

Wireless!

The forces and strategies that shaped a revolution



**Lecture 16- The world of digital
cellular systems- 2G, 3G, 4G and 5G**

Courtesy Ryan's Spring Break in New Orleans



Lecture 16- Classwork

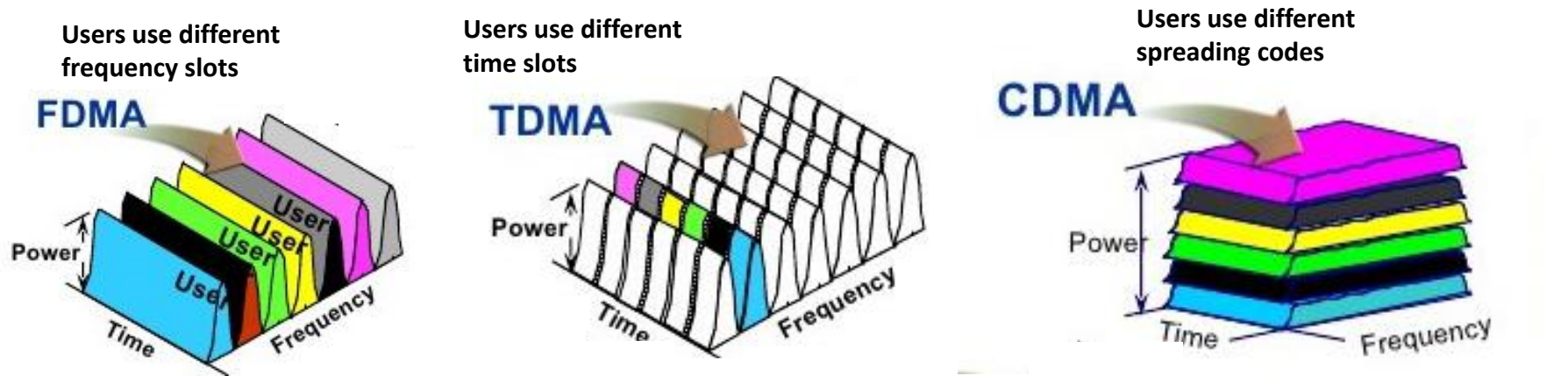
1. Please summarize in 3-4 sentences the Pre-Lecture reading for Lecture 16 including some important takeaways from your reading.
2. Why was text messaging so profitable compared to voice calls in 2G?
3. How might have the profitability of text messaging influenced the cellular service providers expectations for profitability of internet services for 3G?
4. How was the 70x gain in 3G achieved through a combination of new cells, new spectrum, new technology, one way communications and 24/7 usage?
5. What was the outlook for 5G back in 2020? Was it real or hype?

First a 2G standards war broke out in the US, between Ericsson's TDMA and Qualcomm's CDMA

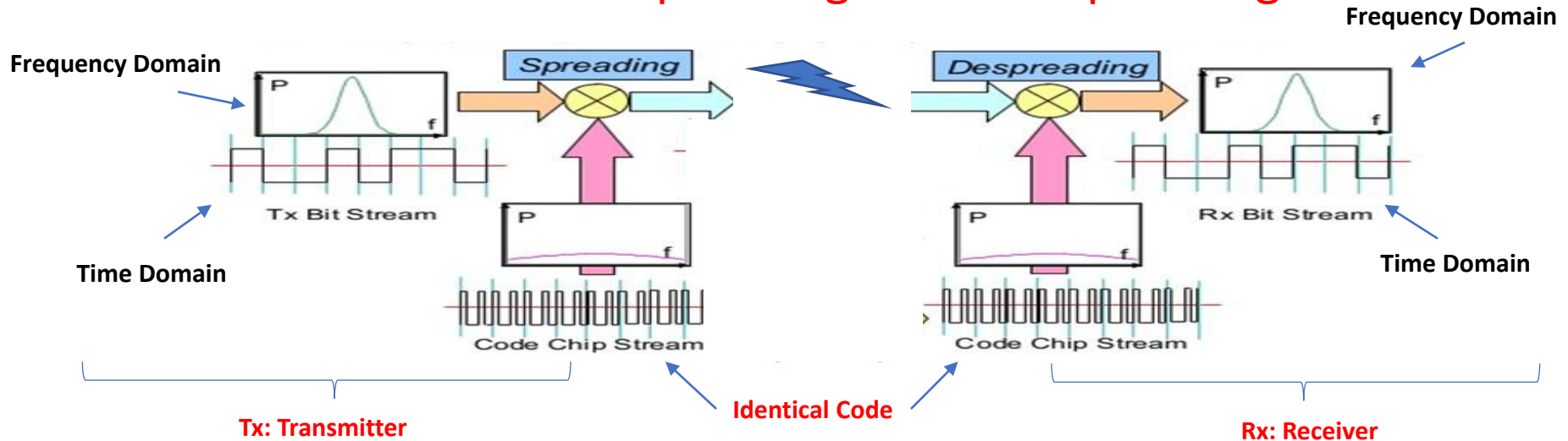
- ❑ Both relied on voice compression to increase spectrum efficiency 3X, but they used very different radio technologies
- ❑ Complex and conflicting claims of vastly superior capacity caused uncertainty
- ❑ TDMA vs CDMA?

TDMA vs CDMA

□ Time Division Multiple Access vs Code Division Multiple Access



CDMA Codes: “Spreading” and “Despreading”



Delays in 2G adoption in US

- ❑ TDMA and CDMA relied on voice compression to increase spectrum efficiency 3X
- ❑ 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 sales to be delayed in the US
- ❑ Meanwhile, the European GSM standard focused on seamless international roaming and “personal communications service” and made significant competitive gains

There was a huge increase in users, but they started to talk more

- “Call packages” encouraged more calling
 - The pocket phone encouraged day-long usage
- By the end of the 2G period cellular was almost universal and users were talking as much as they wanted to.
- The revenue from voice calls fell 20% but new revenues from text-messaging made up the difference and growth reduced SG&A/user.

Digital text-messages and Voice

- ❑ Text messages need very little of the cell's capacity
 - One character = 1 Byte
 - Short Message Service (SMS) message limit?
 - 160 characters
 - Maximum SMS message size is 160 Bytes
 - Longer messages are handled via message concatenation
 - iPhone messages?
 - ❑ Typically limited at 4000 characters
 - 🤖 Emoji?
 - ❑ Usually 7 characters
- ❑ What about digital voice?
- ❑ How many Bytes is 1 minute of voice? (e.g.15 kbps)

Digital text-messages were very profitable

- Text messages in 2G needed very little of the cell's capacity
 - One character = 1 Byte
 - Entire messages require on average less than 100 Bytes and bring in 5 cents or more
 - A minute of voice requires ~100,000 Bytes and brings in the same 5 cents!!!
 - Huge revenues with almost no new investment in capacity were very attractive to the providers
- Text messaging made up the lost voice revenues and generated new profits
 - It quickly became 20% of revenues, using less than 0.1% of system capacity

Illusion of wireless vs wired internet

- ❑ Increasing fiber capacity created the Internet
 - But radio channel capacity didn't increase
- ❑ Data compression using DSPs brought digital to the wireless world
 - Users benefited from cheap minutes
 - Providers benefitted from growth in users as cellular became almost universal
 - Digital text-messaging became very profitable and probably made providers optimistic about 3G
 - ❑ But what about those Byte-hungry "3G" services like video and music?

After 2G and Text Messaging— a grand vision for “3G”

- ❑ With digital radio and profitable texting services, the providers turned their eyes to the Internet
- ❑ They planned high speed data services using new “3G” radio technology that actually allowed more bits/sec/Hz for the first time
- ❑ Rates like 384 Kbps on the uplink and 2 Mbps on the downlink were planned
 - Music; movies; Internet access
- ❑ They saw The Holy Grail:
 - A “convergence” of “communications, information and entertainment”
 - Demos of fantastic download rates were made (by putting the entire spectrum of the system into 1 cell, and assigning it to 1 customer!!!)

LTE: Dreaming of wireless Broadband

Stacey Higginbotham (tech reporter)

"After a quick demonstration of Ericsson's LTE base station, which boasted a throughput of 150 Mbps on download and 30 Mbps for uploads, I experienced one of those moments of technology utopia. I could see a world without wires, a life with fewer cables running into the house and no phone jacks on the wall.

... "With speeds like that, ... the landline might finally be ready to give up the ghost. ... Streaming HD movies while someone else talks on the phone or transfers files requires a lot of bandwidth. It looks like LTE could do that.

Things that seem too good to be true are often too good to be true

3G Euphoria: Providers began to buy spectrum (and each other) at very high prices

Germany's 3G auction fetches EU50bn

“Six bidders have won 3G mobile phone licenses in Germany.

18 August 2000

After 14 days of bidding, the German auction for third-generation (3G) mobile phone licenses came to an end on August 18 2000, with the six winners paying around EU50.5bn between them.”

UK wireless license auctions close at 22.48 billion pounds

April 28, 2000

“Damned if you do. Damned if you don't.

That was the resounding message following the close of the UK government's auctions for third-generation (3G) mobile phone spectrum licenses. After one hundred fifty rounds and nearly eight weeks, the five winners -- Vodafone, British Telecommunications, One2One, Orange, and Telesystem International Wireless UTMS -- have coughed up a shocking \$35.4 billion dollars.”

Early 2000s: And the morning after, and the mourning after ...

Operators and investors concerned over just how 3G investment will ever be recouped. **(they had a right to be concerned)**

Worldwide roll-out of 3G networks delayed by the enormous costs of upgrading the equipment and spectrum licensing fees.

3G handsets unfit for consumers, operators say

“Third-generation (3G) mobile phones offering fast Internet access should be kept from European stores as they are unreliable, expensive, bulky and offer too limited services, mobile operators said on Thursday. Others said no handset could yet deliver all the promises of 3G telephony such as high-speed Internet access, crystal clear voice, video telephony and smooth handovers between radio base stations.” **(at least that problem got solved)**

3G's killer application?

“Remember those distant days when we imagined a golden age of **3G** phones would mean person to person video calls to Australia, downloading the new Radiohead album on the bus, and e-mail on tap everywhere. How naïve we were. Apparently, the killer application for 3G is, err..., Voice calls.” **(and that did change)**

Eventually, 3G service did begin (~2004)

- ❑ By 2008, about 15% of users had smartphones, but their data usage was about the same as talking
 - Less than 1GB per year per user
 - It took a while (and many apps) to adjust to the new service.
- ❑ Today, over 90% of users have smart phones, and they use about 5-10 GB per user per month!
 - Operators invested \$150B to upgrade cells to 3G/4G technology (\$500K/cell) and another \$100B for spectrum to support this increase (that's a quarter of a Trillion dollars!)
 - They planned for premium pricing for 3G/4G but once again competition has caused monthly revenues per user to fall
 - We need to explore how this happened, and what it has meant to operators, and how they have responded

How was the 70x increase in system capacity created?

- ❑ Our prior knowledge from the use of cell-splitting to increase capacity suggests that 70x the capacity would require 70x the investment which would be ridiculous. The increase was achieved in a variety of ways.
 - New cells essentially matched the final growth to universal service (a factor of **1.5**)
 - Spectrum was pretty cheap, so they bought more (about **3x**)
 - 3G/4G technology allowed more bits/sec/Hz (about **5x**)
 - Data service is primarily one-directional, while voice was 2-way, which increased true spectrum efficiency (about **2x**)
 - 3G/4G load is spread over 24 hours, so system use was more efficient than for voice (about **1.5x**)
- ❑ **$1.5 \times 3 \times 5 \times 2 \times 1.5 = 67.5$**

Calculating incremental revenues required from smart phone users based on the investment made by providers

Balance Sheet

Assumptions: 60M new users,
\$50/month for service, 270M
existing users

Provide 100K new cells
@\$1M/cell \$100B

Upgrade base stations
for 3G and 4G \$200B

Add 150 MHz spectrum
At \$1/MHz/POP \$150B

**TOT increase
in assets \$450B
(10% return on equity)**

P&L

Incremental revenue per smart
phone user = $\$69\text{B} / 270\text{M} = \$256/\text{user}$
= \$21/month

Remaining Incremental Rev of
 $\$105\text{B} - \$36\text{B} = 69\text{B}$ must be paid by
all 270M Smart Phone users

Incremental Rev paid by 60M new
users @ \$600/year /new user = \$36B

Reqd incr revenue \$105B ↑

Tot incr Expenses \$38B

10% Depreciation \$30B

→ 5% Amortization \$ 8B

Req BT Earnings \$67B

33% Tax \$22B

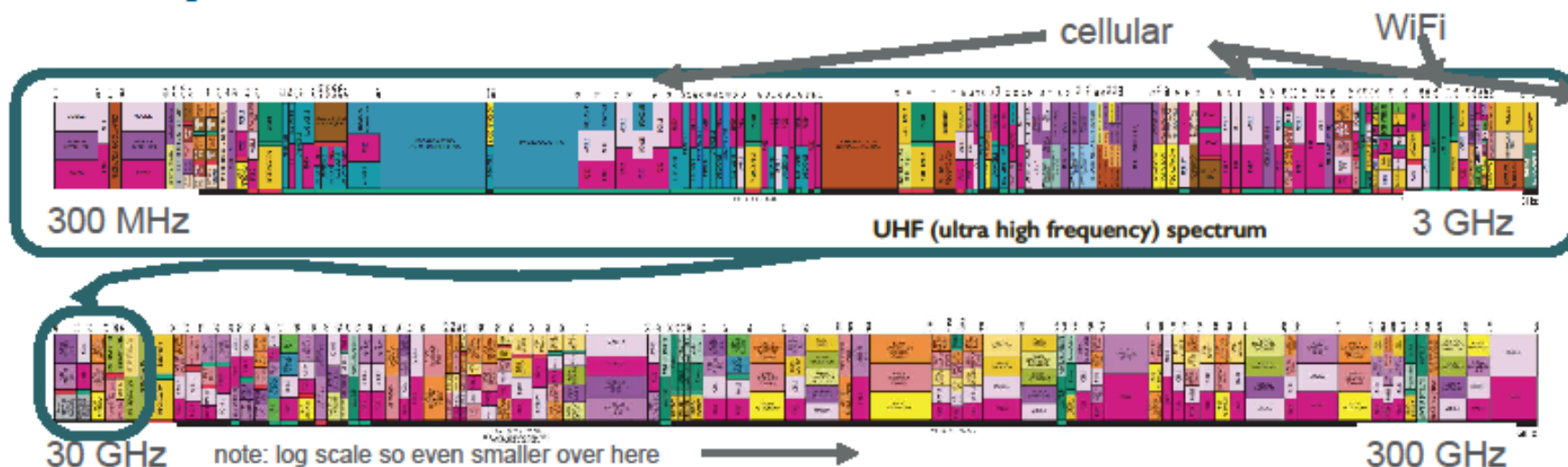
Reqd incremental Profit → **\$45 B**

So what is 5G

- ❑ Further increases in capacity will depend on spectrum, and even \$1/MHz/POP for spectrum leads to significant investment that won't be covered without new services.
- ❑ Enter millimeter wave (mmWave), a new source of spectrum that is huge and almost free.
 - Operators will obviously be interested
 - The problems are many and serious
 - But the hype is intense

Millimeter waves (30, 40 or 60 GHz) for “5G” cellular

Why millimeter wave for 5G?



- ◆ Huge amount of spectrum possibly available in mmWave bands
- ◆ Technology advances make mmWave possible for cheap consumer devices
- ◆ mmWave research is as old as wireless, e.g. Bose 1895 and Lebedew 1895

mmWave spectrum auctions resulted in cheap spectrum:
less than \$0.01/MHz/POP

5G: A hype opportunity for everyone

Investors: The opportunity of the decade

5G Could Be The Single Biggest Investment of 2019

If you aren't up to speed on "5G" yet, then get ready, because it's expected to be one of the biggest stories of 2019.

Politicians: Trump campaign pushes 5G (let's beat China)

The president's reelection team is backing a plan the wireless industry fears would impose a heavy government hand over America's communications future.

Providers: AT&T's "vision"

"Much like 4G introduced the world to the gig economy, we believe mobile 5G will jumpstart the next wave of unforeseen innovation. AT&T is the only U.S. carrier that has a standards-based, mobile 5G network live in parts of a dozen cities."

The problems of millimeter wave

□ Very short range

- Some sources suggest $\frac{1}{4}$ mile or even 1 mile
- But a credible study by Rappaport suggested a few hundred feet in Manhattan
 - This is less than even the $\frac{1}{4}$ mile cells currently deployed, and with no building penetration and some vulnerability to rain and snow.
 - It also requires steerable antennas and new cell phones
 - It will have deployment problems even where the smallest cells are in use, and real problems in larger cells.
 - Even with almost “free” spectrum the costs of providing millimeter wave radios in base stations **and smart phones** will be huge, probably with no increase in revenues.

State of 5G (2024) (source [5G Americas](#))

- ❑ Global 5G Connections Hit 2 Billion Milestone in Q3 2024
- ❑ Key Highlights:
 - ❑ Global Wireless Growth Accelerates: Over 170 million new 5G connections added in Q3 2024 alone.
 - ❑ North America Leads the Way: 264 million 5G connections, covering 70% of the population.
 - ❑ Future-Proof Networks: 5G in North America is projected to surpass 4G by 2025, reaching 391 million connections.
- ❑ US cellular service providers like T-Mobile, Verizon, and AT&T are actively deploying 5G networks, with T-Mobile leading in 5G download speeds and coverage, while Verizon excels in 5G upload speeds and is expanding its mid-band 5G network.

State of Spectrum use in 5G (2026)

❑ **Mid-band Spectrum:**

- ❑ Mid-band spectrum (around 2.5 GHz and 3.7-4.2 GHz) is considered the "sweet spot" for **T-Mobile** 5G, providing a balance of coverage and speed.

❑ **C-band Spectrum:**

- ❑ C-band spectrum (around 3.7-4.2 GHz) has been a key focus for **Verizon** and **AT&T**, enabling them to boost 5G performance.

❑ **Low-band Spectrum:**

- ❑ Low-band spectrum (like 600 MHz) used by **all service providers** yields broad coverage, while high-band spectrum provides fast speeds with a limited reach.

❑ **mmWave Spectrum:**

- ❑ Deployments have been minimal, and by many accounts they have failed!