Wireless Networks
Lecture 22:
Cellular - Principles

Peter Steenkiste
CS and ECE, Carnegie Mellon University

Peking University, Summer 2016

Overview

- **Cellular principles**
  - » Cellular design
  - » Elements of a cellular network
  - » How does a mobile phone take place?
  - » Handoff
  - » Frequency Allocation, Traffic Engineering
- **Early cellular generations: 1G, 2G, 3G**
- **Today's cellular: LTE**

Cellular versus WiFi

	Cellular	WiFi
Spectrum		
Service model		
MAC services		

- Implications for level of service (SLAs), cost, nature of protocols, …?

The Advent of Cellular Networks

- Mobile radio telephone system was based on:
  - » Predecessor of today's cellular systems
  - » High power transmitter/receivers
  - » Could support about 25 channels
  - » in a radius of 80 Km
- To increase network capacity:
  - » Multiple low-power transmitters (100W or less)
  - » Small transmission radius -> area split in cells
  - » Each cell with its own frequencies and base station
  - » Adjacent cells use different frequencies
  - » The same frequency can be reused at sufficient distance

The origin of mobile phone

- America’s mobile phone age started in 1946 with MTS
- First mobile phones bulky, expensive and hardly portable, let alone mobile
  - » Phones weighed 40 Kg~
- Operator assisted with 250 maximum users

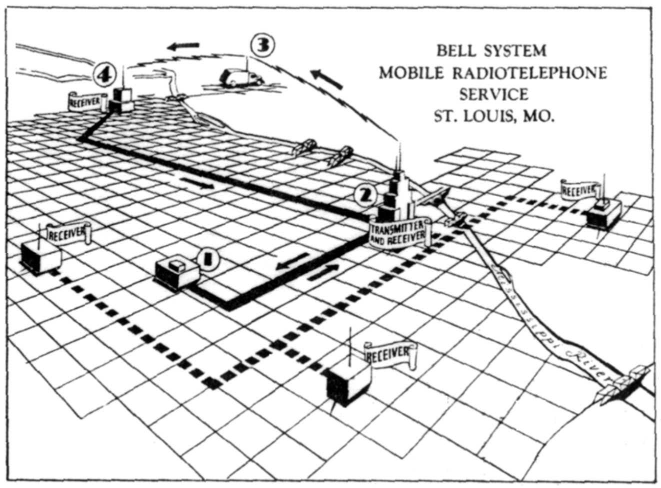
The Cellular Idea

- In December 1947 Donald H. Ring outlined the idea in a Bell labs memo
- Split an area into cells with their own low power towers
- Each cell would use its own frequency

- Did not take off due to “extreme-at-the-time” processing needs
  - » Handoff for thousands of users
  - » Rapid switching infeasible – maintain call while changing frequency
  - » Technology not ready

The MTS network

http://www.privateline.com/PCS/images/SaintLouis2.gif



… the Remaining Components

- In December 1947 the transistor was invented by William Shockley, John Bardeen, and Walter Brattain
- Why no portable phones at that time?
- A mobile phone needs to send a signal – not just receive and amplify
- The energy required for a mobile phone transmission still too high for the high power/high tower approach – could only be done with a car battery

… and the Regulatory Bodies

The FCC commissioner Robert E. Lee said that mobile phones were a status symbol and worried that every family might someday believe that its car had to have one.

Lee called this a case of people "frivolously using spectrum" simply because they could afford to.

From The Cell-Phone Revolution, AmericanHeritage.com

DynaTAC8000X: the First Cell Phone

The "brick":
- weighed 2 pounds,
- offered 30 mins of talk time for every recharging and
- sold for $3,995!

It took 10 years to develop (1973-1983) and cost $100 million! (delay due to infrastructure)

Size primarily determined by the size of batteries, antennas, keypads, etc.

Today size determined by the UI!

Dr. Martin Cooper of Motorola, made the first US analogue mobile phone call on a larger prototype model in 1973

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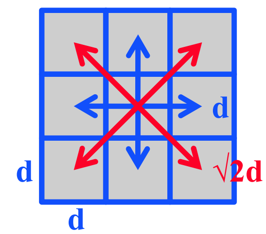
Some slides based on material from
"Wireless Communication Networks and Systems"

How To Design a Cellular Network?

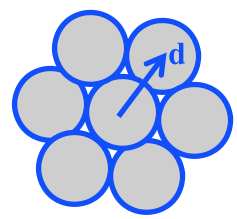
- **Need to get good coverage everywhere**
- **Must be able to plan network based on demand**

Cellular Network Design Options

- **Simplest layout**
  - » Does not match any propagation model
  - » Adjacent antennas not equidistant – how do you handle users at the edge of the cell?

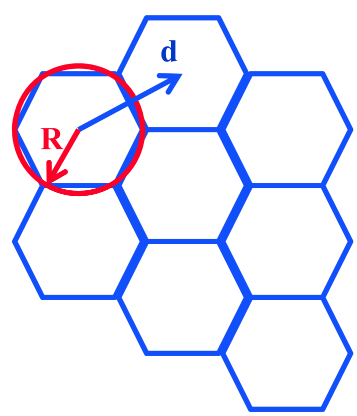


- **Ideal layout**
  - » Based on a naïve propagation model – bad approximation but better than squares
  - » Does not cover entire area!



The Hexagonal Pattern

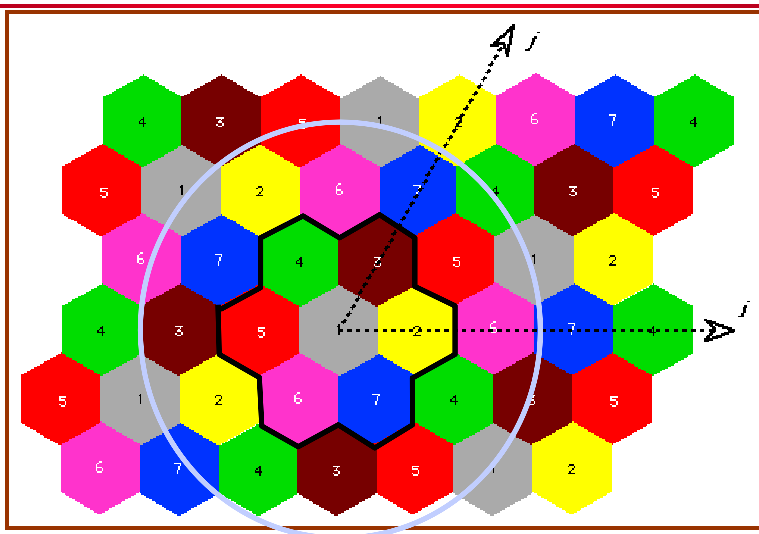
- **A hexagon pattern can provide equidistant access to neighboring cell towers**
- **d = √3R**
- **In practice, variations from ideal due to topological reasons**
  - » Signal propagation
  - » Tower placement



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
- 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

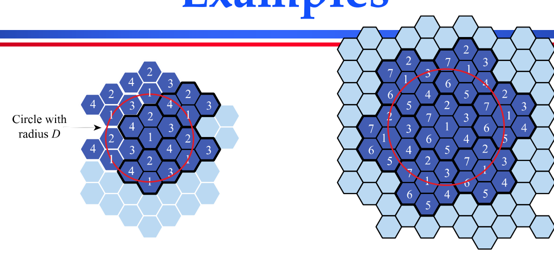
- D = minimum distance between centers of co-channel cells
- R = radius of cell
- d = distance between centers of adjacent cells
- N = number of cells in a repetitious pattern, i.e. reuse factor
- Hexagonal pattern only possible for certain N:

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

- The following relationship hold

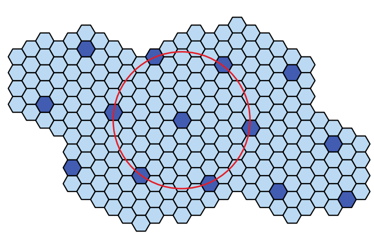
$$\frac{D}{R} = \sqrt{3N} \quad \text{or} \quad \frac{D}{d} = \sqrt{N}$$

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 = Cluster of cells which collectively use the complete set of available frequencies

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

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

$$\Rightarrow \qquad C = MkN = MS$$

$C = MkN = MS$ Tradeoffs

- If N $\downarrow \Rightarrow$ k $\uparrow$ since S is a constant
  $\therefore$ M $\uparrow$ for a fixed geographical area if the same cell radius is maintained
  $\Rightarrow$ Capacity increases
- Reuse distance: $\frac{D}{R}\downarrow \qquad \Rightarrow$ Co-channel interference $\uparrow$
- NOTE: To reduce co-channel interference

$$\frac{D}{R}\uparrow \quad \Leftrightarrow N\uparrow \quad \Rightarrow M\downarrow \quad \therefore \text{Capacity} \downarrow \text{ since } kN = S = \text{fixed}$$

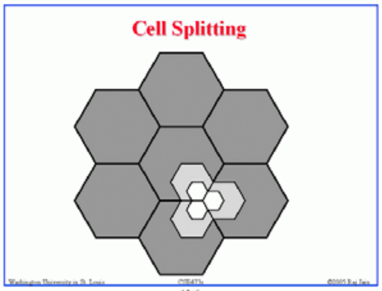
- There is a trade-off between capacity and interference reduction

Approaches to Cope with Increasing Capacity

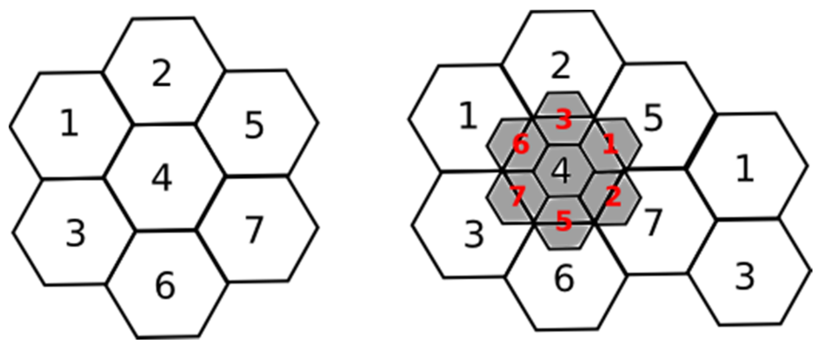
- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into wedge-shaped sectors, each with their own set of channels
- Network densification – 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
- Requires careful power control and possibly more frequent handoffs for mobile stations
- A radius reduction by a factor of F reduces the coverage area and increases the required number of base stations by a factor of F^2



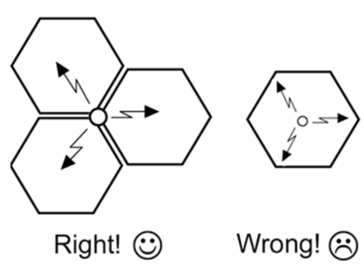
Cell splitting



Radius of small cell half that of the original

Cell sectoring

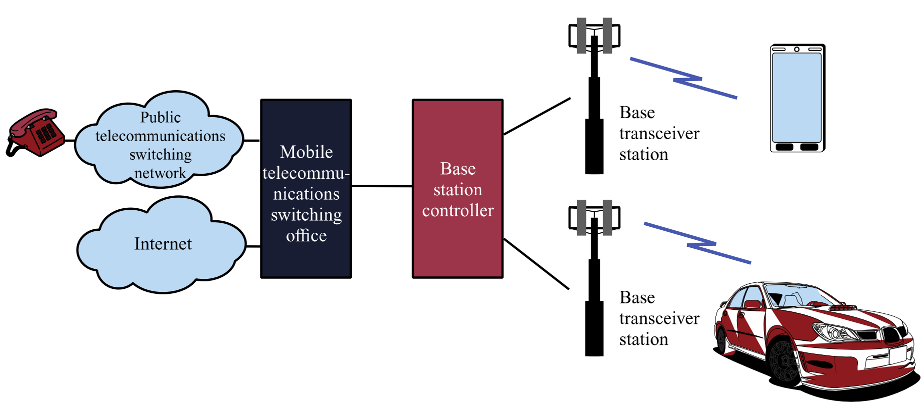
- Cell divided into wedge shaped sectors
- 3-6 sectors per cell, each with own channel set
- Subset of cell's channel, use of directional antennas



Elements of a cellular system

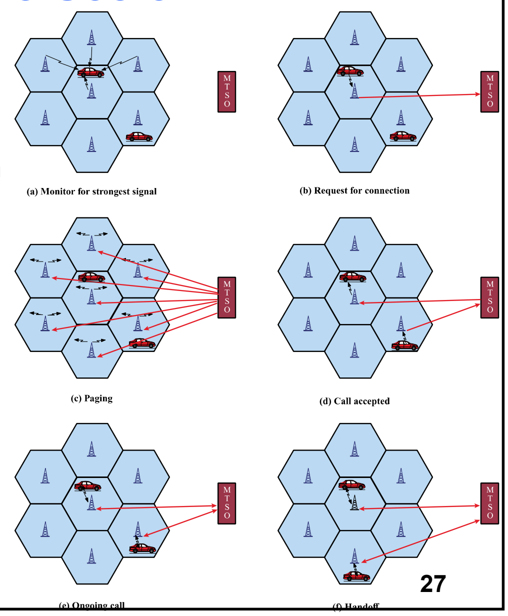
- **Base Station (BS): includes antenna, a controller, and a number of transceivers for communicating on the channels assigned to that cell**
- **Controller handles the call process between the mobile unit and the rest of the network**
- **MTSO: Mobile Telecommunications Switching Office, serving multiple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

Overview of Cellular System



MTSO Sets up Call between Mobile Users

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



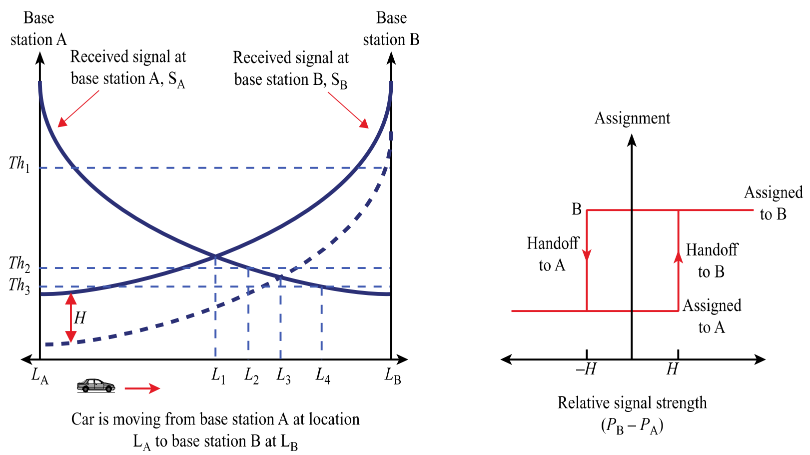
Paging

- 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



(a) Handoff decision as a function of handoff scheme **(b) Hysteresis mechanism**

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 are 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

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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.

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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