1 Cellular Systems Intro

1.1 Generation Zero

The study of the history of cellular systems can help us understand the need for the system design concepts we have today.

One of the major developments in WWII was the miniaturization of FM radio components to a backpack or handheld device (the walkie-talkie), a half-duplex (either transmit or receive, not both) push-to-talk communication device. After returning from war, veterans had the expectation that wireless communications should be available in their civilian jobs [4]. But the phone system, the Public Switched Telephone Network (PSTN) was: wired, and manually switched at telephone exchanges. In 1952, the Mobile Telephone System (MTS) was designed to serve 25 cities in the US [3] (including one in Salt Lake City [2]). In each city, an additional telephone exchange office was created for purpose of connection with the mobile telephones [4]. The MTS and later the improved mobile telephone system (IMTS), introduced in 1964, were not particularly spectrally efficient.

- They were allocated a total bandwidth of about 2 MHz. Frequency modulation (FM) was used. For multiple user access, the system operated frequency division multiple access (FDMA), in which each channel was allocated a non-overlapping frequency band within the 2 MHz.

- The PSTN is full duplex (transmit and receive simultaneously) in IMTS, so it required two channels for each call, one uplink (to the base station) and one downlink (to the mobile receiver). Note MTS had been half duplex, i.e., only one party could talk at once.

- The FCC required them to operate over an entire city (25 mile radius). Since the coverage was city wide, and coverage did not exist outside of the cities, there was no need for handoff.
Initially channels were 120 kHz [1], due to poor out-of-band filtering. The channel bandwidth was cut to 60 kHz in 1950 and again to 30 kHz in 1965. Thus there were 2 MHz / 2 / 120 kHz or 8 full duplex channels at the start, and up to 32 in 1965, for the entire city.

Control was manual, and the control channel was open for anyone to hear. In fact, users were required to be listening to the control channel. When the switching operator wanted to connect to any mobile user, they would announce the call on the control channel. If the user responded, they would tell the user which voice channel to turn to. Any other curious user could listen as well. A mobile user could also use the control channel to request a call to be connected. The system was congested, so there was always activity.

The demand was very high, even at the high cost of about $400 per month (in 2009 dollars). There were a few hundred subscribers in a city [3] but up to 20,000 on the waiting list [4]. The only way to increase the capacity was to allocate more bandwidth, but satisfying the need would have required more bandwidth than was available.

The downsides to MTS took a significant amount of technological development to address, and the business case was not clear (AT&T developed the technologies over 35 years, but then largely ignored it during the 1980s when it was deployed [3]).

1.2 Cellular

The cellular concept is to partition a geographical area into “cells”, each covering a small fraction of a city. Each cell is allocated a “channel group”, i.e., a subset of the total list of channels. A second cell, distant from a first cell using a particular channel group, can reuse the same channel group. This is called “frequency reuse”. This is depicted in Figure 3.1 in Rappaport. This assumes that at a long distance, the signals transmitted in the first cell are too low by the time they reach the second cell to significantly interfere with the use of those channels in the second cell.

There are dramatic technical implications of the cellular concept. First, rather than one base station, you need dozens or hundreds, deployed across a city. You need automatic and robust mobility management (handoff) to allow users to cross cell lines and continue a phone call. Both of these are actually enabled by semiconductor technology advancement, which made the base stations and the automated wired PSTN cheaper [4].

Frequency reuse and handoff are topics for upcoming lectures.

1.3 Key Terms

Communication between two parties (a “link”), in general, can be one of the following:
• **Simplex**: Data/Voice is transferred in only one direction (e.g., paging). Not even an acknowledgement of receipt is returned.

• **Half Duplex**: Data/Voice is transferred in one direction at a time. One can’t talk and listen at the same time. One channel is required.

• **Full Duplex**: Data/Voice can be transferred in both directions between two parties at the same time. This requires two channels.

In a cellular system, there is full duplex communication, between a base station and a mobile. The two directions are called either uplink (from mobile to base station) or downlink (from BS to mobile). The downlink channel is synonymous with “forward channel”; the uplink channel is synonymous with the “reverse channel”.

Simultaneous communication on the many channels needed for many users (radios) to communicate with a base station can be accomplished by one (or a combination) of the following multiple access methods.

• **Frequency division multiple access (FDMA)**: Each channel occupies a different band of the frequency spectrum. Each signal can be upconverted to a frequency band by multiplying it by a sinusoid at the center frequency of that band, and then filtering out any out-of-band content (see ECE 3500).

• **Time division multiple access (TDMA)**: Every period of time can be divided into short segments, and each channel can be carried only during its segment. This requires each device to be synchronized to have the same time clock.

• **Code division multiple access (CDMA)**: Many channels occupies the same frequency band, at the same time. However, each channel occupies a different “code channel”. Like sinusoids at different frequencies are orthogonal (non-interfering), sets of code signals can also be made so that all code signals are orthogonal to each other. One user’s channel is multiplied by one code in the set, and at the receiver, can be separated from the other signals by filtering (like frequency bands can be filtered to remove out-of-band content).


Physical “parts” of a cellular system:

1. Public switched telephone network (PSTN): Wired telephone network, connecting homes, businesses, switching centers.

2. Mobile switching center (MSC), a.k.a. mobile telephone switching office (MTSO): Controls connection of wireless phone calls.
through the base stations to the PSTN. Connected either by wire or by wireless (microwave relay) to the base stations.

3. Base station (BS): Maintains direct wireless connection to cell phones in its cell. Typically maintains many connections simultaneously. Has multiple antennas, some for downlink and some for uplink.

See Figure 1.5, page 14, in the Rappaport book.

In cellular systems, there are actually two types of channels: (1) Control, and (2) Communication. The control channel is needed to tell the mobile device what to do, or for the mobile to tell the BS or MSC what to do. The communication channel is the “voice channel” or data channel, the actual information that the user / system needs to convey in order to operate. Since we also have a forward and reverse channel (for full duplex comms), we have

1. FCC: Forward control channel
2. FVC: Forward voice channel(s)
3. RCC: Reverse control channel
4. RVC: Reverse voice channel(s)

Quite a bit of work goes into planning for frequency reuse. We have two goals. First, a radio should be in range of at least one BS; so BSes must have a certain density so to cover all of an area. Next, a radio must avoid co-channel interference from other BSes using the same channel, which means that base stations using the same channel should be widely separated. These are conflicting goals! The first section of this course will teach you how to engineer a cellular system that works to a desired specification.

References


