

Wireless!

The forces and strategies that shaped a revolution



Lecture 3- Mobile Telephone Systems Before Cellular

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The forces and strategies that shaped a revolution



Lecture 2- Wires and waves The Age of Fast Communications

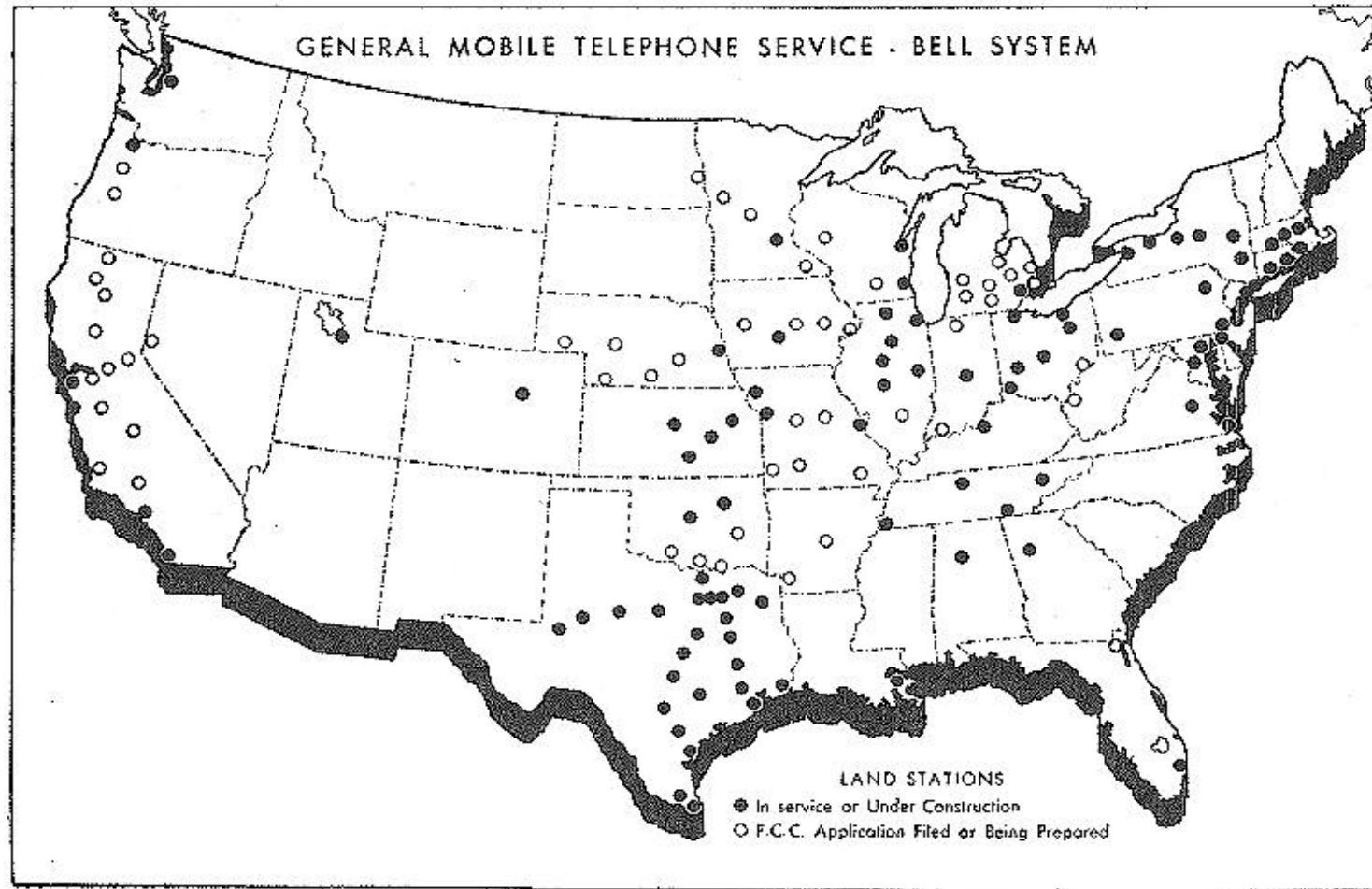
Lecture 2- Classwork

1. Please summarize in 3-4 sentences the Pre-Lecture reading for Lecture 2 including some important takeaways from your reading.
2. Why was a telegraph network able to cover the country quickly?
 - ❑ Railroads were expanding and created routes between most places that could be used. They also needed telegraphy to schedule and keep track of the trains.
3. Can you provide an example from this lecture that illustrates how Technology can advance even without fully understanding the Science behind it?
 - ❑ Creation of telegraph before electricity/magnetism was fully understood, etc.
4. Why was the telephone a more difficult problem than telegraph?
 - ❑ It wasn't just on-off signaling. They needed a way to turn a complex pressure wave into an electrical signal. Real-time 2-way communications.
5. Why were radio channels for many popular and important services so limited before 1950?
 - ❑ Only a fraction of the spectrum we use today was possible because low-cost radios were limited to relatively low frequencies.

Lecture 3- Classwork

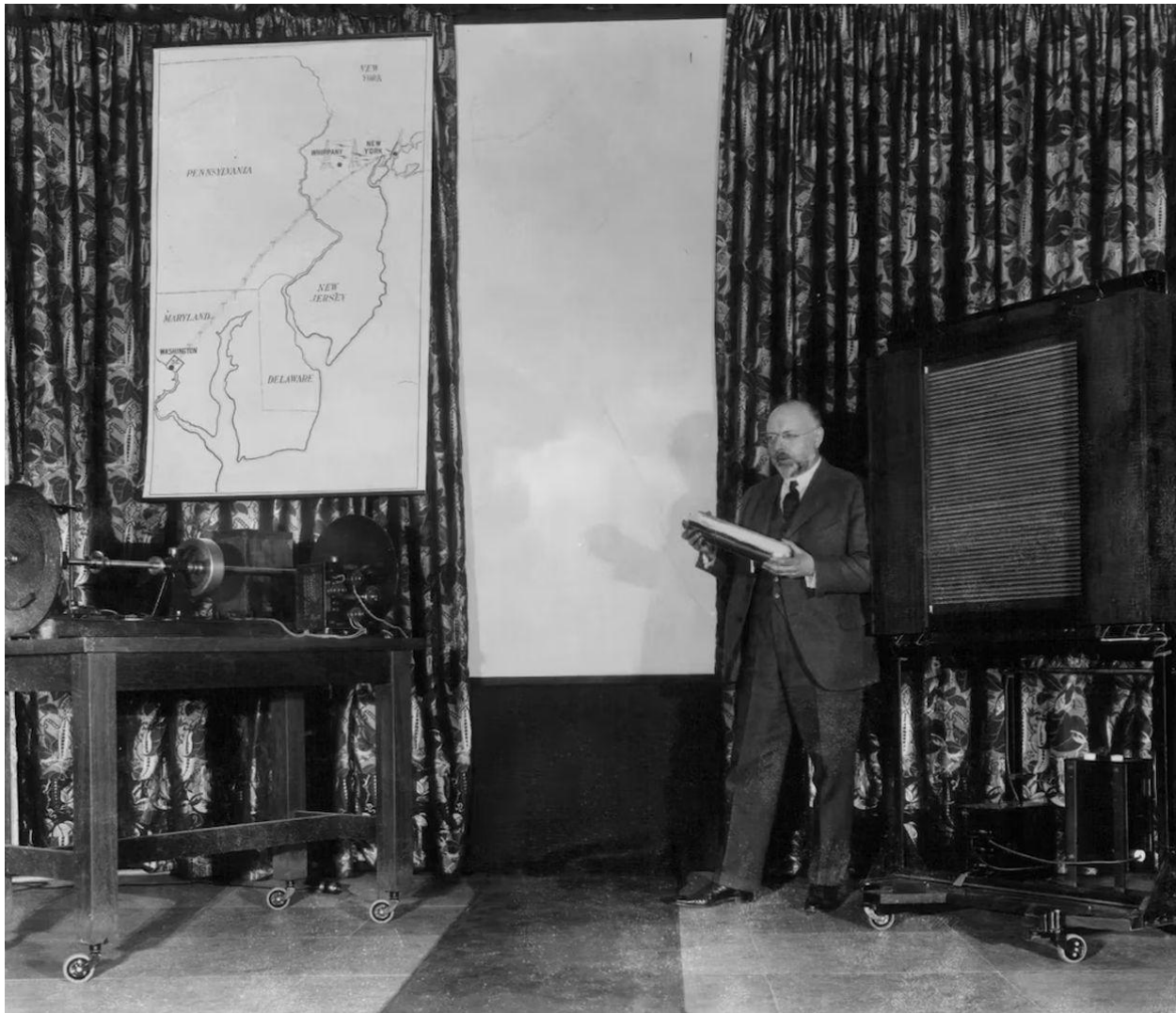
1. Please summarize in 3-4 sentences the Pre-Lecture reading for **Lecture 3** including some important takeaways from your reading.
2. Why were there many fewer channels available in the 1940s?
3. What public benefit did the FCC decide should be served by 500 MHz of new spectrum in the 1950s?
4. Why was the FCC willing to reassign 14 TV channels for mobile radio in 1968? What condition did they require?
5. Why did the FCC license two mobile telephone systems in every coverage area?
6. How is radio interference generally controlled between systems that use the same channels?

Radio telephone systems installed and planned in 1947



What does this slide suggest about AT&T's enthusiasm?

Aside: Bell Labs TV Demo in 1927



Radio Phone Coverage was like broadcast TV-

Lots of power from a central base station



What is the “quality of service” going to be at the edges of coverage?

A car phone in 1924?

Bell Labs is on the case!



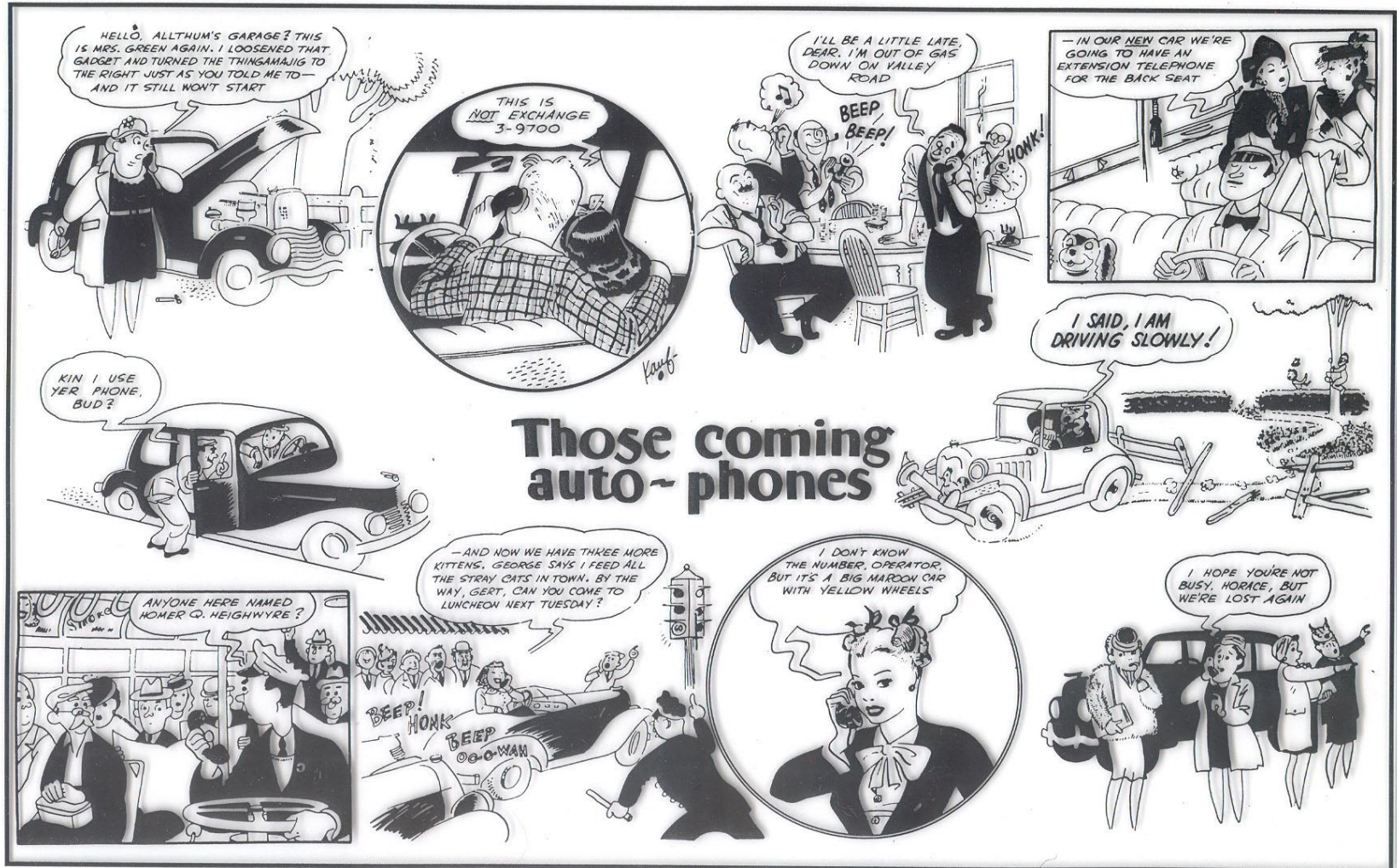
Copyright © 2000 Lucent Technologies.
<http://www.bell-labs.com/history/75/gallery.html>

Detroit police radio dispatch- 1928



Mobile Telephone c. 1945

Catching the public imagination



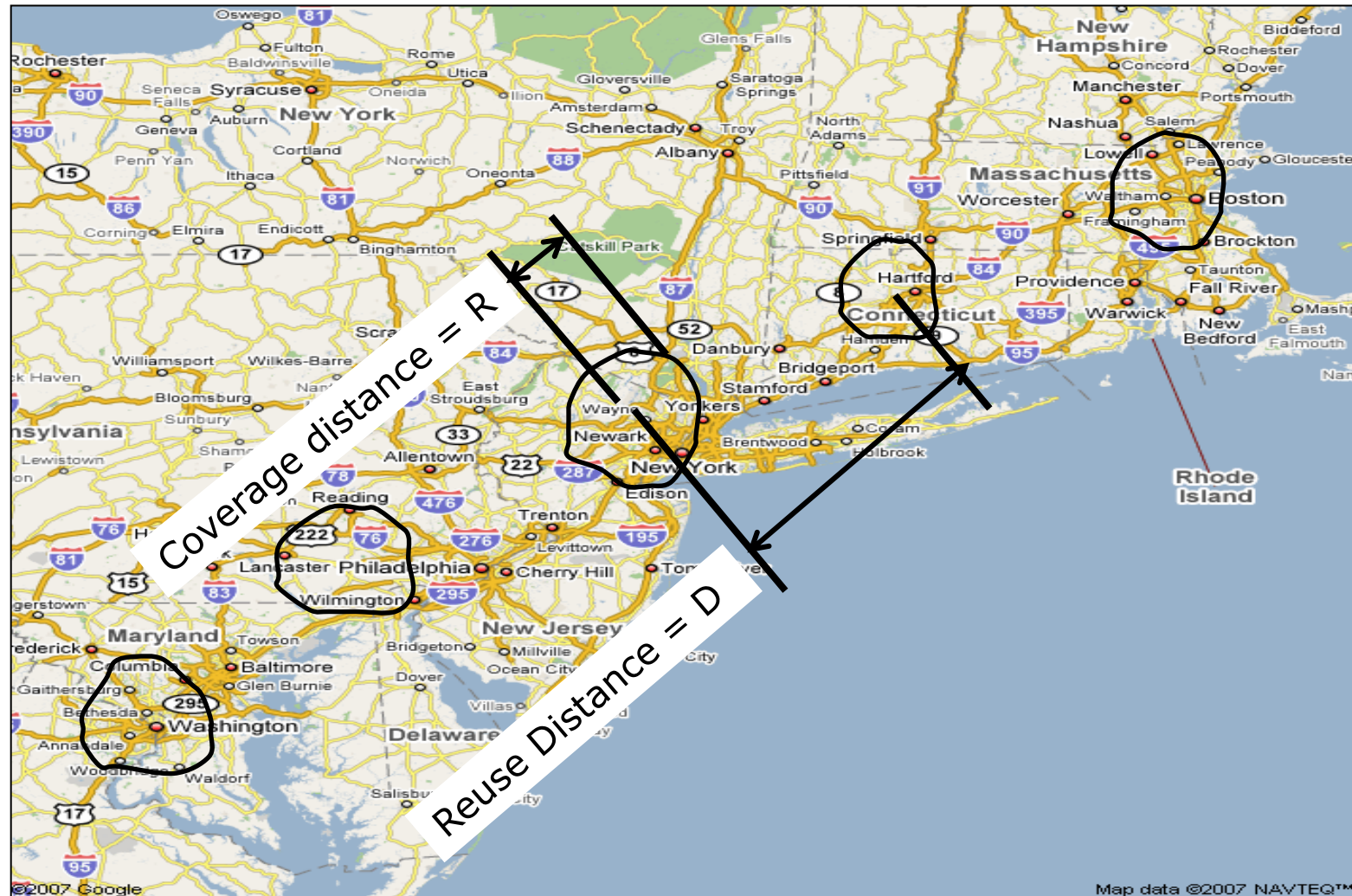
The car had lower power
so the system used “satellite” receivers



Is this a cost-effective system architecture?

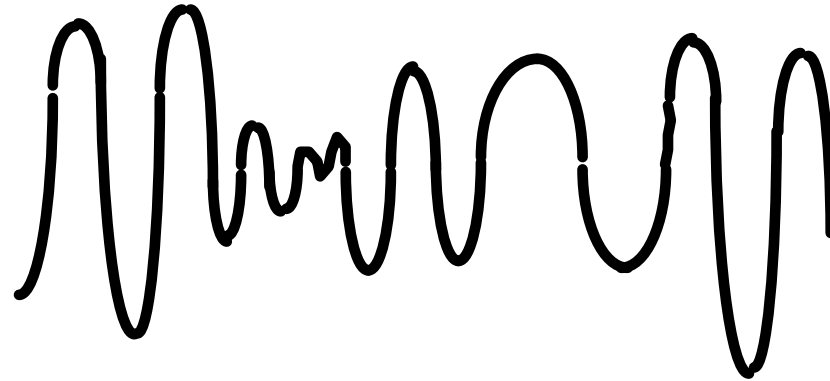
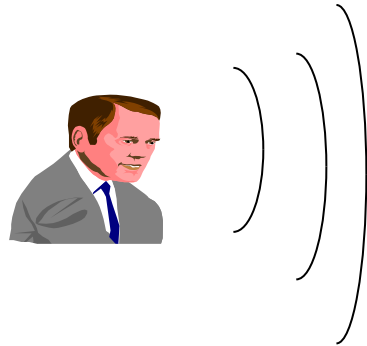
Coverage in large cities (R) was about 30-40 miles
Large-city channels could be re-used at distances (D) of 100-150 miles

Q2



Putting voice on a “Channel”

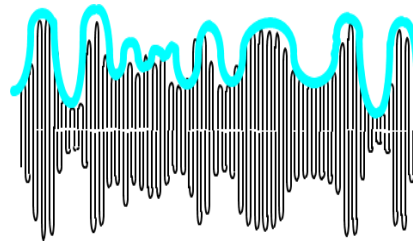
A complicated pressure wave



Air
pressure



Information
Signal in Time
Domain



Modulated
Radio Signal in
Time Domain



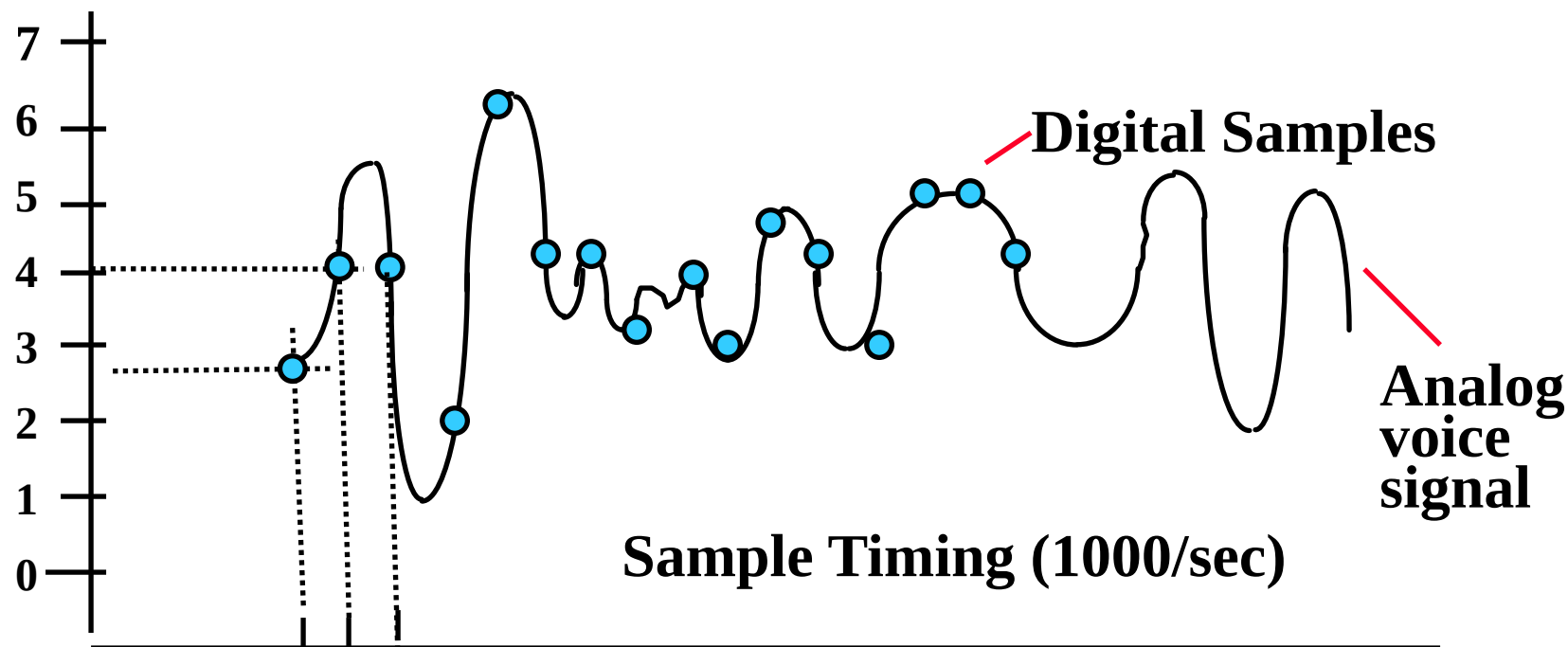
Information
Signal in
Frequency
Domain

“Channel”



Digital R(E)volution: “Sampling” and “digitizing” the voice wave

“amplitude” (levels)



3,4,4,2,6,4,4,3,4,3,5,4,3,5,5...Voice samples

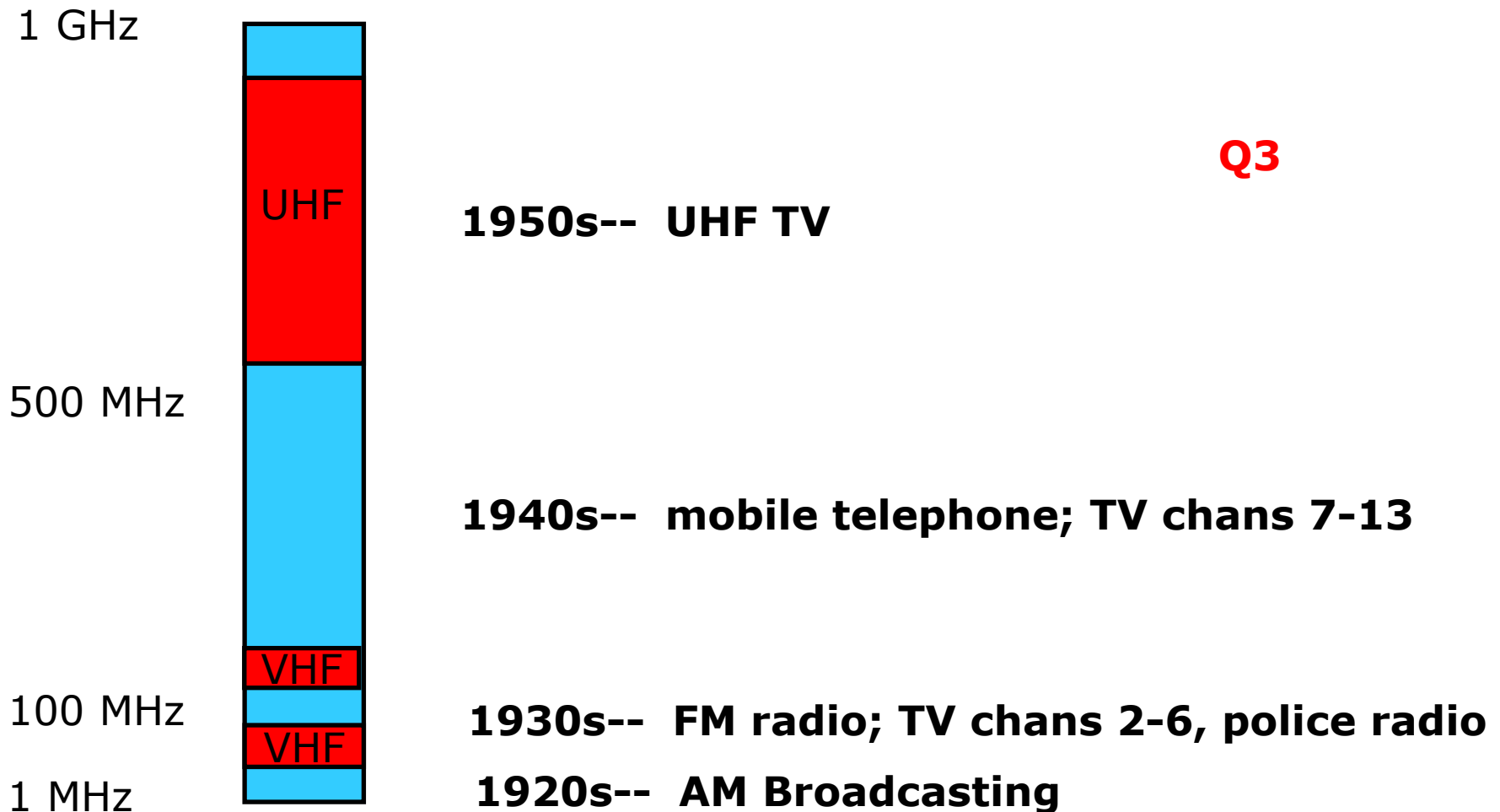
011 100 100 010 100 100,... Binary Coded Voice
1000 samples/sec x 3 bits/sample = 3000 Bits/second

Evolution of Analog to Digital Conversion (ADC)

- ❑ 1910s: Vacuum Tubes
- ❑ 1920s: Pulse Code Modulation (PCM)
- ❑ 1920s: The Nyquist Theorem
- ❑ 1930s: PCM Improvements
- ❑ 1940s: The First Successive Approximation ADCs
- ❑ 1950s: Solid State Amplifiers and the Integrated Circuit
- ❑ 1950s: Dawn of the Computer Age
- ❑ 1970s: ADCs Interface with CPUs
- ❑ 1980s: Music Goes Digital

“Consumer” spectrum: the moving frontier

500 MHz of new spectrum in 1950



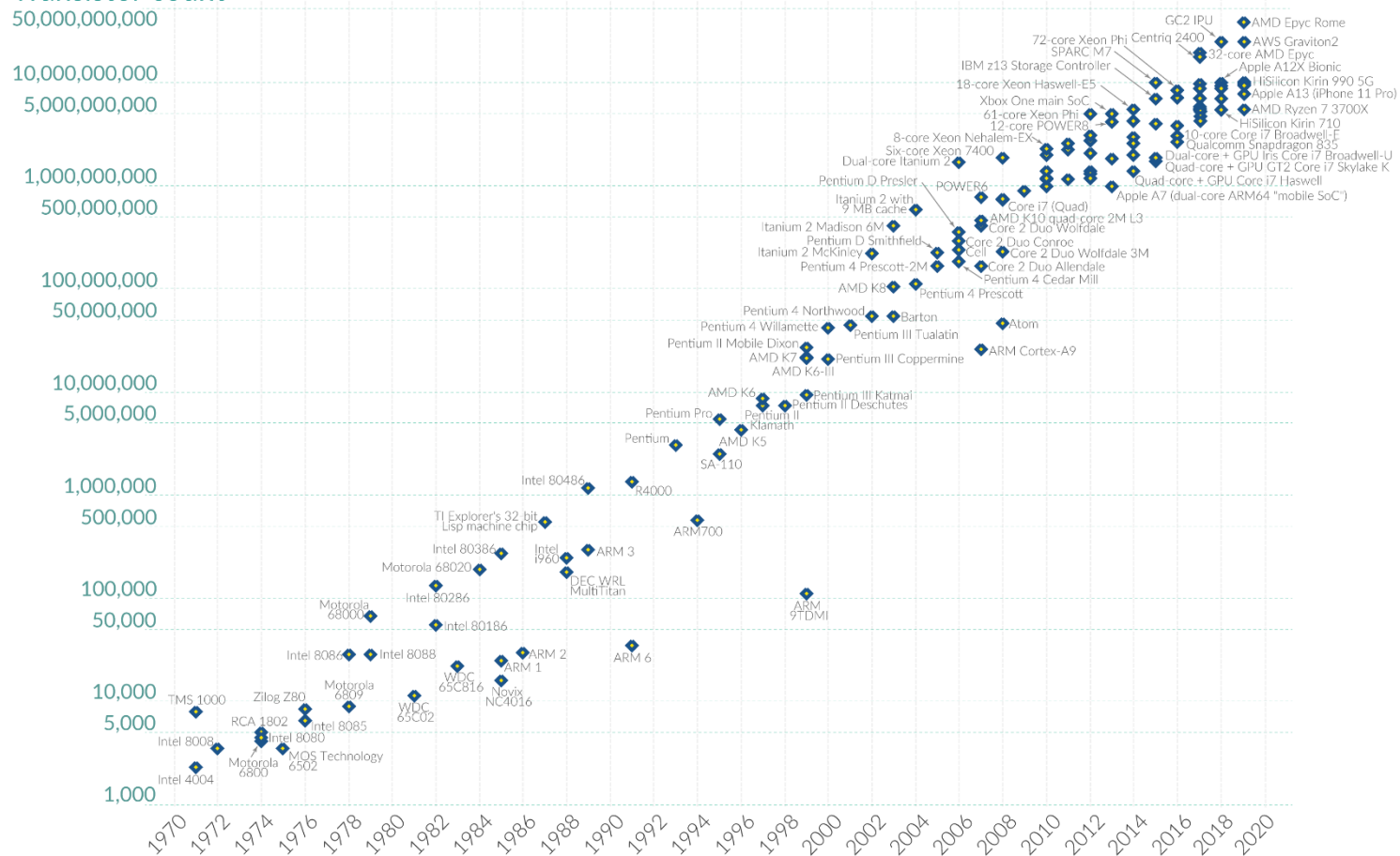
Moore's Law

Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Our World
in Data

Transistor count

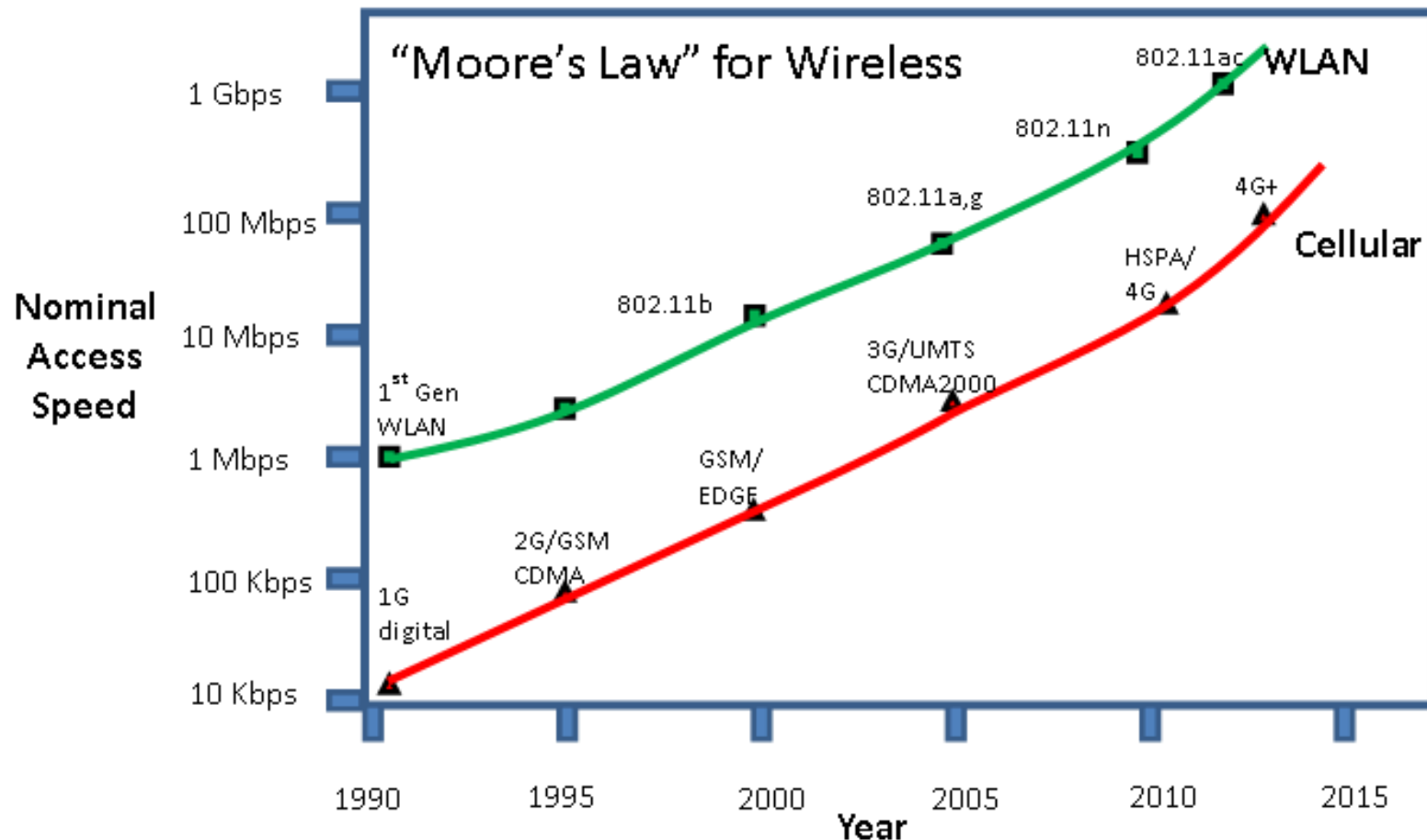


Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)

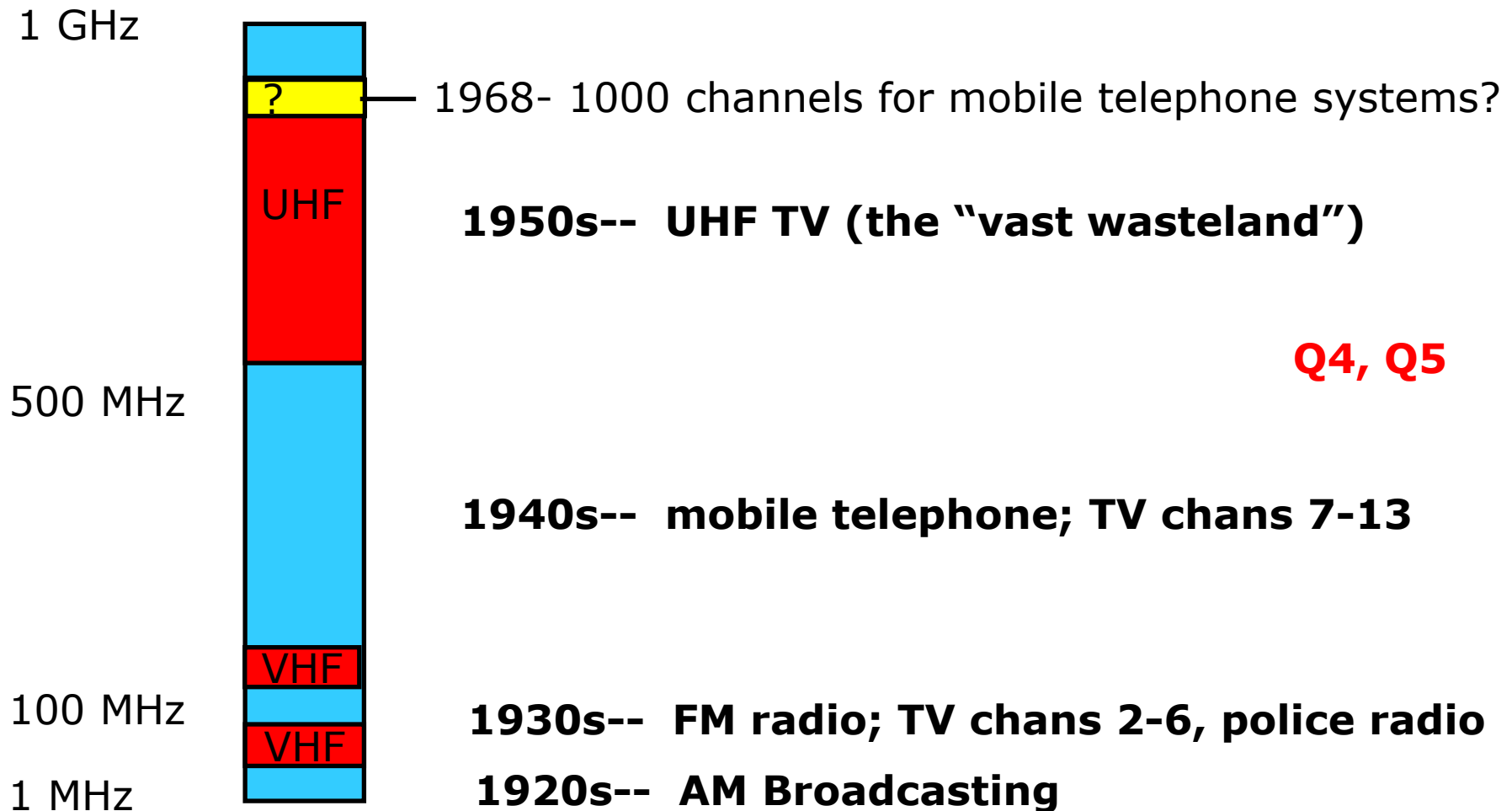
OurWorldinData.org – Research and data to make progress against the world's largest problems.

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“Moore’s Law” for Wireless



Cellular was created with the re-allocation of 14 TV channels
(the spectrum was shared with other “mobile radio” systems)



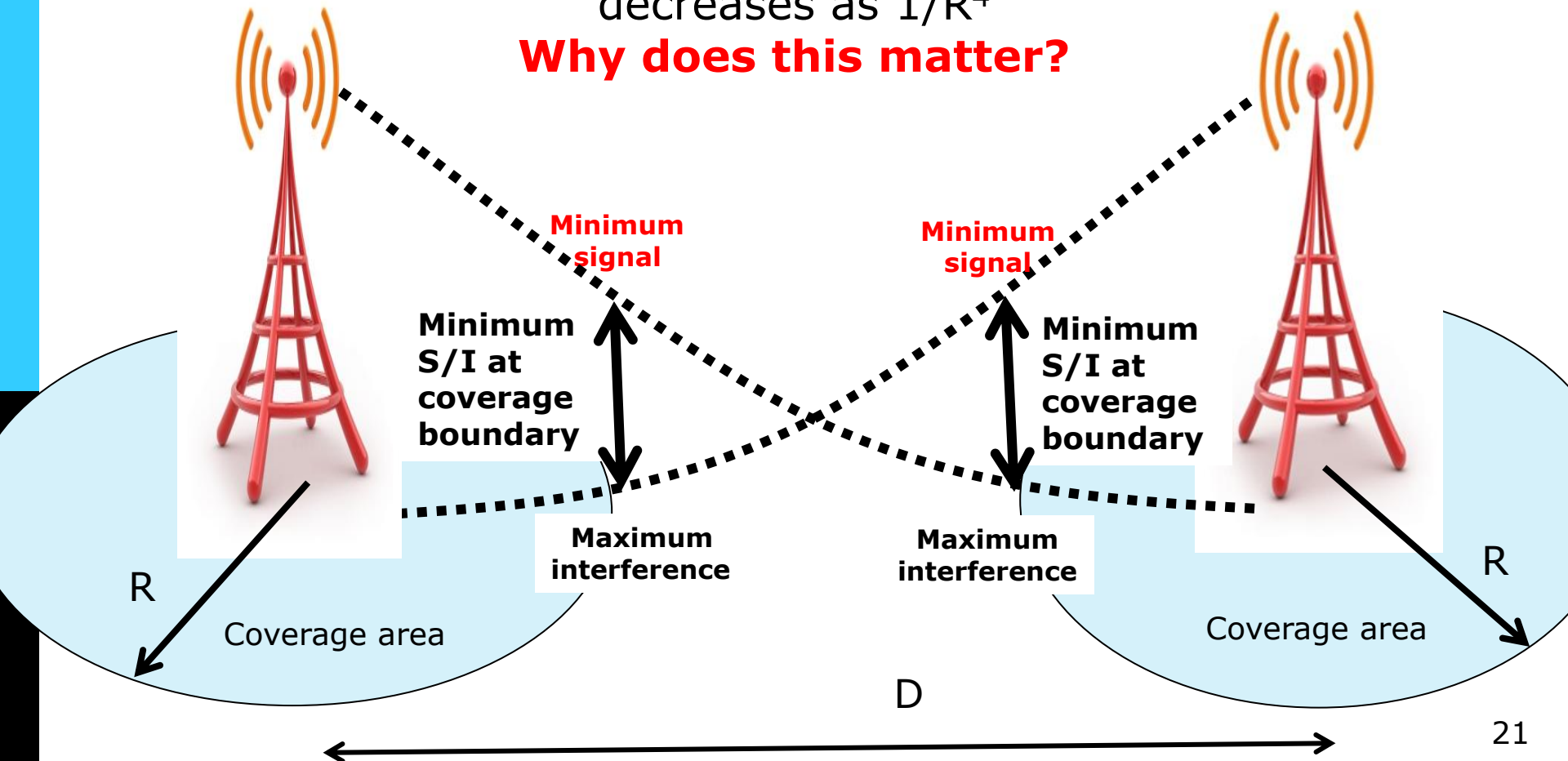
100



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

As we will see in Lecture 13, the power of a radio signal in the real world decreases as $1/R^4$

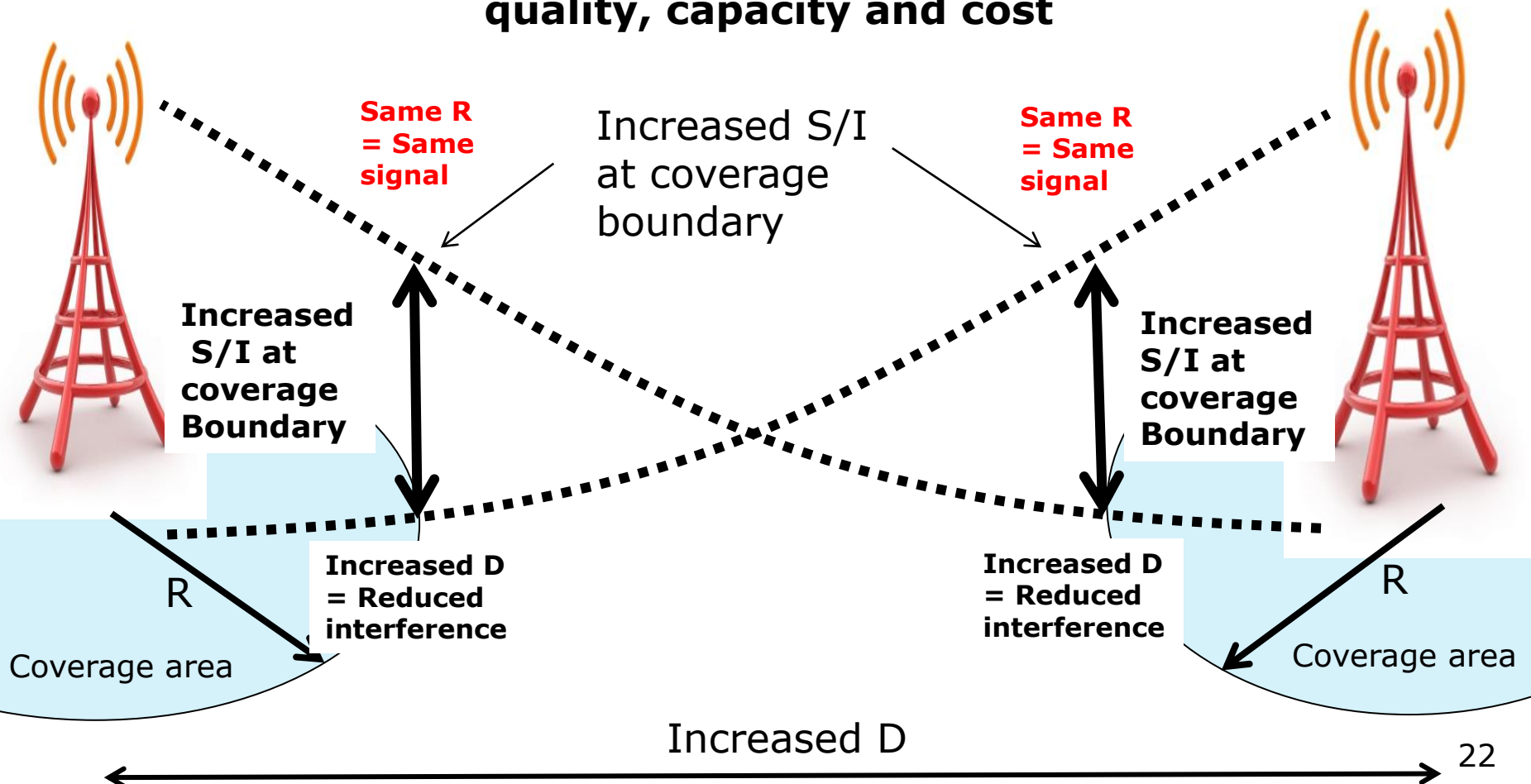
Why does this matter?



To improve voice quality, we can increase D (as shown below) to reduce interference, or we can decrease R to increase signal

What's the downside of each action?

**As we will see in cellular systems,
The selection of D/R becomes a trade-off between
quality, capacity and cost**



Why does it matter that radio signal
(and interference) decrease as $(1/\text{distance})^{(4\text{th power})}$
in the ranges we are interested in?

- ❑ Note that the expected S/I ratio at the cell boundary would now be $[(D-R)/R]^4 = (D/R - 1)^4$
- ❑ The quality of a wireless signal depends on D/R (not on the separate values of D and R)
 - For example, quality is about the same for
 - ❑ 1-mile coverage areas with 4-mile separation
 - ❑ 2-mile coverage areas with 8-mile separation
 - ❑ 4-mile coverage areas with 16-mile separation
 - The importance of this will become obvious in the next two lectures. It is the basis for the huge capacity of cellular systems.
 - If $D/R = 4$, the expected S/I ratio at the cell boundary is $3^4 = 81 = 19 \text{ dB}$
 - dB (or decibels) = $10 \log_{10} (S/I)$ and is generally used in radio

Why might we need such a high S/I ratio?

S/I Ratio and Radio Channel Capacity

□ Shannon Capacity

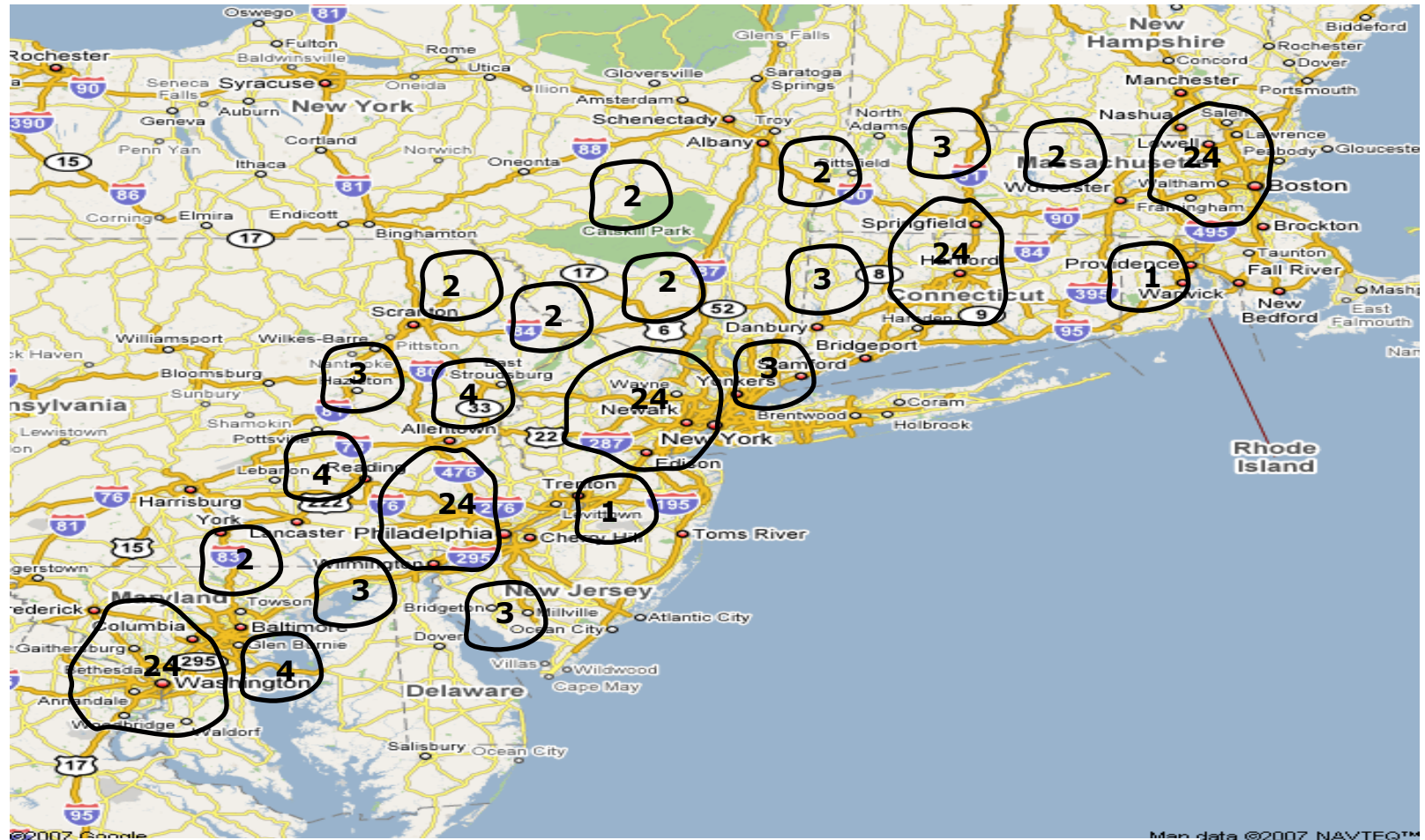
- $C = B \log_2 (1 + S/I) \text{ bits/sec}$

- B : Channel Bandwidth

- S : Signal Power

- I : Interference (and Noise) Power

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

“Automatic” car phone c. 1965



Where are we going?

- ❑ Four lectures on “getting to cellular”
 - L4- CHANNEL REUSE: THE TECHNOLOGY OF CELLULAR
 - L5- CELLULAR ECONOMICS: THE MILLION DOLLAR CELL
 - L6- PROFIT AND LOSS: AN INTRO TO CORPORATE FINANCE
 - L7- CELLULAR POLITICS: MONOPOLY OR COMPETITION?
- ❑ How spectrum got allocated from then to now
 - L8- SPECTRUM AND ITS COST: HEARINGS, LOTTERIES AND AUCTIONS
- ❑ Amazing growth from then to now
 - L9- THE EVOLUTION OF CELLULAR: PORTABILITY, DIGITAL VOICE AND SMART PHONES
- ❑ We finish in Lecture 10 with a movie and discussion
 - AND ALONG THE WAY IT'S ALWAYS BEEN ABOUT THE WHOLE PICTURE (TECHNOLOGY, POLITICS, COMPETITION AND COST)