Wireless!

The forces and strategies that shaped a revolution

Narayan B. Mandayam

WINLAB, Rutgers University

IEEE Distinguished Lecture

Wireless Revolution

- 1940s- The first "conventional" radio telephones & the first cellular proposals
  - But few channels and limited technology
- Four decades later- only 50 thousand "conventional" subscribers (US)- Cellular begins
- A decade later- 50 million cellular subscribers
- Today- 6 billion cellphones worldwide!

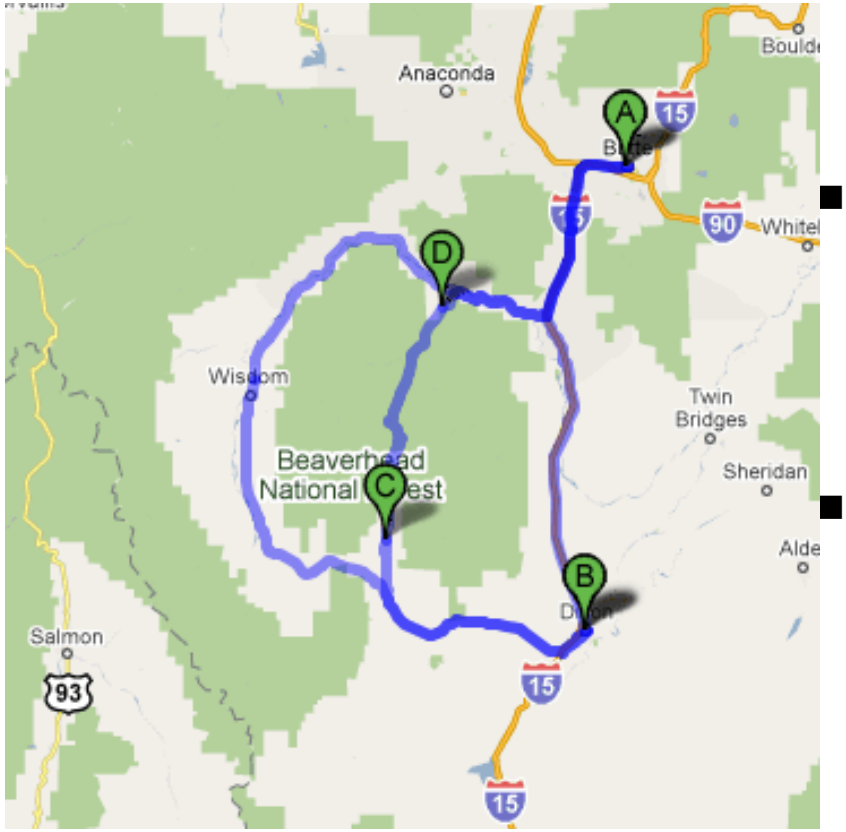
An Innovation in Multidisciplinary Education

- Course introduced in Fall 2008
- Open to all juniors and seniors at Rutgers
  - Humanities/Social Sciences elective for students in School of Engineering
  - Technical elective for students in School of Arts & Sciences, School of Communication & Information, etc.
- Created and co-taught with Richard Frenkiel
  - Inventor of the Cellular System
  - National Medal of Technology Winner (1994)
  - Member of the National Academy of Engineering
  - Winner of the Draper Prize (2013)
  - Former Mayor of Manalapan, NJ

Course Objective

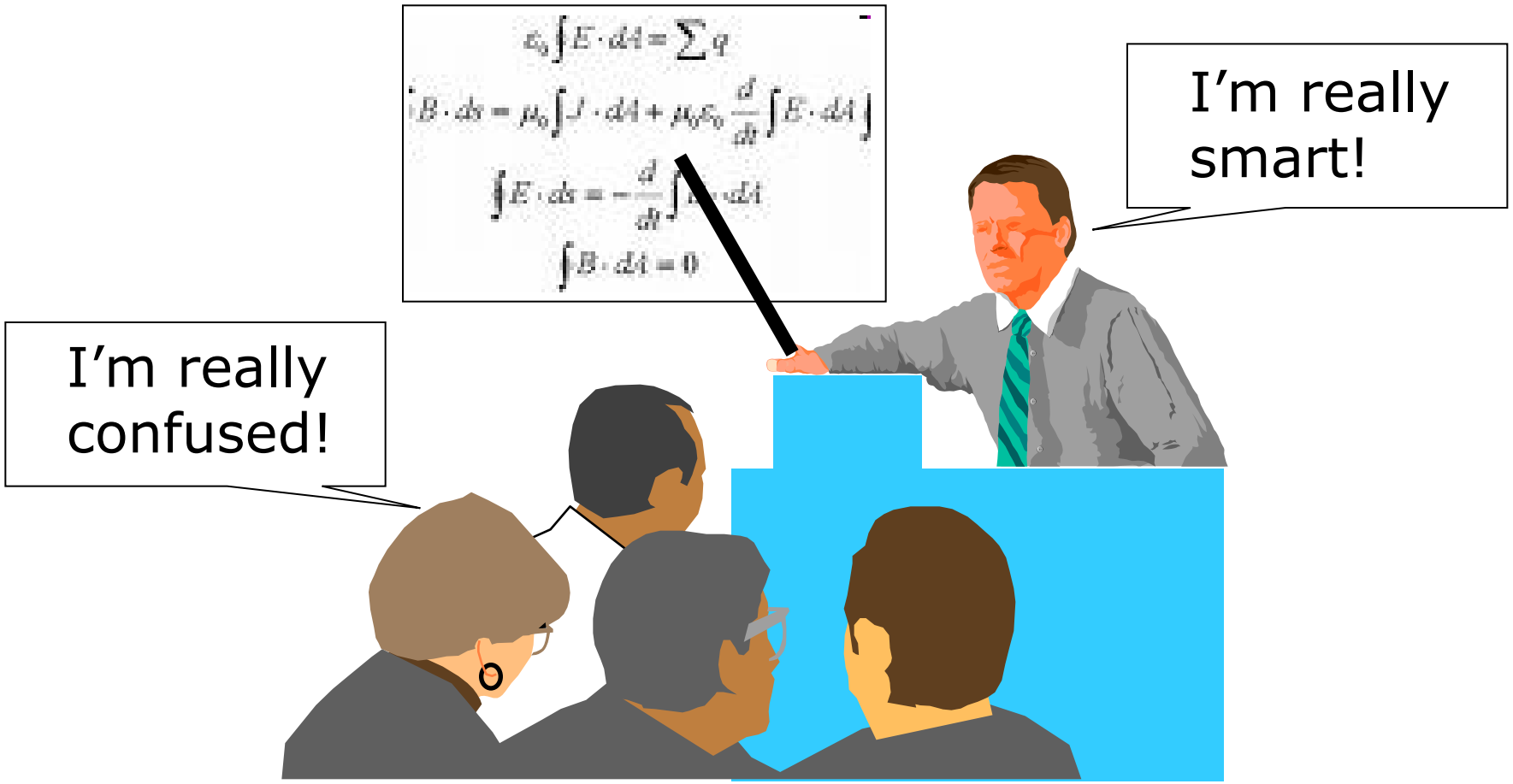
- To broaden the student's understanding of the business world with its multidisciplinary problems, and to develop strategic skills
- Why just wireless? MBA programs use Harvard Business Cases to explore many situations (from lobster fishing to pile driving and executive search)
  - Because wireless is important and complex and exciting
  - Because our experience is in wireless
  - By limiting our focus to one industry we can develop a more complete understanding, as we would in a real job
- But the approach used here "works" in any strategic situation
  - From MacDonnell Douglas to McDonalds

Strategic Thinking - "Apples and Oranges" problems



- We solve many multi-dimensional problems in life
  - Example: picking a job
  - The solution just "feels right"
- Group decisions are harder
  - Example: Planning a vacation
  - Participants may be stubborn
  - "It feels right" doesn't work
  - Persuasion is necessary
- Good strategic decisions in business are usually group decisions
  - A half-dozen experts in a room can't solve a problem
  - One or more people need to understand all the issues
  - Persuasion is necessary

Learning from the experts
The power of Ignorance (and Curiosity)



Multidisciplinary Interaction: Simplicity

Course Outline

- Lecture 1: Introduction & Historical Perspective
- Lecture 2-5: Cellular as a case history
- Lecture 6-9: Technology
- Lecture 10: 3G and the cost of bits
- Lecture 11: Unlicensed spectrum
- Lecture 12: Midterm
- Lecture 13-14: Infostations, 4G (class project intro)
- Lecture 15-18: Finance
- Lecture 19: Class Project Discussion
- Lecture 20-24: Case Histories
- Lecture 25-28: Class Project Presentations & wrapup

Wireless!

The forces and strategies that shaped a revolution

- Setting the stage for cellular
- The long road to cellular
- First generation, 2G, 3G and beyond

Wireless!

The forces and strategies that shaped a revolution

- The Forces and Strategies that shaped the Wireless Revolution are intricately tied to the story of AT&T

(with all due to respect to Marconi, Bose, Armstrong, Shannon and other giants)

Western Union's strategic blunder
Turning down the telephone patent (1876)

"Messers Hubbard and Bell want to install one of their "telephone devices" in every city. The idea is idiotic on the face of it. Furthermore, why would any person want to use this ungainly and impractical device when he can send a messenger to the telegraph office and have a clear written message sent to any large city in the United States?

In view of these facts, we feel that Mr. G.G. Hubbard's request for $100,000 for the sale of this patent is utterly unreasonable, since this device is inherently of no use to us. We do not recommend its purchase."

- Bell bought Western Union six years later, in 1882

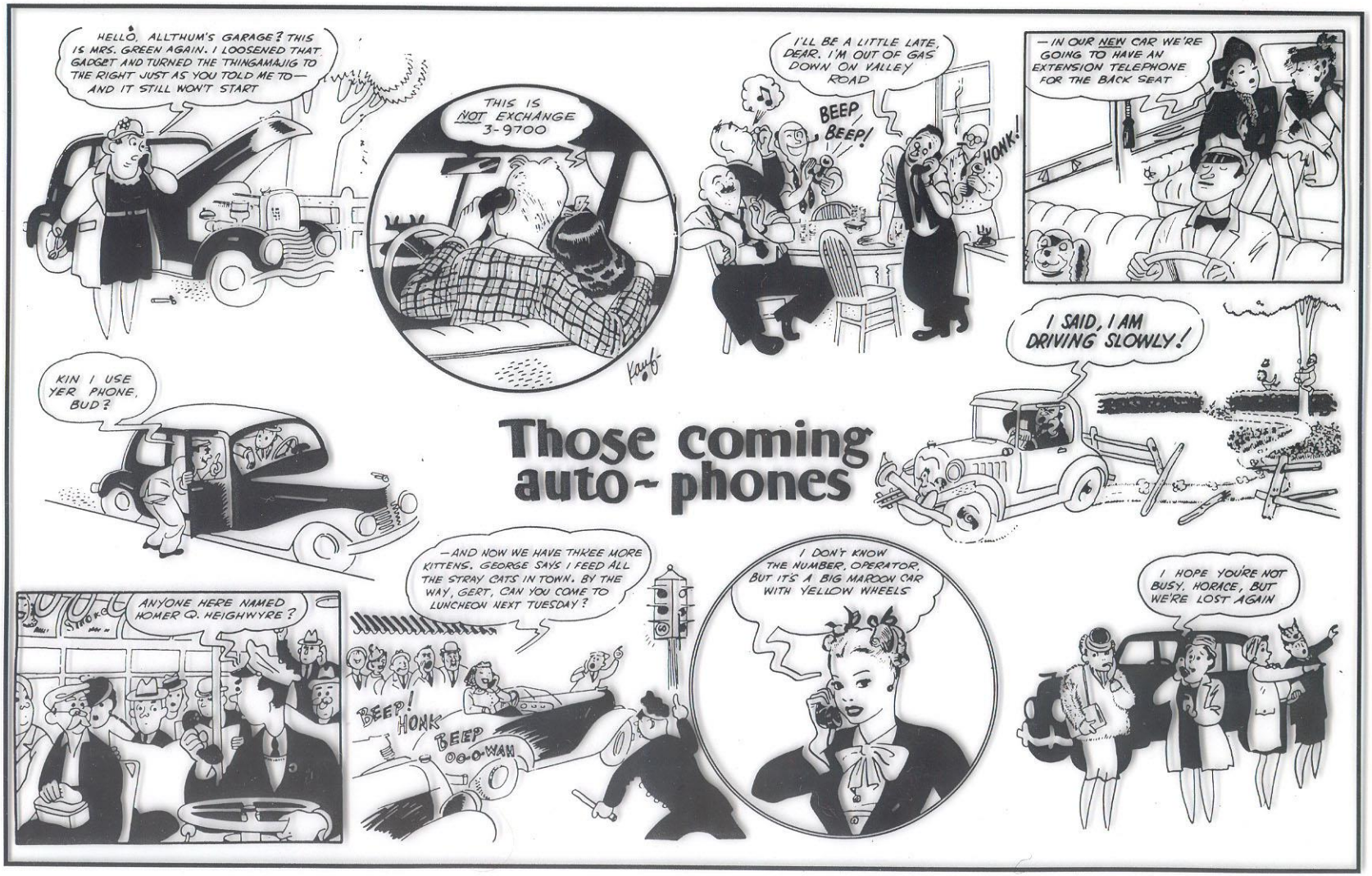
The Bell System Monopoly
A wonder of technology and universal service

- Bell created a vast new network
  - Buying up competitors
  - Eliminating the mess of competing wires
- A focus on technology and service
  - Lower cost
  - Better service
  - Universal, end-to-end service
- Result: the world's best telephone service

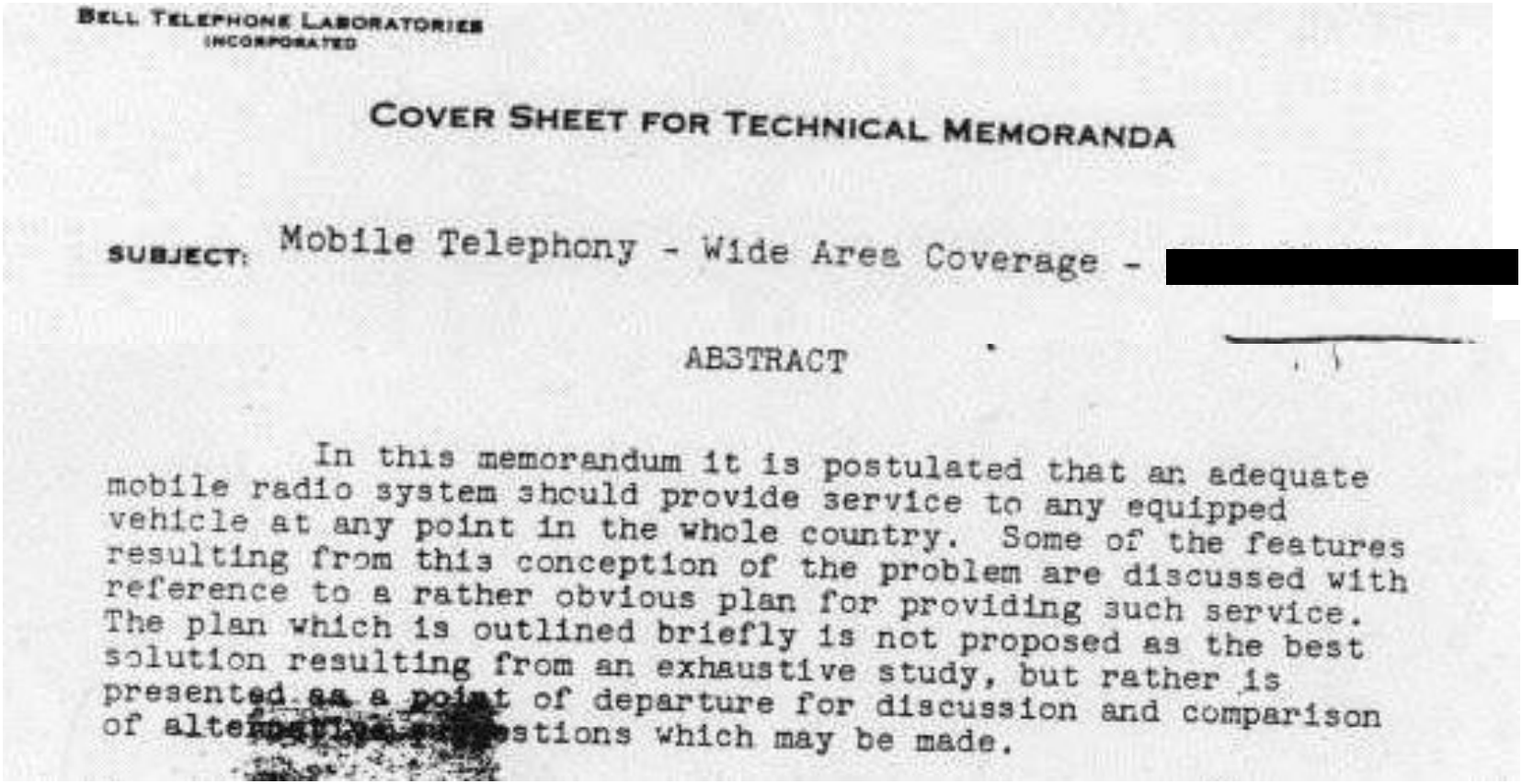
Setting the Stage for Cellular

- Mobile Telephony before Cellular
  - Limited coverage
  - Few channels (and customers)
  - Overload and poor service
- Big Common Carrier Systems and the Issue of AT&T's Monopoly
  - The case for (and against) the AT&T monopoly
  - The gradual erosion of AT&T's monopoly
- The FCC finally acts

1945- The first cellular proposals are made at Bell Labs
No channels are available



Bell Labs Memorandum from 1947 (courtesy: R. Frenkiel)



BELL TELEPHONE LABORATORIES
INCORPORATED

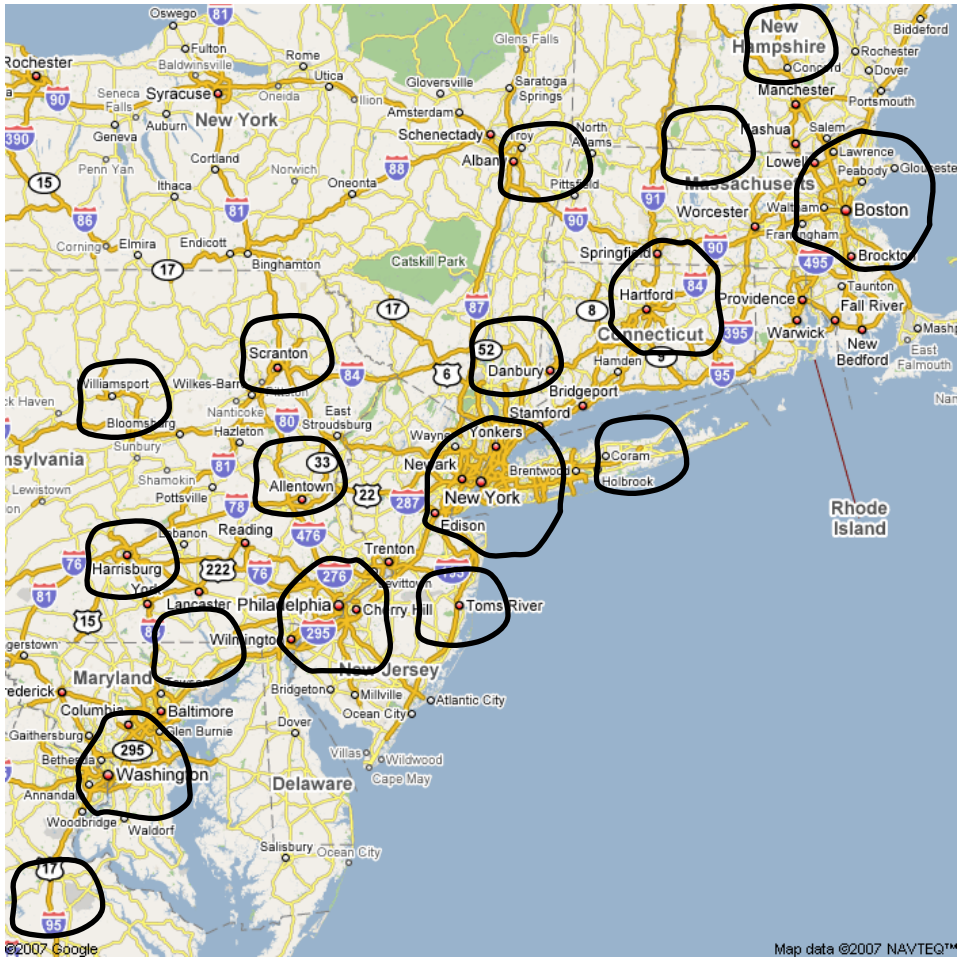
COVER SHEET FOR TECHNICAL MEMORANDA

SUBJECT: Mobile Telephony - Wide Area Coverage - [redacted]

ABSTRACT

In this memorandum it is postulated that an adequate mobile radio system should provide service to any equipped vehicle at any point in the whole country. Some of the features resulting from this conception of the problem are discussed with reference to a rather obvious plan for providing such service. The plan which is outlined briefly is not proposed as the best solution resulting from an exhaustive study, but rather is presented as a point of departure for discussion and comparison of alte[redacted]stions which may be made.

Mobile telephone before cellular
~200 calls in the Northeast US



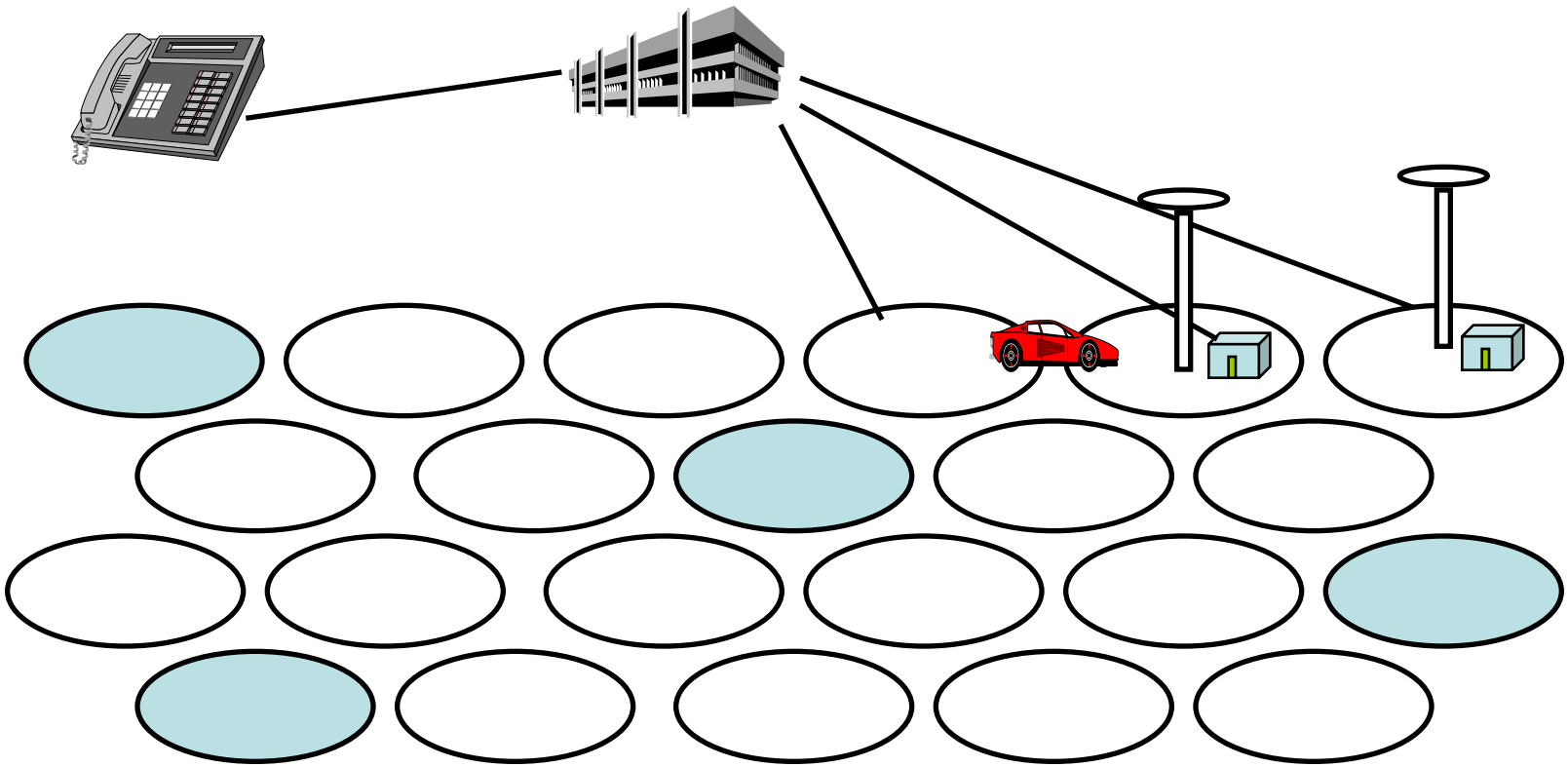
What was needed for cellular? More Channels and Better Technology

- From 50 channels to 1000

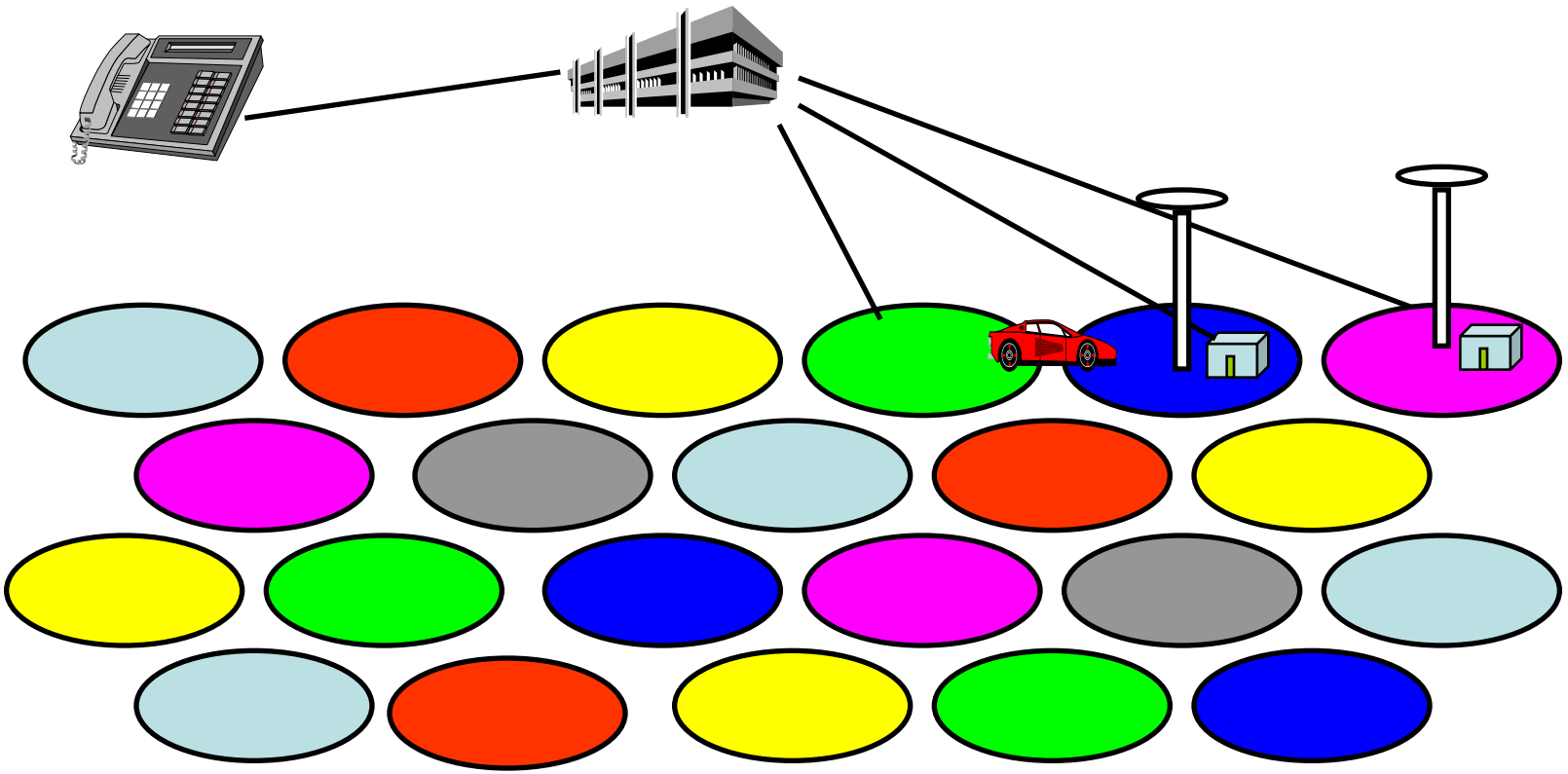
  But a perpetual shortage of channels

  – Competing uses (police, military)
    - Telephone isn't important
- 1950s- Big new allocations for TV
- 1968- The FCC reconsiders
  – Should TV lose a few channels to mobile?
  – Is new technology possible? Can 20 times the channels create 1000 times the service?

Channel Reuse
The key to Capacity



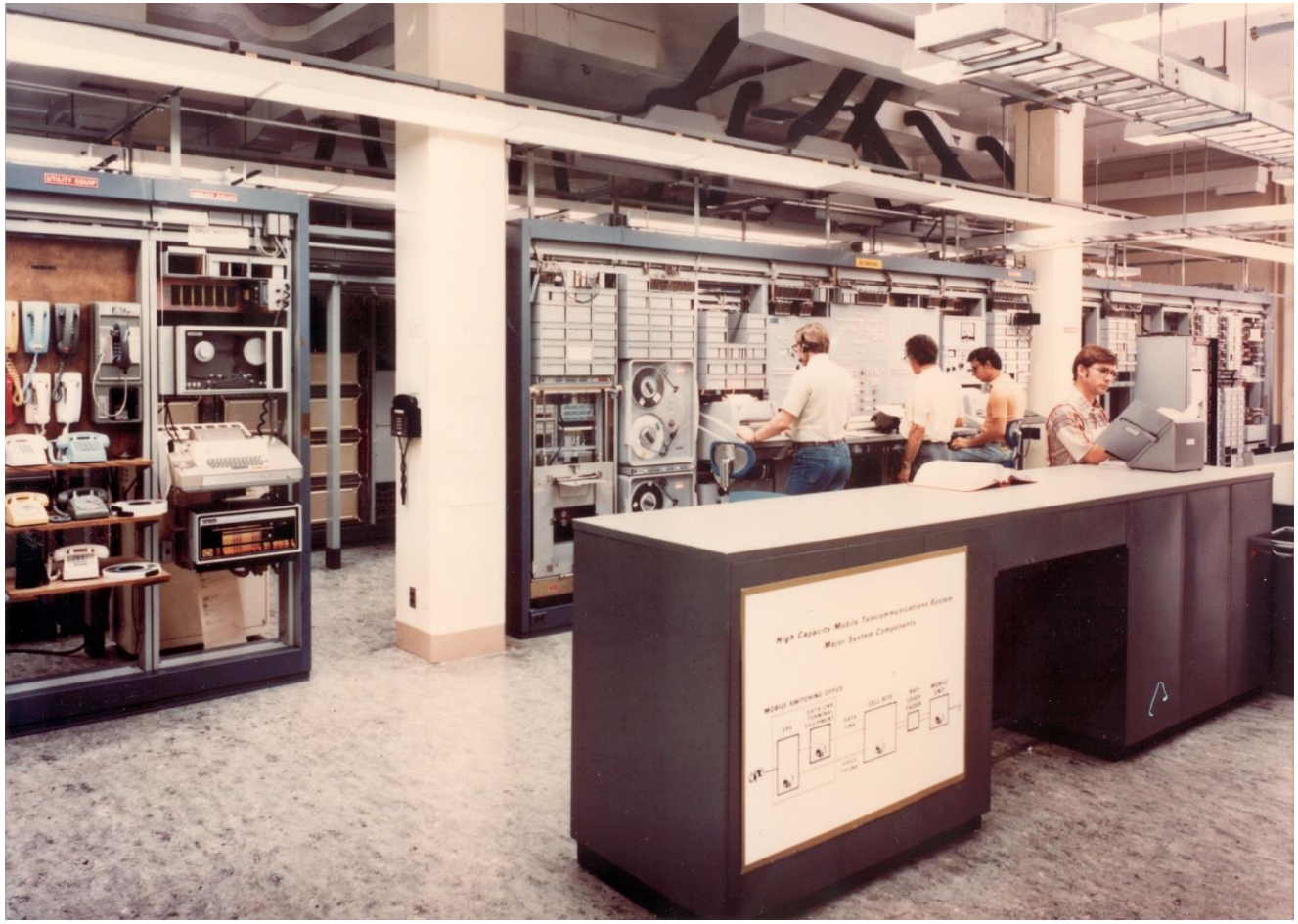
Smaller cells yield larger capacity (and introduce new problems in switching and control)



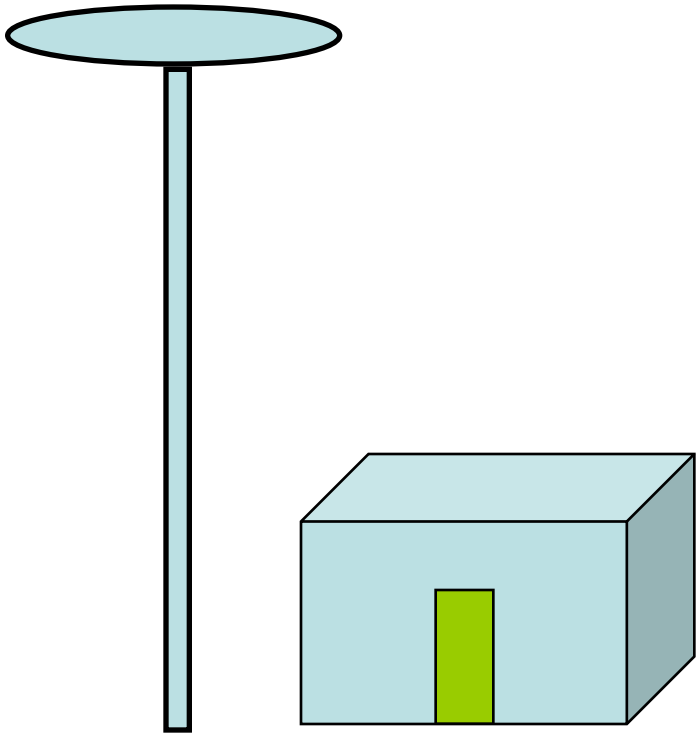
Technology was the fun part– not the problem

We need computers to control the mobile telephone and the switch

(enter the microprocessor and the "ESS")



The Problem became Economic

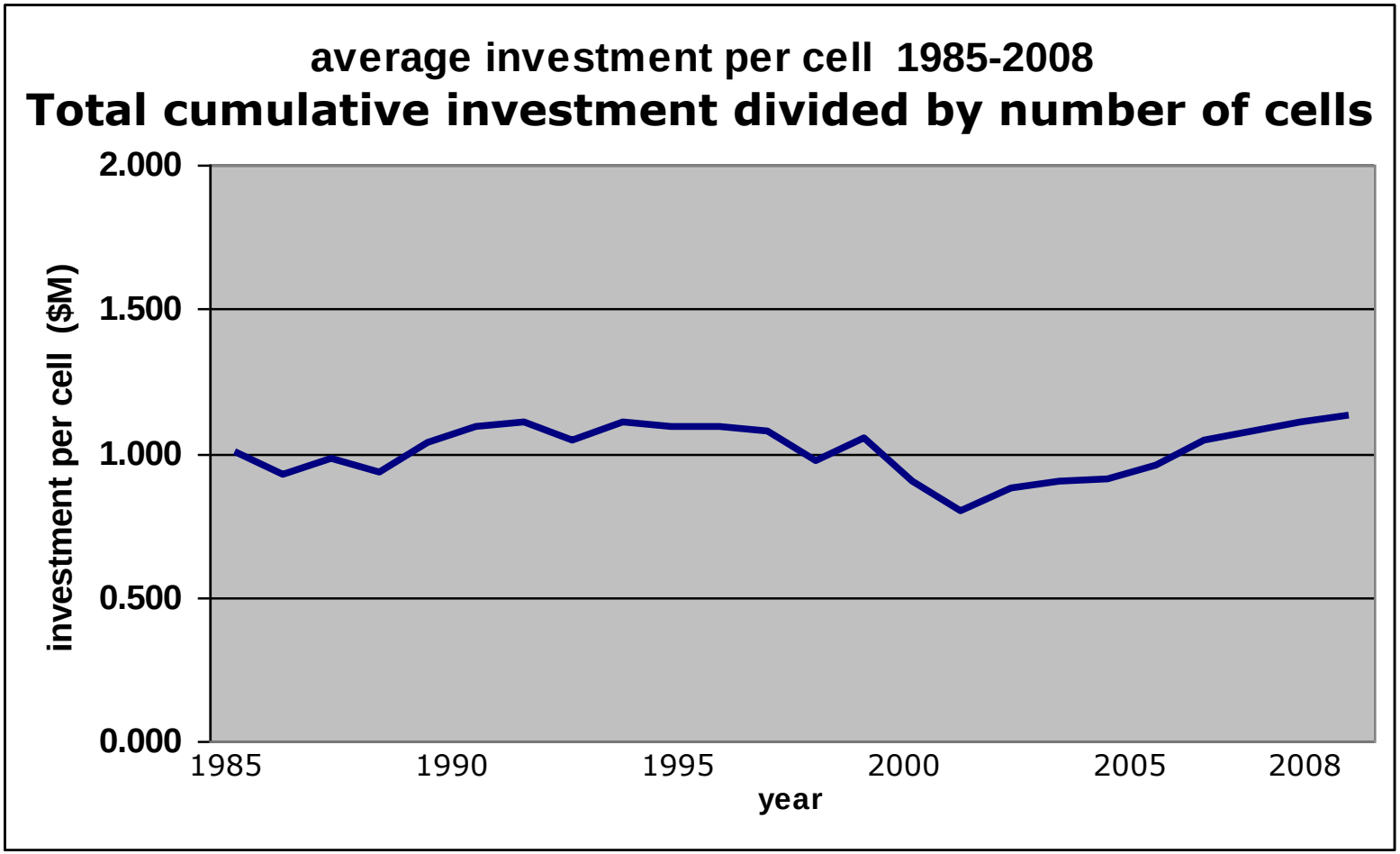


The Million-dollar cell

- Land (acquisition & legal fees)
- Engineering & Improvements
- Building and Mast
- Radios and Antennas
- Combiners and cables
- Maintenance & Information
- Power (and backup)
- Backhaul to switch

We need a lot of users to share each million-dollar cell!

Average investment per cell (all US systems (1985-2008) (CTIA data)



For AT&T (then the Bell System) the answer was obvious

A monopoly service would clearly result in the lowest cost per user

The Bell System Monopoly Revisited

Just a wonder of technology and universal service?

- Bell created a vast new network
  - Buying up competitors
  - Eliminating the mess of competing wires
- A focus on technology and service
  - Lower cost
  - Better service
  - Universal, end-to-end service
  - Any color phone, as long as it's black ☺
- Result: the world's best telephone service
  - But not everyone was happy ☹

Some other views of the Bell System

- Unfair to other manufacturers
  - Always buys from Western Electric
- Anti-competitive and unnecessary
  - A target for the "trust busters" at the Department of Justice
- Result: A long-term erosion of the Bell monopoly
  - Connection of independent telephone companies (Kingsbury Decision, 1913)
  - Restricted to regulated businesses (Consent Decree, 1956)
  - Carterphone and "Radio Common Carriers" (1960s)
  - MCI and Long Distance competition (1970s)
- This political tension had a big effect on cellular
  - Was a cellular monopoly in the public interest?
  - Controversy and delay

The endless world of cellular politics

- The new system would change everything
  - From specialized systems to "one size fits all"
  - From radio technology to telephone technology
  - From a modest investment to a very big one
- All this fit the big Bell monopoly very well
  - Monopoly wealth and Bell Labs technology
- But would the RCCs & manufacturers survive?
  - Was the expertise and wealth of the Bell System really necessary to making it happen?
  - Was it a great idea or a big threat? (yes)

Cellular politics: The many "stakeholders"

- FCC- Wanted to get "land mobile" off their backs
- DOJ- Wanted to prevent a Bell System monopoly
- Broadcasters- Wanted to keep their TV channels
- Motorola- Feared the loss of its profitable and dominant business in private "turnkey" systems
- AT&T- Wanted to offer an expanded mobile telephone service
  - Not everyone at AT&T was enthusiastic
- RCCs- Wanted to stay in business
  - Did they have the resources to compete?

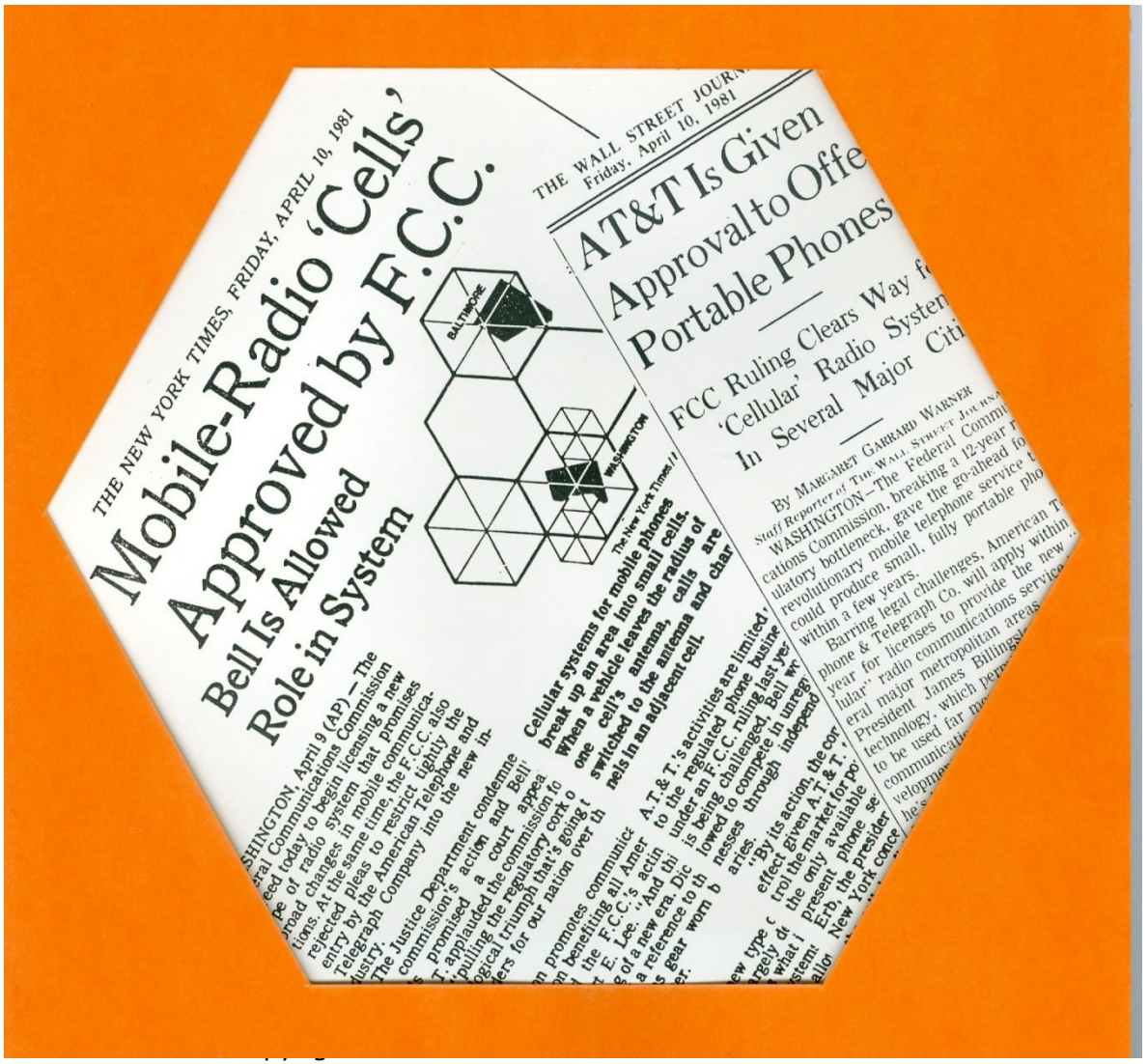
Cellular politics: The long road to cellular

- FCC Notice of Inquiry- 1968
- AT&T commits to a proposal in 18 months
- Comments on the proposals
- Rebuttals on the comments
- Oral testimony
- Petitions to courts
- New proposals
- New comments
- Arguments over technology, cost, spectrum, services, trials, standards
- On, and on, and on…. for 15 years!

More on the long road to cellular

- AT&T: Insisting on all the channels
  - A monopoly mind-set in a new world
  - Arguing technology issues with Motorola
- Too complex to prove who's right
  - Delay favored Motorola (kill or delay cellular)
- Other manufacturers
  - Cellular a new market opportunity
- John Q. Public- would have supported cellular but not represented in the fight
- U.S. led in technology but ….
  - Europe and Japan had operational 1st Generation cellular systems in place first!

April 10, 1981- The FCC finally acts! Bell begins nationwide service planning



THE NEW YORK TIMES, FRIDAY, APRIL 10, 1981

Mobile-Radio 'Cells' Approved by F.C.C.

Bell Is Allowed Role in System

THE WALL STREET JOURNAL Friday, April 10, 1981

AT&T Is Given Approval to Offe Portable Phones

FCC Ruling Clears Way f 'Cellular' Radio Systen In Several Major Citi

By MARGARET GARRARD WARNER
Staff Reporter of THE WALL STREET JOURN

WASHINGTON—The Federal Commu cations Commission, breaking a 12-year r ulatory bottleneck, gave the go-ahead fo revolutionary mobile telephone service t could produce small, fully portable pho within a few years.

Barring legal challenges, American T phone & Telegraph Co. will apply within year for licenses to provide the new lular'' radio communications service eral major metropolitan areas. President James Billings technology, which perm to be used far m communicati velopme he's

SHINGTON, April 9 (AP) — The eral Communications Commission eed today to begin licensing a new pe of radio system that promises broad changes in mobile communica- tions. At the same time, the F.C.C. also rejected pleas to restrict tightly the entry by the American Telephone and Telegraph Company into the new in- dustry. The Justice Department condemne commission's action and Bell' promised a court appea applauded the commission fo pulling the regulatory cork o gical triumph that's going t ers for our nation over th

Cellular systems for mobile phones break up an area into small cells. When a vehicle leaves the radius of one cell's antenna, calls are switched to the antenna and char nels in an adjacent cell.

BALTIMORE WASHINGTON

The New York Times/1

A.T.&T.'s activities are limited under an F.C.C. ruling last ye to the regulated phone busine is being challenged. Bell wo lowed to compete in unregu nesses through independ aries.

n promotes communicc n benefitting all Amer the F.C.C.'s actin E. Lee. "And thi g of a new era. Dic a reference to th s gear worm b er.

"By its action, the cor effect given A.T.&T. trol the market for po the only available present phone se Erb, the presider New York conce

ew type c rgely de what i stem. allo

A brief euphoria before the disaster

- AT&T seemed to win the battle for Cellular
  - No monopoly, but half the cellular channels- 1981
  - First system: Chicago-- 1983
- But the AT&T monopoly was broken up in 1984, so the victory was short lived
  - Cellular went to the RBOCs
  - AT&T would be out of the cellular service business for a decade, before buying McCaw Cellular in 1994 (and selling it a decade later, and …..)
- Monopolies and regulation were eliminated in many industries, beginning under Reagan
  - Airlines, trucking, telephone, power
  - The effects have been profound

As summarized by Stephen Colbert

The trends that shaped cellular after 1981

- Spectrum– hearings, lotteries and auctions
  - From the 10-year channel to the $10M channel
- From car trunk to pocket
  - The dawn of true personal communications
- The slow path to roaming service
  - Fraud and mistrustful carriers
  - "PCS"
- Different approaches to standards
  - The US (TDMA/CDMA) and Europe (GSM)
- Europe was ahead again in 2G system deployment!
  - GSM everywhere
  - CDMA (Qualcomm) vs. TDMA (Ericsson) wars
- "3G" and the coming of "data" services

How cellular spectrum has been assigned

- Hearings (until mid-1980s):
  - The FCC determines the public interest
  - Long hearings; A-band licenses delayed

- Lotteries (mid- 1980s to mid- 1990s)
  - Rolling the dice
  - Fast; efficient
  - Attracts gamblers instead of operators
  - McCaw saw opportunity; begins to buy up licenses

- Auctions (since 1994)
  - Show me the money
  - Fast; provides revenues to the government
  - $/MHz/POP: 14-60¢ (1994), $10 (2001), $1 (2008)
  - What about 2014???
  - Increases the cost of service
  - Still has a "public benefit" component
    - Part of 2008 auction was earmarked for "public safety" systems

And an after-thought on monopoly for the lowest cost

- In the early-mid 1990s, digital speech compression tripled the capacity of the million dollar cell
  - A tremendous increase in profits?
  - The post-monopoly AT&T used the new capacity for competitive advantage
    - They introduced nationwide calling “packages”
    - Cost per minute fell 70%
    - Minutes per subscriber tripled
    - Carrier revenues and profits fell
- Competition works too!

Flat rate packages for text messaging

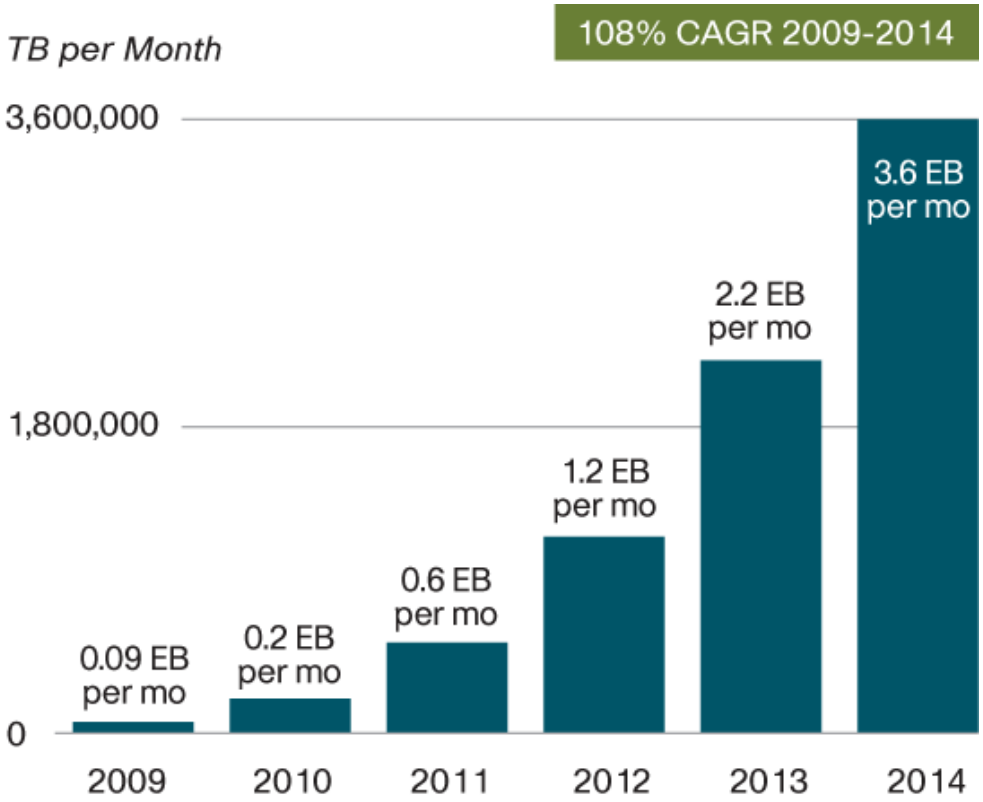
- $20 for unlimited messages (100 messages a day)?
- 3000 messages/month x 1000 bits/message = 3M bits
- 3M bits = about 3 minutes of voice (which costs 15 cents)
- At $20/month, texting is 100 times as profitable as voice
  - Even at 100 messages a day!
- Messages are cumbersome to enter, so we don't have to worry about 1000 messages per day, and even that would be 10 times as profitable as voice
- This is a great deal for the cellular operator!
  - 20% of revenues using much less than 1% of capacity!
- Strategy: raise message rates to push people into packages!
  - We want to maximize revenues, and this time we don't care about capacity.

But texting is not the beginning of "3G"

- In many ways it is the opposite
  - Text messaging is very profitable, because it uses many fewer bits than voice
  - 3G content like music and video uses many more bits than voice
  - Kbps vs. Mbps ⇨ A Picture is worth a thousand words!
  - 10 minutes of You Tube is the same as 3 hours of voice!
- And radio is not fiber
  - The radio channels are limited in how much information they can carry
    - MIMO, OFDM can help but …..
- This is a fundamental strategic problem for 3G that is often not recognized

Mobile/Cellular Systems: Wireless Data?

- Data volume doubling annually!
  - 3G, 4G, LTE-Advanced rollout, WiFi
  - AT&T reported 5000% increase in mobile traffic in last 3 years

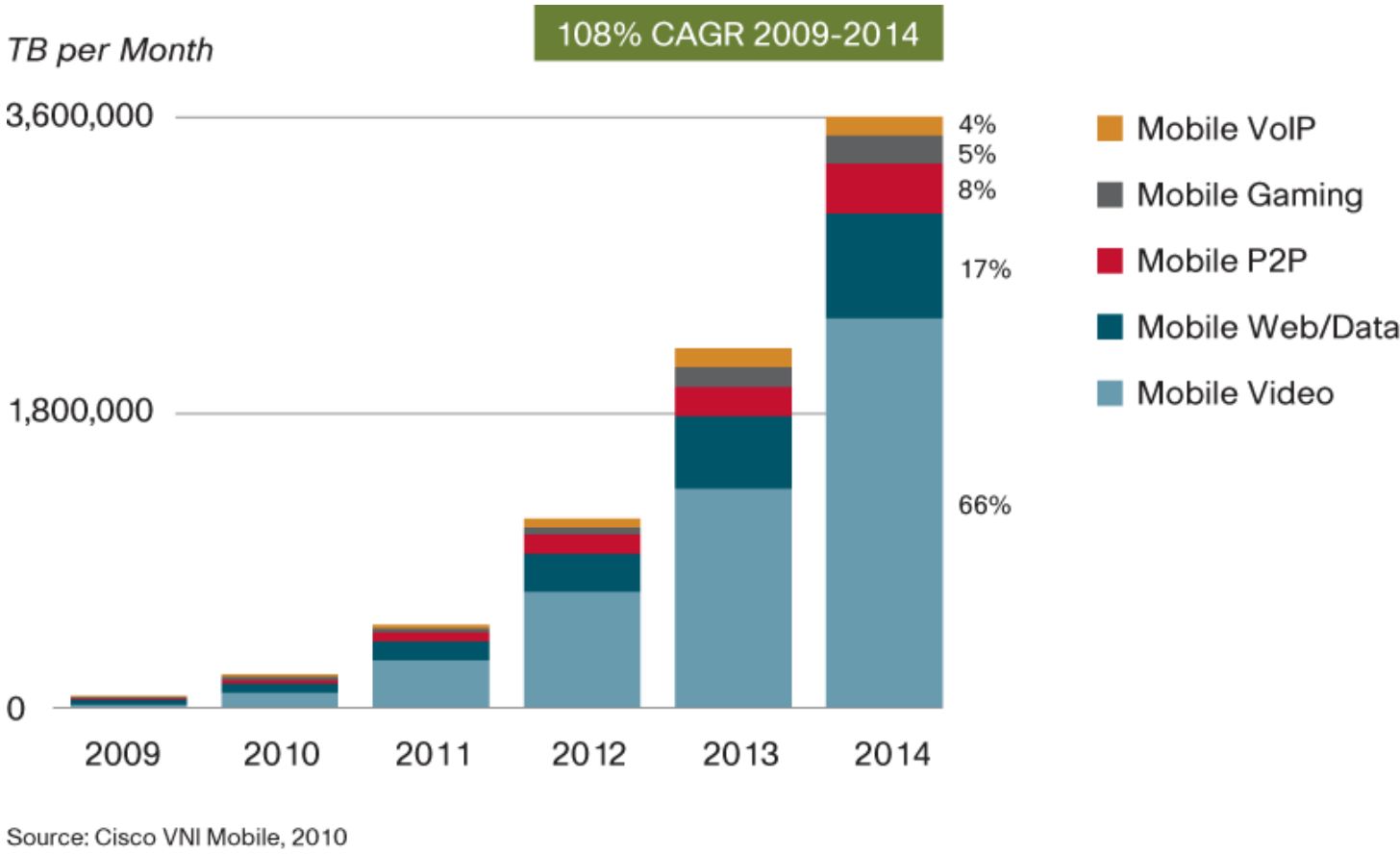


3.6 ExaBytes/month in 2014

1 EB = 10^{18} Bytes

Mobile Video Growth

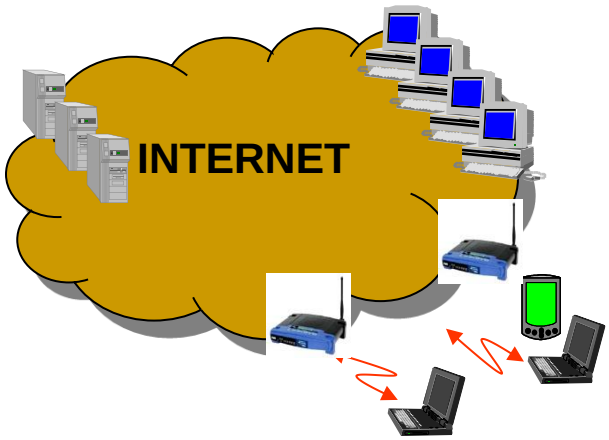
- Mobile video ~ 66% of volume
  - Smart phones, iPAD, etc.
  - Social networking



Source: Cisco VNI Mobile, 2010

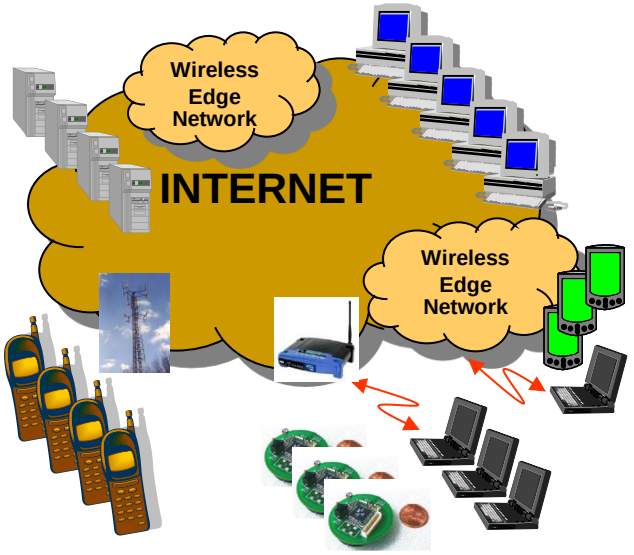
Wireless Network (R)Evolution: Internet?

~500M server/PC's, ~100M laptops/PDA's



2005

~1M servers/PC's, >2B laptops, PDA's, cell phones, sensors



2015

"Wireless" is overtaking "Wired" as the primary mode of connectivity to the Internet

Usage scenarios: mobile data, mesh networks, sensor, V2V, M2M

3G will not replicate increasingly video-centric Internet experience

- Current US Internet usage is 100s-1000s of MB/day/person. For video users, it is thousands of MB a day, and growing fast.
- 3G is limited. It is not a portal into the real uses of the Internet today
  - We can't buy even 10 times more spectrum
  - We can't split cells if 3G isn't paying for cells
  - We can't expect a big boost from technology (radio isn't fiber)
- We need a lot more capacity and 3G cellular doesn't seem to be the answer
- WiFi (the tiny cell) offers some interesting possibilities

4G and Beyond – Technology Issues

- Small Cells
- Lots of Antennas (Massive MIMO)
- More Spectrum
- Offload to WiFi
- Dynamic Spectrum Access (DSA) & Other Spectrum
  - TV white space
  - 3.5 GHz
  - 60 GHz
- Cooperation and Coexistence
- Cloud Assisted Spectrum Sharing

Smart Phones and Apps

- New dynamics
  - Reevaluate Uplink and Downlink
- End-user power
  - Device “usage” is unpredictable
  - Newer interfaces
- Disruptive business models
  - Content is king

And the revolution goes on …..

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