

Lecture 3- Pre-lecture reading

Mobile telephone systems before cellular (and the first steps toward cellular systems)

Early systems

By the 1930s, mobile radios had gotten small enough and rugged enough to be put in the trunk of a car (the radio was still so large that it took up most of the trunk of the car). As a result, mobile radio began to be used by police departments, and in the mid-1940s a few channels were assigned for mobile telephone systems. AT&T immediately began to plan and install systems.

Radio telephone systems installed and planned in 1947



Spotted on this map are the locations where facilities for mobile radio telephone service are being established

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These early systems resembled the entertainment “broadcast” systems of the day (AM and FM radio, and television), except, of course, that they provided two-way communication, so there had to be a transmitter in the car and a receiver at the central broadcast location. They typically used powerful radio transmitters (~100 watts), placed on a hilltop or on the roof of a tall building at the center of a city, and they covered a radius of 20-40 miles.

Coverage of the NYC System c. 1950



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The radio units in cars had to be lower in power (~10 watts) so they had less range. To make up for that range difference, there would often be several “satellite” receiver locations spread around the service area, connected by wire to the central location, and the one that received the strongest signal would be selected at any given moment. The system would be monitored by a mobile operator with a switchboard connected to the telephone system [slide 4].

The car had lower power
so the system used “satellite” receivers



Is this a cost-effective system architecture? Any ideas?

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Because of limitations in the capabilities of low-cost radios in the mid-20th century (filters, amplifiers, antennas, etc.), mobile radio devices and broadcast radio and TV devices had to operate at relatively low frequencies (less than 100 Megahertz in the 1940s), which greatly limited the total number of channels that were available. The issues of radio frequency, channels and spectrum will be discussed in some detail in Lectures 12-14, but for now we only need to understand that in the middle of the 20th century, frequency limitations created an acute shortage of channels for all radio services. With the emergence of entertainment services like television (which required very wide channels for video “information”) and FM broadcast radio, and demand for communications channels by government agencies and businesses, and public service uses like police and fire departments, there was a great competition for channels. The Federal Communication Commission (FCC) had the task of evaluating these competing needs and assigning the available channels to the most valuable services. There was always competition and contention, leading to lengthy “comparative hearings” that caused long delays in the allocation of any new channels. The hearings that led to cellular channel allocations took almost 15 years! As we will see in a later lecture, the long FCC hearings to decide who gets channels have been replaced, in many cases, by spectrum auctions—a much faster process, and one that brings the government billions of dollars. In the mid-20th century, however, spectrum was assigned through long deliberations by the FCC to determine the “public good”, and mobile telephone systems got only a few channels nationwide.

By the late 1950s, the spectrum that the FCC had “allocated” to specific uses had increased to about 500 Megahertz, but mobile telephone was not considered as important as entertainment, public safety (police and fire) or commercial fleet dispatch operations. As a result, there were less than 50 channels for mobile telephone service (about 3% of the allocated spectrum). Those few channels were divided equally between the local telephone companies (most of which were owned by AT&T) and entrepreneurs called Radio Common Carriers (RCCs) that were created by the FCC to provide competition to the AT&T monopoly. In New Jersey, for example, the local telephone company was New Jersey Bell, which is now part of Verizon, and there were many different RCCs operating in towns and cities.

Radio coverage and channel reuse

To prevent excessive interference, a radio channel that was used in one location couldn’t be re-used in another system for a significant distance (D). We call D the reuse distance. The reuse distance was roughly 4 times the coverage distance (R), which was the distance from the central transmitter to the boundary of service).

Channels that were used in the largest systems like Philadelphia, Washington, Boston, and Hartford had “coverage distances” of about 30-40 miles and reuse distances of 100-150 miles. (Slide 6, below)

Telephone company coverage in big cities was 30+ miles
 Large-city channels could be re-used at distances of 100-150 miles

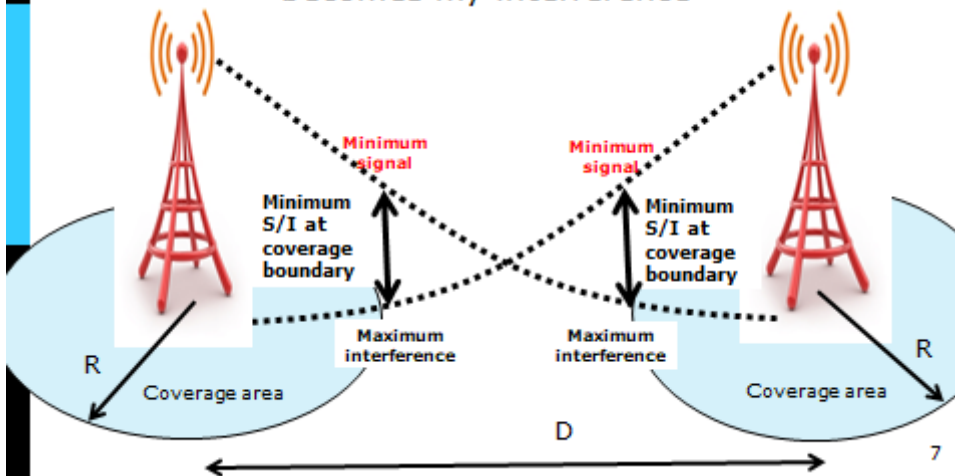


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The worst-case voice quality in a mobile radio communication system (the minimum Signal-to-Interference ratio, or S/I) occurs at the boundary of a coverage area, where the user is at the maximum distance (R) from the desired transmitter and at the minimum distance (D-R) from the interfering transmitter) (see slide 7, below).

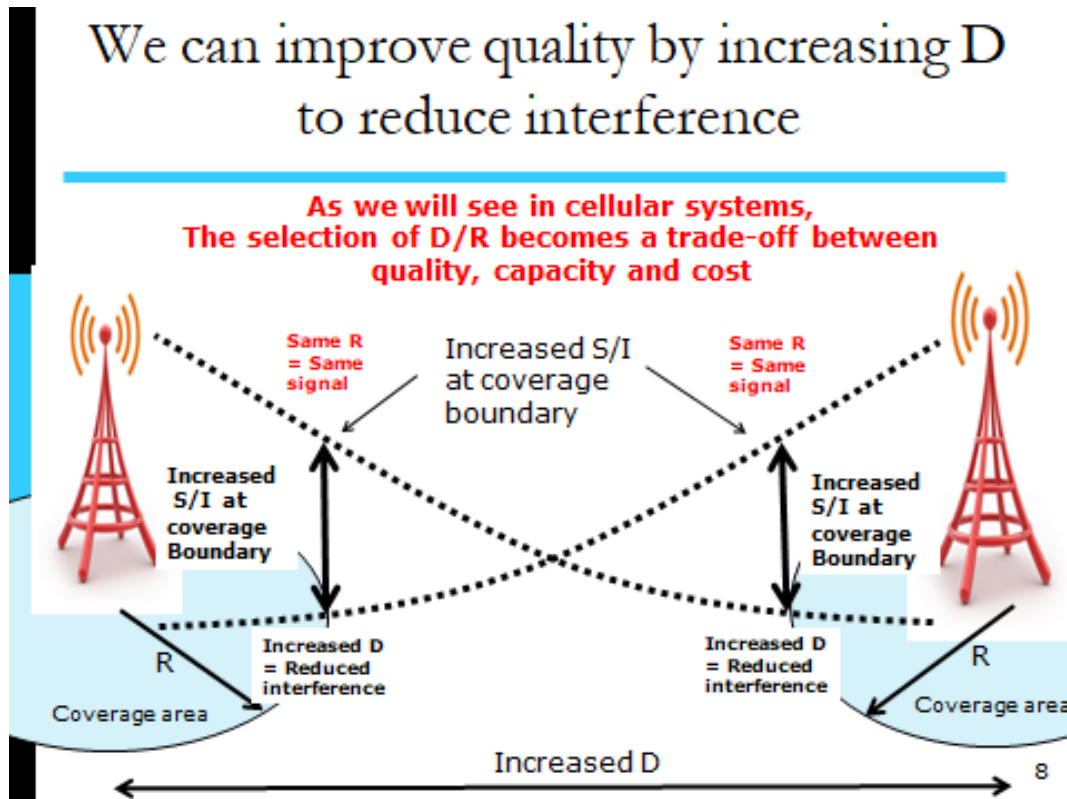
The ratio of reuse distance to coverage range (D/R)
 determines the Signal/Interference ratio (S/I)
 and therefore the voice quality ($S/I \sim D/R$)

Your signal, reduced by distance,
 becomes my interference



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If necessary, we can improve the quality of the voice signal by increasing (D) the separation between systems that use the same channels (as shown in slide 8, below) or by reducing the coverage distance (R) in each of the systems. Thus, improving quality will result in fewer systems, or smaller coverage areas, or systems with fewer channels. When we discuss cellular systems in the coming lectures, it should not be surprising that the values of (D) and (R) in a cellular system represent a trade-off between voice quality, capacity and cost.



Returning to our picture of the old radiotelephone systems in the NE corridor, the large cities like New York got about half the available channels, with the other half reserved for many smaller cities and towns, as shown in slide 9, below. Each channel could be used about 4 times on average, so the 50 channels that were available only allowed about 200 channels to be deployed in the area shown. Thus, there could be fewer than 200 simultaneous calls in the entire northeast corridor, from Boston to Washington, DC!

The original radiotelephone systems, with large coverage areas and few channels, could only provide about 200 simultaneous calls in the NE corridor



How many calls on Busch Campus right now?
Notice the spaces with no service

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Because there were so few channels available and more people wanted service than could be properly accommodated, the telephone companies and RCCs were forced to overload their systems with about 60 customers per channel, which meant that all the channels were busy most of the time. There would usually be a lot of people waiting to make calls, and the radios had buttons to select a channel, so users would listen to calls in progress and try to jump in first when that call ended. Because of this lack of privacy, many people spoke in sort of a code (e.g., “tell you-know-who that I’ll meet him where we met last time”).

The early systems used mobile operators to place calls, but in the 1960s, the telephone companies started an “automatic” mobile telephone service in which a user could dial and receive calls without an operator (slide 15, below). They put an “idle tone” on a channel that was available (if a channel was available). All the mobile phones would scan the possible channels, looking for that tone, and would “camp” on that channel. If a call came in for a mobile customer, the system would send out the customer’s ID on the idle channel as pulses of tone, which could be decoded by a big logic board (using those wonderful new devices called transistors) and the car phone would ring. Alternatively, if you went “off hook” (raised the handset) to place a call, your radio would “seize” the idle channel and give you a dial tone, and the idle tone would move to another channel. You would dial the number you wanted, using pulses of tone.

“Automatic” car phone c. 1965



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This worked reasonably well for making calls from the car, although all the channels were frequently in use so users still listened in on calls to be first to grab the idle channel. Calling to a mobile customer from a “land-line” phone was virtually impossible in a heavily loaded system—you would have to dial the call in the few seconds when there was an idle channel, and since you didn’t know the system status this was a matter of luck. Calling the car was easier in the old manual systems with the assistance of a mobile operator.

Even with this heavy loading on channels and the poor service that resulted, there were thousands of people on waiting lists for service, and opportunities went to “priority” customers like doctors (or politicians). In the 1960s, there were about 50,000 mobile telephone customers in the US (one in a few thousand people). On the other hand, most people had never used (or even seen) a car phone and didn’t particularly want one. Three decades after the first cellular systems began serving users in 1984, everyone had a cell phone and couldn’t live without it. How that happened is a fascinating story.

The first steps toward cellular

As early as 1947, when the first manual mobile telephone systems were being installed, AT&T was already petitioning the FCC for a large block of channels for a greatly expanded mobile radio telephone system (an early vision that would later become cellular), but no channels were available at that time. By the late 1940s, channels up to frequencies of about 500 MHz were fully used, but in the 1950s improving radio designs allowed frequencies up to 1000 MHz (1 GHz) to be used for practical purposes like TV or mobile radio. This doubled the

available spectrum and thus made a huge amount of new spectrum available for assignment.

The FCC held hearings in the early 1950s to determine how this newly available spectrum should be used. AT&T and other “mobile radio” operators argued their case forcefully, but the (relatively new) technology of broadcast TV was hugely popular at the time. The TV broadcasters argued that with a huge increase in channels they could bring cultural and educational programming to the masses. The FCC accepted this vision of the “public good” and in the mid-1950s all the new frequencies (almost 500 MHz of spectrum!) were used to create “Ultra High Frequency” (UHF) TV channels 14-83. [What were “Ultra High Frequencies” in the 1950s are thought of as low frequencies today, but the name remains.] As we will discuss in Lecture 12, TV channels must carry much more information than voice channels and as a result are much wider than voice channels (each TV channel was about 6 MHz wide (an amount of spectrum that could have provided 100 2-way mobile telephone voice channels).

By the late 1960s, the FCC had become disappointed in the results of the huge UHF-TV allocation. FCC chairman Newton Minow, in a famous speech, called TV broadcasting a “vast wasteland,” which he described in greater detail as “a procession of game shows, formula comedies about totally unbelievable families, blood and thunder, mayhem, violence, sadism, murder, western bad men, western good men, private eyes, gangsters, more violence, and cartoons, and endless commercials.”

Despite this “constructive criticism”, TV programming didn’t improve, and in 1968, the FCC lost patience. They opened “Docket 18262,” which offered to reallocate a slice of that spectrum (14 of the UHF-TV channels) for “mobile communications” (mobile telephone systems and private radio systems (police, fire, fleet dispatch, etc.). This would create well over 1000 2-way mobile radio channels, and the FCC specifically asked for **“innovative new technologies” that would serve more people per channel**”. They were tired of endless requests for mobile radio channels and wanted to see improved technology so the organizations that got these new channels would stop asking for more channels. As we will see, AT&T’s cellular proposal would fit that requirement rather well, but opposition to the AT&T monopoly being given all those channels would lead to 15 years of conflict and delay.

As we will see in later lectures, cellular technology did add dramatically to the capacity per channel (as the FCC had hoped), but the demand for cellular service was far more than anyone could have imagined. Compared to the pre-cellular days, we have increased the number of users from 50 thousand to 300 million in the US (a factor of 6000). Those users spent a lot more time talking than was possible in the crowded old systems and with the coming of the smart phone the total capacity demanded per user has increased by a factor of about 500. The resulting increase in nationwide capacity has therefore been 6000×500 , **a factor of 3 million**. A lot of new technology was created along the way, but the demand for additional channels (more radio “spectrum”) has never ended.