

Wireless!

The forces and strategies that shaped a revolution



Lecture 9- The evolution of cellular Portability, Digital Voice and Smart Phones

Lecture 9- Classwork

1. Please summarize in 3-4 sentences the Pre-Lecture reading for Lecture 9 including some important takeaways from your reading
2. In what fundamental way did the pocket phone change cellular service?
3. What was the big advantage of digital voice compression in 2G? What did it end up teaching us about monopoly vs competition?
4. Why do you think text messaging was so popular? Why was it so profitable?
5. Why did 3G/4G/LTE systems need much more capacity than 1G and 2G?

The trends that shaped cellular after 1981

- ❑ From car trunk to pocket
 - The dawn of true personal communications
- ❑ “2G” (Digital voice and voice compression)
 - More voice capacity; New standards
 - Text messaging (a popular and profitable new service)
- ❑ “3G/4G/LTE” (new technology with complex coding and “smart” antenna arrays for high-speed data)
 - Similar to the Internet, but without the “unlimited” capacity of fiber
- ❑ “5G” for variety of multimedia applications
 - Larger antenna arrays
 - Higher frequencies: mmWave (26-28 GHz, 60 GHz)

From car trunk to pocket

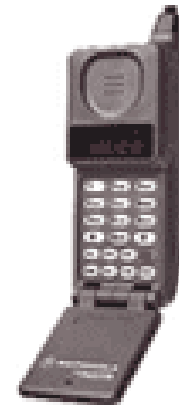
The dawn of true personal communications



**A radio in the
car trunk- 1983**



**DynaTAC
1983**



**MicroTAC
1989**

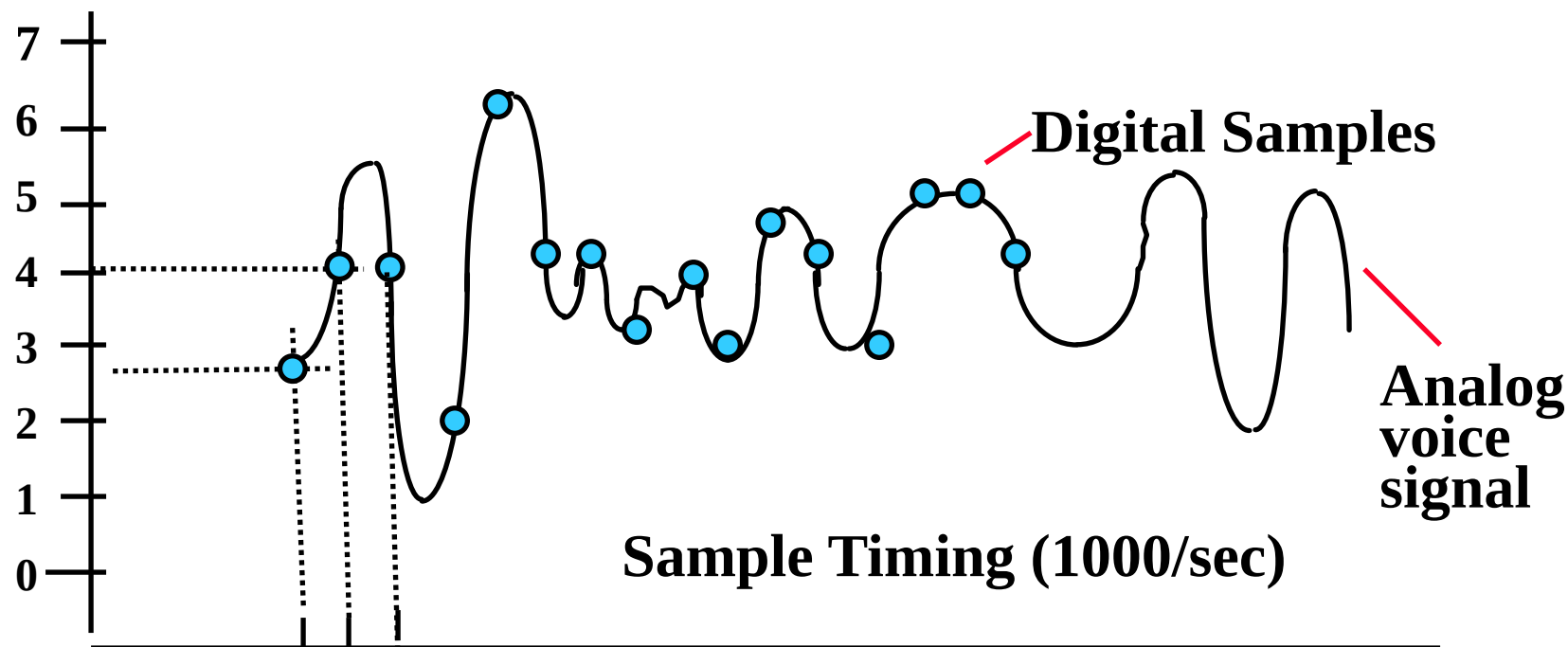


**RAZR
2004**

Q2

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

The transition to 2G digital channels

- ❑ 2G digital voice tripled the capacity of cellular systems, but it did not increase the “information capacity” of a cellular channel”
 - The information capacity of a 30 kHz one-way cellular channel was only about 45,000 bits/second
 - 1.5 bit/sec/Hz (about the same capacity as earlier radio systems)
 - This is based on Shannon’s Law, a fundamental tenet of Information theory
 - $C = W \log_2(1 + S/N)$, where C is the channel capacity in bits per second (bps), W is the bandwidth in Hertz, and S/N is the signal-to-noise ratio (SNR).
 - The information capacity of a radio channel is limited by its bandwidth and its “quality” (the ratio of “signal power” to “noise (and interference) power”)
 - Real-world radio channels were always noisy, and cellular channels were always “interference limited” (to minimize D/R)
 - ❑ $S/(N+I)$ varies greatly for a moving vehicle in a cellular system but 1.5 bits/sec/Hz was a reliable assumption
 - To increase the information capacity of a channel we would need to improve the quality of the signal
 - ❑ This improvement happened (to a degree) for smart phones in the era of 3G/4G/LTE, but for 2G it was still 1.5 bits/second/Hz

How 2G tripled the voice capacity of cellular systems

- ❑ What did happen in 2G was **digital voice compression**
 - “Telephone quality” (wired) voice had always required 64,000 bits/sec
 - ❑ More than the 45,000 bits/sec we could put on a 30kHz cellular channel
 - Voice compression allowed good quality with only 15,000 bits/sec
 - ❑ That 30kHz cellular channel could now carry three voice signals
 - ❑ This tripled the voice capacity of every base station
 - ❑ Similar compression techniques also allowed MP3 music, HDTV on narrower channels and compressed photographic images

And how was that new capacity used?

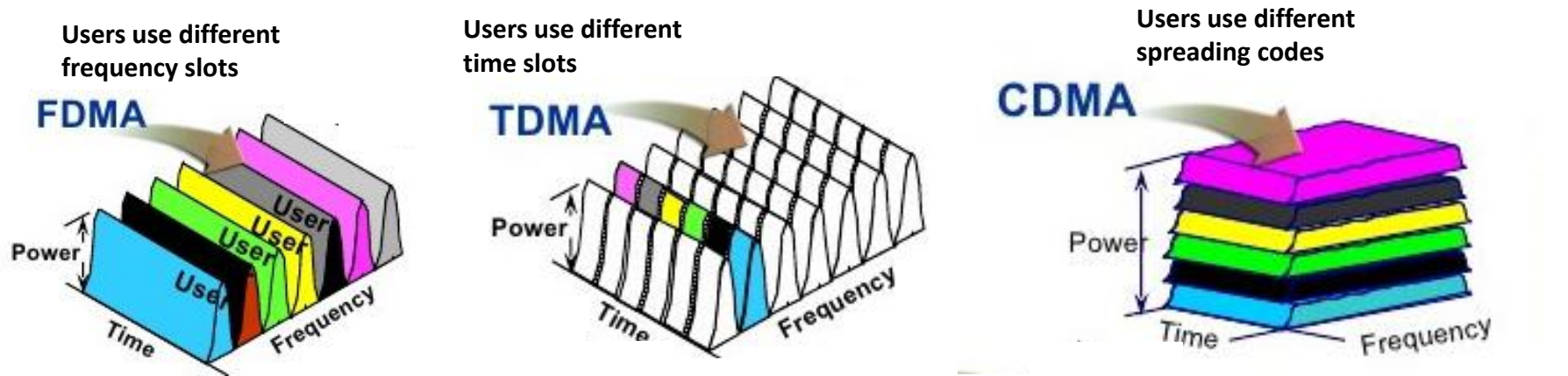
- ▣ In a moment, we'll discuss that after highlighting a controversy that led to delays in 2G deployment in the US

Competition leads to 2G Delay in US: Standards war broke out in the US, between Ericsson's TDMA and Qualcomm's CDMA

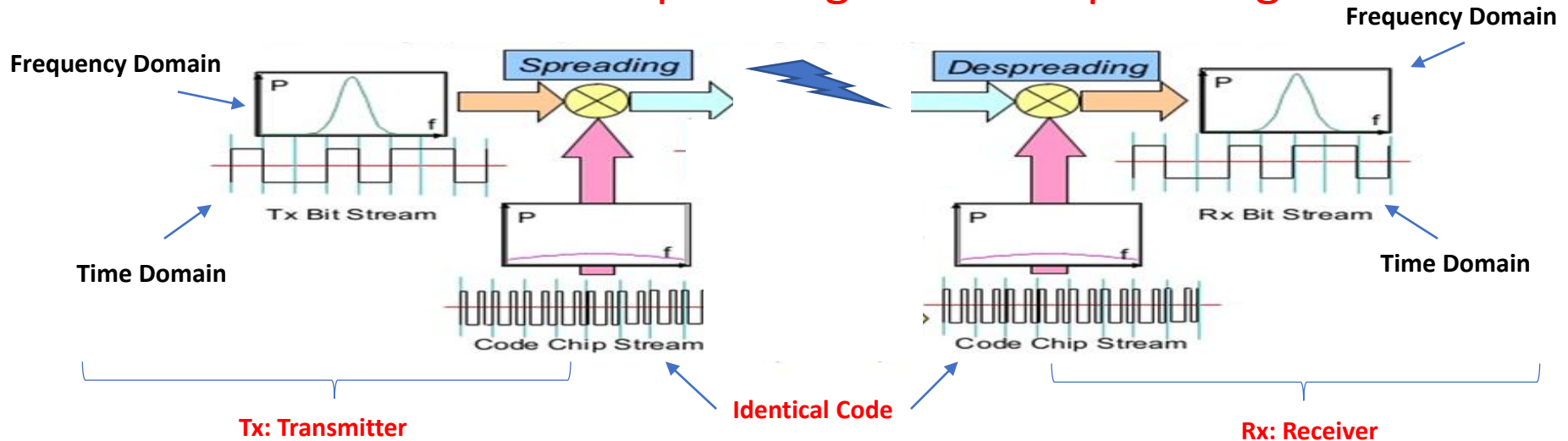
- ❑ Both relied on voice compression to increase spectrum efficiency 3X, but they used very different radio technologies
- ❑ Complex and conflicting claims of vastly superior capacity caused uncertainty
 - The FCC took a "hands off" approach, arguing that competition would select the winner
 - Confusion caused deployment delays in the US
- ❑ Meanwhile, the European GSM standard focused on seamless international roaming and "personal communications service" and made significant competitive gains

TDMA vs CDMA

□ Time Division Multiple Access vs Code Division Multiple Access



CDMA Codes: “Spreading” and “Despreading”



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How was that new 2G capacity used?

- ❑ If cellular were a monopoly service, 2G could have tripled the number of users (and revenues) with little investment (thus increasing profits dramatically)
 - Perhaps with a small reduction in charges to keep the regulators happy?
- ❑ In a competitive world the benefits of Digital Voice Compression went to the users of cellular service
 - Ironically, the leader in causing this to happen was AT&T, the old monopoly
 - The new, competitive AT&T decided to get back into the cellular business it had created a decade earlier

AT&T buys McCaw cellular and offers a lesson in competition

- ❑ McCaw bought licenses from lottery winners at low prices and created a “nationwide” network
 - But he borrowed \$4B to install base stations (bonds instead of stockholders) and was at risk **Why did he finance with bonds?**
 - **From the McCaw 10K report in 1993:** “The Company does not expect its operations to generate sufficient cash to meet its expenditure requirements for the next few years. In order to meet its substantial debt service obligations and to fund its other operating and capital requirements, the Company will have to borrow significant additional amounts under the McCaw Bank Credit Facilities. There are conditions in the McCaw Bank Credit Facilities which must be satisfied before the banks will lend additional amounts. If these conditions are not satisfied, the banks may conclude it is not in their best interests to lend additional amounts to the Company.” (See Footnote 16 -- Merger with American Telephone and Telegraph Company.)
- ❑ AT&T bought the McCaw network in 1996 for \$16B
 - And AT&T wanted big growth for their new systems
 - 2G offered an exciting possibility

Enter the “calling package”

- ❑ In the early 1990s, cellular users paid a fixed monthly fee plus a per-minute charge. This added up to the desired monthly costs we have been discussing, but it discouraged calling
- ❑ AT&T used the greater capacity that 2G voice compression offered to offer “calling packages” with many minutes for an attractive fixed charge
 - These packages were very popular
 - Its competitors were losing customers, so they offered bigger, cheaper packages
 - The attractive packages also brought in new customers, and everyone talked more
 - In a competitive world the benefits of 2G went to the users
 - But it was a golden age for service providers as well

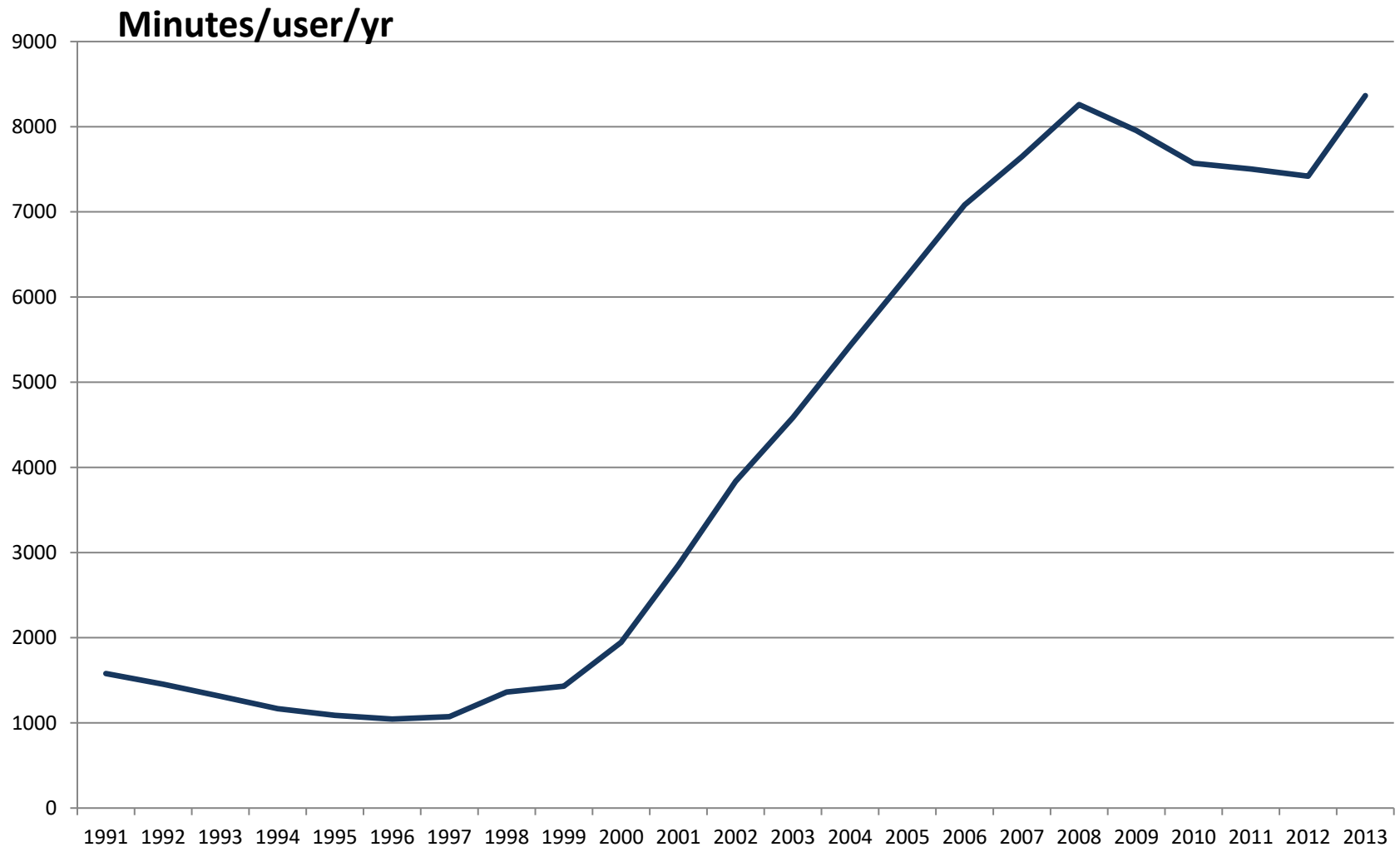
A golden age for both users and service providers

- ❑ Voice compression reduced the cost of service and increased the “minutes” per user
- ❑ The calling packages started by AT&T caused dramatic growth in users and minutes/user
- ❑ By the end of the 2G era, cellular service was almost universal
- ❑ The dramatic growth in users reduced SG&A, so even with falling revenues, profits were increasing

Might this change (or confirm) your views on “monopoly vs competition”?

- ❑ Text messaging, a new digital service, was very popular and very profitable as well

How could the increases in minutes/user be bigger than the 3x that came from voice compression?



3G/4G/LTE: The age of the smart phone

A golden age for users, but “not so much” for service providers

- ❑ The age of 2G convinced service providers that digital services were very profitable Q4
 - They were used to the “fiber-based” Internet, where capacity seemed “unlimited and free”
 - Supplier “demos” of high-speed downloads were misleading
- ❑ Compared to fiber, cellular was slow and expensive Q5
 - The smart phone would require huge increases in system capacity
 - Downloads of media like music and video that require a lot of bits.
- ❑ New antenna and signal processing technologies did increase the “information capacity” of 3G/4G/LTE channels by about 5x
 - But system capacity would have to increase by 100x. How?

The providers invested almost half a trillion dollars to provide that 100x increase in capacity

- ❑ Hardware alone for 3G/4G/LTE cost hundreds of billions of dollars (see the increase in base station investment 2008-2018)
 - And that only increased capacity about 5x
- ❑ New cells and new spectrum have added more to the capacity, but at a huge price
- ❑ And competition caused monthly revenue to fall!
- ❑ It continued to fall, and demand kept increasing
 - We will return to this problem in future lectures

Why might service providers invest more when monthly revenues are dropping?

What are the strategic options?

What is the role of 5G?

“5G” Strategies for the cellular operators are still evolving

- ❑ Huge amounts of cheap “millimeter wave” spectrum at 28 GHz, 60 GHz
 - But why is it cheap?
 - ❑ Very limited range and poor building penetration
 - ❑ How can you cover whole systems?
 - ❑ And it will mean more investment (base stations)
- ❑ More revenues (But from where?)
 - New users?
 - ❑ Everyone already has service
 - ❑ 5G Home Internet?
 - New kinds of customers?
 - ❑ Driverless cars? “The Internet of Things”? Remote surgery?
 - ❑ These are all futuristic and speculative to some extent
 - ❑ They will take investment and years of development
 - May AI be the magic bullet?
 - ❑ “AI for Wireless” and “Wireless for AI”

As we finish the first segment of our course
it's worth a look backward and forward

- ▣ Our broadest goal was to understand the “world”
 - It's a complex world where technology, politics, finance, and competition sometimes lead to unexpected results
 - Is it beginning to make sense?

Lecture 1-9: A summary and discussion of the first half of the semester

- Lectures 1-5: Strategic Issues in Cellular
 - History, Technology, Regulation, Economics and Politics
- Lectures 6-8: Financial Implications for Design Choices
 - Balance Sheets, Profit and Loss calculations, Monopoly and Competition, and Spectrum Allocation
- Lecture 9
 - Cellular Evolution

Strategic issues in cellular

- ❑ Cellular history: long delays; no spectrum
- ❑ The basic idea: Channel reuse multiplies spectrum
- ❑ The technology challenge: Logic and Control for large systems; new needs like locating and handoff; cellular was more a matter of (new) computers than radios
- ❑ The economic problem: The strange economics of the million dollar cell
 - The advantages of an AT&T monopoly vs the desire for competition

Some key results of cellular economics and the million-dollar cell

- ❑ Splitting up the spectrum raises costs significantly
 - Half the channels doubles the cost of a system
 - Users pay more
- ❑ All competitors need equal spectrum
 - Competing with less spectrum is difficult
- ❑ Buying more spectrum raises costs but delays cell splitting
 - Depending on the cost of the spectrum and the growth rate of the system it can be a good or bad idea

The (different) economics of startup

- Cellular systems start with a “few” large cells
 - They add cells gradually, by cell-splitting (and to expand system coverage at the edges)
 - Start-up costs are low, so profitability is achieved relatively quickly
- Higher frequencies create a problem
 - Smaller cells at start-up; higher initial price
 - Takes longer to make a profit
 - Angry investors and a competitive disadvantage
 - Paying a big price for spectrum at the beginning has the same effect

We need to consider our competition's costs as well as our own

- We have seen that a system with only 200 channels is economically feasible
 - They just require higher prices, and as a result the market will develop more slowly
- Having less spectrum is not competitively feasible if others have more spectrum
 - Because then we can't charge those higher prices
- Paying for our spectrum is the same– a competitive problem if the others got it free
- Higher frequencies also a competitive problem
 - More expensive at startup (and even later on)

Lecture 12 and beyond

- ❑ In the next segment we will learn some technology (at a “high level”) and more realistic financials (stocks, bonds and investing)
 - Radio coverage (why frequency matters)
 - Capacity, Bandwidth and Spectrum
 - The world of the G’s- 2G, 3G, 4G and 5G
 - Push for newer spectrum and unintended consequences
 - Unlicensed spectrum- Cordless, WiFi, Bluetooth
 - 2nd Midterm
 - Stocks, Bonds and Financing on Cellular
 - Case Studies
 - Personal Finance

Midterm Prep

- ❑ In class on **Thursday, February 26**: **1 hour and 20 min**
- ❑ **No laptop, No smart devices: phones/watches/glasses**
- ❑ **Scientific Calculator allowed**
- ❑ **1 “cheat sheet” of paper allowed: You can write whatever you like on it (both sides), no font restriction**
- ❑ Topics you will be tested on
 - Channel Reuse and Cell Splitting
 - Spectrum Policy and Regulation
 - Creation of Cellular and Cellular Evolution
 - Balance Sheets and P&L Analysis for Service/Design choices
 - Will require some descriptive answers
- ❑ How to study?
 - Review pre-lecture readings; Lecture slides; Classwork assignments