Cellular Wireless Networks

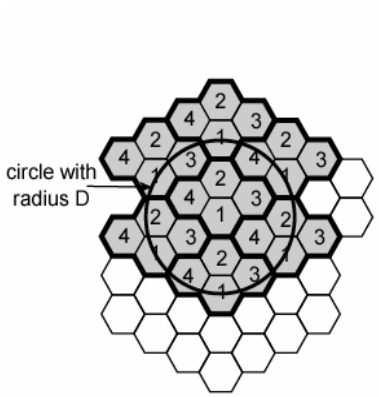
Raj Jain
Washington University
Saint Louis, MO 63131
Jain@cse.wustl.edu

These slides are available on-line at:

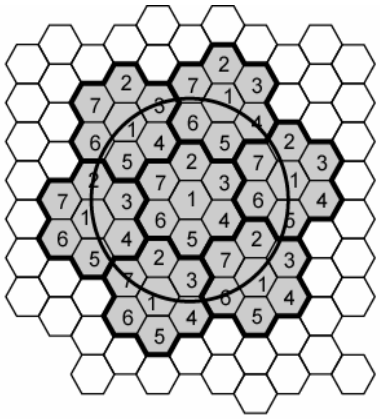
http://www.cse.wustl.edu/~jain/cse473-05/

- Overview of Cellular System
- PHY Issues in Cellular Systems
- Wireless Generations
- First Generation - AMPS
- Second Generation: CdmaOne
- 3G
- Evolution of Cellular Technologies

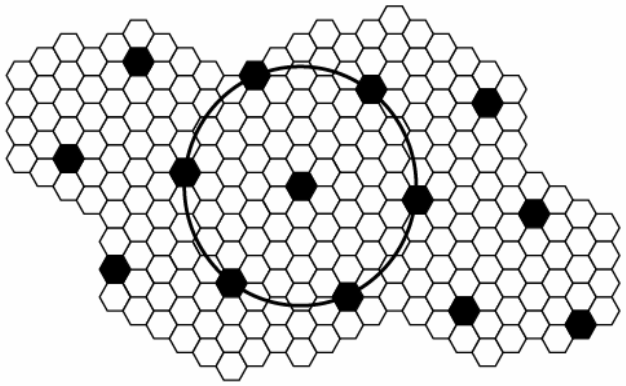
Cellular Frequency Reuse



(a) Frequency reuse pattern for N = 4



(b) Frequency reuse pattern for N = 7



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

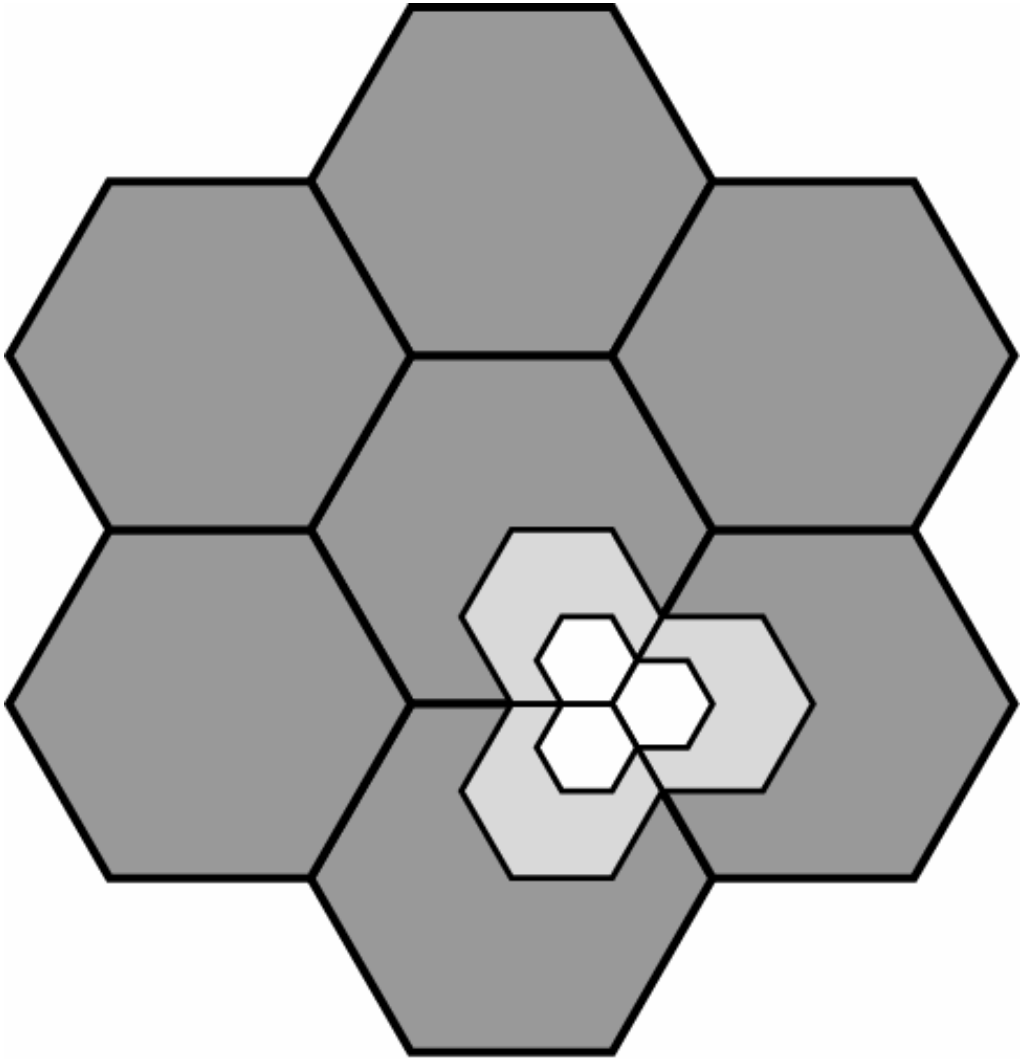
Characterizing Frequency Reuse

- D = minimum distance between centers of cells that use the same band of frequencies (called co-channels)
- R = radius of a cell
- d = distance between centers of adjacent cells (d = R)
- N = number of cells in repetitious pattern
  - Reuse factor
  - Each cell in pattern uses unique band of frequencies
- Hexagonal cell pattern, following values of N possible
  - $N = I^2 + J^2 + (I \times J)$, $I, J = 0, 1, 2, 3, \ldots$
- Possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, …
- $D/R = \sqrt{3N}$
- $D/d = \sqrt{N}$

Increasing Capacity

- Add new channels
  - Not all channels used to start with
- Frequency borrowing
  - Taken from adjacent cells by congested cells
  - Or assign frequencies dynamically
- Cell splitting
  - Non-uniform distribution of topography and traffic
  - Smaller cells in high use areas
    - More frequent handoff, More base stations

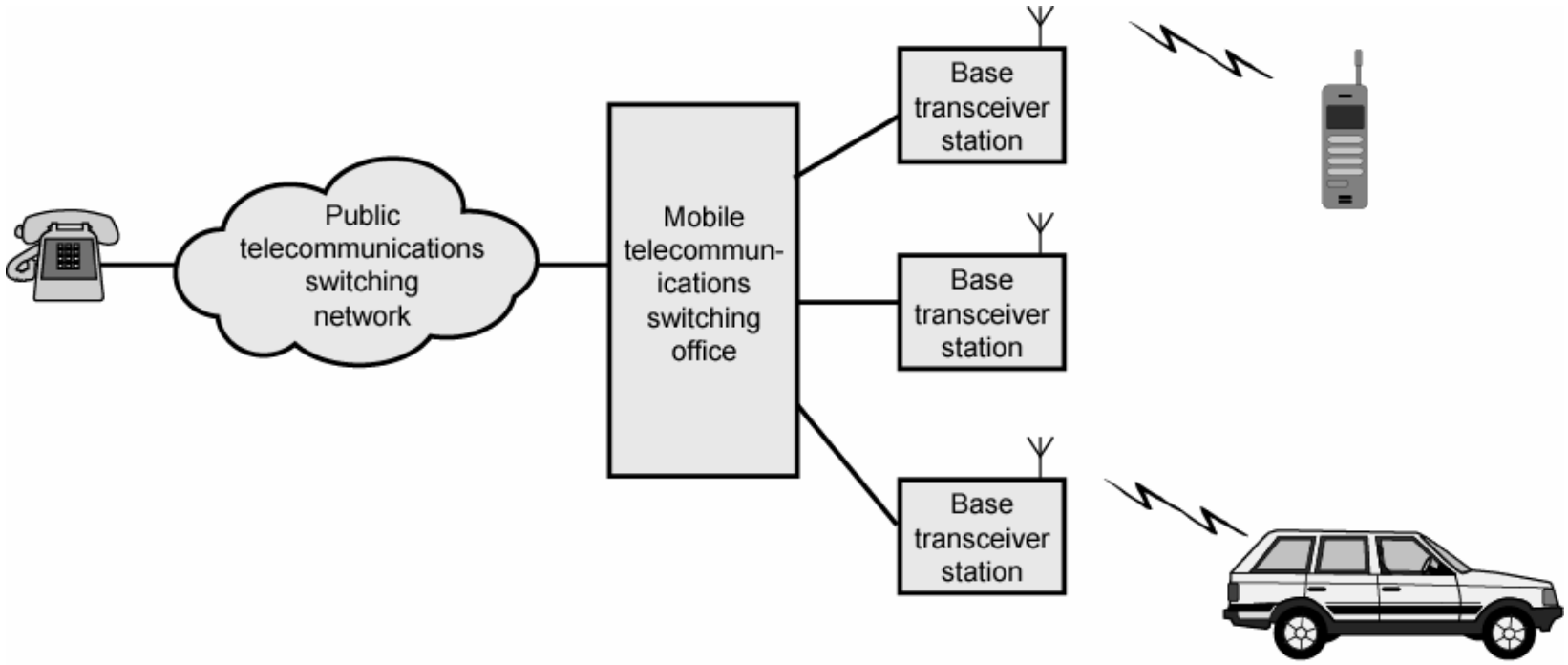
Cell Splitting



Increasing Capacity

- Cell Sectoring
  - Cell divided into wedge shaped sectors
  - 3 – 6 sectors per cell, Each with own channel set
  - Subsets of cell's channels, Directional antennas
- Micro cells
  - Move antennas to tops of small buildings Even lamp posts
  - Form micro cells, Reduced power
  - Good for city streets, along roads and inside large buildings

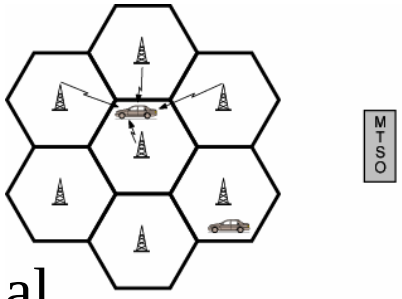
Overview of Cellular System



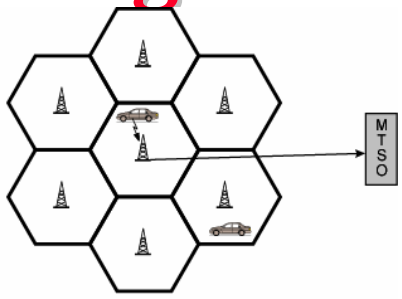
- Base station (BS) at center of each cell
  - Antenna, controller, transceivers
- MTSO handles channel assignment, call connection, billing and handoff

Call Stages

Monitor for strongest Signal



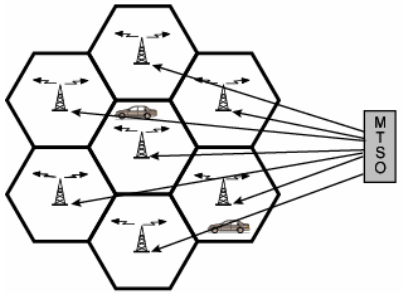
(a) Monitor for strongest signal



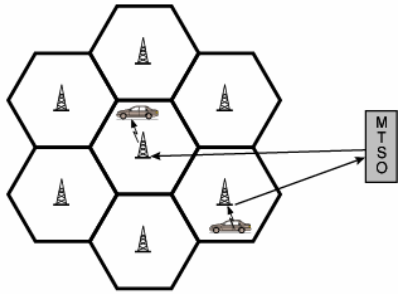
(b) Request for connection

Request for connection

Paging



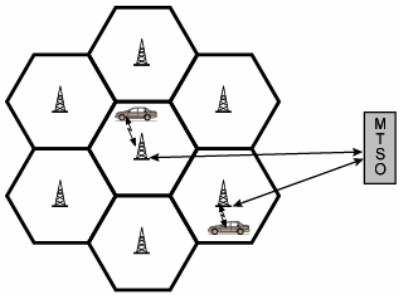
(c) Paging



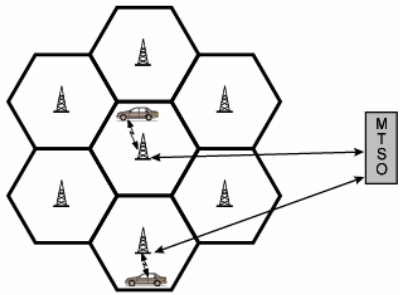
(d) Call accepted

Call accepted

Ongoing Call



(e) Ongoing call



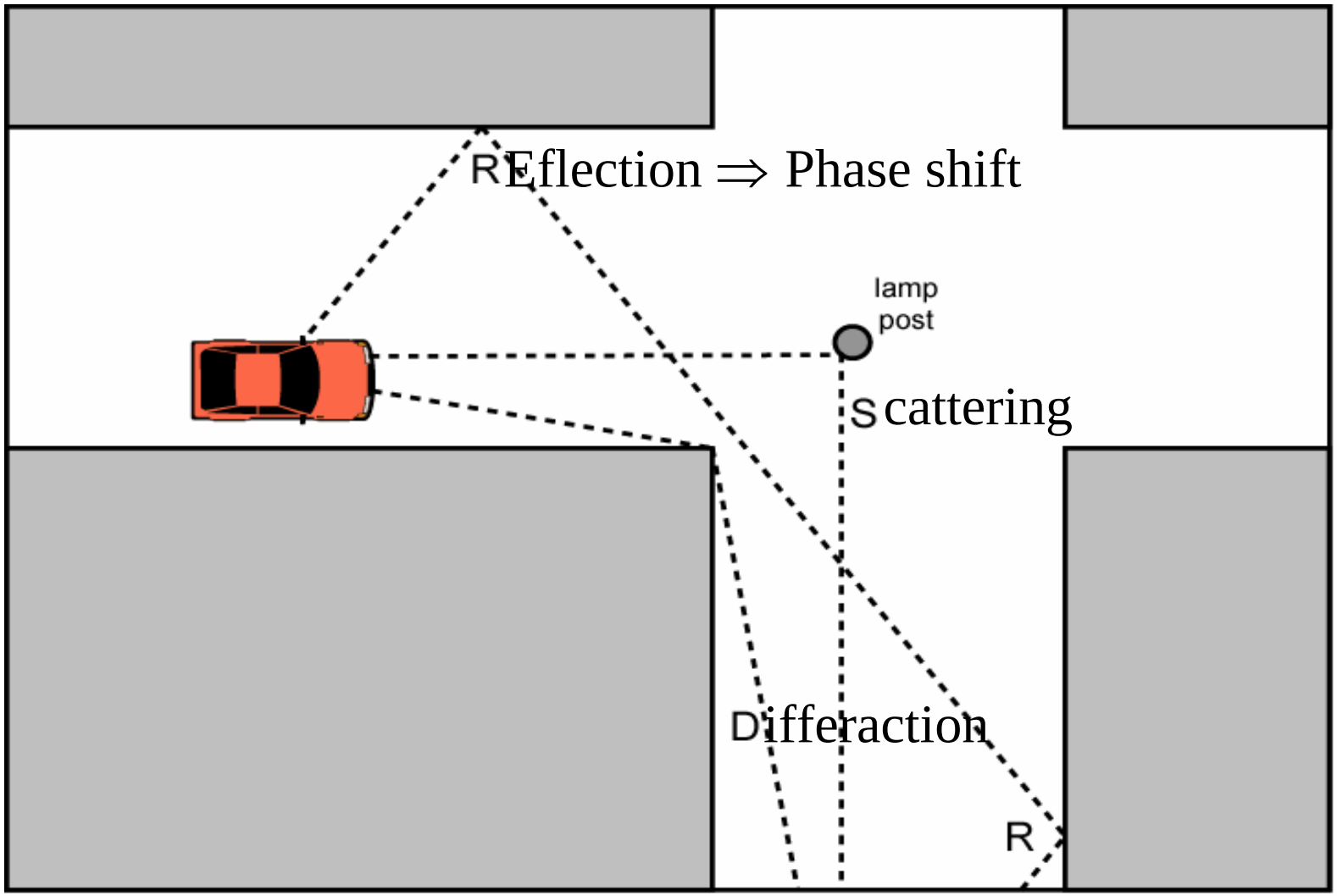
(f) Handoff

Handoff

Other Functions

- Call blocking
  - On mobile-initiated calls, if all channels busy, mobile retries
  - After number of retries, busy tone returned
- Call termination: User hangs up
  - MTSO informed. Traffic channels at two BSs released
- Call drop: BS cannot maintain required signal strength
  - Traffic channel dropped and MTSO informed
- Calls to/from fixed and remote mobile subscriber
  - MTSO can connect mobile user and fixed subscriber via PSTN
  - MTSO can connect to remote MTSO via PSTN or via dedicated lines
  - Can connect mobile user in its area and remote mobile user

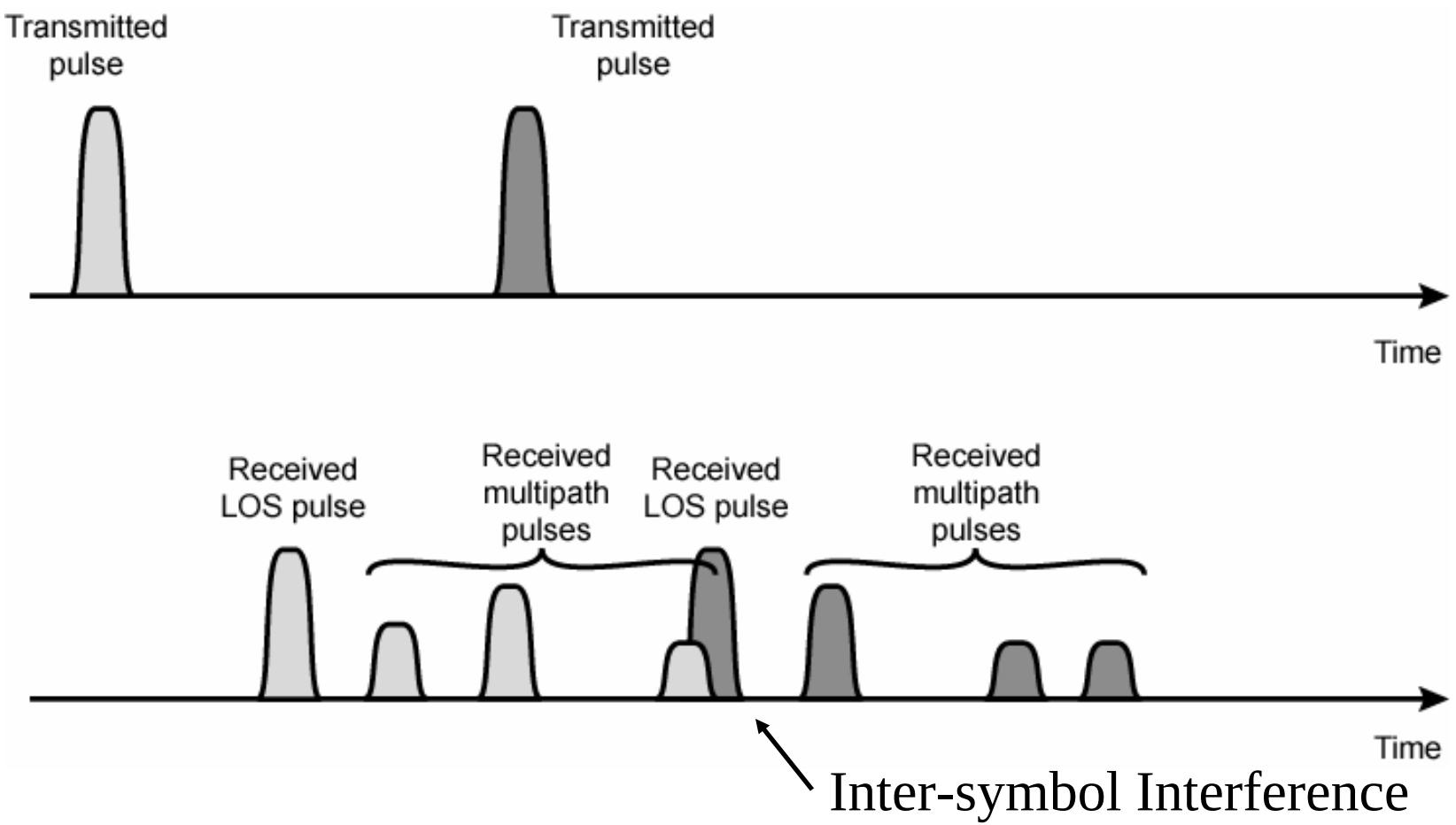
Reflection, Diffraction, Scattering



Reflection, Diffraction and Scattering

- Reflection: Surface large relative to wavelength of signal
  - May have phase shift from original
  - May cancel out original or increase it
- Diffraction: Edge of impenetrable body that is large relative to λ
  - May receive signal even if no line of sight (LOS) to transmitter
- Scattering
  - Obstacle size on order of wavelength. Lamp posts etc.
- If LOS, diffracted and scattered signals not significant
  - Reflected signals may be
- If no LOS, diffraction and scattering are primary means of reception

Multipath Propagation



Types of Fading

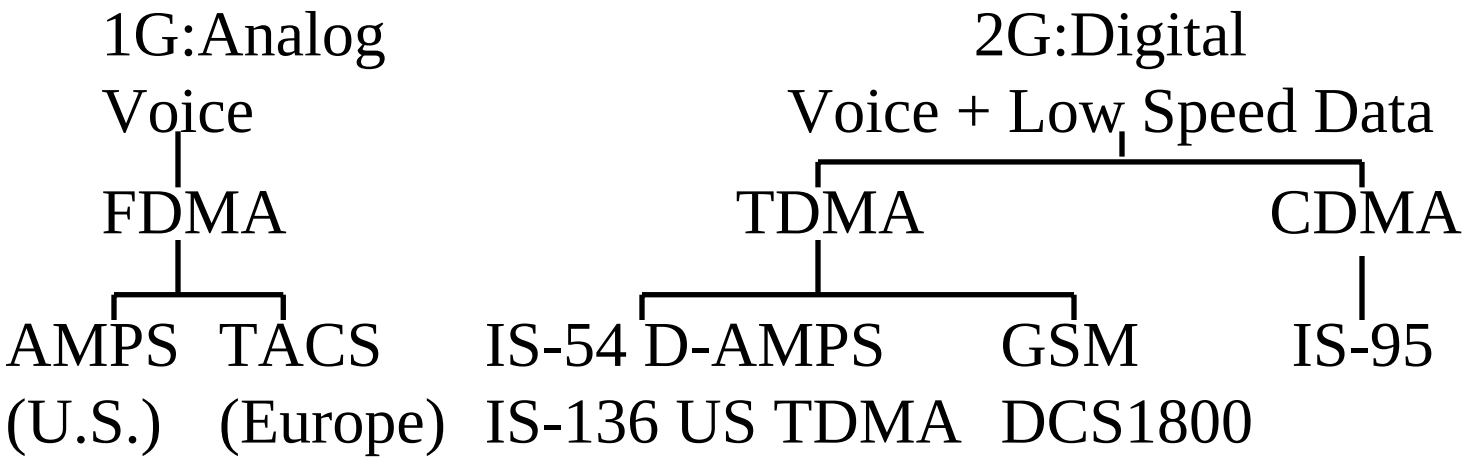
- Fast fading
  - Rapid changes in strength over distances about half λ
  - 900MHz wavelength is 0.33m. 20-30dB
- Slow fading
  - Slower changes due to user passing different height buildings, gaps in buildings etc.
  - Over longer distances than fast fading
- Flat fading
  - Non-selective
  - Affects all frequencies in same proportion
- Selective fading
  - Different frequency components affected differently

Error Compensation Mechanisms

- Forward error correction
  - Typically, ratio of total bits sent to data bits between 2 and 3
  - Big overhead: Capacity one-half or one-third
- Adaptive equalization
  - Used to combat inter-symbol interference
  - Gathering the dispersed symbol energy back together into its original time interval
  - Techniques include so-called lumped analog circuits and sophisticated digital signal processing algorithms
- Antenna Diversity: Multiple antenna in, Multiple Antenna out
- Space Diversity: Directional antennas with multiple beams
- Frequency Diversity: OFDM

Wireless Generations

- 1G: Analog Cellular Phones. Needs a modem. 9.6 kbps max.
- 2G: Digital Cellular Phones. No modem required. 19.3 kbps max. GSM, CDMA
- 2.5G: GPRS. 144kbps. Data only.
- 3G: Future high-speed data with Voice. 64 kbps to 2 Mbps.



IS-54 has analog control channel for compatibility with AMPS. Did not succeed.

First Generation Analog

- Original cellular telephone networks
- Analog traffic channels
- Early 1980s in North America
- Advanced Mobile Phone Service (AMPS)
  - AT&T
- Also common in South America, Australia, and China

Spectral Allocation In North America

- Two 25-MHz bands are allocated to AMPS
  - Downlink: BS to mobile unit (869–894 MHz)
  - Uplink: mobile to base station (824–849 MHz)
- In each market two operators are accommodated
- Each operator is allocated only 12.5 MHz in each direction
- Channels spaced 30 kHz apart $\Rightarrow$ 416 channels per operator
- Twenty-one channels allocated for control. 395 to carry calls
- Control channels are 10 kbps data channels
- Conversation channels carry analog using frequency modulation
- Control information also sent on conversation channels in bursts as data

Operation

- AMPS-capable phone has numeric assignment module (NAM) in read-only memory. It contains
  - Number of phone: Assigned by service provider
  - Serial number of phone: Assigned by the manufacturer
- When phone turned on, transmits serial number and phone number to MTSO
- MTSO has database of mobile units reported stolen
  - Uses serial number to lock out stolen units
- MTSO uses phone number for billing

Call Sequence

1. Subscriber initiates call by keying in number and presses send
2. MTSO validates telephone number and checks user authorized to place call
3. MTSO issues message to user's phone indicating traffic channels to use
4. MTSO sends ringing signal to called party
5. When called party answers, MTSO establishes circuit and initiates billing information
6. When one party hangs up, MTSO releases circuit, frees radio channels, and completes billing information

AMPS Control Channels

- 21 full-duplex 30-kHz control channels
  - Transmit digital data using FSK
  - Data are transmitted in frames
- Control information can be transmitted over voice channel during conversation
  - Mobile unit or the base station inserts burst of data
    - Turn off voice FM transmission for about 100 ms
    - Replacing it with an FSK-encoded message
  - Used to exchange urgent messages
    - Change power level
    - Handoff

Second Generation

- Digital traffic channels: Voice traffic digitized
  - Support digital data
  - Higher quality signals
  - Higher data rates
  - Support of digital services
  - Greater capacity
- Encryption: Simple to encrypt digital traffic
- Error detection and correction $\Rightarrow$ Very clear voice reception
- Channel dynamically shared by users via
  Time division multiple access (TDMA) or
  Code division multiple access (CDMA)

CdmaOne

- Code Division Multiple Access (CDMA)
- CdmaOne = 2G, WCDMA,CDMA2000 = 3G
- Each user uses the entire spectrum. 22-40 calls per carrier.
- Different spreading code for each user.
- Neighboring cells can use the same frequency spectrum (but different codes).
- Precise power control is critical.
- Can serve more users than TDMA or GSM
- Data users limited to 9.6 kbps
- IS-95: CdmaOne

3G

- Also known as ITU IMT-2000 Project. Started in 1980.
- Goal: To have one world-wide standard and a common frequency band for mobile networking
- Result:
  - Three frequency bands: Below 1 GHz, 1.7GHz, 2.5GHz
  - Three different technologies: W-CDMA (Europe) CDMA2000 (North America) , and TD-SCDMA in China.

WCDMA

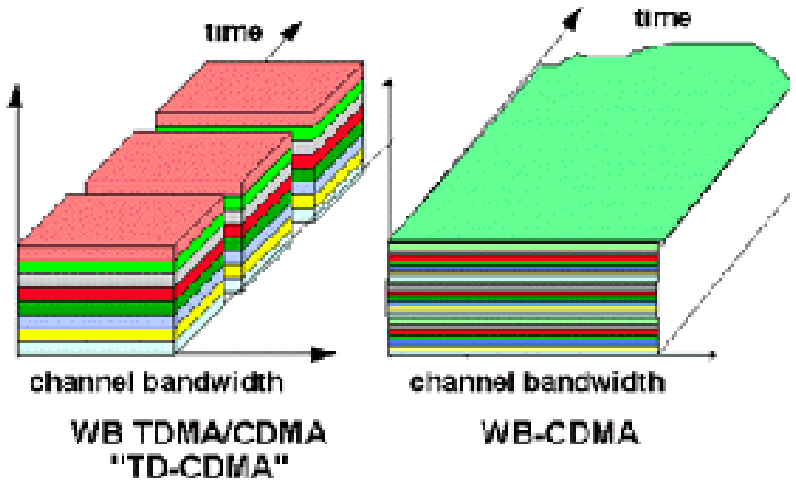
- Wideband CDMA
- Proposed by European Telecom Std Inst (ETSI) Alpha group
- WCDMA has 5MHz single carrier system w Freq Div Duplexing and direct seq (FDD-DS)
- 3rd Generation Partnership Project (3GPP.org)
- 2.5G:
  - GPRS (General Packet Radio Service)
    144 kpbs data only
  - EDGE (Enhanced Data for GSM Evolution)
    384 kbps data
  - HSDPA (High-speed downlink packet access)
    Asymmetric. 2 Mbps+ downlink.

CDMA2000

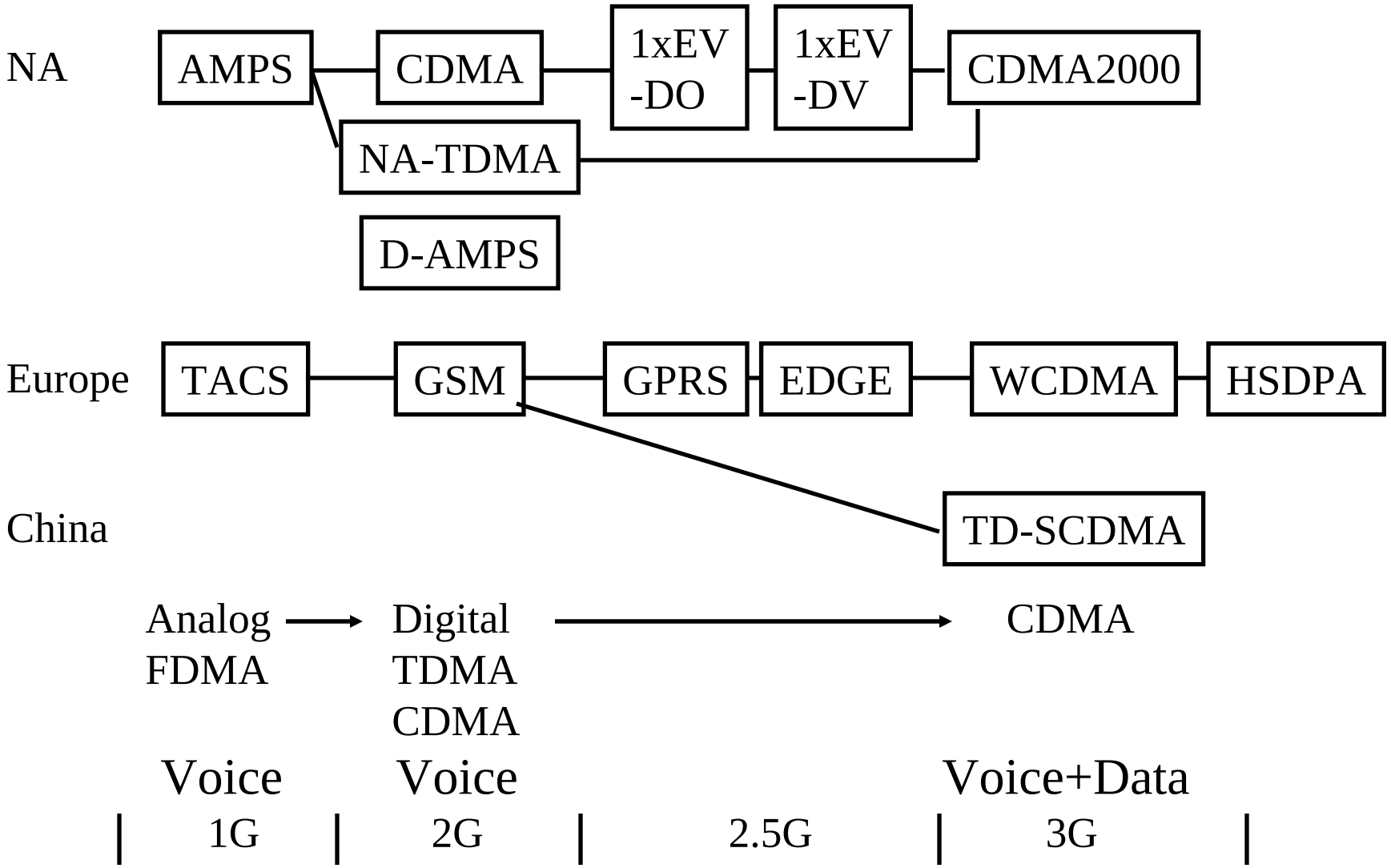
- Proposed by Third Generation Partnership Project 2 (3GPP2.org).
- 3GPP2: Partnership of 5 Telecom standards bodies: ARIB and TTC in Japan, CWTS in China, TTA in Korea and TIA in North America
- Full backward compatibility with IS-95B (cdmaOne)
- CDMA2000 3x also known as CDMA-MC (multi-carrier) is a 3G technology. It uses n carriers of 1.2288 MHz each. 1x, 3x, 6x, 9x, 12x
- Operators can overlay CDMA2000 1x now over cdmaOne.
  - Also known as CDMA2000 1xEV.
  - Implemented in two steps: 1xEV-DO (Evolution data only),
    - 1xEV-DV (Evolution data and voice on one carrier). These are 2.5G technologies.

TD-SCDMA

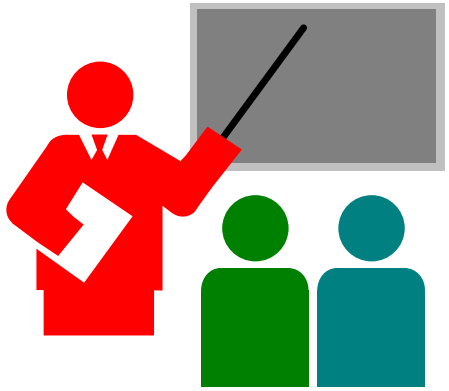
- Time Division Synchronous CDMA
- Proposed by China Wireless Telecommunication Standards group (CWTS)
- Uses Time Division Duplex (TDD)
- Synchronous ⇒ All base station clocks are synchronized
- http://www.tdscdma-forum.org/



Evolution of Cellular Technologies



Summary



- Geometry of cells and frequency reuse
- Fading, diffraction, scattering, multi-path
- Three generations: 1G (Analog), 2G (digital), 3G (Data)
- AMPS
- IS-95
- IMT2000 (W-CDMA, CDMA2000, TD-SCDMA)

Reading Assignment

- Read Chapter 14 of Stallings and try to answer the review questions