Data Link Layer-6
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BLM 3051 Veri İletişimi
Wireless MAC & Switching-2

Tech. Assist. Kübra ADALI
Assoc. Prof. Dr. Veli Hakkoymaz

References:

- *Computer Networks*, Andrew Tanenbaum, Pearson, 5th Edition,2010.
- *Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.
- **BLG 337 Slides** from İTÜ prepared by Assoc. Prof.Dr. Berk CANBERK

Overall Internet Architecture

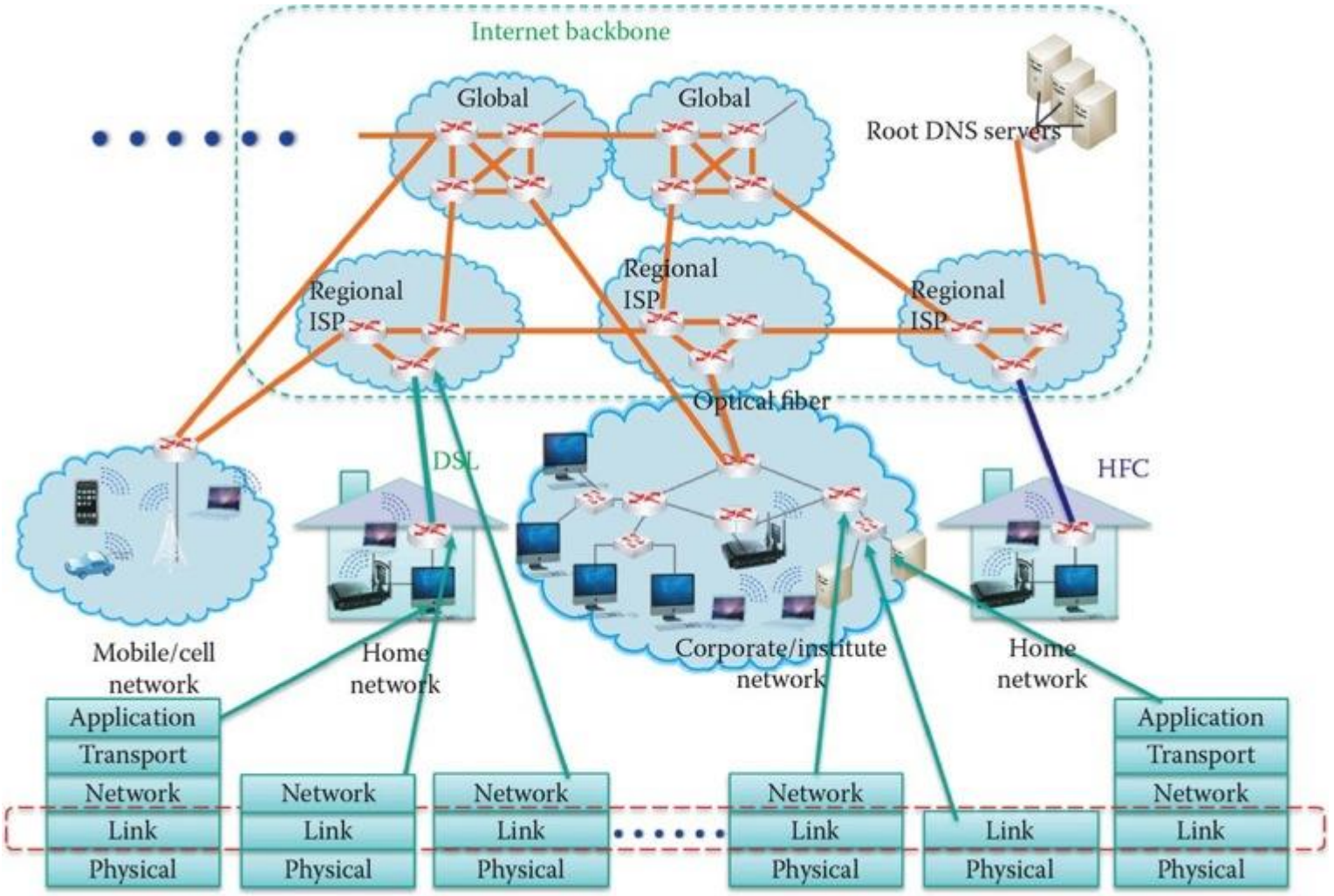
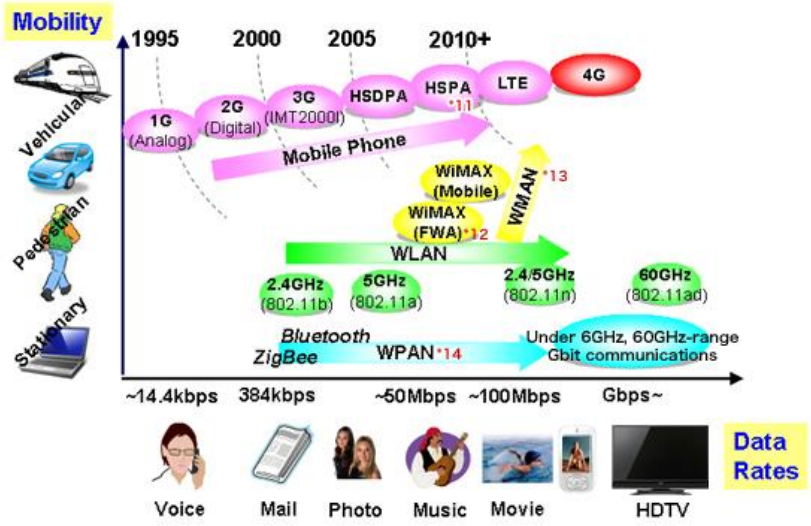
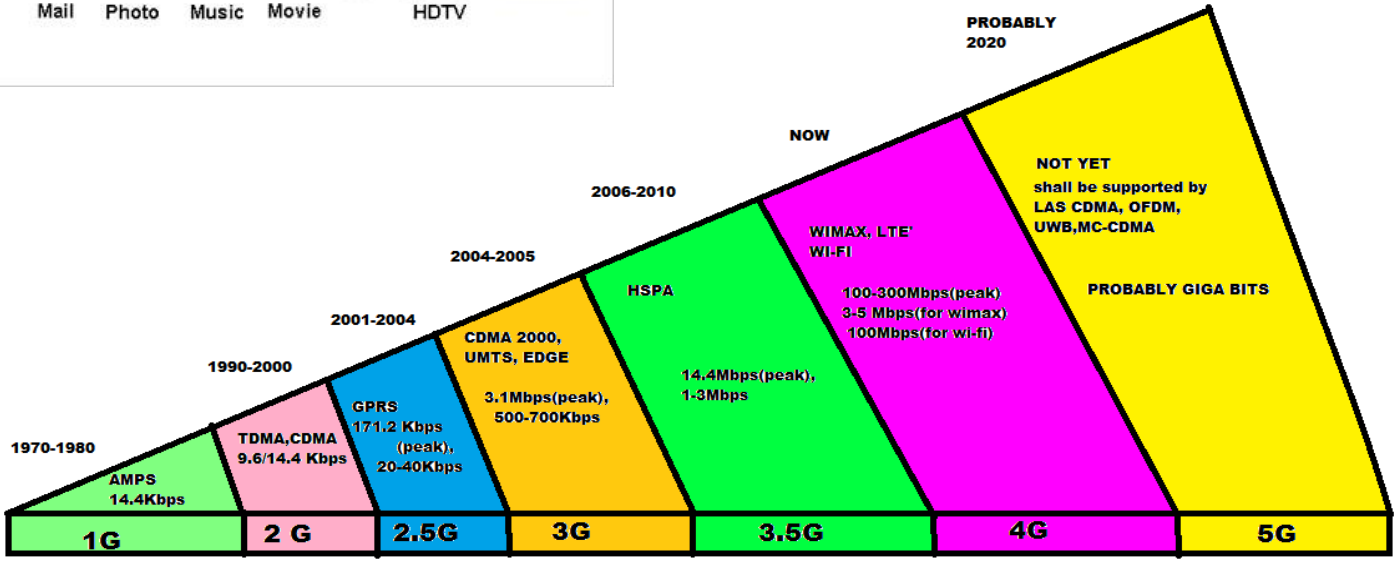
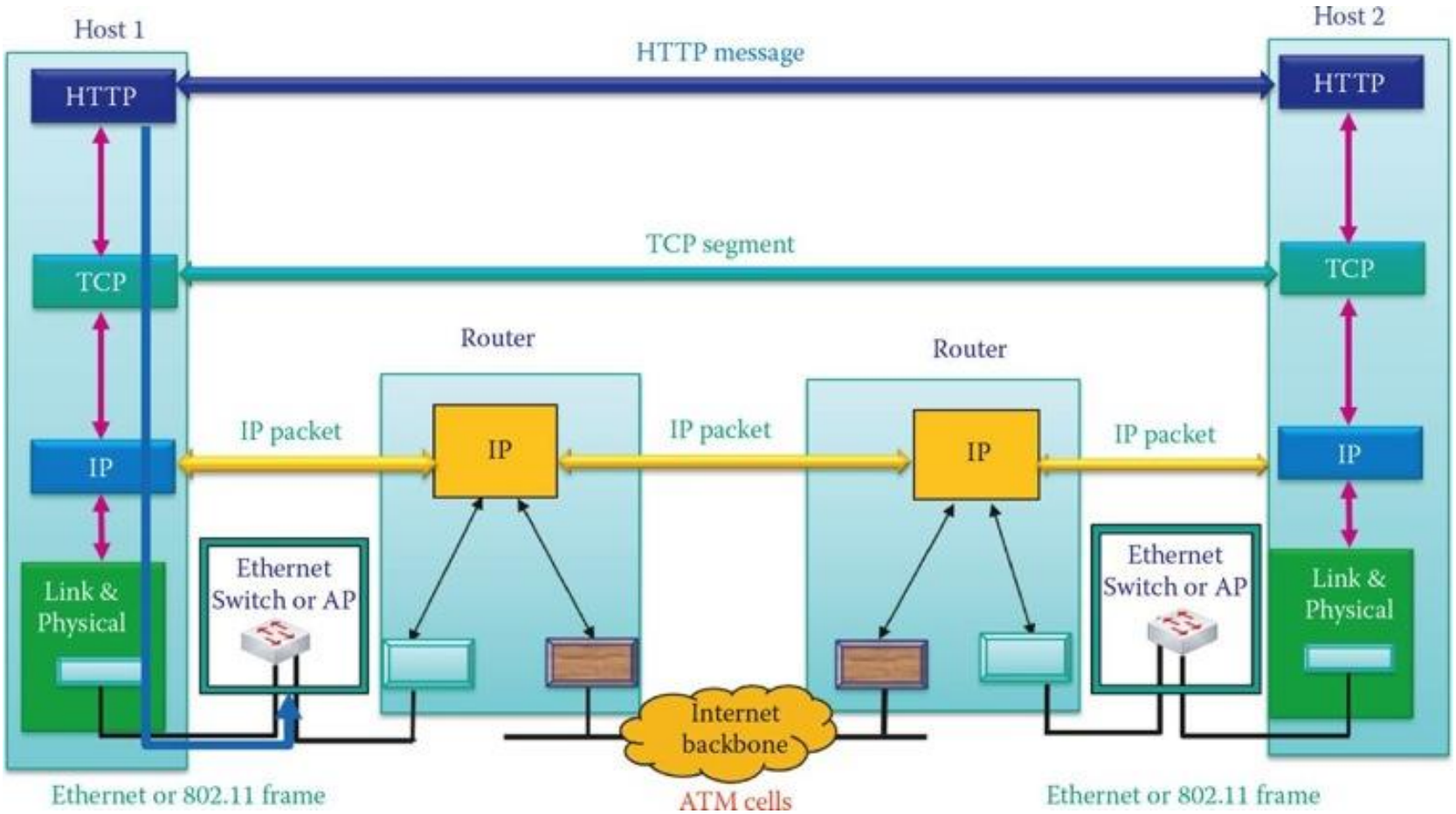


Fig. 1.2 Trend of wireless communications systems.





MAC Architecture



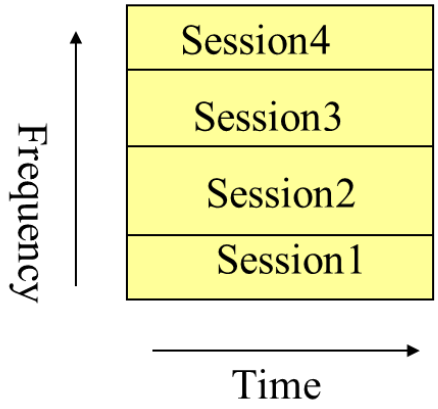
The History of Cellular Networks: From 1G to 3G

- 1G: First generation wireless cellular: Early 1980s
  - Analog transmission, primarily speech: AMPS (Advanced Mobile Phone Systems) and others
- 2G: Second generation wireless cellular: Late 1980s
  - Digital transmission
  - Primarily speech and low bit-rate data (9.6 Kbps)
  - High-tier: GSM, IS-95 (CDMA), etc
  - Low-tier (PCS): Low-cost, low-power, low-mobility e.g. PACS
- 2.5G: 2G evolved to medium rate (< 100kbps) data
- 3G: future Broadband multimedia
  - 144 kbps - 384 kbps for high-mobility, high coverage
  - 2 Mbps for low-mobility and low coverage
- Beyond 3G: using 4G and 5G

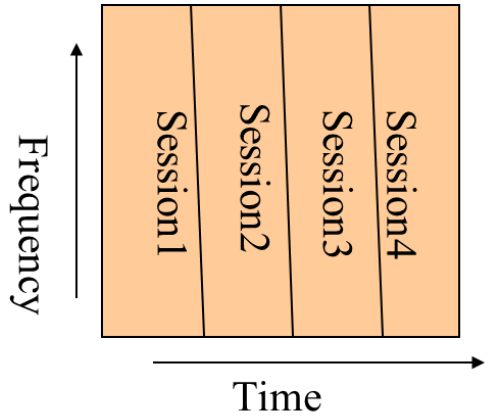
Issues Vital to Cellular MAC Design

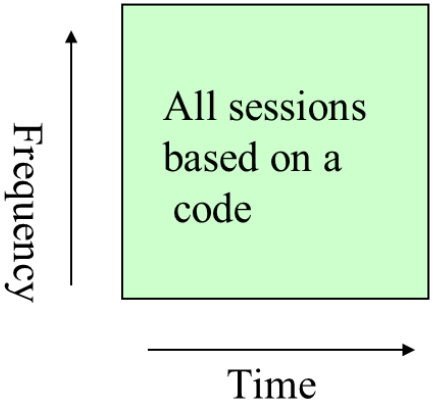
- **Frequency Allocation**
  - Licensed
  - Many providers
- **Multiple Access**
  - Many users
  - Wide area of coverage
  - Traffic management
- **Location Management**
  - High Mobility (in cars, trains)
  - Multiple suppliers
  - Handoff management, roaming.

Multiple Access Techniques: How to allocate users



Frequency Division
Multiple Access (FDMA)
1G Cellular (AMPS)

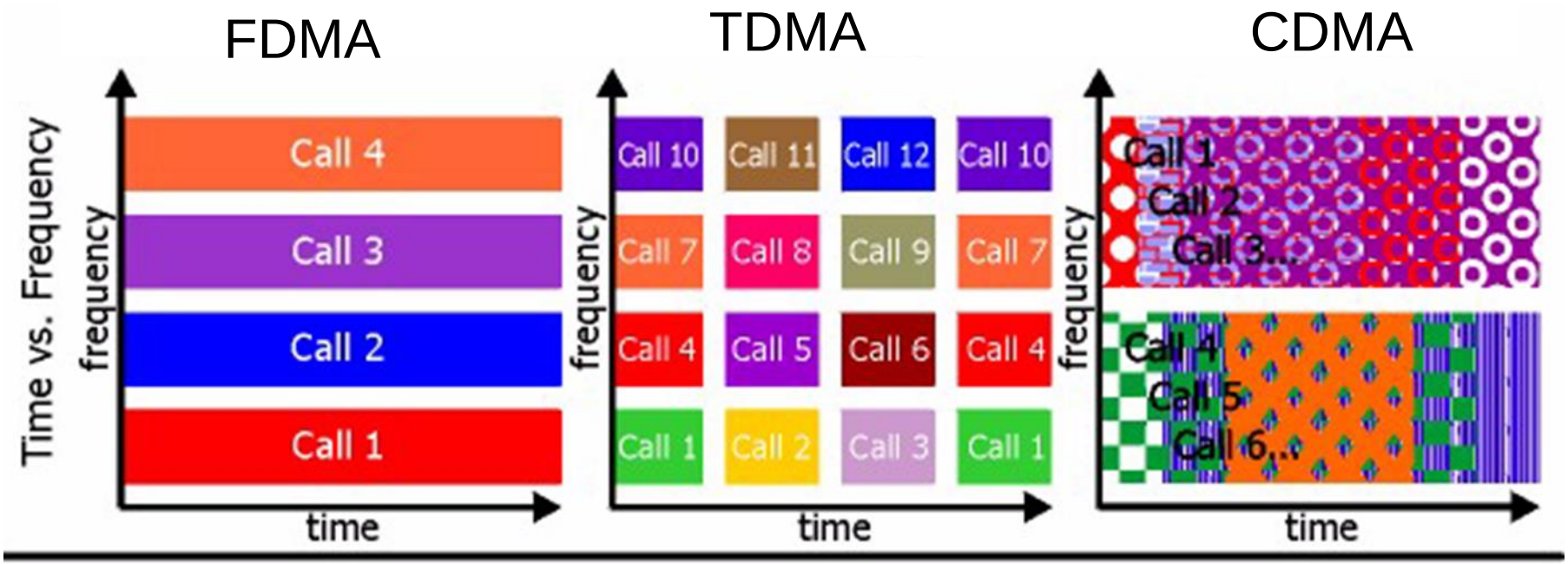




2G CDMA (IS-95)
3G CDMA

Code Division
Multiple Access (CDMA)

Differences between FDMA,TDMA and CDMA



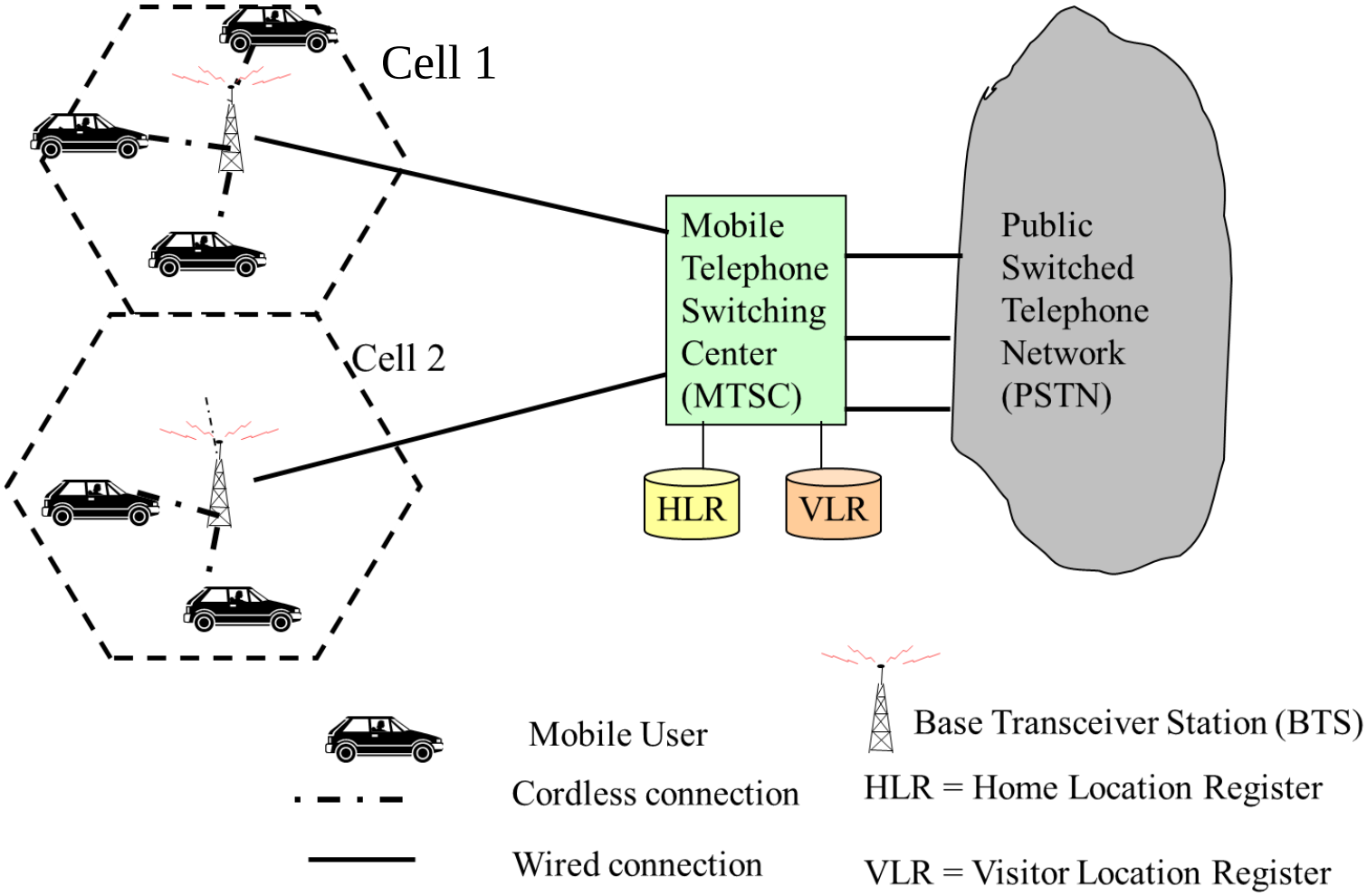
Conversation Analogy

Everyone talks in a different room to prevent interference. Since the conversation can't be heard from another room, it can be filtered from the other by going to the other room.

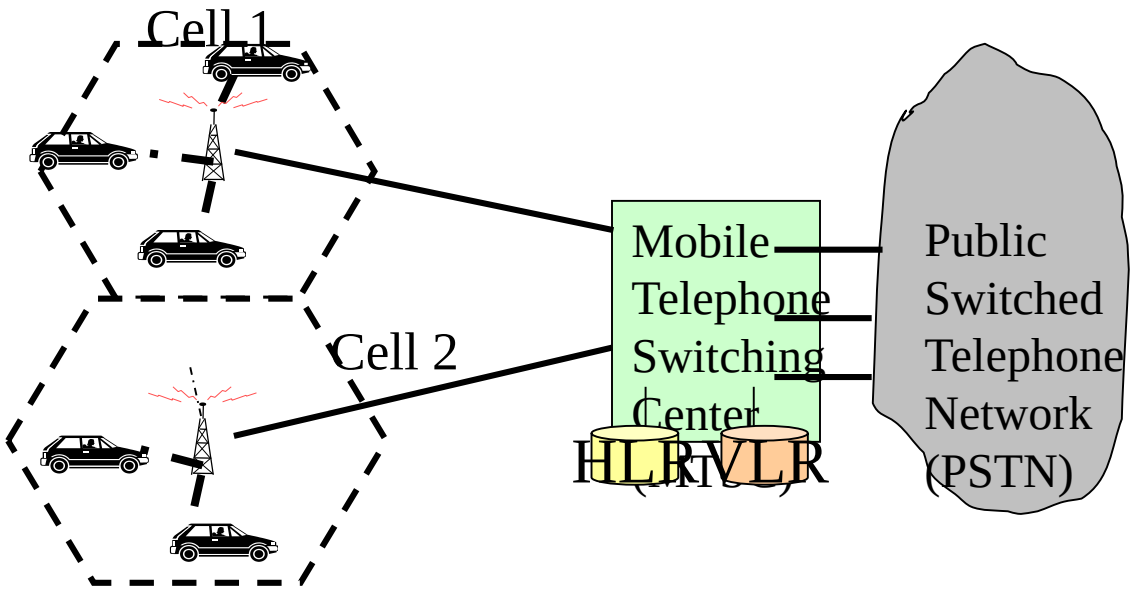
Within each room, everyone takes turns talking to prevent interference. Within each room, one person is talking at once, so they must talk fast to say everything.

Everyone speaks a different language at the same time in the same room. Since each language is unique, one may be filtered from another.

A Cellular Network



Cellular System



Handoffs (typically 30 mseconds):

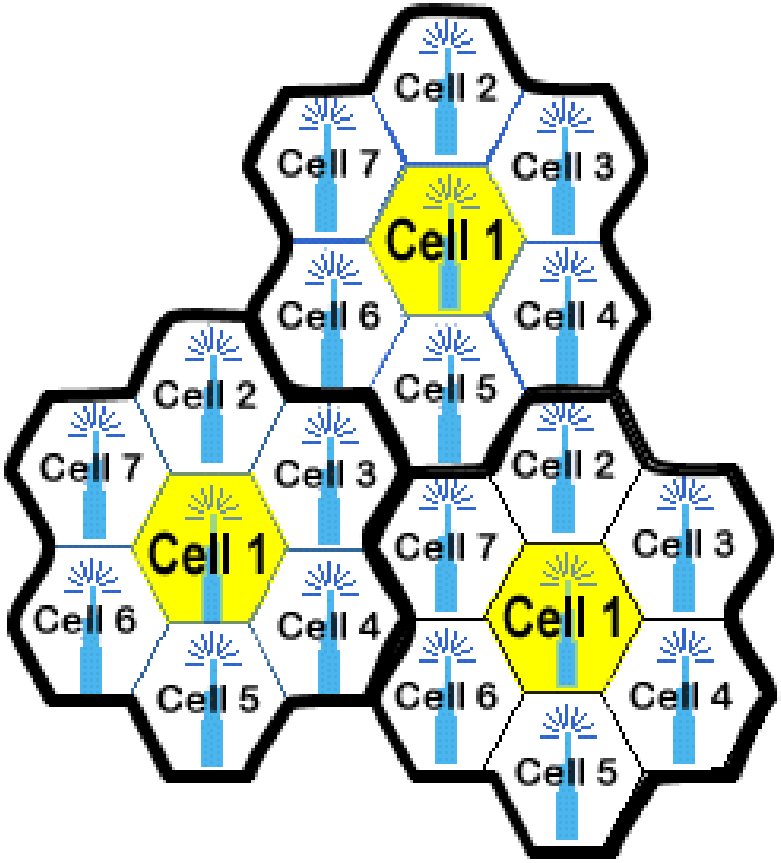
1. At any time, mobile station (MS) is in one cell and under the control of a BS
2. When a MS leaves a cell, BS notices weak signal
3. BS asks surrounding BSs if they are getting a stronger signal
4. BS transfers ownership to one with strongest signal
5. MTSC assigns new channel to the MS and notifies MS of new boss

Frequency Reuse

- ✓ The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area
  - Cells are assigned a group of channels that is completely different from neighbouring cells
  - The coverage area of cells is called the footprint and is limited by a boundary so that the same group of channels can be used in cells that are far enough apart

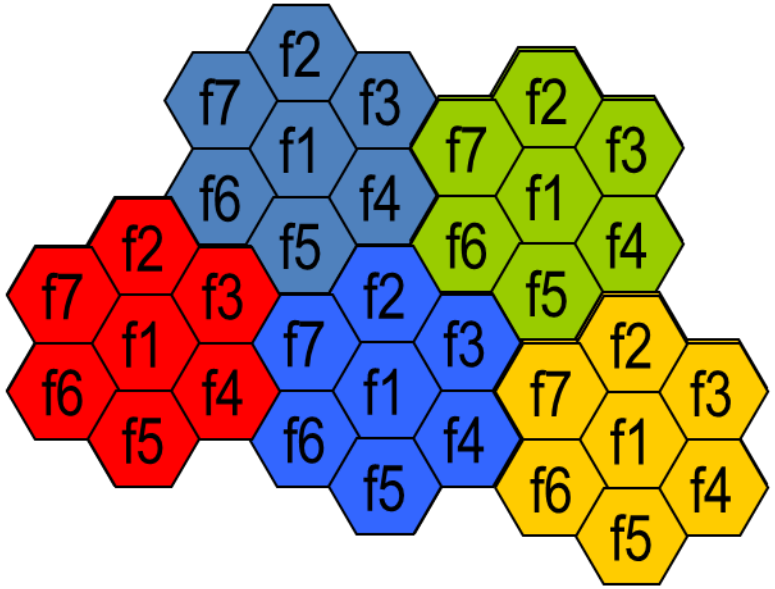
Frequency Reuse

- ✓ Cells with the same number have the same set of frequencies

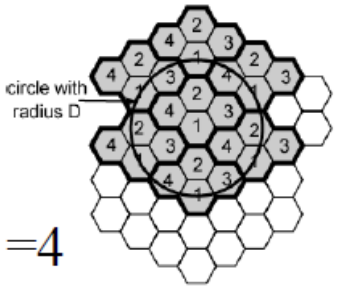


Frequency Reuse using 7 frequencies allocations

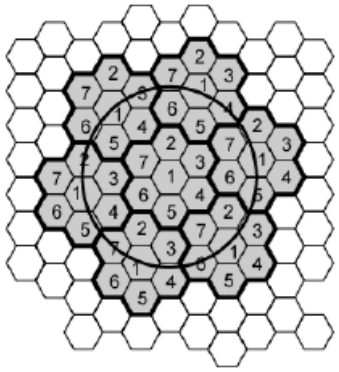
- ✓ Each cell is generally 4 to 8 miles in diameter with a lower limit around 2 miles



Cellular Frequency Reuse

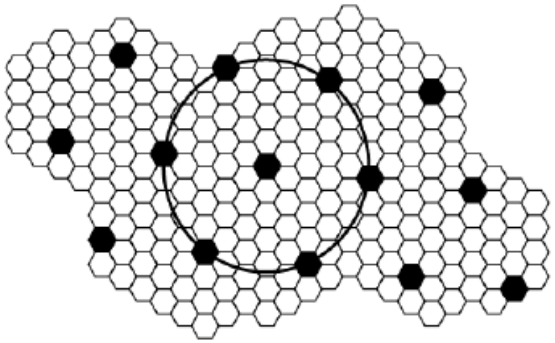


Cluster Size =4



Cluster Size =7

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



Cluster Size =19

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

0G Wireless

- Mobile radio telephones were used for military communications in early 20th century
- Car-based telephones first introduced in mid 1940s
  - Single large transmitter on top of a tall building
  - Single channel used for sending and receiving
  - To talk, user pushed a button, enabled transmission and disabled reception
  - Became known as “push-to-talk” in 1950s
  - CB-radio, taxis, police cars use this technology
- IMTS (Improved Mobile Telephone System) introduced in 1960s
  - Used two channels (one for sending, one for receiving)
  - No need for push-to-talk
  - Used 23 channels from 150 MHz to 450 MHz

First-Generation Cellular

- Advanced Mobile Phone Service (AMPS) invented at Bell Labs and first installed in 1982
- Used in England (called TACS) and Japan (called MCS-L1)
- Key ideas:
  - Exclusively analog
  - Geographical area divided into cells (typically 10-25km)
  - Cells are small: Frequency reuse exploited in nearby (not adjacent) cells
  - As compared to IMTS, could use 5 to 10 times more users in same area by using frequency re-use (divide area into cells)
  - Smaller cells also required less powerful, cheaper,smaller devices

Cellular Network Organization

- Cell design (around 10 mile Radius)
  - Served by base station consisting of transmitter, receiver, and control unit
  - Base station (BS) antenna is placed in high places (churches, high rise buildings) -
    - Operators pay around $500 per month for BS
  - 10 to 50 frequencies assigned to each cell
  - Cells sCelllet up such that antennas of all neighbors are equidistant (hexagonal pattern)

- In North America, two 25-MHz bands allocated to AMPS
  - One for transmission from base to mobile unit
  - One for transmission from mobile unit to base

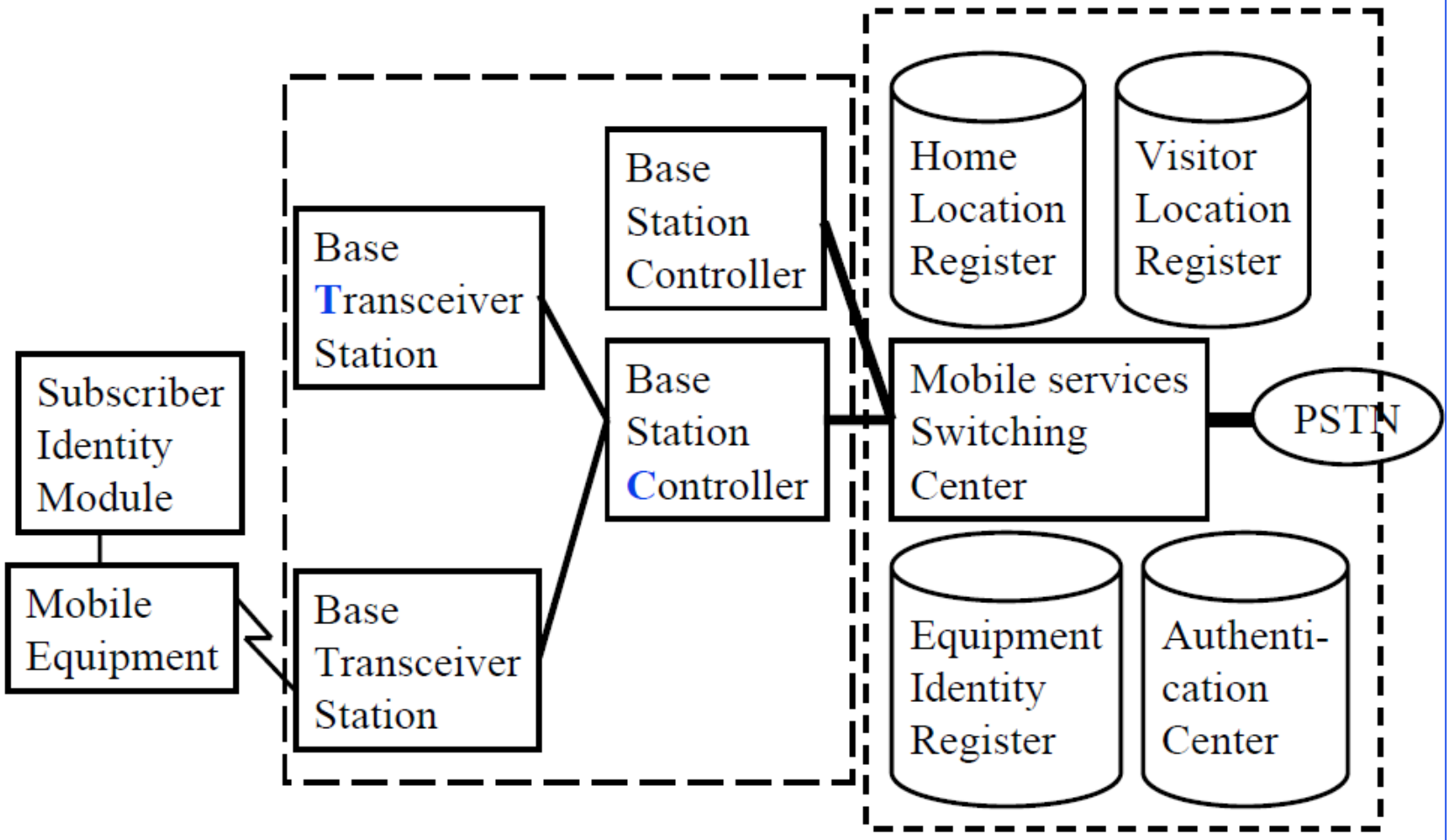
Approaches to Increase Capacity

- ✓ Adding/reassigning channels - some channels are not used
- ✓ 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
- ✓ Microcells – antennas move to buildings, hills, and lamp posts

Second Generation Cellular

- ✓ Based on digital transmission
- ✓ Different approaches in US and Europe
- ✓ US: divergence
  - Only one player (AMPS) in 1G
  - Became several players in 2G due to competition
  - Survivors
    - IS-54 and IS-135: backward compatible with AMPS frequency allocation (dual mode - analog and digital)
    - IS-95: uses spread spectrum
- ✓ Europe: Convergence
  - 5 incompatible 1G systems (no clear winner)
  - European PTT development of GSM (uses new frequency and completely digital communication)

Cellular Architecture



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.

Advantages of Digital Communications for Wireless

- ✓ Voice, data and fax can be integrated into a single system
- ✓ Better compression can lead to better channel utilization
- ✓ Error correction codes can be used for better quality
- ✓ Sophisticated encryption can be used

Differences Between First and Second Generation Systems

- ✓ Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
- ✓ Encryption – all second generation systems provide encryption to prevent eavesdropping
- ✓ Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
- ✓ Channel access – second-generation systems allow channels to be dynamically shared by a number of users

Integrating Data Over Cellular

- ✓ Direct access to digital channel
- ✓ Voice and data using one handset
- ✓ PCS 1900 (GSM-1900)
  - 9.6 kbps circuit switched data
  - 14.4 kbps under definition
  - Packet mode specified
  - Short message service
- ✓ IS-95-based CDMA
  - 13 kbps circuit switched data
  - Packet mode specified
  - Short message service

GSM (Global Systems for Mobile Communication

- ✓ Completely designed from scratch (no backward compatability)
- ✓ Uses 124 channels per cell, each channel can support 8 users through TDM (992 users max)
- ✓ Some channels used for control signals, etc
- ✓ Several flavors based on frequency:
  - GSM (900 MHz)
  - GSM 1800 (called DCS 1800)
  - GSM 1900 (called DCS 1900) - used in North America
- ✓ GSM 1900 phone only works in North America.

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.
  Slow Associated Control Channel (SACCH)
  If SACCH does not have sufficient capacity, Fast Associated Control Channel (FACCH) is used by stealing ½ of some bursts.
- Stealing bits identify whether the 1/2-slot carries data or control
- 200 kHz = 270.8 kbps/8 slots ⇒ 34 kbps/slot
  15/26 ms/slot ⇒ 270.8*15/26 = 156.25 bits/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

Cellular System Capacity Example

- 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?

Cellular System Capacity (Cont)

- 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?
     49 MHz/7 = 7 MHz/cell
     FDD $\Rightarrow$ 3.5 MHz/uplink or downlink
  2. How many users per cell can be supported using FDMA?
     10 kbps/user = 10 kHz $\Rightarrow$ 350 users per cell
  3. What is the cell area?
     100 users/sq km $\Rightarrow$ 3.5 Sq km/cell
  4. What is the cell radius assuming circular cells?
     $\pi r^2 = 3.5 \Rightarrow r = 1.056$ km

Cellular System Capacity (Cont)

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?

   3.5 MHz/35 = 100 kHz/Channel = 100 kbps

2. How many time slots are needed in a TDMA frame to support the required number of users?

   10 kbps/user $\Rightarrow$ 10 users/channel

3. If the TDMA frame is 10ms, how long is each user slot in the frame?

   10 ms/10 = 1ms

4. How many bits are transmitted in each time slot?

   1 ms x 100 kbps = 100 b/slot

GSM (2G-TDMA)

- Circuit mode data
  - Transparent mode
  - Non-transparent mode using radio link protocol
  - Data rate up to 9.6kb/s
- Short message service
  - Limited to 160 characters
- Packet mode data: Plans for GSM Phase 2+
- Architecture specification very detailed (500 pages)
- Defines several interfaces for multiple suppliers