This lecture is being recorded

18-452/18-750
Wireless Networks and Applications
Lecture 14: Cellular Introduction

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Spring Semester 2022

http://www.cs.cmu.edu/~prs/wirelessS22/

Announcements

- **Please sign up for a P2 meeting**
- **P1 wrap up**
  - **Help session with Anh after class for those who need it**
  - **For Windows users who still have issues, a linux laptop or USB sticks with Linux are available**

Overview

- Cellular principles – "classic" view
  - A bit of history
  - Cellular design
  - How does a mobile phone call take place?
  - Handoff
  - Frequency Allocation, Traffic Engineering
- Early cellular generations: 1G, 2G, 3G
- Today's cellular: 4G – LTE
- Emerging: 5G widely advertised

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

Cellular versus WiFi

	Cellular	WiFi
Spectrum	Licensed	Unlicensed
Service model	Provisioned "for pay"	Unprovisioned "free"
MAC services	Fixed bandwidth SLAs	Best effort no SLAs

- Implications for Service Level Agreements (SLAs), cost, nature of protocols, …

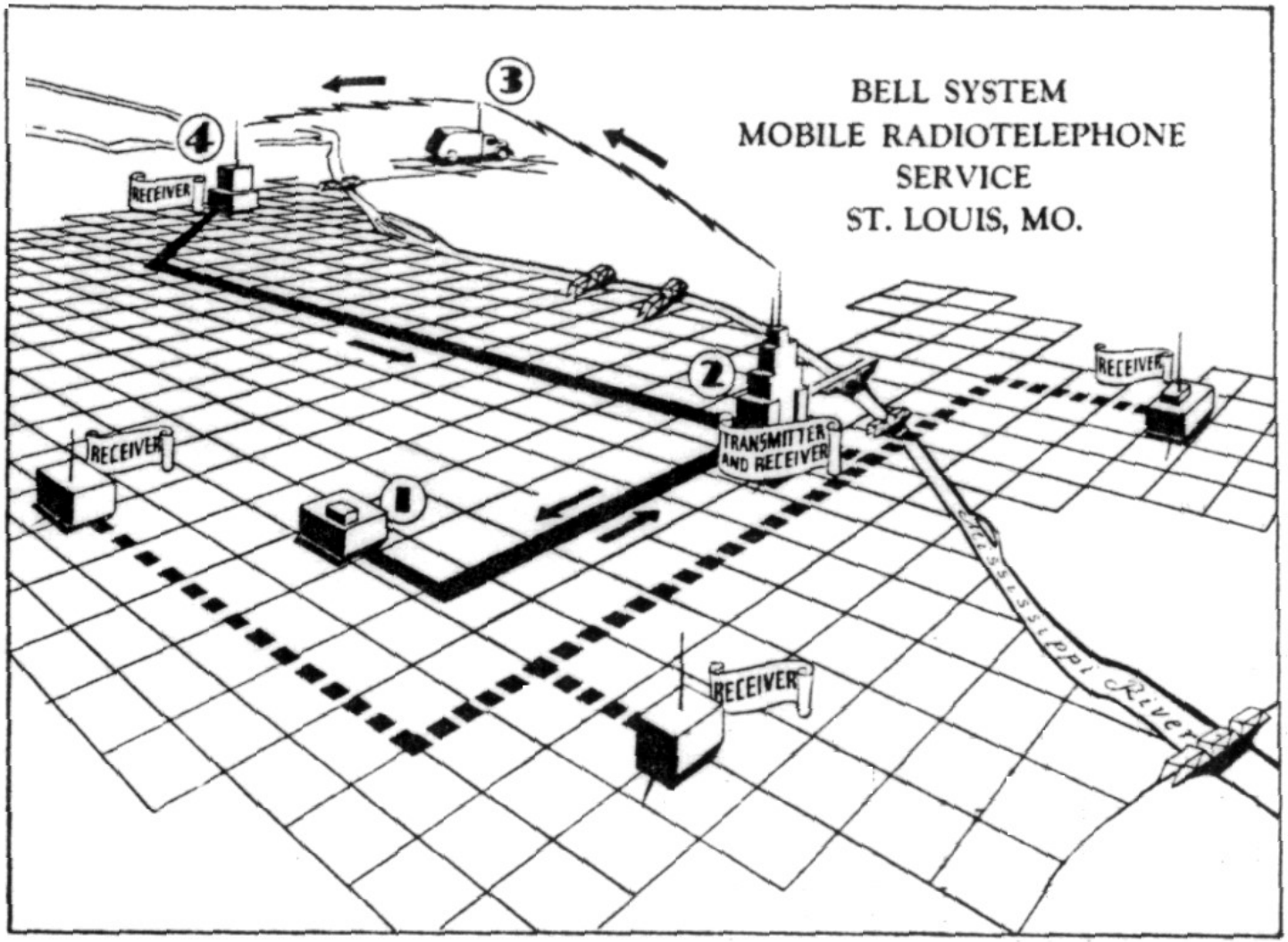
The Cellular Idea

- In December 1947 Donald H. Ring outlined the idea in a Bell labs memo
- Split an area into cells, each 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 Early Mobile Phones

- **First mobile phones bulky, expensive and hardly portable, let alone mobile**
  - » **Phones weighed ~40 Kg**
  - » **Some early prototypes were much bulkier than shown in the pictures (think: large backpack)**
- **Operator assisted with maximum 250 users**

… 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.

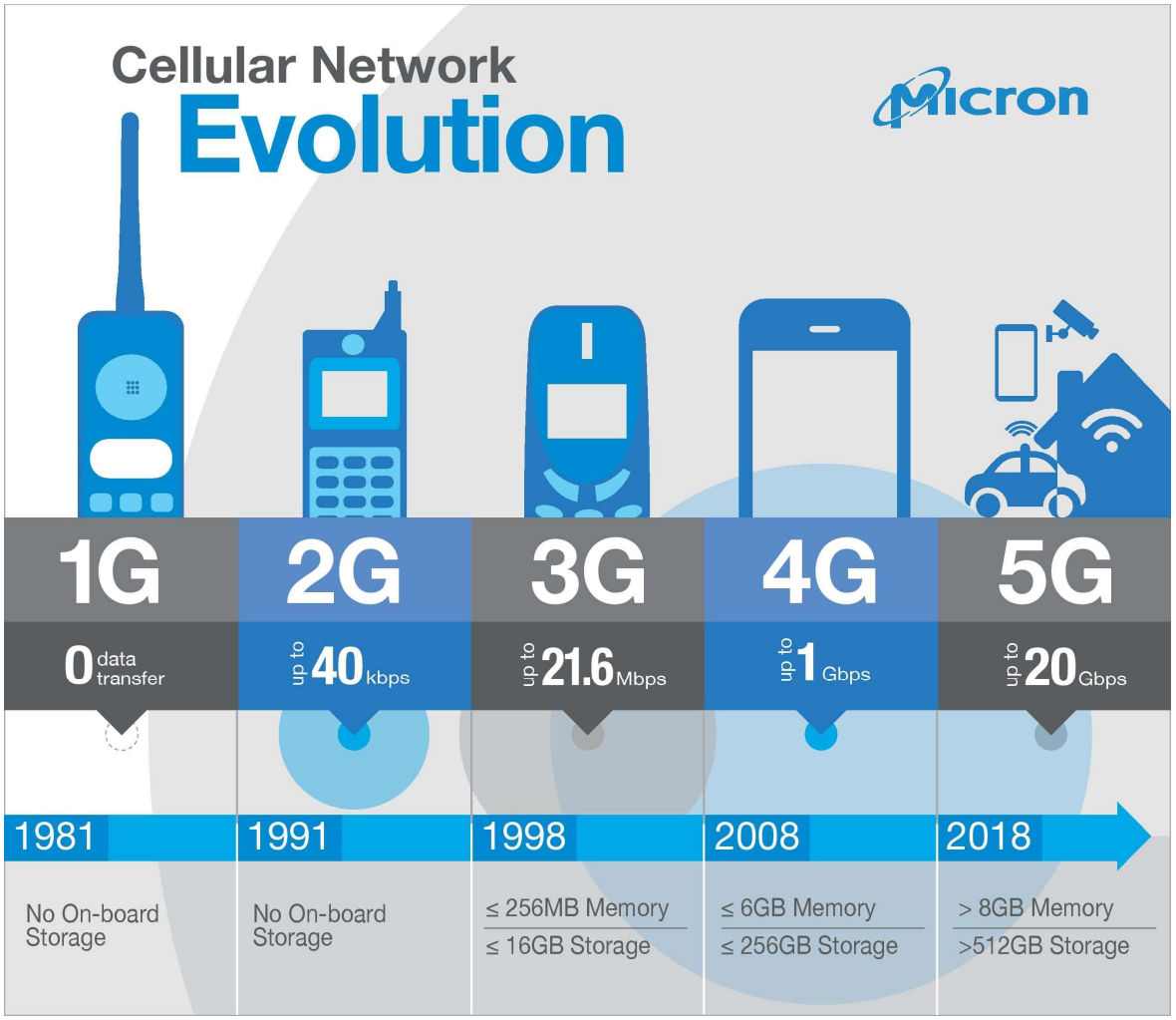
From The Cell-Phone Revolution, AmericanHeritage.com

DynaTAC8000X: the First Cell Phone

- The "brick":
  - Weighed 2 pounds
  - Offered 30 mins of talk time
  - Sold for $3,995!
- It took 10 years to develop (1973-1983) at a cost of $100 million!
  - Size determined by size of batteries, antennas, keypad, etc.
  - Today size determined by the UI!
- First commercial service in early 80s
  - FCC allocated spectrum in 70s

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

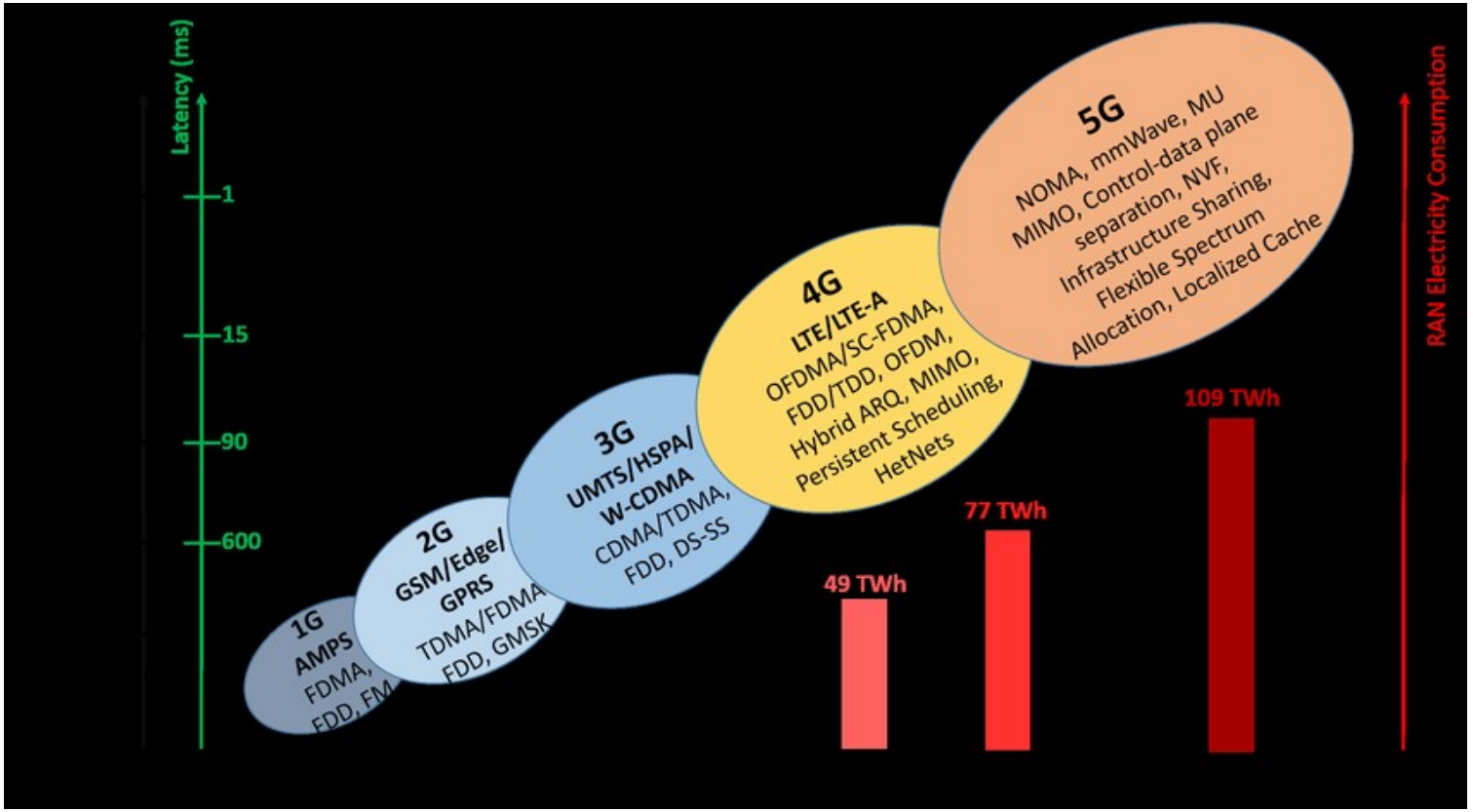
Cellular Generations



eetimes.com

- **Roughly one generation every 10 years**
- **Spectrum allocation for mobile broadband has increased significantly**
  - » **Shift to higher frequencies**

Technologies Used



- **We have already seen many of these technologies!**
- **Terminology for 5G is a bit different – How?**

Standardization Process

- **Standardization takes as much as 10 years**
  - » **Setting goals, identifying technologies**
  - » **Standardization: many releases**
  - » **Product development and trials**

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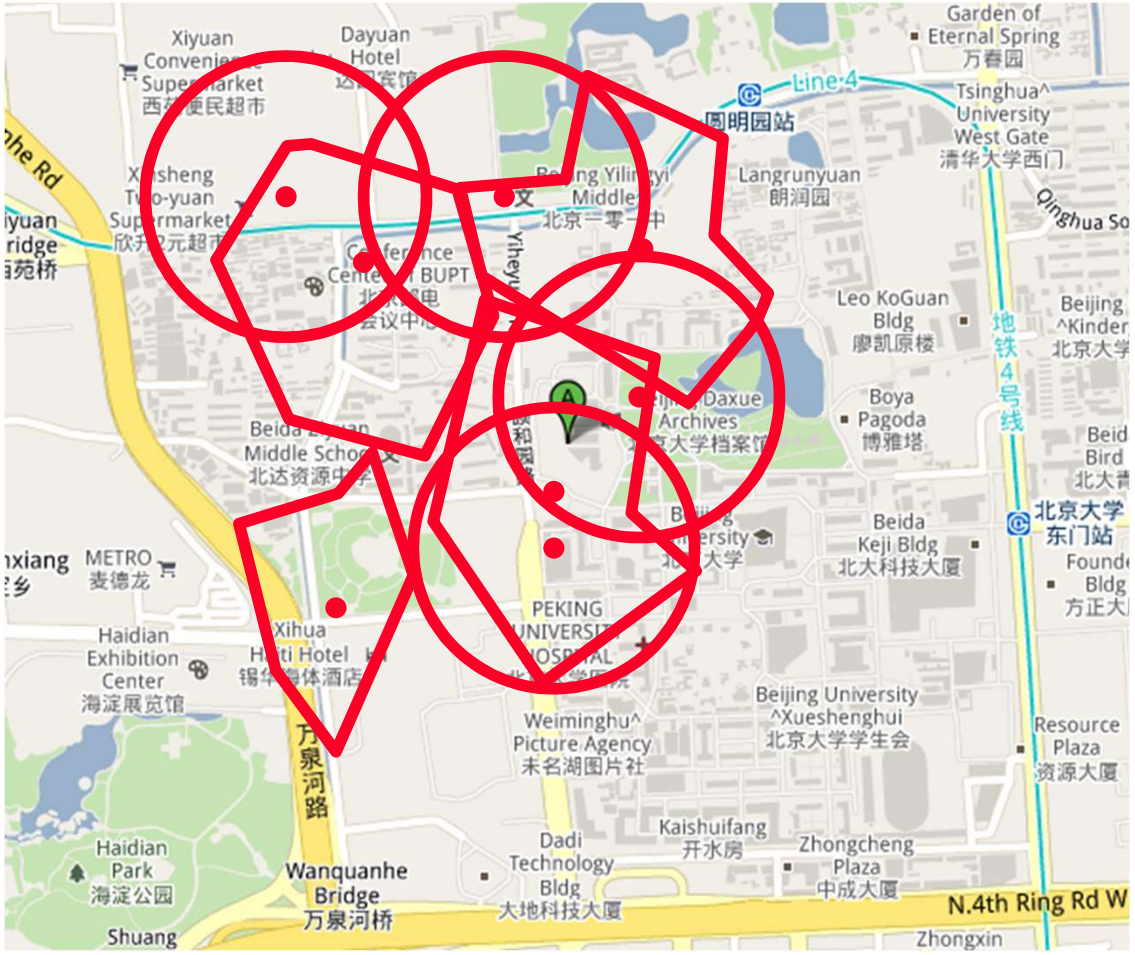
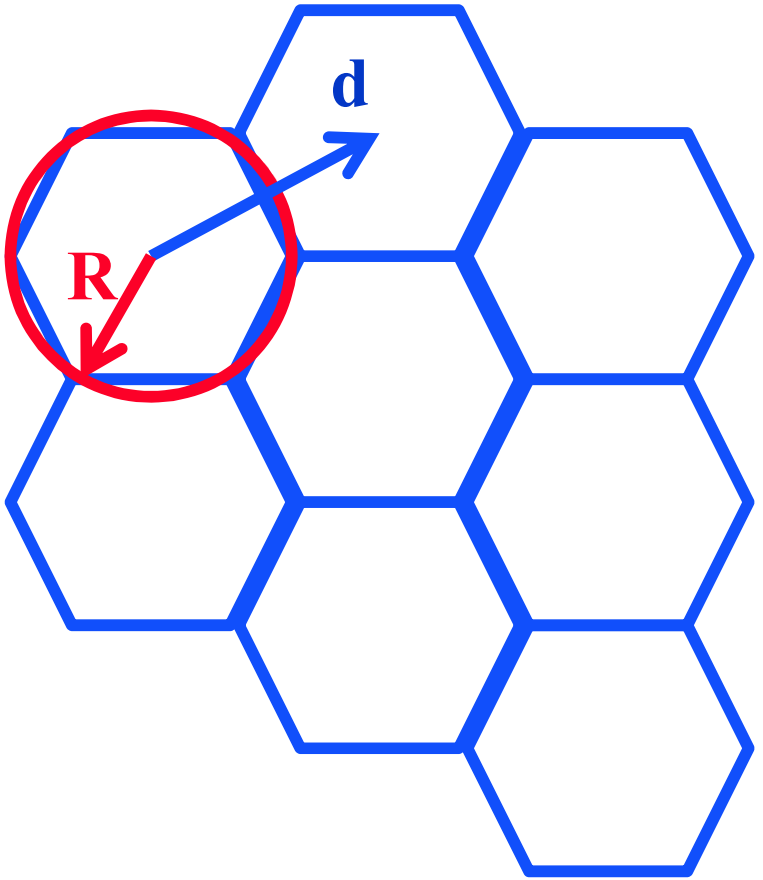
How To Design a Cellular Network?

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



The Hexagonal Pattern

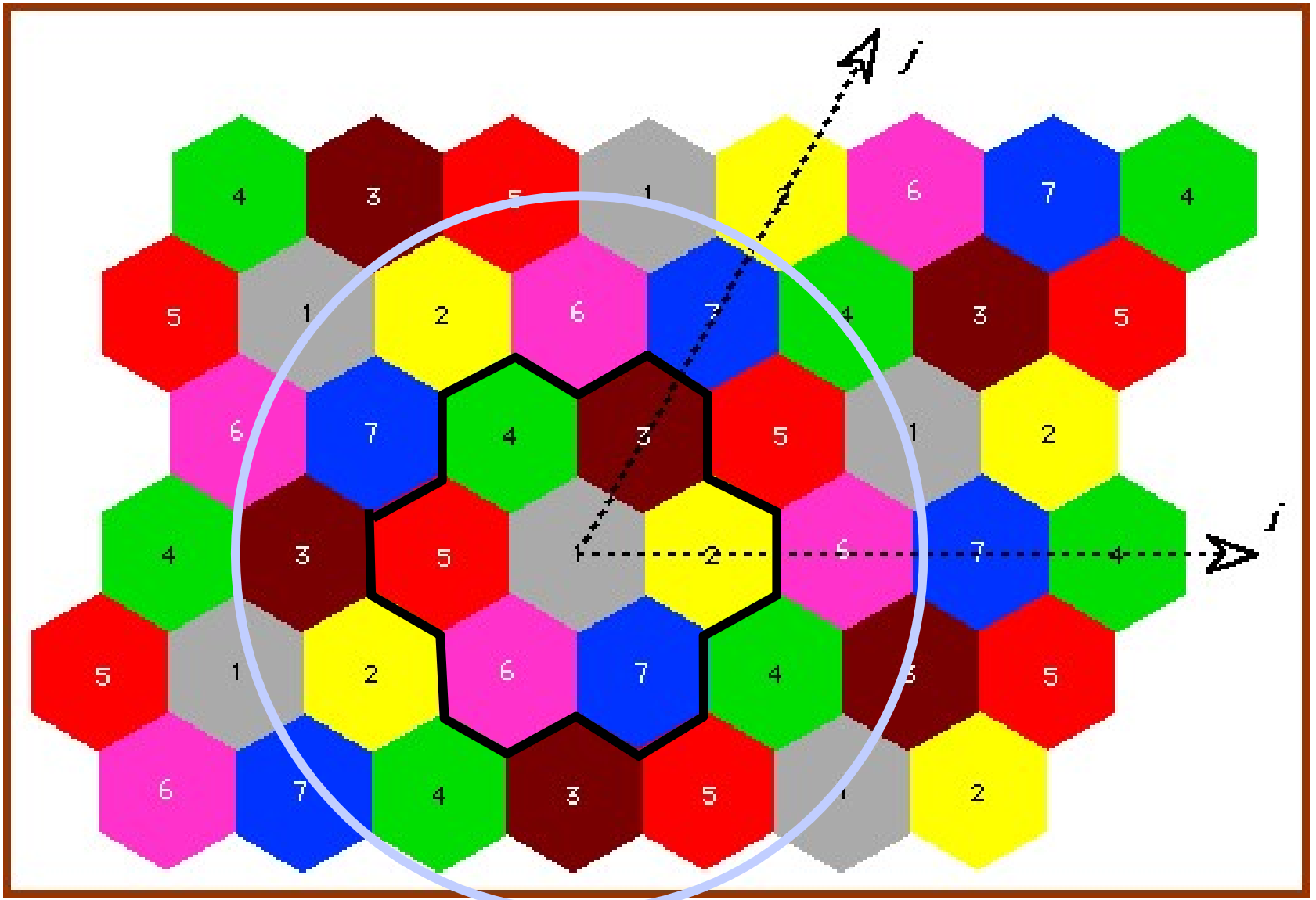
- Network consists of cells each served by a cell tower
  - » Transmit range few kilometers
- Each cell is modeled as a hexagon
  - » d = $\sqrt{3}$R
  - » Hexagons fit to cover a region
  - » Convenient for capacity planning
- In practice, variations from ideal due to topological constraints
  - » Signal propagation
  - » Tower placement, …



Frequency reuse

- Each cell features one cell tower
- 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 noise and interference” ratio

Minimum separation?

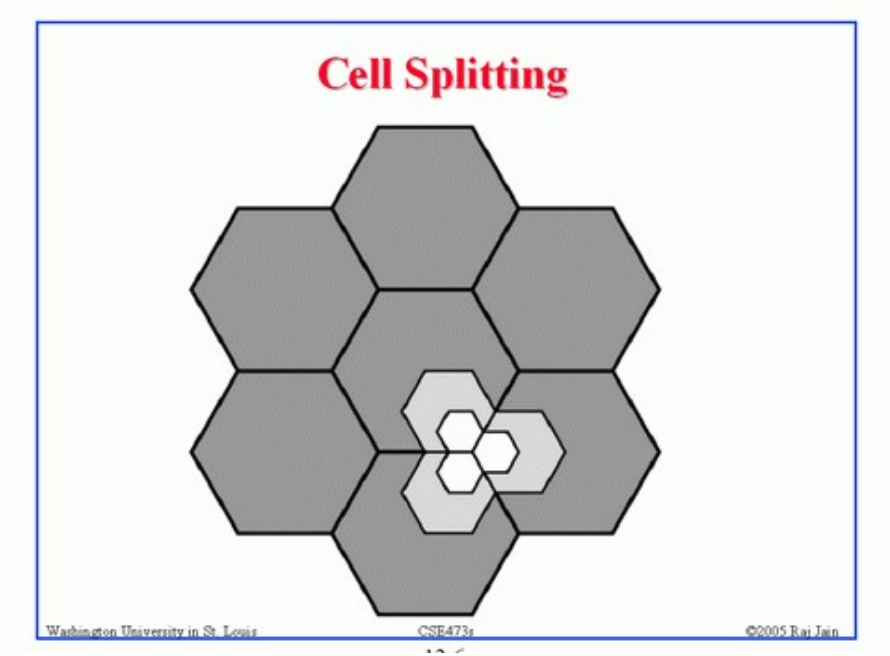


Approaches to Cope with Increasing Capacity

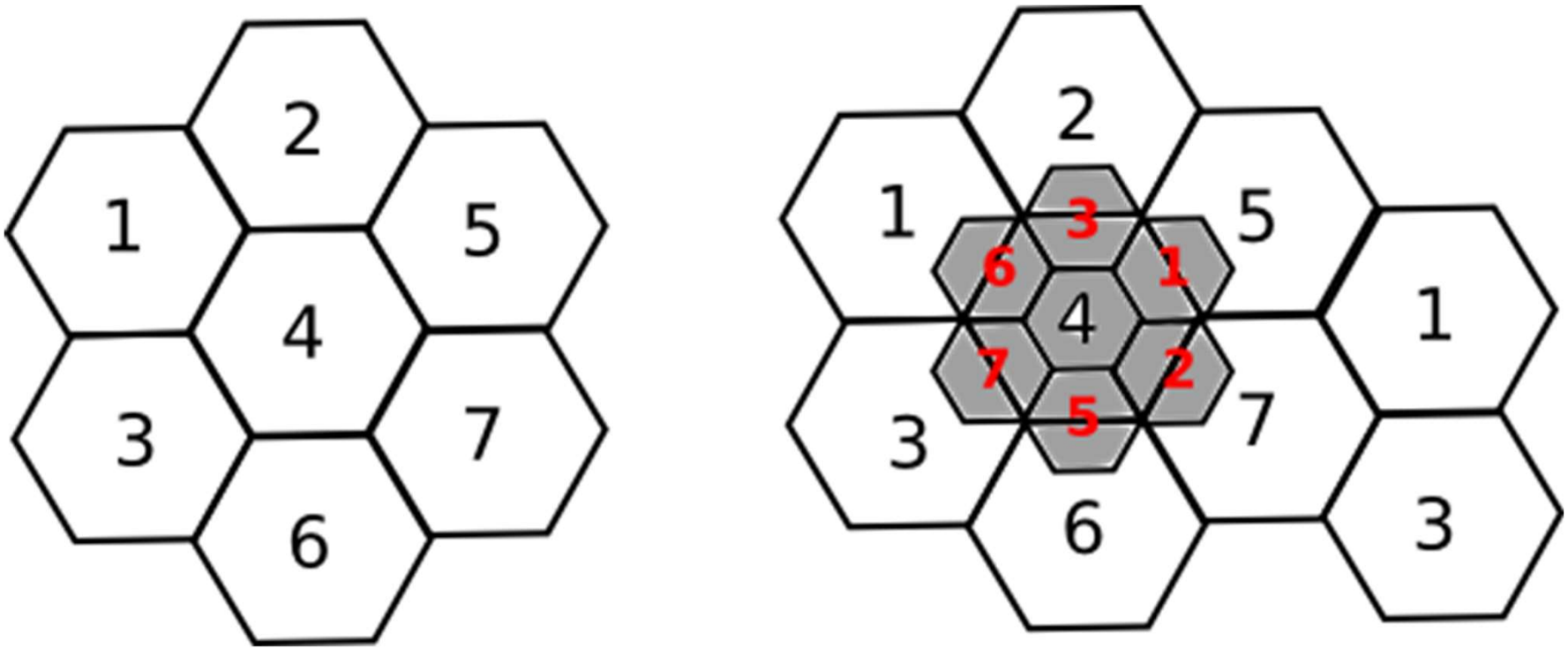
- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into wedge-shaped sectors, each with their own set of channels
- Network densification – 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