Lecture 1: Introduction to Wireless Systems

How Much Do You Know About Cellular Systems?

Q0. The term "Cell" used to describe "Cell Phones" comes from the fact that

a) Cell phones need many battery cells to work properly.
b) Manufacturers sell a lot of phones each year but "sell" was misspelled with a "C" instead of "S"
c) The transmitter inside the phone is shaped like a human cell.
d) The inventor of cell phones came up with his invention while he was in a jail cell.
e) All of the above are stupid answers. It must be a different reason but I have no clue.

A0. The correct answer is (e). The reason cell phones are called cell phones is that the region that they operate in is divided into smaller regions each is called a cell with a cell tower around the center of the cell.

Q1. As the distance (R) between your location and an antenna that radiates electromagnetic power increases, the amount of power you receive increases (T/F).

A1. The power decreases as the distance increases because the radiated power is distributed over a larger area.

Q2. **IN FREE SPACE**, the drop in power received at a distance (R) from the transmitting antenna is proportional to R^X. What is the value of X?

A2. Since the radiated power spreads as spheres with surface area $4\pi R^2$, the drop in the received power is proportional to R^2, which means that X = 2.

Q3. **IN CELLULAR SYSTEMS**, the drop in power received at a distance (R) from the transmitting antenna is proportional to R^X. Is the value of X equal to 2, greater than 2, less than 2?

A3. Due to many phenomena that interfere with the transmitted signals in cellular systems (will be discussed later), the drop is much faster (X > 2). From practical experiments, it was found that X is in the range 3 to 4.

Q4. What is the main difference between modern cellular phone system and old mobile phone systems?

A4. In old mobile phone systems, a band of frequency was assigned to cover a large area (called service coverage area) of the order of a city with a radius of around 50 km. One tower at the center of the coverage area was providing service to every user of the system within the coverage area. Modern cellular phone systems divide a large coverage area into smaller regions

(called cells). The same band of frequencies is divided into smaller bands that are used in different cells and the same bands are used in faraway cells.

Q5. Is a higher value of X in the attenuation R^X better or worst for a cellular system?

A5. Believe it or not, a relatively high value of X (up to a specific value) is better for cellular systems because it allows us to reuse frequencies use for communication multiple times with little interference between cells using the same set of frequencies. An extremely large value of X is not good because it means that very high power must be transmitted and yet the range of the transmitted power is extremely small, so cellular towers must be installed over very short distances.

Q6. How many calls does a cellular tower typically carry (1s, 10s, 100s, 1000s, 10000s)?

A6. The number of calls a cellular tower can serve at any time is called the tower capacity. A cellular tower typically can serve around 100 to 200 customers at any time. Different configurations can increase or decrease the tower capacity.

Q7. What is the typical coverage area of a cellular phone tower (0.25 km^2, 1 km^2, 4 km^2, 25 km^2, 100 km^2, 2500 km^2, 10000 km^2)

A7. The coverage area of a typical cellular tower is around 25 km^2.

Q8. In regions of low population, will the coverage area of a cellular tower be maid larger or smaller? In regions of high population, will the coverage area of a cellular tower be maid larger or smaller?

A8. The coverage area may be maid larger for regions of low population and maid smaller for regions of high population.

Q9. To provide the best coverage to an area by a single cellular tower, where should the tower be placed with respect to the coverage area?

A9. The best coverage is provided when you place the tower at or close to the center of coverage area.

Q10. What is the meaning of “Call Trunking”?

A10. When a region with a large population is allocated a small number of phone lines, all calls from the population of this region get routed through the small number of phone lines. This process is

called "Call Trunking" similar to a tree with many branches representing the large population but a single trunk representing the small number of phone lines.

Q11. What is the meaning of "Call Blocking"?

A11. When the number of calls originating from or directed to a region exceeds the number of phone lines dedicated to that region, the calls originating or received beyond the capacity of the lines of that region are "blocked". Call blocking is generally very rare in well designed networks. However, even networks with the best quality of service may experience high call blocking in emergencies where many people try to make phone calls beyond network capacity.

Q12. Which provides more reliable (less call blocking), having region 1 with X_1 population and L_1 dedicated phone lines and region 2 with X_2 population and L_2 dedicated phone lines, or one combine region with $X_1 + X_2$ population and $L_1 + L_2$ dedicated phone lines?

A12. As you will see later, combining regions together and combining the dedicated lines for each region provides better quality of service in terms of lower call blocking. The reason is that for two separate regions, call blocking may occur in one region while there are free lines in the other region and vice versa. When the two regions are combined, this situation is eliminated.

Q13. Who owns the frequency spectrum in different regions: (a) clearly no one owns the spectrum, (b) first one to start transmitting owns the spectrum he reserved, (c) governments own the spectrum, (d) cellular companies own the spectrum, (e) cellular companies, radio and TV stations, and other broadcasting companies agree to share spectrum.

A13. The spectrum is owned by governments. It costs cellular companies a lot of money to lease the spectrum. Mobily paid the Saudi government around SR 13,000,000,000 to be the second cellular service operator. From an unconfirmed source, Zain paid around SR 22,000,000,000 to be the third operator.

Q14. The quality of the signal received by a cell phone (or any communication system) is measured in terms of: (a) amount of signal power, (b) amount of noise power, (c) signal to noise power, (d) amplitude of received signal, (e) bandwidth of received signal.

A14. The quality of the received signal is measured in terms of signal to noise ratio (Ratio of Signal power to noise power).

Q15. The quality of the signal received by a cell phone (or any communication system) is measured in terms of: (a) amount of signal power, (b) amount of noise power, (c) signal to noise power, (d) amplitude of received signal, (e) bandwidth of received signal.

A15. The quality of the received signal is measured in terms of signal to noise ratio (Ratio of Signal power to noise power).

Q16. The amount of traffic (calls) that a channel of a telephone system is carrying has units of (a) Alphas, (b) Erlangs, (c) Quasars, (d) Calls/channel, (e) Users/line, (f) Calls/(min*Hz), (g) Traffic/channel

A16. As you will understand later, it is measured in units of Erlangs

What Classifies as a Mobile Radio Communication System

Most people limits Mobile Radio Communication Systems to cellular phone systems. In general, this terms covers many more systems such as:

- Garage door openers
- Paging systems
- Cordless phones
- Walkie-Talkies
- WiFi systems
- …

History of Mobile Systems

- Marconi invented radio in 1897. Was mostly used for long distance communication across the Atlantic and to communicate with ships in the middle of the Atlantic ocean.
- First **mobile phone** service was developed in 1946 during World War II (mostly Push-to-Talk)
- The **cellular phone** concept (breaking up a coverage area into small cells where frequencies are reused in faraway cells) was conceived by Bell Labs in the 1960s and 1970s.
- The developments of technologies of
    - Miniaturized batteries
    - Analog and digital and circuit miniaturization
    - RF circuit fabrication
    - Efficient digital switching

  in 1970s, 1980s, and 1990 resulted in sparking the wide spread of mobile phones.
- Mobile phones experienced very low market penetration for the first 35 years after their invention due to high unit cost, high service cost, and large equipment size. During the last decade of the past century and first decade of this century, mobile phones have experience a huge increase in market penetration.

Lecture 1: Introduction to Wireless Systems

Development of Mobile Systems in the U.S.

- In 1946, twenty five major US cities adopted the first mobile telephone system
  - Single high-power tower in each city to cover an area with radius around 50 km.
  - Analog FM modulation was used.
  - Push-to-Talk system (half duplex) with 1 channel for transmitted and received signals.
  - Original system used FM modulated signals with bandwidths 120 kHz because of difficulty in manufacturing filters with low transition bands.
  - In 1950s, improvements in circuit technologies reduced channel bandwidths to 60 kHz.
  - In 1960s, channel bandwidths were reduced to 30 kHz. (an improvement of only 4 times was achieved over a period of 20 years)
- In 1950s and 1960s, technology improvement resulted the IMTS (Improved Mobile Telephone Service).
- By mid 1970s, IMTS was saturated. Example: the IMTS system in New York City (with more than 10,000,000 people) had only 12 channels that could serve a maximum of 543 paying customer with a waiting list of 3700 people requesting service. Service in IMTS was poor due to call blocking.
- In 1968, AT&T Bell Labs proposed the concept of cellular mobile system to FCC, but technology was not available until end of 1970s to support this concept.
- In 1983, the FCC allocated a frequency band for the AMPS (Advanced Mobile Phone Service). FCC regulations stated that
  - Analog FM modulation is used
  - FDMA is the access method
  - Total allocated bandwidth was 40 MHz
  - Band is in the range of 800 MHz
  - 666 duplex channels were allocated
  - Bandwidth of each one-way channel is 30 kHz (60 kHz for both-way channel)
  - Each city should have no more than 2 cellular system providers
  - Radio channels were split equally between the two providers
- In 1989, FCC allocated 10 MHz additional bandwidth (166 channels) to meet increasing demand.
- In 1991, first US Digital Cellular system (USDC) based on Interim Standard IS-54 was deployed in major cities.
  - USDC allows cellular service providers to gradually replace the analog channels with digital channels
  - USDC provides 3 times the capacity of AMPS because analog channels are single-user channels while digital channels support 3 users in the same bandwidth of 30 kHz.
  - $\pi/4$ differential quadrature PSK is used
  - Speech coding is used
  - TDMA is used
- In 1993, a cellular system based on CDMA was introduced based on Interim Standard IS-95
  - Uses wideband 1.25 MHz channels with variable number of users per channel
  - Direct sequence spread spectrum (CDMA) is the access method

- Because CDMA is more resistant to co-channel interference (can operate at lower SNRs) than narrowband systems, frequency reuse is done at a higher rate to give a higher capacity system (more users per MHz)

- In 1994, bands in the range 1800/1900 MHz were auctioned for use with the new Personal Communication service (PCS) (Similar to European GSM system)
  - Uses TDMA
  - Uses Gaussian Minimum Shift Keying (GMSK)
  - Channel bandwidth is 200 kHz with 8 users per channel

Important Definitions

- **Mobile Station (MS):** is the part of a mobile communication system that changes its position as time passes. Cellular phones are a type of mobile stations.
- **Base Station (BS):** is the part of a mobile communication system that is stationary (does not move). The base station communicates with all mobile stations and takes a central position surrounded by mobile stations. Cellular towers are a type of base stations.
- **Full Duplex Systems:** are communication systems in which transmission between the mobile and base stations occurs in both directions at the same time (transmit and receive at the same time) such as cellular phone systems. The regular phone at your house is a type of full duplex systems because you can talk and listen to other side talking at the same time.
- **Half Duplex Systems:** are communication systems in which transmission between the mobile and base stations occurs at different times (transmit and receive at different times) such as push-to-talk systems.
- **Simplex Systems:** are communication system in which transmission of information occurs in one direction only such as a garage door opening system.
- **Forward Channel:** is the communication channel used to transmit information from the base station to the mobile station.
  - **Forward Control Channel (FCC):** is the channel used by the base station to inform mobile stations of a call directed to them, and to instruct mobile stations of the voice channels they should use to send and receive information.
  - **Forward Voice Channel (FVC):** is the channel used by the base station to transmit the voice signal to the mobile station.
- **Reverse Channel:** is the communication channel used to transmit information from the mobile station to the base station.
  - **Reverse Control Channel (RCC):** is the channel used by the mobile station to request from a cellular tower to initiate a phone call.
  - **Reverse Voice Channel (RVC):** is the channel used by the mobile station to transmit the voice signal to the base station.
- **Multiple Access Techniques:** are methods by which multiple mobile stations in a communication system request that part of the limited spectrum of the system be reserved for

its communication and then release the reserved spectrum once the communication is completed.

- **Time Division Multiple Access (TDMA):** the system assigns different time slots to transmit/receive information for each mobile station that would like to use the resources of the system. Multiple mobile stations using the system transmit/receive information at the same frequency.
- **Frequency Division Multiple Access (FDMA):** the system assigns different frequency slots to transmit/receive information for each mobile station that would like to use the resources of the system. All mobile stations using the system transmit/receive information at the same time.
- **Code Division Multiple Access (CDMA):** the system assigns different SPREADING codes to transmit/receive information for each mobile station that would like to use the resources of the system. Multiple mobile stations using the system transmit/receive information at the same frequency and the same time. The different spreading codes assigned to different mobile stations are orthogonal to allow the use of the same codes to extract the desired information from the spread signal without the interference of transmissions of other mobile stations.

- **Call Blocking:** occurs when more calls are initiated or received in a region or zone beyond the number of channels (or phone lines) dedicated to that region or zone. In this situation, some calls will be blocked.
- **Coverage Footprint:** is the region around a base station in which a mobile stations will receive service from that base station as long as it is in its coverage footprint. Once the mobile station leaves the coverage footprint of a base station, its service will either be transferred to another base station or it will loose coverage completely.
- **Mobile Switching Center:**