Cellular - Mobile Communications

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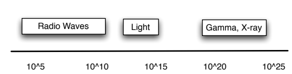
Radio Waves

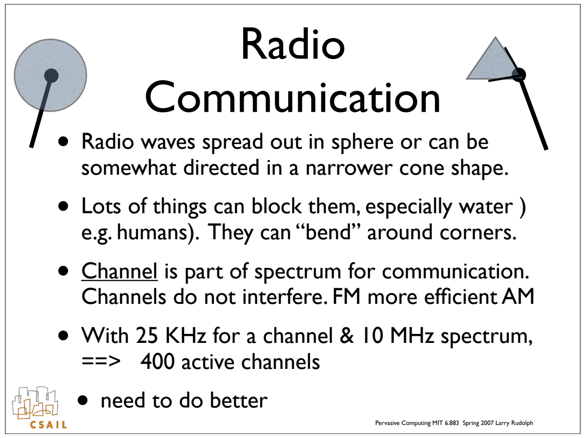
Albert Einstein, when asked to describe radio, replied:
"You see, wire telegraph is a kind of a very, very long cat. You pull his tail in New York and his head is meowing in Los Angeles. Do you understand this? And radio operates exactly the same way: you send signals here, they receive them there. The only difference is that there is no cat."



The right place for us to start is with understanding how cellular communication works and that requires some understanding of of radio communication. It is assumed that the reader has some understanding as to how radio communication works or, at the very least, is willing to accept the pictures and explainations.

Let me begin, however, by personally admitting that I still find radio communication magical, despite
understanding how it works. The fact that this little box that I hold in my hand can somehow communicate with a cell tower that I cannot see and might take me an hour to get to is hard to fully accept. I do not believe in mental telepathy, but cellular communications certainly feels like it. And it is not too hard to imagine hooking up a phone to a a neuron so that one's thoughts can be silently transmitted to another person.

Getting back to the main point, it is possible to generate a radio wave at a particular frequency and power level and have that signal received at a remote unit at that same frequency and with the same modifications to the power level.



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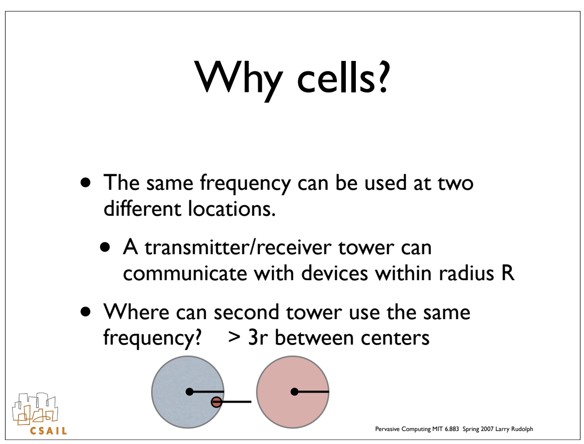
So what do we need to know about radio waves and communication via these waves? Without anything special, they radiate in a sphere, but can be somewhat directed. Cell towers usually have six different antenna's equally spaced around the tower.

Water, buildings, mountains, and other structures all interfere somewhat with the radio signals. They can even bend around a building or reflect off a surface. Reception can drastically change by moving just a few feet.

Signals are encoded into the radio waves as either amplitude or frequency modulation. Amplitude modulation (AM radio) varies the amplitude of the wave or its power. This makes it very easy to transmit sound: use a microphone to modulate the amplitude and then at the receiver, the amplitude of the signal at the given frequency is used to drive a speaker after it is amplified. A frequency is modulated but there still must be sufficient spread between frequencies so that signals do not interfere. Modulating the amplitude of the frequency causes sidebands which interfer with nearby frequencies. AM encoding is inefficient.



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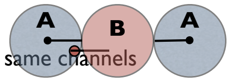
Since a transmitter/receiver has only a finite communication radius, the same frequency can be used if the areas do not overlap. The idea is that a handset uses one channel while it is communicating with a tower and a different handset in a different cell can also be using that channel. But, when a handset moves between cells, it may use a different channel.

Suppose a tower, A, can cover an area of radius r. Any device within the area covered by tower A, must also be able to reach the tower, but that might interfere with an adjacent cell. So the next cell that uses the same frequency must be at least 3 r separated from the first tower.

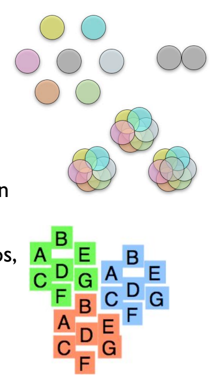
Channels / cell



- Non-adjacent cells can use same channels
  - Cells A and cells B use different channels
- What about the boundaries?
  - overlap with other cells (different channels)
- What about other dimension? More cells
- How to organize them?

OK, so we divide into several different sets of channels (not just two). The challenge is how to overlap them in an organizing principle.

Clusters



- A <u>cluster</u> has 7 different cells
  - sometimes it is 12
- There is lots of overlap between them
  - top picture is without overlaps, imagine moving the six surrounding ones, in towards the center one.

A <u>cluster</u> has 7 to 12 cells overlapping in are but not in channels. These clusters are then used to tile the whole coverage area. The pictures describe the story a bit clearer. The cells overlap to form a cluster and clusters overlap as well. The bottom picture shows a tiling.

Cell Sizes

- Different Sized Cells
  - Macro Cell: 10 KM
  - Micro Cell: 1 KM
  - Pico Cell: building
- Small cells ==> high bandwidth; more drops
- Large cells ==> fewer towers; fewer handoffs

Small cells means more bandwidth since there are lots of reuse of channels. But lots of cells means ltos of towers which is a larger expense for hte network. But it also means lots more handoffs. Handoffs are tricky since if there is no available channel in the new cell, then the call will be droped in the middle and no one likes that. Can avoid dropped calls by reserving a large fraction of channels for handoffs. But this reduces the number of calls that can be initiated. Clearly, if only one subscriber was allowed into the system, there will always be an available channel for handoffs. Operators can to vary these parameters to improve marketting claims.

Standard terminology, classifies cells into macro (10 kilometers), micro (1 kilometer) and pico (100's of meters). Urban environments use micro cells and rural macro cells. Of course there are many constrains in placing towers. Finding a place to rent with network and electricity access. In Japan, in urban environment, there are vending machines in nearly every corner, they make great places for pico cells. Cell phones in Japan are usually very small since the towers are nearby.

Of course cells do not really look like we described. It is only an approximation to the

Multiple Use of Spectrum

- Divide (multiplex access)
  - FDMA (Frequency Division); TDMA (Time)
    - Frequency Shift Keying (2 freqs rep 0 & 1)
  - CDMA Code Division Multiplex Access
    - allow overlap but distinguish via code
- Simplex vs Duplex: allocate two freqs or two times for up & down channel transmission

AM is simple, but poor use of spectrum
FM in first generation used about 75 kHz per channel (much less now)
Freq Shift Keying: Use two frequencies, one representing a 0 and the other a 1, and use one per "clock" to send digital data.
CDMA: Use code and allow channels to overlap in freq.

Random Channel Allocation

- Suppose there are N channels. A simple allocation scheme: Pick one at random.
- Listen:
  - if free, use it
  - if in use, go try another one
- Like m balls in n buckets, throw again on collision

Rather than statically allocating a frequency to each subscriber, a scheme is needed to allocate a channel to communicate.

Here is an obvious scheme that is based on the Aloha scheme (which was the precursor to ethernet). Aloha used wireless communication to connect to the internet.

Here is the idea: whenever a handset wants to communicate, it randomly chooses a channel. It listens on that channel to see if anyone else is using that channel. If it is in use, then a new channel is chosen at random. If no success, perhap backoff just to save battery power. If channel is quiet, then use it.

It is fairly easy to analyze this scheme using “n balls in m buckets” theory. This is a well studied problem but evern if you do not know the theory, it is worthwhile to have the right intuition. Very briefly and approximately, randomly throwing n balls in n buckets results in about half the buckets being empty, a quarter having one ball, and eight having two balls, a sixteenth with three balls, and one bucket with about log n balls. So, about 1.2 the balls will need to be retossed and about half of these (1/4 of n) will fall in the empty buckets.

Network Channel Allocation

- Turn on phone and register with network
  - send physical phone code (IMEI) and phone number and any other info
  - Look up and verify
- Paging channel: administration & allocation
  - “attach”/”detach” message on power up/down
  - get temp id, temp key for encryption
  - Home location registry; visitor registry

To setup a call? Some time slots or freq are reserved for “paging” -- that is, for non-conversation communication. Mostly, it is straight-forward and boring to see how exactly what is done. Here, we just cover the general idea as the specifics can always be looked up elsewhere.

The paging channel is used for the phone to indicate it’s existence to the network. The phone issues an “attach” message on the paging channel giving all the relevant information. The network looks up the info in the home location registry. If this is on a different network or in a different country, then the visitor location registry is used. The network needs to know the cell in whose control the phone resides currently. Depending on the system used, the phone may get a temporary id used for communication (that is much smaller than the full id, thereby saving bandwidth on all communications). The phone may also get a key for use with encrypted communication.

The phone periodically checks in with the tower but is mostly quiet unless it is involved in some communication, a handoff, or a power down (where it sends a detach message).

The Paging Channel

- Paging Channel is a Random Access Channel
- Listening is more expensive than speaking
- Too expensive to listen all the time
  - listen every 1/10 of time, depending on last digit of phone number

The paging channel is used for administrative communication between handset and network. It could be very busy if many phones get turned on / off, initiate or receive calls, move into and out of a cell. At least two paging channels -- one for communication from tower and one for communication from handset.

Every time the tower looks for a phone so it can accept a phone call, it broadcasts the temporary id on the paging channel. All phones listen and respond if it is their number. But it is expensive to listen all the time and the paging channel can get oversubscribed. At the very least, the paging time slots are divided into 10 slots, one for each last digit of the phone number. So, a phone only listens on 1/10 of the paging slots, ignoring the others. This uses less power and is better use of spectrum, but it means phone may take a lot longer to initiate a call or respond to an incoming call.

When we all have phones in class, we should try some experiments to see if this is really true. Think about how we can do that.

Analog ==> Digital

- First Generation: analog audio
  - simpler handset, spectrum wasteful
- Second Generation: Digital
  - CDMA: US, GSM: rest of world
- Third Generation:Voice + Data

Needless to say, communications get very complex as the handsets have more computational power, as the operators try to maximize their use of spectrum and minimize their costs.

Streaming video is probably going to be the next major use of the spectrum.

GSM

- SIM Card
  - personalized subscriber info
  - “easy” to switch phones

Problem Set

- Real cells do not look like the cartoon