Phone or Walkie-Talkie?

• Mobile phones are radios that communicate over the PSTN (Public Switched Telephone Network) or POTS (Plain Old Telephone System).

• Each phone is assigned a telephone number. They can communicate with each other and also with land-line phones.
Mobile Phone (0 G): 1950s-80s

- Analog, push-to-talk (PTT), half-duplex, operator assisted dialing, heavy (car phones)
- No *cells*. Limited number of users in a region (city).
- Technologies: MTS, IMTS, AMTS, RCC
1 G Cell Phones: 1980s-90s

- Assigned radio channels to specific cells and reused channels in adjacent clusters (Fig 1.1) to increase the number of users.

- Analog (FM), full-duplex achieved using transmit and receive paired frequencies (Fig 1.2). No data, voice only (no SMS, no Snapchat, no Netflix, no YouTube)

- Technologies: AMPS (Bell Labs)
Figure 1.1
The various letters correspond to different radio channels. The shaded regions use the same radio channel. This pattern is a seven-cell reuse pattern.
AMPS Channel Separation

**Figure 1.2.** Concept of AMPS and similar analog systems employing frequency division multiple access (FDMA) for different users, with each user having a radio channel of bandwidth 30 kHz, one to transmit and another one to receive. The channel separation is 45 MHz.
2 G Cell Phones: 1990s-00s

- Digital voice with encryption to prevent eavesdropping.
- Data: SMS (texting) and MMS (images)
- Cameras and color displays
- The first iPhone was 2G.
- Technologies
  - GSM via TDMA (AT&T, T-Mobile).
  - cdmaOne via CDMA (Verizon, Sprint)
Figure 1.3. Concept of TDMA. Three users share the single radio channel, each using the bandwidth at a different time.
Multiple Access (MA) Methods

- Frequency Division Multiple Access (FDMA)
  - Each call uses a different frequency.
- Time Division Multiple Access (TDMA)
  - Each call gets a time slot on a particular frequency.
- Code Division Multiple Access (CDMA)
  - Each call gets a unique code and spreads the call over multiple frequencies (spread spectrum).
A Multiplexing Analogy

- Two people want to talk to each other from different spots in a noisy factory. Each person is given a full-duplex headset radio.

- Now a second pair of people decide that they want to talk to each other also. How do we expand our communication system? A few possible methods are described on the next slide.
FDM/TDM/CDM

1) We buy a new pair of radios that use a different frequency (channel). This is FDMA. It uses more of the spectrum.

2) We buy an identical pair of radios that use the same channel. The two pairs must take turns talking. This is TDMA. It does not require additional spectrum.

3) We buy an identical pair of radios that use the same channel. The second pair must speak Spanish. The English and Spanish speaking pairs use the channel simultaneously. This is (roughly) analogous to CDMA.
Advantages/Disadvantages

- All methods allow us to double the number of users.
  - FDMA uses more of the spectrum.
  - TDMA uses less spectrum, but the channel is only available half the time.
  - In CDMA the channel is always available, but there is interference (the other language.) Note: The CDMA analogy is not great. CDMA implementations actually use more of the spectrum.

- How can the methods be extended so that we might be able to support even more users? (There is no hard limit on the number of users with CDMA as the number increases the interference level rises.)
Hybrid Systems

- Modern cell systems are hybrid systems. The first generation system used multiple FDM channels. In the second generation TDM was used to triple the number of users in a cell without adding additional channels (no additional spectrum). The transmitted voice signal was changed from analog to digital.
Extending the Analogy

- We can extend the analogy even further. We may be able to use the same communication system in a different building (cell) and again double the number of users.

- If the buildings are too close together (causing the interference between channels to be too high) you might imagine *clustering* the buildings and only allowing channels to be reused when the users are in different clusters that are sufficiently far apart.
SDM (Channel Reuse)

- The technique of reusing frequencies/channel that are separated by distance is sometimes referred to as Space Division Multiplexing (SDM). It is, of course, commonly used in broadcast radio and television (and with cell phones!).
Multiplexing or Multiple Access?

- The process of using different frequencies (channels) to transmit different signals is Frequency Division Multiplexing (FDM).
- The process by which individual users are automatically assigned a particular frequency is known as Frequency Division Multiple Access (FDMA).
- The two acronyms are often used interchangeably in the literature. The same is true regarding TDM and TDMA and also for CDM and CDMA.
Signal-to-Interference Ratio

- In the previous course we found that system performance was primarily a function of the signal-to-noise ratio. With channel reuse we also have to worry about the signal-to-interference ratio (S/I).

- We will see that S/I is function of the number of cells in a cluster rather than the size (area) of a cluster. I will increase as the cluster size decreases, but so does S (due to the smaller cell size). The ratio remains constant.
3 G Cell Phones: 2000-08

- Characterized by faster data
- Streaming audio and video
- The first Android was 3 G.
- Technologies
  - UMTS using CDMA (AT&T, T-Mobile).
  - CDMA2000 (Verizon, Sprint)
4 G Cell Phones: 2008-18

• Even faster data rates
• All-IP packet switched network
• Technologies
  – LTE using OFDMA (All networks)
Phone Compatibility

• The major carriers in the US use 4G LTE, but at different frequencies. Most newer phones support the different frequencies.

• If you are in an area without 4G coverage, you will need a GSM phone for AT&T and T-Mobile and a CDMA phone for Verizon and Sprint. GSM vs CDMA is a 3G difference. A (very) few phones support both GSM and CDMA.

• As a rule of thumb, you can usually take an unlocked phone between AT&T and T-Mobile or between Verizon and Sprint. If you bought a locked phone on contract, you may be able to unlock it.
Components of a Cellular System

- Mobile Station or Mobile Unit (MU) – The portable device carried by the user.
- Base Station (BS) – Fixed station that communicates with MUs within the cell. It consists of receive and transmit antennas mounted on a tower. The BS is the link between the MU and the MTSC.
- Mobile Switching Center (MSC) or Mobile Telephone Switching Center (MTSC) or Office (MTSO) – The MTSC provides the link to the public switched telephone network (PSTN). Multiple BSs usually connect to a single MTSC.
Figure 1.4. A generic mobile unit.

PA: Power amplifier
LNA: Low-noise amplifier
Figure 1.6. A generic base station.

DUP: Duplexer  LNA: Low-noise amplifier  PA: Power amplifier  
RF: Radio frequency  TX: Transmitter  RX: Receiver  
MSC: Mobile switching center (or MTSO: Mobile telephone switching center)
Figure 1.7. An overview of the cellular system. Each base station has an antenna, and all the base stations are connected to the mobile telephone switching office, which provides the link to the landline.
Terminology

- **Cell** – Smallest area covered by a base station. A region consists of many cells. Channels may be re-used in adjacent cells or cell clusters.

- **Control Channel** – Control channels are used for call setup, call requests, call initiation, call termination, etc.

- **Duplex Systems** – Full-duplex systems allow simultaneous two-way communication. Half-duplex systems only allow a user to transmit or receive at any one time.
Terminology

- Forward Channel – Radio channel used for transmission from BS to MU.
- Forward Link (Downlink) – Connection from BS to MU.
- Hand-Off – Process in which MU is transferred between channels or base stations.
- Reverse Channel – Radio channel used for transmission for MU to BS.
- Reverse Link (Uplink) – Connection from MU to BS.
- Simplex System – A one way comm link.