Department of Electrical Engineering
University of Arkansas

ELEG 5693 Wireless Communications
Introduction

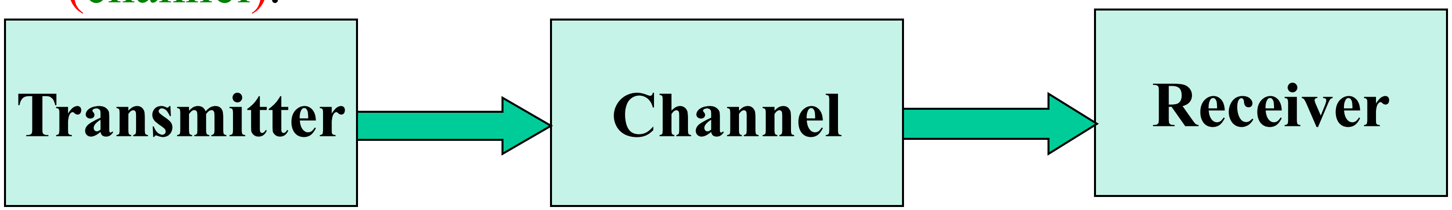
Dr. Jingxian Wu
wuj@uark.edu

OUTLINE

- Background
- Major modern wireless communication standards
- Basic Concepts
- Block diagrams of a wireless communication system

BACKGROUND

- **Wireless Communications:**
  - Transmit information from transmitter to receiver through the propagation of unguided electromagnetic (or acoustic) waves (channel).



Wireless communication: channel is wireless!

- **Wireless channel imposes numerous challenges.**
- **This course:**
  - How to characterize the wireless channel?
  - How to efficiently and accurately transmit signal over the wireless channel? (How to format signals based on the properties of wireless channel?)

BACKGROUND: MILESTONES

- **1864. Maxwell predicted the existence of electromagnetic wave (radio wave).**
- **1887 Hertz demonstrated the existence of radio wave.**
- **1901 Marconi realized first across Atlantic wireless transmission (England to Canada)**
- **1906 First radio broadcast (AM radio)**
- **1946 First public mobile telephone systems**
- **1948 C. Shannon, “A Mathematical Theory of Communications” was published**
- **1981 First analog cellular system in Scandinavia.**
  - Prototype of current cellular systems.
  - 1983, Advanced Mobile Phone Service (AMPS) in North America.
- **2019 First 5th generation (5G) services launched in US and China**

UNIVERSITY OF ARKANSAS

BACKGROUND: SPECTRUM

- **Radio Frequency (RF)**
  - 1MHz to 1GHz (general classification, not absolute)
  - 100 MHz to 1GHz (more widely used definition)
  - Applications: AM radio, FM radio, TV, some cellular telephone systems, etc.
- **Microwave**
  - 1 GHz to 300 GHz (general)
  - 1 GHz to 100 GHz (more widely used)
  - Most cellular telephone systems, wireless LAN, Satellite, etc.
- **Trends towards use of higher frequencies**
  - Maximum bandwidth ≈ 10% of carrier frequency
  - More users and higher data rate
  - More difficult to design ➔ more $$

BACKGROUND: EXAMPLES

- **Garage door opener**
- **Remote control**
- **Paging system**
- **Cordless telephone system**
- **Fixed microwave**
  - Point-to-point link for long distance telephone
  - Most have been replaced by fiber optics.
- **Cellular telephone system**
- **Wireless local area network (LAN)**
- **Wireless sensor networks (WSN)**
- **Vehicular Ad-hoc network (VANET)**
- **Internet-of-Things (IoT)**

OUTLINE

- Background
- **Major modern wireless communication standards**
- Basic Concepts
- Block diagrams of a wireless communication system

STANDARDS: MOBILE TELEPHONE SYSTEMS

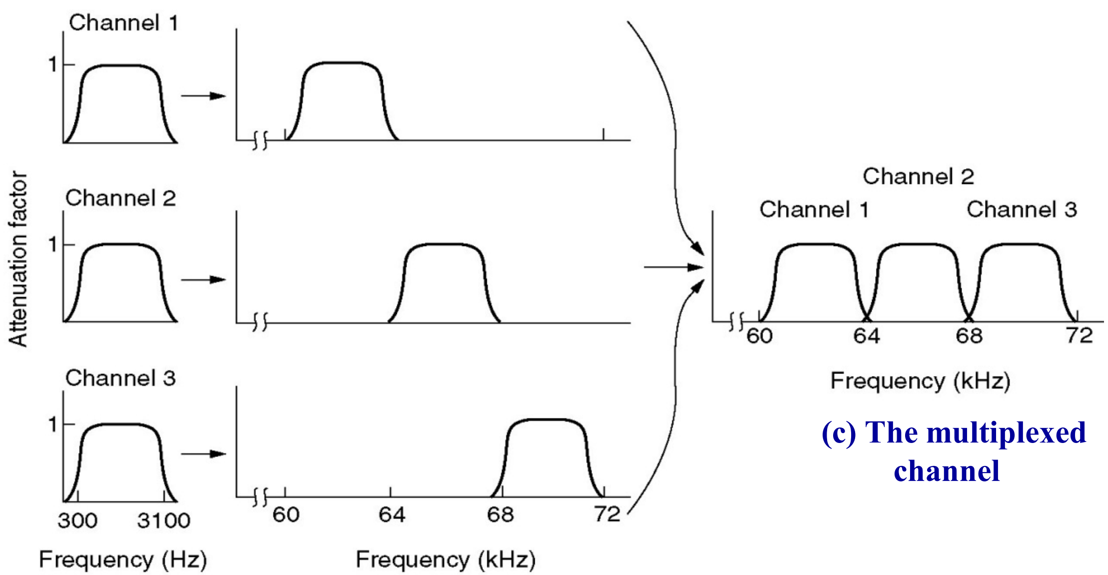
- **1st generation: analog voice**
  - Example: Advanced Mobile Phone Service (AMPS)
- **2nd generation: digital voice and narrowband data**
  - Examples: GSM (T-Mobile, Cingular, AT&T, Verizon), D-AMPS (AT&T), IS-95 (Interim Standard-95) (Sprint)
  - 2.5 generation: EDGE, GPRS
- **3rd generation: digital voice and broadband data**
  - Examples: WCDMA (HSDPA), cdma2000 (EV-DO)
- **4th generation: broadband multimedia communication**
  - LTE (long term evolution)
  - LTE advanced (true 4G)

STANDARDS: MOBILE TELEPHONE SYSTEMS

- **5th generation: seamless wireless coverage everywhere**
  - Standard: IMT-2020 (International Mobile Telecommunication 2020)
    - It specifies all the requirements for 5G
  - 3GPP develops the actual standards that meet all IMT-2020 requirements
    - NR (new radio),
    - NB-IoT (narrowband Internet-of-Things),
    - LTE-M (Long term evolution – Machine type communications)
  - Usage scenarios:
    - Enhanced Mobile Broadband (eMBB)
    - Ultra-Reliable Low-Latency Communications (URLLC)
    - Massive Machine-Type Communications (mMTC)

STANDARDS: MOBILE TELEPHONE SYSTEMS

- **AMPS**
  - Advanced Mobile Phone System
  - 1983, AT&T
  - Analog voice (control information is digital)
- **Frequency Division Multiple Access (FDMA)**
  - Available spectrum divided into channels
  - each user is assigned a channel



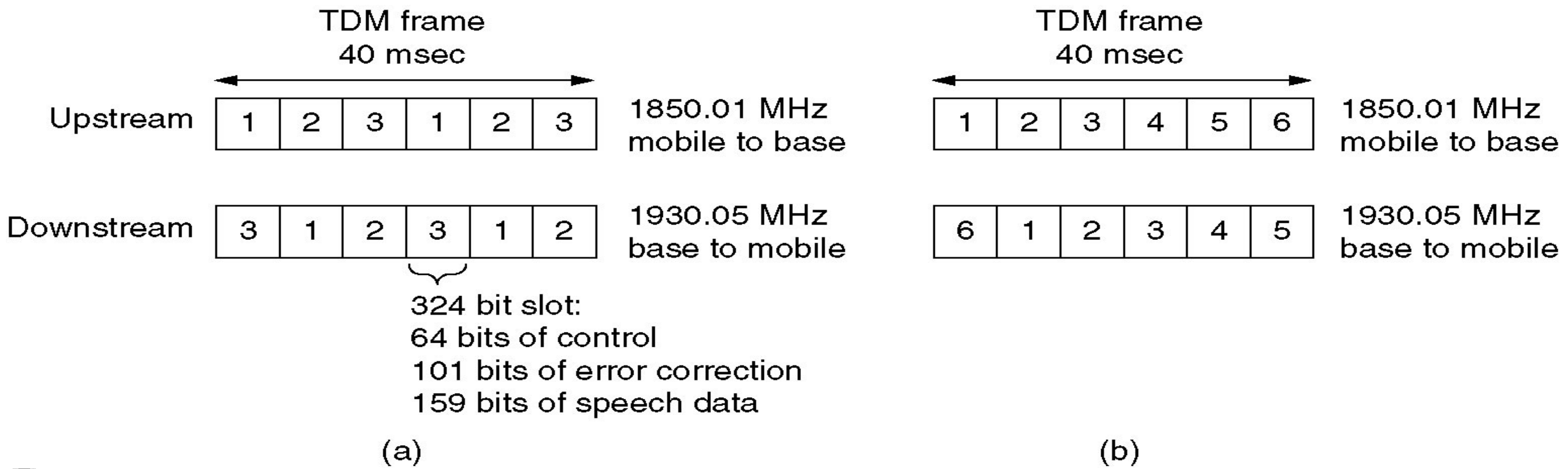
(a) The original bandwidths

(b) Bandwidths raised in frequency

(c) The multiplexed channel

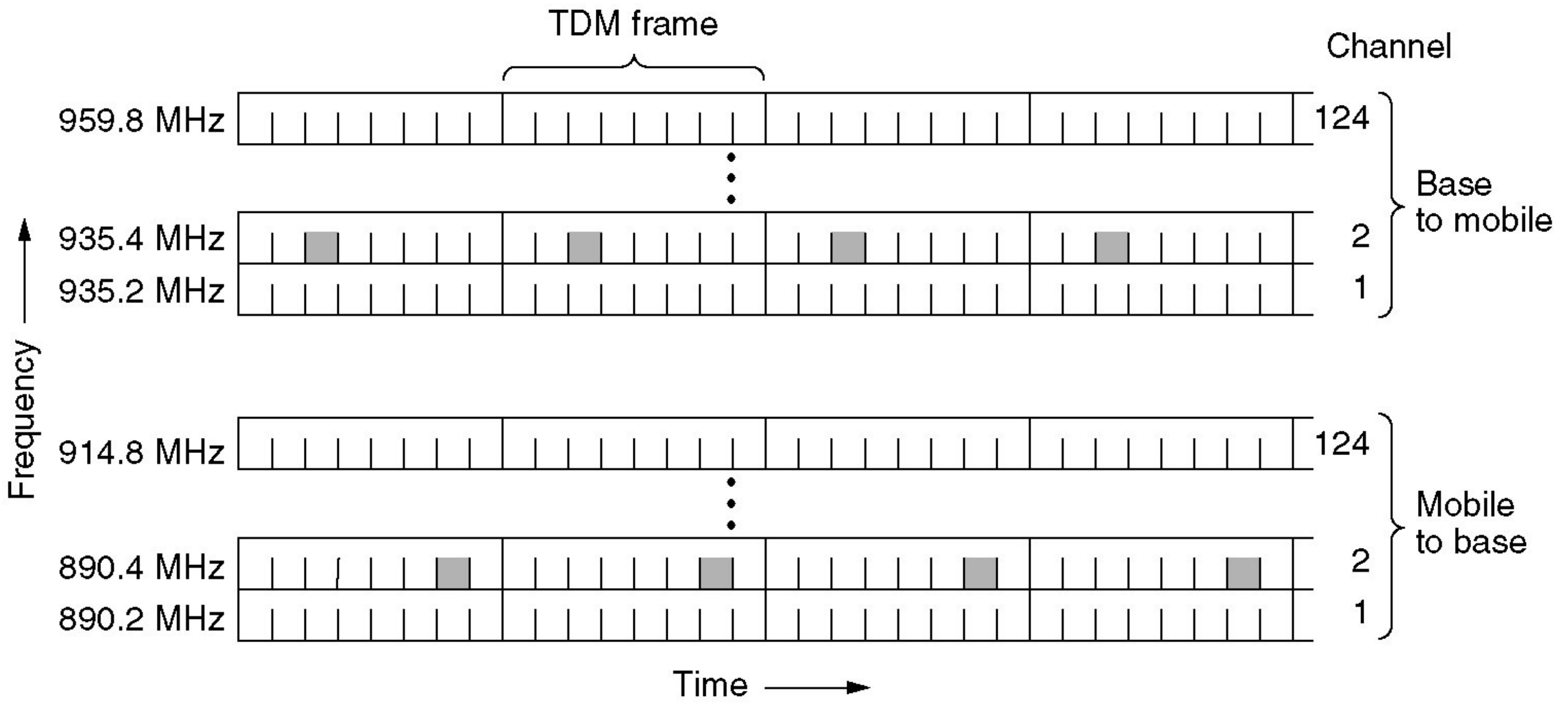
STANDARDS: MOBILE TELEPHONE SYSTEMS

- **D-AMPS (IS-54/136)**
  - Digital AMPS
  - Digital voice: analog voice is digitalized and compressed by vocoder before Tx
- **Time Division Multiple Access (TDMA)**
  - Time is divided into frame, frame divided into slots
  - Each user is assigned one or more slots
  - TDMA is usually on top of FDMA (30 KHz channel, 6 users per channel)



STANDARDS: MOBILE TELEPHONE SYSTEMS

- **GSM (Global System for Mobile communication)**
  - The most widely used 2nd generation system
  - Similar to D-AMPS, but with different format



STANDARDS: MOBILE TELEPHONE SYSTEMS

- **IS-95 (Narrowband CDMA)**
  - Code Division Multiple Access
  - All users Tx simultaneously using the same frequency and same time.
  - Different codes are used to separate the signals from different users.
- **CDMA**
  - Each user is assigned a unique code
  - The code is known at both transmitter (Tx) and receiver (Rx)
  - All users Tx at the same frequency and time
  - Receiver uses codes to pick up desired signals
  - Also called spread spectrum
  - (details will be discussed in Ch. 9)

STANDARDS: MOBILE TELEPHONE SYSTEMS

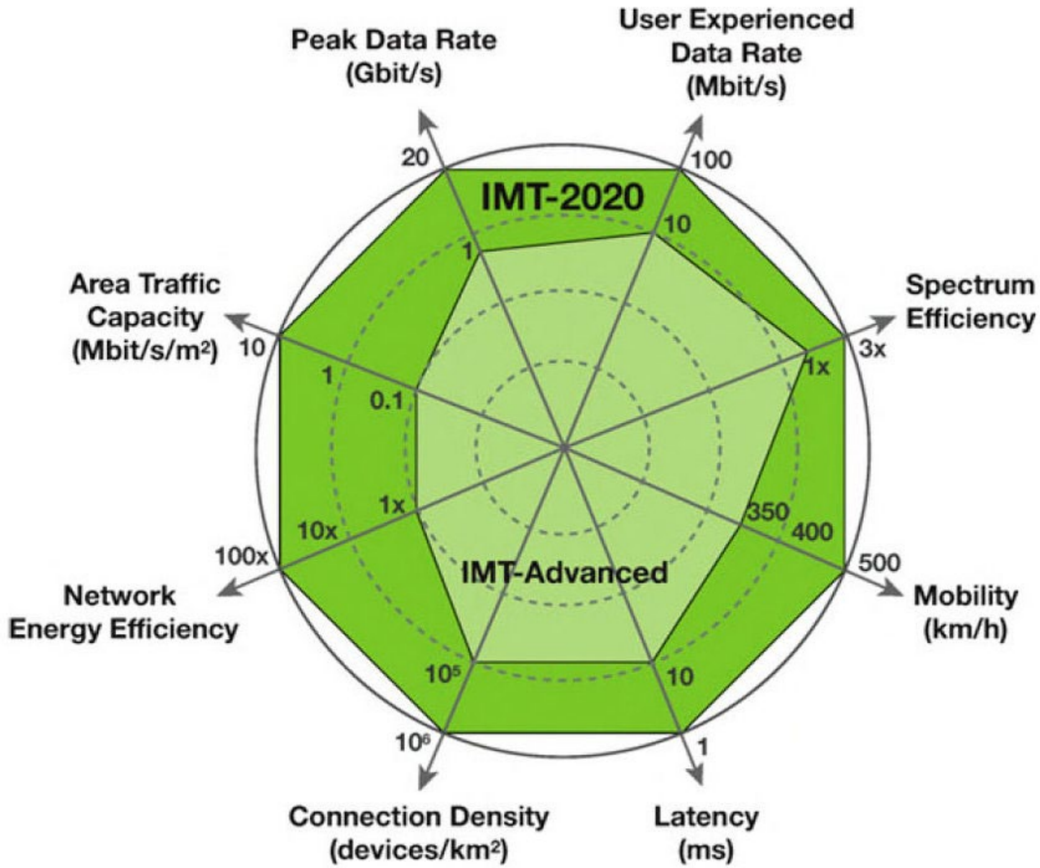
- **WCDMA (Wideband CDMA)**
  - Also called UMTS (Universal Mobile Telephone System)
  - Proposed by Ericsson, Standardized in 3GPP
  - Will mainly be used in Europe
  - Data: HSDPA (High Speed Downlink Packet Access, 1.8 Mbps-7.2 Mbps)
- **cdma2000**
  - Proposed by Qualcomm, Standardized in 3GPP2
  - Will mainly be used in North America
  - Data: 1xEV-DO (Evolution Data Optimization, 1x: one 1.25 MHz channel, up to 4.9 Mbps in the downlink)
- **Both standards use CDMA**
  - Only some detailed technical differences

STANDARDS: MOBILE TELEPHONE SYSTEMS

- **4G: LTE (long term evolution)**
  - Standard finalized in 2008
  - First LTE service in North America launched by Verizon in 2010.
  - An upgrade of 3G UMTS
- **Some main features**
  - OFDMA (orthogonal frequency division multiple access) for downlink; FDMA for uplink
  - Scalable carrier bandwidth: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz
  - Low latency: sub-5 ms latency for small packets in optimal conditions
  - Peak download rate: 299.6 Mbps; Peak upload rate: 75.4 Mbps
  - Cell size: tens of meters radius (femto and picocells) up to 100 km (62 miles) radius marcocells. (Typical radius 5 – 30 kms)

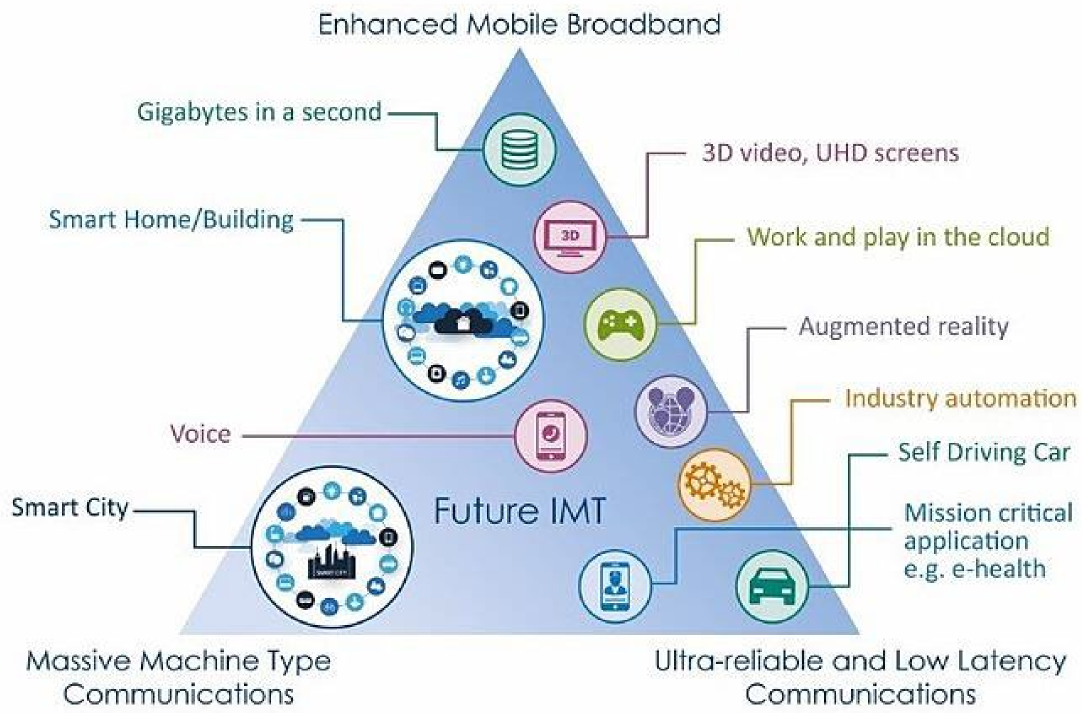
STANDARDS: MOBILE TELEPHONE SYSTEMS

- **5G**
  - IMT 2020: issued in 2015, published in 2021
  - 3GPP Release-18 completed in 2019



STANDARDS

- **5G usage scenarios**
  - Enhanced Mobile Broadband (eMBB)
  - Ultra-Reliable Low-Latency Communications (URLLC)
  - Massive Machine-Type Communications (mMTC)



STANDARDS

- **5G requirements**

Capability	Description	5G requirement	Usage scenario
Downlink peak data rate	Minimum maximum data rate technology must support	20 Gbit/s	eMBB
Uplink peak data rate		10 Gbit/s	eMBB
User experienced downlink data rate	Data rate in dense urban test environment 95% of time	100 Mbit/s	eMBB
User experienced uplink data rate		50 Mbit/s	eMBB
Latency	Radio network contribution to packet travel time	4 ms	eMBB
		1 ms	URLLC
Mobility	Maximum speed for handoff and QoS requirements	500 km/h	eMBB/URLLC
Connection density	Total number of devices per unit area	$10^6/km^2$	mMTC
Energy efficiency	Data sent/received per unit energy consumption (by device or network)	Equal to 4G	eMBB
Area traffic capacity	Total traffic across coverage area	$10 Mbps/m^2$	eMBB
Peak downlink spectrum efficiency	Throughput per unit wireless bandwidth and per network cell	30 bit/sector/Hz	eMBB

STANDARDS: WIRELSS LAN

- **IEEE 802.11 (WiFi)**
  - IEEE 802.11a (Oct. 1999)
    - Operating at 5.8GHz, up to 54Mbps
    - Orthogonal Frequency Division Multiplex (OFDM)
  - IEEE 802.11b (Oct. 1999)
    - Operating at 2.4GHz, up to 11Mbps
    - Direct Sequence Spread Spectrum (DSSS, CDMA)
  - IEEE 802.11g (Jun. 2003)
    - Operating at 2.4GHz, up to 54Mbps
    - OFDM
  - IEEE 802.11n (2009)
    - Operating at 2.4 GHz or 5.8 GHz, up to 540 Mbps
    - Channel bandwidth up to 40 MHz
    - MIMO (Multiple input multiple output, up to 4 x 4)
  - IEEE 802.11ac (2011 to present)
    - Operating at 5.8 GHz, up to 1 Gbps for multi-station WLAN, upto 500 Mbps for a single link
    - Wider bandwidth (up to 160 MHz), MIMO (up to 8x8), multi-user MIMO, high density modulation (upto 256 QAM)
  - IEEE 802.11ad (2014 to present)
    - 60 GHz carrier frequency, upto 7 Gbps (WiGig)

OUTLINE

- Background
- Major modern wireless communication standards
- **Basic concepts**
- Block diagrams of a wireless communication system

CONCEPTS

- **In most wireless communication systems, the wireless communication occurs between mobile station (MS) and base station (BS)**
  - MS: Cell phone, wireless laptop, wireless PDA, etc.
  - BS: wireless access point, wireless router, etc.

- **Downlink**
  - Radio channel for transmission from BS to MS
  - Also called forward link

- **Uplink**
  - Radio channel for transmission from MS to BS
  - Also called reverse link

CONCEPTS: SIMPLEX AND DUPLEX

- **Simplex**
  - Communication occurs only in one direction
  - E.g. paging system
- **Half Duplex**
  - Tx can occur in either direction, but only one way at a time.
  - E.g. Walki-Talki (police radio)
- **Full Duplex**
  - Tx can occur at both direction simultaneously
  - E.g. Telephone.
  - Two simplex ➔ One Full Duplex

CONCEPTS:FDD V.S TDD

- **Frequency Division Duplex (FDD)**
  - Two distinct frequencies are used for downlink and uplink.

e.g. AMPS: forward link: 824 ~ 849 MHz
reverse link: 869 ~ 894 MHz

- **Time Division Duplex (TDD)**
  - Two distinct sets of time slots at the same frequency are used for downlink and uplink
- **TDD ≠ TDMA, FDD ≠ FDMA**
  - TDMA or FDMA: multiple users use different time/frequency
  - TDD or FDD: uplink and downlink (belonging to same user) use different time/frequency
  - TDD can be used in FDMA, TDMA, and CDMA systems
  - FDD can be used in FDMA, TDMA, and CDMA systems
  - E.g. FDD and TDMA can be in one system.

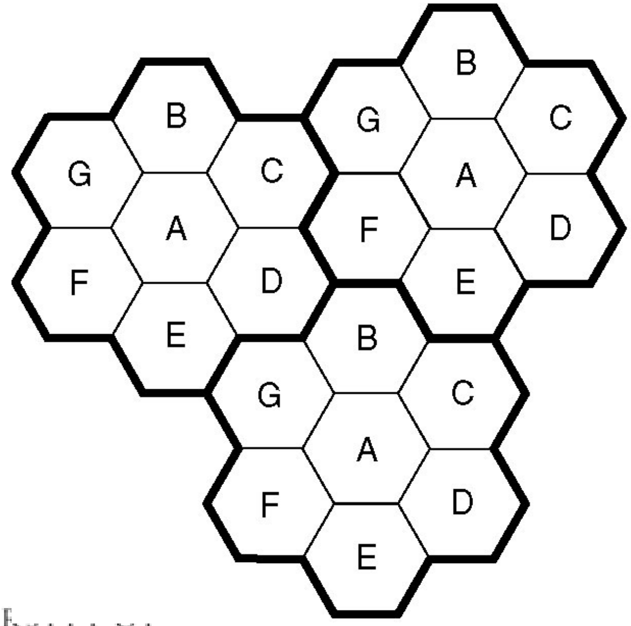
CONCEPTS: CELLUAR

- **Motivations**
  - Early mobile phone system uses a single high Tx tower to cover a large spatial area (high tower, high power)
  - Limited spectrum can only support a small number of users.
  - How can we support simultaneous communications of practically unlimited number of users?

- **Solution: cellular concept with frequency reuse**
  - Many Tx towers (base station)
  - Each covers a certain area: cell
  - Frequencies can be reused from area to area

CONCEPTS: CELLULAR

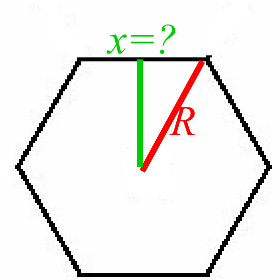
- **Cellular Concept with Frequency Reuse**
  - The entire coverage area is divided into cells
  - A base station (BS) in the center of each cell.
  - Communication occurs between BS and Mobile Stations (MS) in cell.
  - The same frequency (channels) can be reused by nearby cells ➔ Frequency Reuse
    - But not by adjacent cells!➔Reduce co-channel interference (CCI).

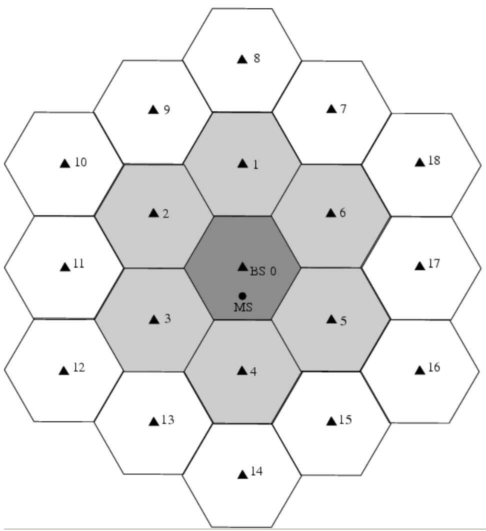


- **Hexagonal shape only for the convenience of analysis**
  - Circle leaves gaps
- **Actual cell "footprint" is amorphous**
  - No specific shape

CONCEPTS: CELLULAR

- **Cluster**
  - Cluster: Group of N cells using complete set of available channels.
  - Cells belonging to the same clusters use different frequencies
- **For hexagonal cells, the cluster size N must satisfy**
  - $N = i^2 + i\,j + j^2$ where $i, j \geq 1$
  - typical N values → 3, 7, 12
    - $(i, j) = (1,1)$ ➔ $N = 1+1+1 = 3$
    - $(i, j) = (1, 2)$ ➔ $N = 1+2+4 = 7$
    - $(i, j) = (2, 2)$ ➔ $N = 4+4+4 = 12$
    - $(i, j) = (2, 3)$ ➔ $N = 4+6+9 = 19$
- **Cell radius R:**
  - AMPS: 10 ~ 20 km
  - WCDMA: 1 ~ 2 km

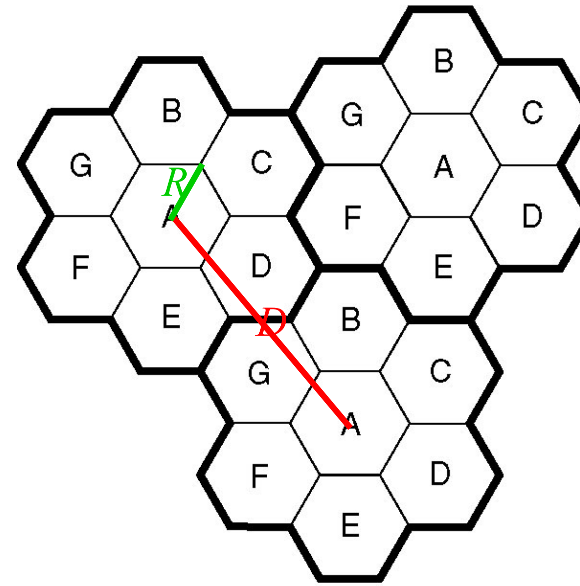




CONCEPTS: CELLULAR

- **Reuse factor Q:**

$$Q = \frac{D}{R}$$



  - D: distance between cells using the same frequency
  - R: cell radius
  - For hexagonal cells,

$$Q = \frac{D}{R} = \sqrt{3N}$$

← cluster size

  - E.g. $N = 7$, $Q = \sqrt{21} = 4.58$

- $Q \uparrow$ ➔ spatial separation relative to cell coverage $\uparrow$ ➔ CCI $\downarrow$ ➔ Good
- $Q \uparrow$ ➔ $N \uparrow$ ➔ bigger cluster size ➔ less frequency reuse (or, less clusters) ➔ smaller capacity ➔ less users can be served ➔ Bad
- Tradeoff between: voice quality and system capacity

CONCEPTS: CELLULAR

- **Example:**

  A total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system. The system uses two 25KHz simplex channels to provide full duplex voice and control channels. If 1MHz is dedicated to control channel. How many voice users can be supported per cell for system with reuse factor $N = 7$? What is the reuse factor?

Sol:

CONCEPTS: CELLULAR

- **Advantages of Cell with Frequency Reuse**
  - Limited frequency resource can be reused to support unlimited number of users
    - Each cell support only limited number of users
    - The number of users supported by system increase linearly with the number of cells
  - Each BS only covers one cell
    - Smaller Tx power at BS ➔ Less interference to other systems
    - Smaller Tx power at MS ➔ Longer battery life
  - A cell can be further divided into smaller cells to support more users
    - Upgradability
- **Disadvantage:**
  - Cells sharing same frequency will interfere with each other ➔ co-channel interference (CCI)
  - We want cells sharing same frequencies to be as further away as possible.

OUTLINE

- Background
- Major modern wireless communication standards
- Basic Concepts
- **Block diagrams of a wireless communication system**

SIMPLIFIED BLOCK DIAGRAM