rate
  - » Mobile to BS: BS base station sends power adjustment command to mobile based on observed signal
  - » BS to mobile: BS adjust power based on information provided by mobile

Fixed Channel Assignment (FCA)

- 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 cell
- If all the channels in that cell are being used the call is blocked → user does not get service
- A variation of FCA: the cell whose channels are all being used is allowed to borrow channels from the next cell. MTSO supervises this operation.

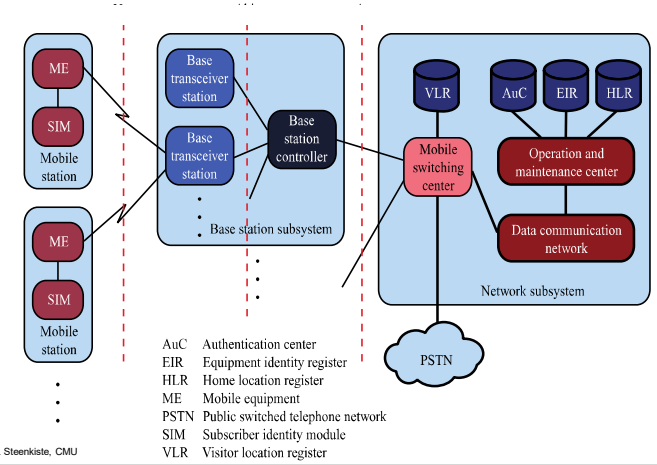
Dynamic Channel Assignment (DCA)

- Channels are not permanently assigned to cells. Instead, for each request the BS requests a channel from the MTSO.
- MTSO allocates a channel using an algorithm that takes many factors into account
  - » The likelihood of future blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions.
  - » MTSO only allocates a channel if it is not being used in the restricted distance for co-channel interference
- DCA can use channels more effectively but incurs measurement, communication, and computer overhead

Traffic Engineering

- If the cell has L subscribers..
- … and can support N simultaneous users.
- If L<=N, nonblocking system
- If L>N, blocking system
- Questions operator cares about:
  - » What is the probability of a call being blocked?
  - » What N do I need to upper bound this probability?
  - » If blocked calls are queued, what is the average delay?
  - » What capacity is needed to achieve a certain average delay?
- Difficult problem but important

Global GSM System



Mobile Switching Center

- Management of the communication between mobiles and the fixed network
  - The Gateway Mobile Switching Controller forms the gateway for calls to and from external networks
- MSC is also responsible for mobility management
  - Handover between Base Station Subsystems
  - Roaming across networks