Wireless Cellular Networks: 1G and 2G

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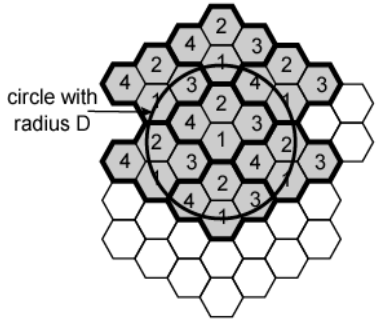
These slides are available on-line at:

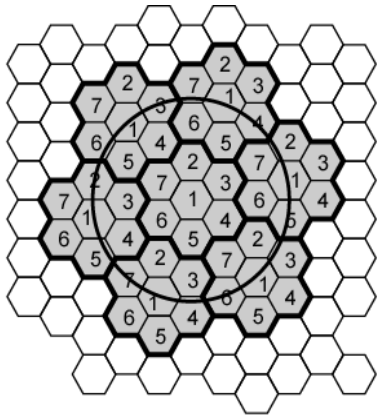
http://www.cse.wustl.edu/~jain/cse574-06/

- Cellular Architecture
- Handoffs
- Advanced Mobile Phone System (AMPS)
- Cellular Digital Packet Data (CDPD)
- Wireless Cellular Generations
- GSM
- CdmaOne

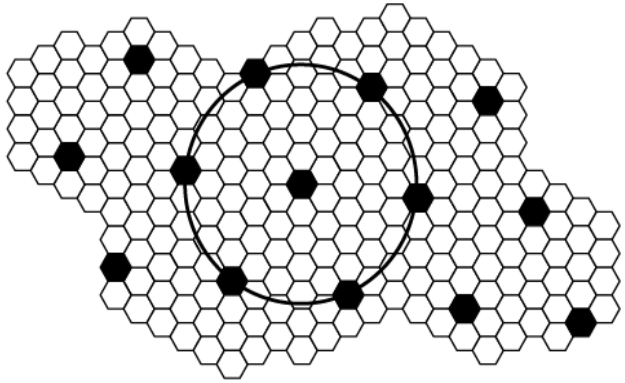
Cellular Frequency Reuse



(a) Frequency reuse pattern for N = 4



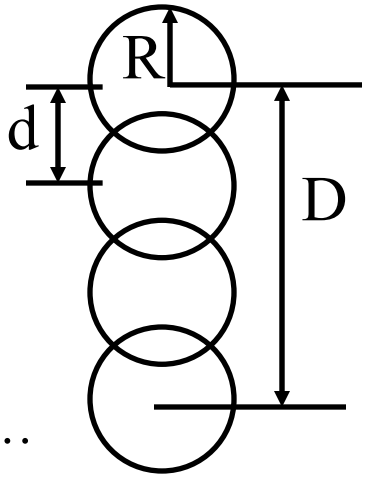
(b) Frequency reuse pattern for N = 7



(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 ($d = R\sqrt{3}$)
- 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, …
- $D/R = \sqrt{3N}$
- $D/d = \sqrt{N}$

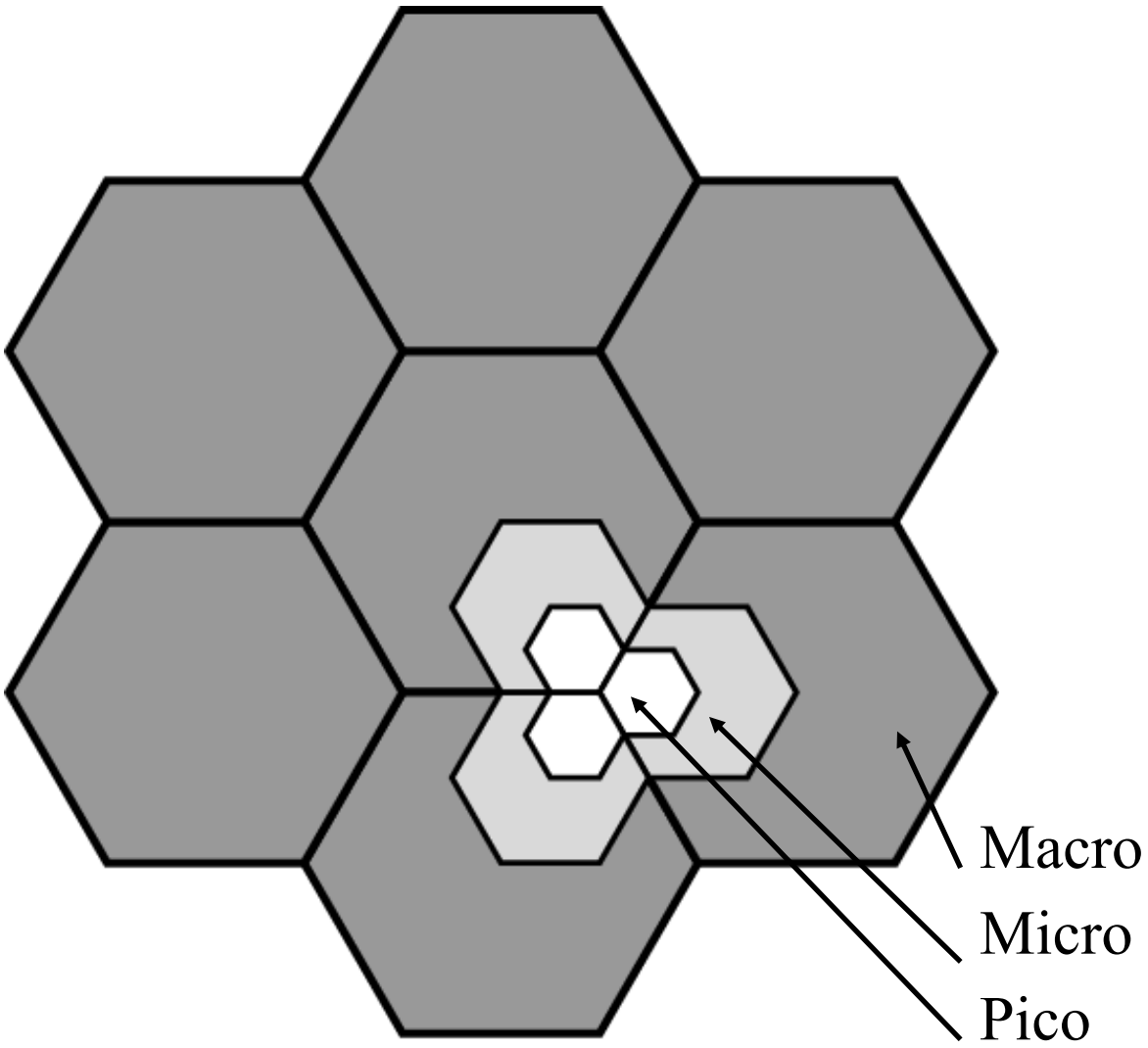


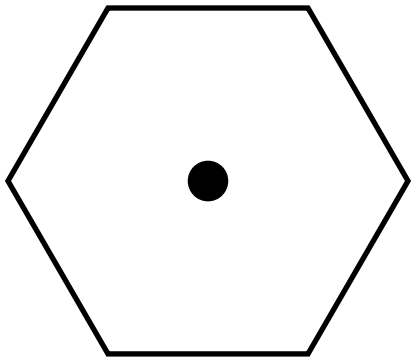
Ref: Derivation in Section 3.2 of Murthy and Manoj

Increasing Cellular Capacity

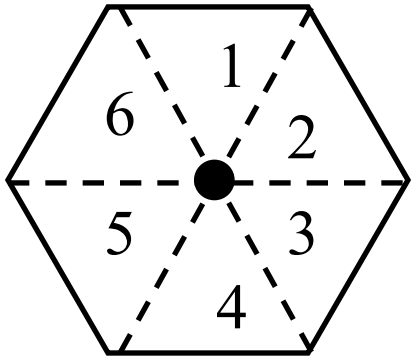
- Add new channels
  - Not all channels used to start with
- Frequency borrowing
  - Taken from adjacent cells by congested cells
  - Or assign frequencies dynamically
- Cell splitting
  - Non-uniform distribution of topography and traffic
  - Smaller cells in high use areas
    - More frequent handoff,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

Cell Splitting and Sectorization





Omni-Directional

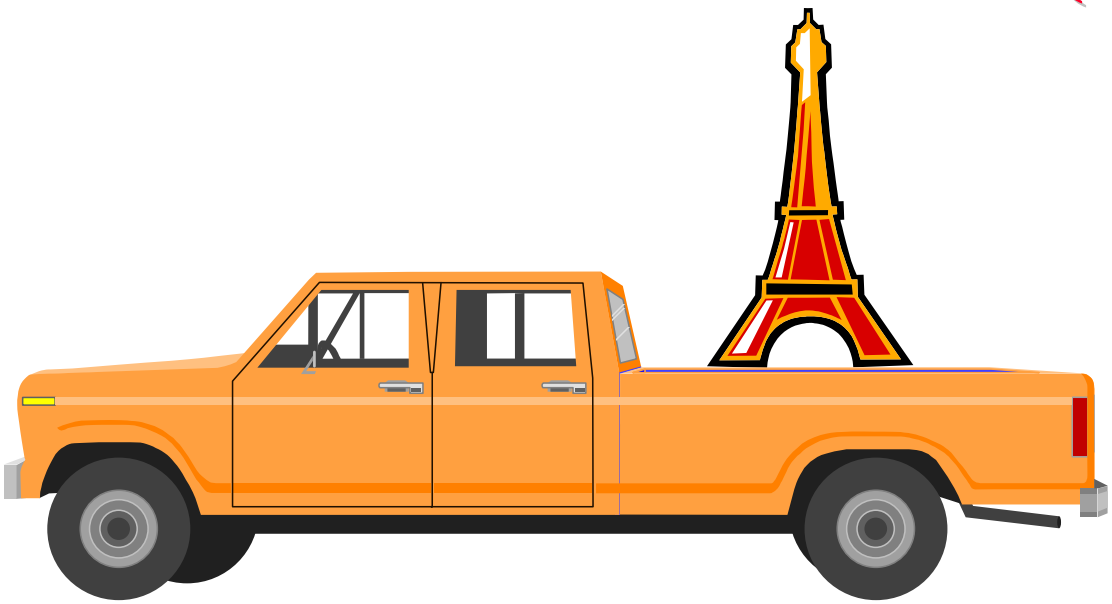


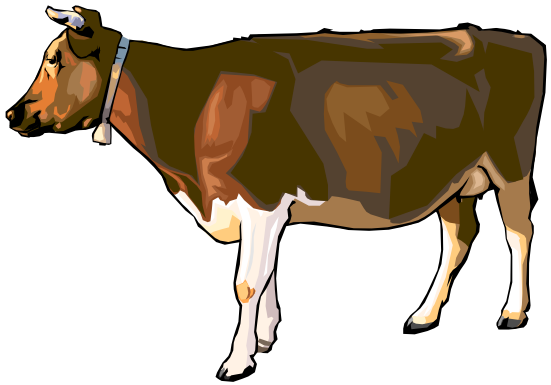
Sectorized

Increasing Cellular Capacity (Cont)

- 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

Cells on Wheels (COW)





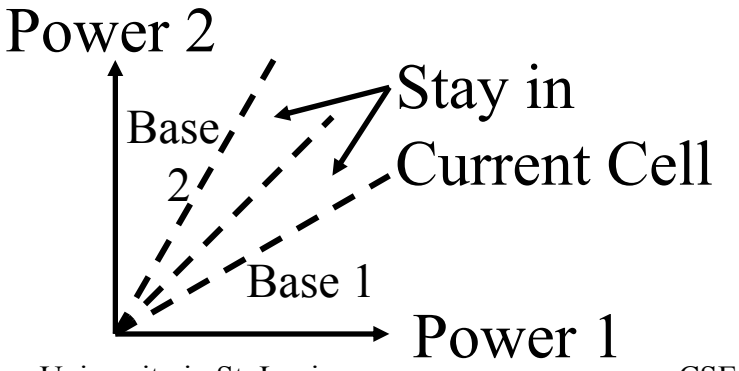
- Cell site mounted on a flatbed tractor-trailer
- Bull = Large size COW
- Calves = Small size COW
- Herd = Large number of COWs

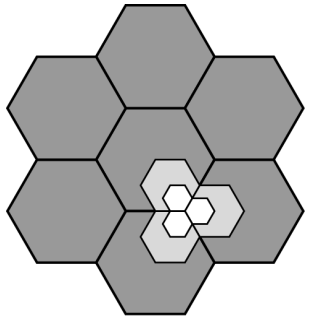
Handoffs

- Handover = Move from one station to next
- Issues:
  - Which BS is optimal?
  - Avoid ping-pong oscillations
  - Avoid data loss
  - Subscriber or BS initiated?
- Quality Metrics:
  - Handoff delay
  - Duration of interruption
  - Probability of successful handoff
  - Probability of unnecessary handoff

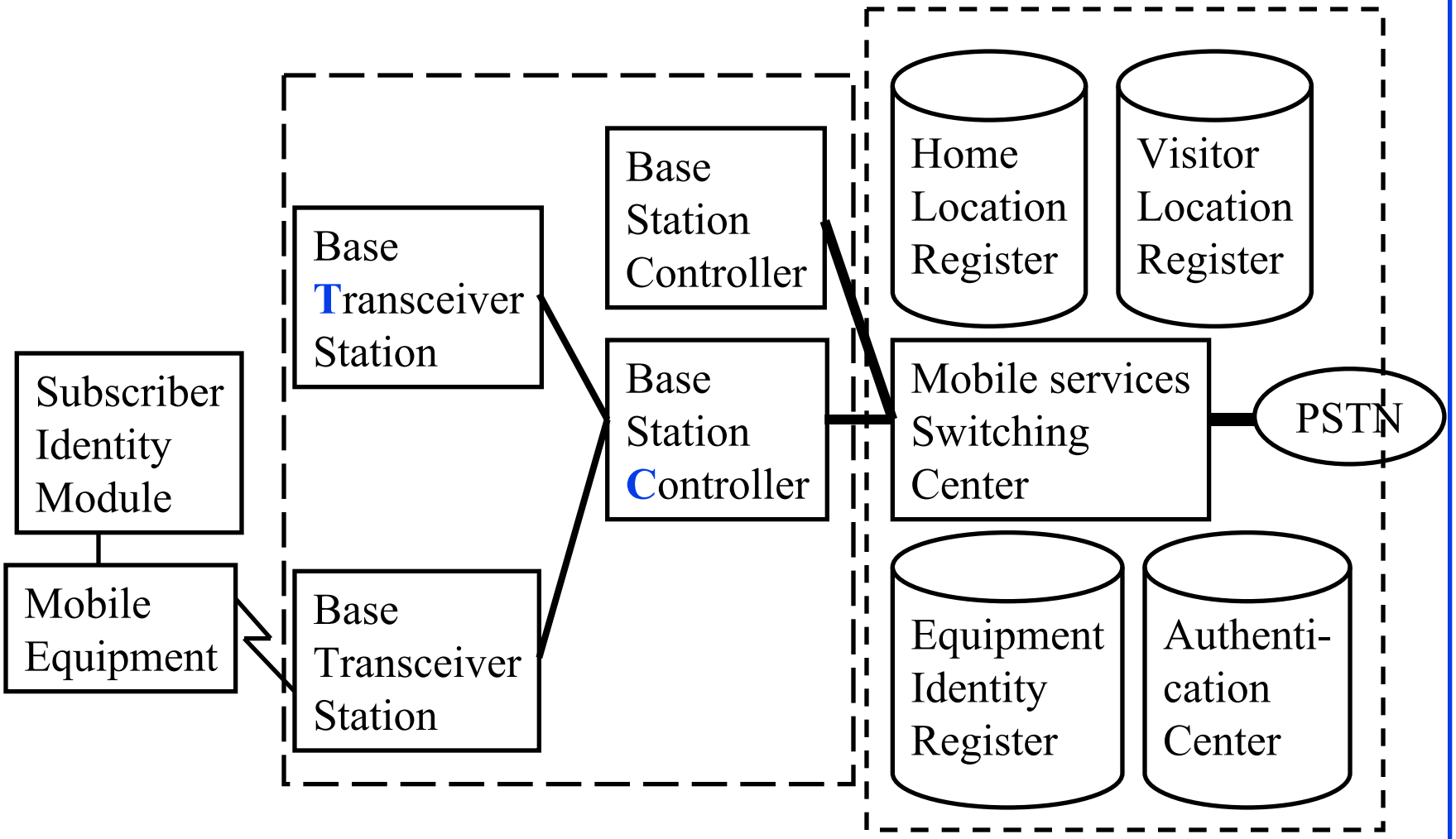
Improved Handoff Strategies

- Higher priority to handoff than new connections
- Hysterisis effect to decide whether new BS is better than old
- Soft Handoffs: Connected to both for a short time
- Predictive handoffs: Use speed and direction
- Adaptive handoffs: Move between pico-, micro-, macro-cellular depending on the mobility





Cellular Architecture



Mobile Station Base Station Subsystem Network Subsystem

Cellular Architecture (Cont)

- Base station controller (BSC) and Base transceiver station (BTS)
- One BTS per cell.
- One BSC can control multiple BTS.
  - Allocates radio channels among BTSs.
  - Manages call handoffs between BTSs.
  - Controls handset power levels
- Mobile Switching Center (MSC) connects to PSTN and switches calls between BSCs. Provides mobile registration, location, authentication. Contains Equipment Identity Register.

Cellular Architecture (Cont)

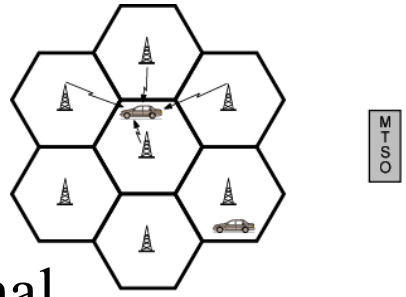
- Home Location Register (HLR) and Visitor Location Register (VLR) provide call routing and roaming
- VLR+HLR+MSC functions are generally in one equipment
- Equipment Identity Register (EIR) contains a list of all valid mobiles.
- Authentication Center (AuC) stores the secret keys of all SIM cards.
- Each handset has a International Mobile Equipment Identity (IMEI) number.

Advanced Mobile Phone System (AMPS)

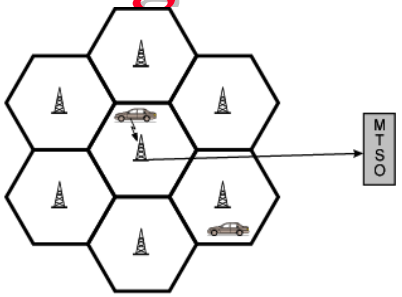
- First generation analog system for North America
- Two 25-MHz bands are allocated to AMPS
  - Forward (Down): BS to mobile unit (869–894 MHz)
  - Reverse (Up): Mobile to base station (824–849 MHz)
- In each market two operators are accommodated
- Each operator is allocated only 12.5 MHz in each direction
- Channels spaced 30 kHz apart $\Rightarrow$ 416 channels per operator
  21 Control/paging/access, and 395 traffic channels
- Each call uses two traffic channels
  Forward = Reverse + 45 MHz
- Control channels are 10 kbps digital channels
  Traffic channels are analog using frequency modulation

Call Stages

Monitor for strongest Signal



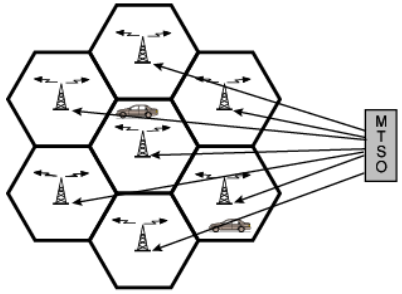
(a) Monitor for strongest signal



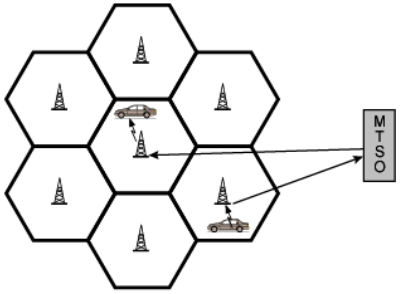
(b) Request for connection

Request for connection

Paging



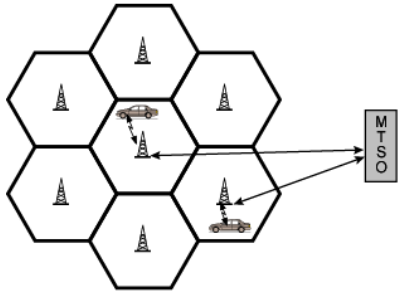
(c) Paging



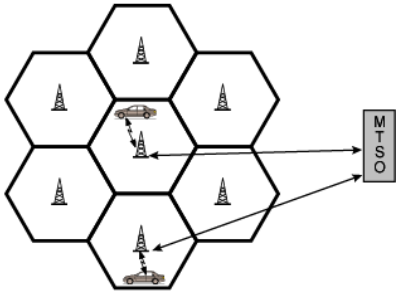
(d) Call accepted

Call accepted

Ongoing Call



(e) Ongoing call



(f) Handoff

Handoff

Typical Call

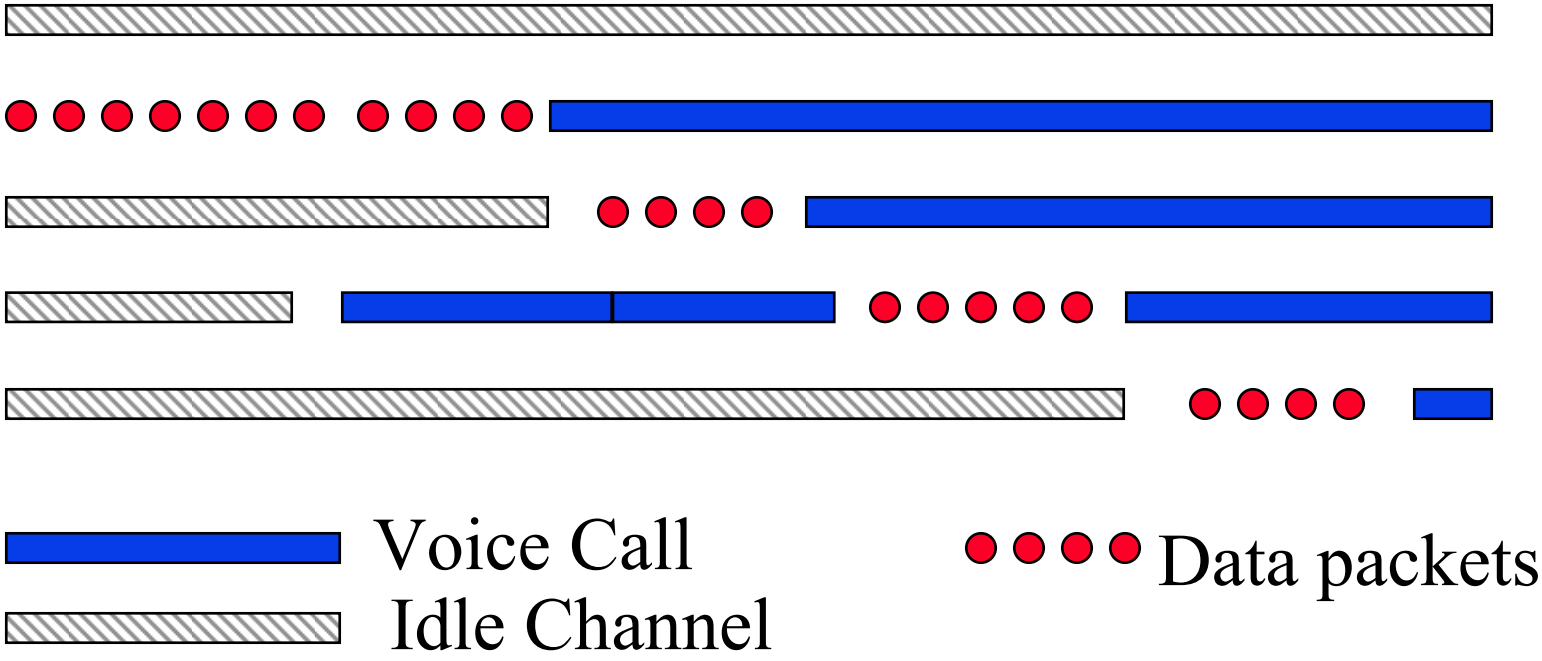
- Mobile unit initialisation
  - Scan and select strongest set-up control channel
  - Automatically selects BS antenna of cell
  - Handshake to identify user and register location
  - Scan repeated to allow for movement
- Mobile originated call: Check set-up channel is free
  - Monitor forward channel (from BS) and wait for idle
  - Send number on pre-selected channel
- Paging
  - MTSO sends the paging message to appropriate BSs
  - Paging signal transmitted on set-up channel

Typical Call (Cont)

- Call accepted
  - Mobile unit recognizes number on set-up channel
  - Responds to BS which sends response to MTSO
  - MTSO sets up circuit between calling and called BSs
  - MTSO selects available traffic channel and notifies BSs
  - BSs notify mobile unit of channel
- Ongoing call
  - Voice/data exchanged through respective BSs and MTSO
- Handoff
  - Mobile unit moves out of range of cell into range of another cell
  - Traffic channel changes to one assigned to new BS
    - Without interruption of service to user

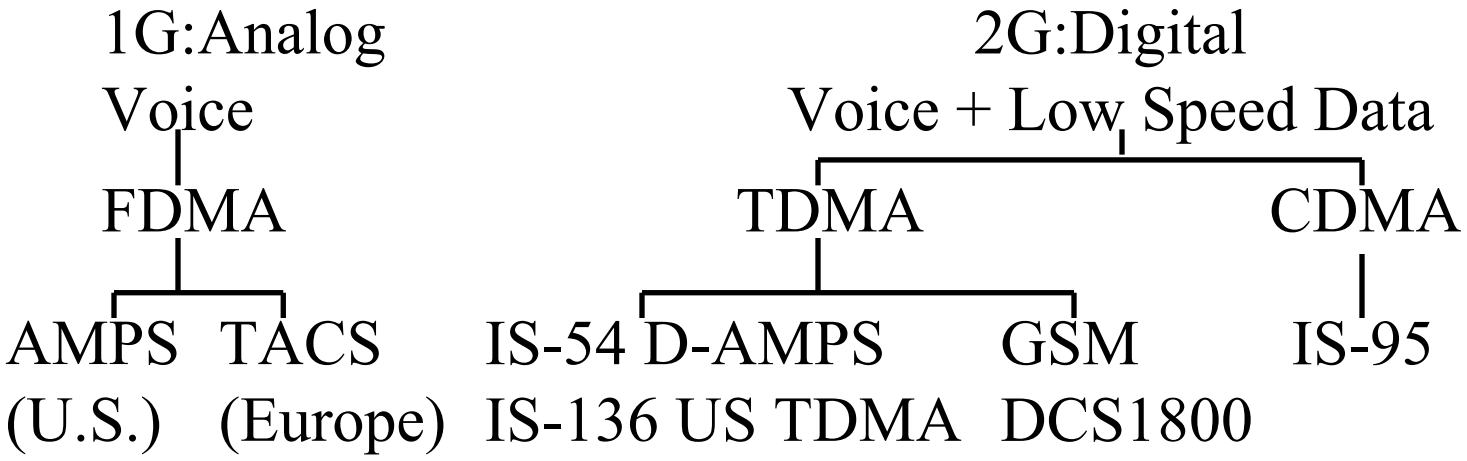
Cellular Digital Packet Data (CDPD)

- Allows data to use idle cellular channels
- Data hops from one channel to next as the channels become busy or idle
- Quickly hops-off a channel grabbed by cellular system. In practice, dedicated channels.



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 => Clear voice, Encryption
- 2.5G: GPRS. 144kbps. Data only.
- 3G: Future **high-speed data** with Voice. 64 kbps to 2 Mbps
- 4G: **IP based**



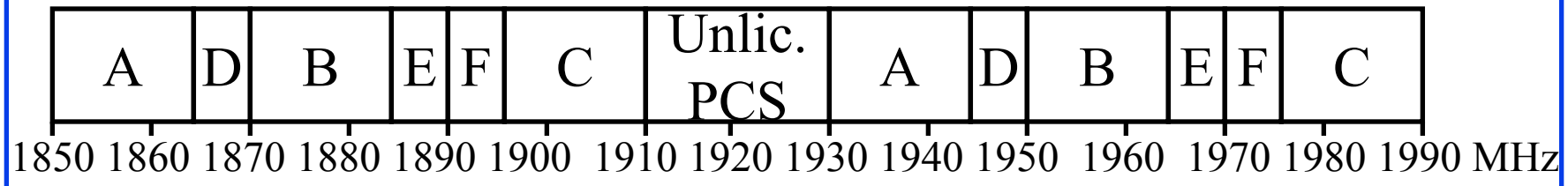
IS-54 has analog control channel for compatibility with AMPS. Did not succeed.

Wireless Generations (Cont)

- Acronyms:
  - Advanced Mobile Phone System (AMPS)
  - Total Access Communication System (TACS)
  - Interim Standard (IS) from Electronic Industry Association (EIA)/Telecommunications Industry Association (TIA)
  - Digital Advanced Mobile Phone System (D-AMPS)
  - Global system for mobile communication (GSM)
  - Digital Communication Network (DCN)
  - North America (NA)
  - Frequency/Time/Code division multiple access (FDMA/TDMA/CDMA)

PCS

- Personal Communication Service (PCS)
- Personal = User specific (vs location specific)
  $\Rightarrow$ Phone # for user regardless of his/her location
- FCC spectrum for PCS requires digital service
- PCS = Digital Cellular = IS-136, GSM, or CDMA
- PCS Spectrum:



Blocks A, B are for major trading areas.
Blocks C, D, E, F are for basic trading areas.
Unlicensed PCS is nationwide.

CdmaOne

- Code Division Multiple Access (CDMA)
- CdmaOne = 2G (IS-95a), CdmaTwo = IS-95b, 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 4.8 and 14.4 kbps
- CdmaTwo extension offers up to 115.2 kbps
- Verizon, Sprint networks are CdmaOne networks

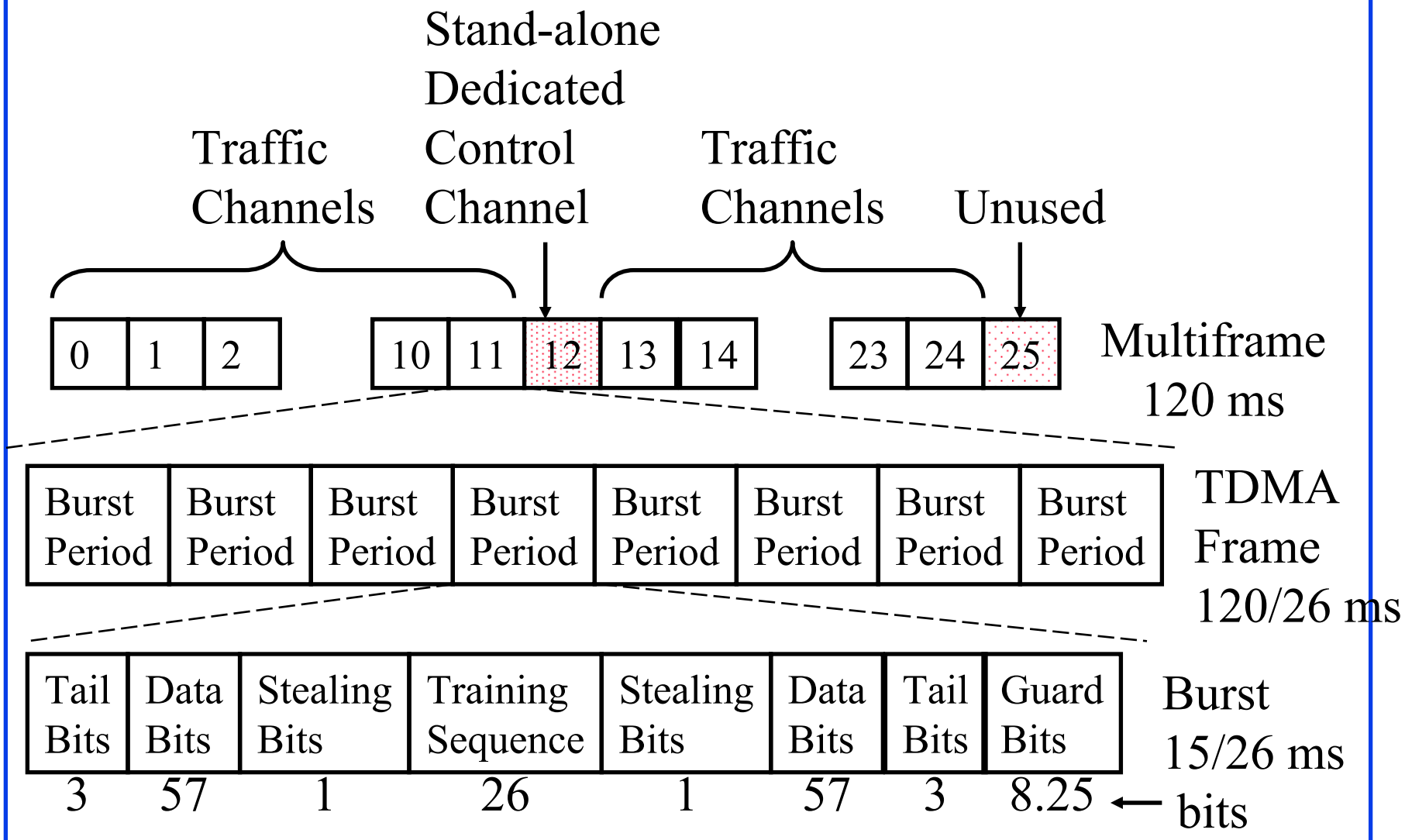
GSM

- Global System for Mobile Communication (GSM)
- 1982: Started as "Groupe Special Mobile" by Conference of European Posts and Telecom (CEPT)
- Good speech quality, ISDN compatibility, and fraud secure.
- Specs completed in 1990, Service began in 1992.
- 900 MHz operation in Europe.
- UK allocated 1800 MHz and adapted GSM standard as "DCS 1800"
- DCS 1800 also used in Russia and Germany.

GSM (Cont)

- FCC allocated 1900 MHz for PCS. Many carriers adapted GSM standard as "DCS 1900" or "North American GSM"
- VoiceStream, Powertel, and Bellsouth Mobility use NA GSM.
- 280 GSM networks in 100 countries worldwide.

GSM Radio Link



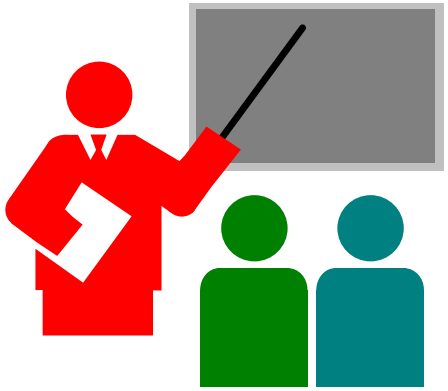
GSM Radio Link (Cont)

- 890-915 MHz uplink, 935-960 MHz downlink
- 25 MHz ⇒ 124 × 200kHz Channels
- Each channel is TDMA with burst (slot) period of 15/26 ms.
- Eight burst periods = TDMA frame of 120/26 ms.
- One channel = one burst period per TDMA frame.
- 26 TDMA frames ⇒ one Multiframe
  24 are used for traffic, 1 for control, and 1 is unused.
- Stealing bits identify whether the slot carries data or control
- 200 kHz = 270.8 kbps/8 slots ⇒ 34 kbps/slot
  ⇒ 9.6 kbps/user after encryption and FEC overhead
- Full rate vocoders ⇒ Voice is sampled at 64 kbps compressed to 16 kbps.

GSM Specs

- Subscriber Identify Module (SIM) contains a micro-controller and storage. Contains authentication, encryption, and accounting info.
  Owners need 4-digit PIN.
- SIM cards can contain additional info such as emergency medical info.
- Mobile Assisted Handoff: Mobile sends identities of six candidate base stations for handoff. MSC selects.
- Short Message Service (SMS)
  - Up to 160 characters
  - Sent over control channel
  - Unicast or broadcast

Summary



1. Geometry of cells and frequency reuse
2. Generations: 1G (Analog), 2G (digital), 3G (Data)
3. AMPS is 1G cellular technology using FDMA
4. IS-95 is 2G cellular technology using CDMA
5. GSM is 2G cellular technology using TDMA

Reading Assignment

- Read sections 3.1 to 3.6 from Murthy and Manoj

Homework 7

- A particular cellular system has the following characteristics: cluster size =7, uniform cell size, user density=100 users/sq km, allocated frequency spectrum = 900-949 MHz, bit rate required per user = 10 kbps uplink and 10 kbps downlink, and modulation code rate = 1 bps/Hz.

A. Using FDMA/FDD:
   1. How much bandwidth is available per cell using FDD?
   2. How many users per cell can be supported using FDMA?
   3. What is the cell area?
   4. What is the cell radius assuming circular cells?

B. If the available spectrum is divided in to 35 channels and TDMA is employed within each channel:
   1. What is the bandwidth and data rate per channel?
   2. How many time slots are needed in a TDMA frame to support the required number of users?
   3. If the TDMA frame is 10ms, how long is each user slot in the frame?
   4. How many bits are transmitted in each time slot?