# CS/ECE 439: Wireless Networking

Fall 2020

# Welcome!

- Introduction
  - Who I am: Robin Kravets
  - Where I live: Department of Computer Science
  - What I have taugh : CS 241, CS 438, CS 439, CS 538 and other grad networking courses
  - What I do: Wireless Networking and Mobile Computing research ➢ IoT!

- Who are you?
  - Grad/undergrad?
  - CS/ECE?
  - Taken CS 241 or ECE 391?
  - Taken CS/ECE 438?





# What will we cover in this class?

- Wireless Networking … from the ground up
  - Wireless architecture
    - Physical layer
    - MAC layer
    - Transport layer
    - Mobility
  - For diverse technologies
    - Wi-Fi
    - Bluetooth
    - ZigBee
    - RFID
    - WiMAX
    - Cellular
  - In diverse environments
    - Mobile-to-mobile networks
    - Ad hoc networks
    - Sensor networks
    - Vehicular networks
    - Delay tolerant networks
    - Mesh networks
    - Internet of Things
  - Supporting diverse applications
    - No one-size-fits-all solution





# What will you get out of this course?

- Learn about the unique challenges in wireless networking
  - Starting point is "regular" wired networks
- Gain an understanding of wireless technologies at the physical, MAC, and higher layers
  - Focus is on wireless protocols
- Get experience in working with wireless networks
  - Implementing protocols, algorithms
  - Measurements of wireless networks
- Get a broad view of the the state of the art and ongoing research in the wireless domain
  - Read and present hot topics and leading edge research papers




# Course Contents

- Class participation 10%
  - You only get out of this class what you put into it!
- Presentation of advanced topic 20%
  - In class presentation (20-30 min)
  - Summary of presentation topic
- Project: team-based, hands-on 55%
  - In-depth study and implementation of a particular problem
- Project Presentation 10%
- Project Evaluations 5%
  - Evaluation of another team's class project
- Exam 20%
  - During second half of semester





# Advanced topics

- For each topic
  - Introduce advanced topics
  - Current technology and research in wireless networking
- Topic Teams = Project Teams
  - Small (2-3 person) teams
  - Based on a small set of papers or articles
  - Summarize the state of the art
  - Apply critical thinking on the applicability and effectiveness of current proposals
  - Compare different solutions
  - Identify interesting future work
- Presentation in class
  - 20 – 30 min
  - Meet with me one week prior to presentation (mandatory)





# Projects

- In-depth study of a particular use of wireless in an IoT environment
  - Performance evaluation studies, protocol modifications, applications, measurements, ..
  - Must be wireless, but otherwise flexible
- Strongly prefer hands on projects
  - Real world is quite different from simulation and analysis
- Must carefully consider platform options
  - Real-world experiments
  - Simulator based
  - Emulator
  - Or could compare results in different environments





# Project Timeline and Deliverables

- September 25
  - Project Proposal – Team members (2-3), topic, references
- October 16
  - Extended Project Proposal – Progress so far (~5 pages)
- November 13
  - Status Report – Initial demos and results
- Dec 9
  - Final report
- Finals Week
  - Project presentations or posters
  - Project Evaluations





# Academic Honesty

- Your work in this class **must** be your own.
- If students are found to have cheated (e.g., by copying or sharing answers during an examination or sharing code for a project or copying any written text from existing material), **all** involved will at a minimum receive grades of 0 for the first infraction.
- Further infractions will result in failure in the course and/or recommendation for dismissal from the university.
- Department honor code:

**https://cs.illinois.edu/academics/honor-code#:~:text=Honor%20Code%20and%20Academic%20Integrity,of%20integrity%20befitting%20a%20scholar.**




# Course Material

- Final slides were prepared by the course instructor
- Some slides contain material from other sources
  - Slides from related courses
    - Special thanks to Nitin Vaidya and Romit Roy Choudhury (UIUC) and Peter Steenkiste (CMU)
  - Some figures are taken from textbooks
  - Some lectures contain material from research presentations prepared by the authors

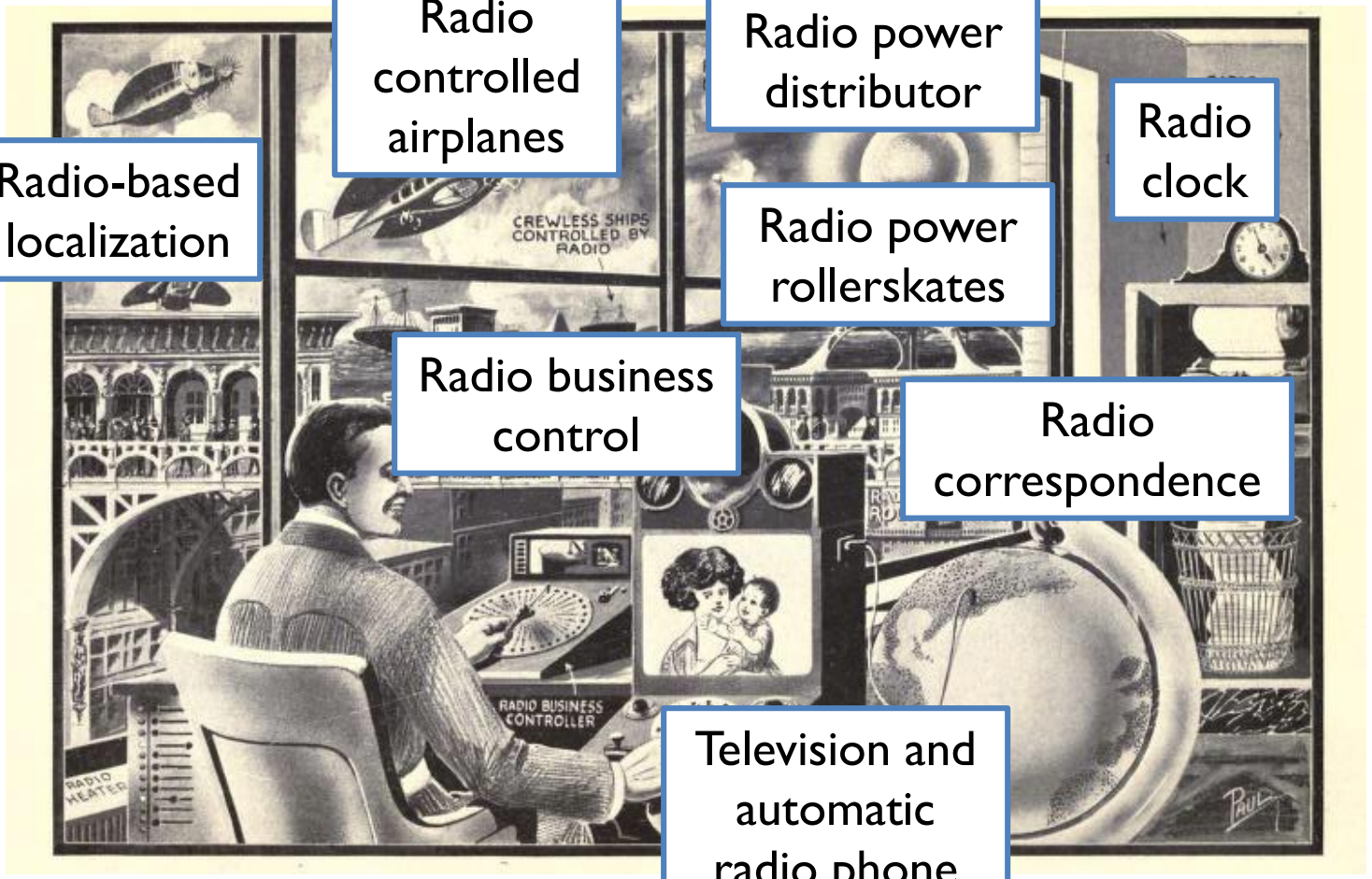




# Wireless Technology

# A glimpse of the future

- 1922: "Radio for All", Hugo Gernsback



# A glimpse of the future

- 1922: "Radio for All", Hugo Gernsback

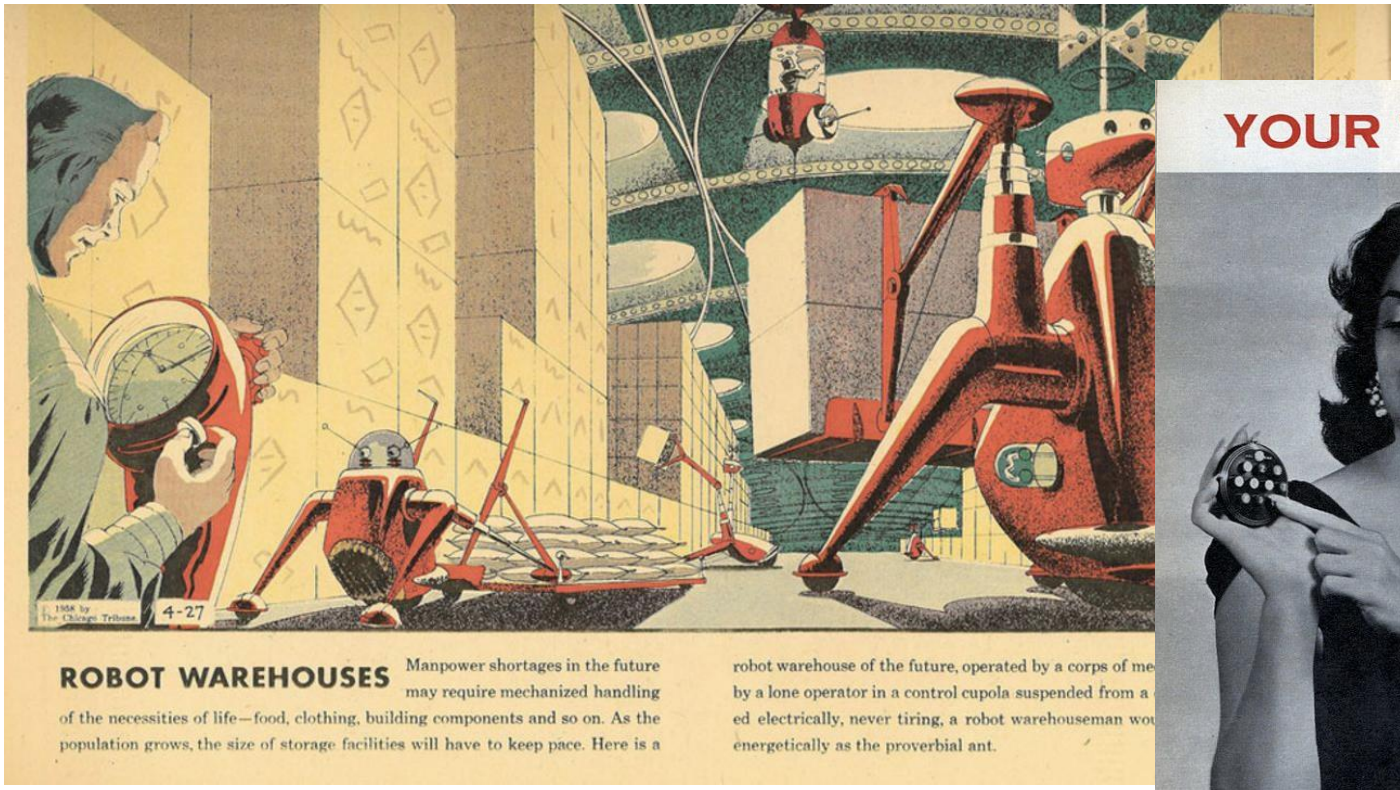

It is a mistake to think that radio is only good for the distribution of intelligence… the great uses of radio have not been touched upon as yet.

# A glimpse of the future

- 1931
  - Erich Kästner's children's book: The 35th of May, or Conrad's Ride to the South Seas
  - "a science fiction nightmare city with mobile phones and moving walkways"

"A gentleman who rode along the sidewalk in front of them, suddenly stepped off the conveyor belt, pulled a phone from his coat pocket, spoke a number into it and shouted: "Gertrude, listen, I'll be an hour late for lunch because I want to go to the laboratory. Goodbye, sweetheart!" Then he put his pocket phone away again, stepped back on the conveyor belt, started reading a book..."

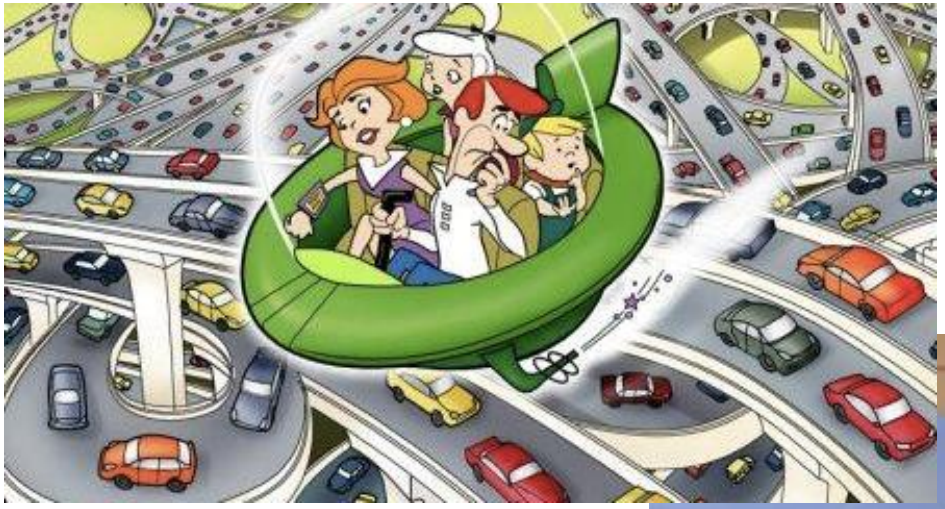
# A glimpse of the future





1950s

# A glimpse of the future

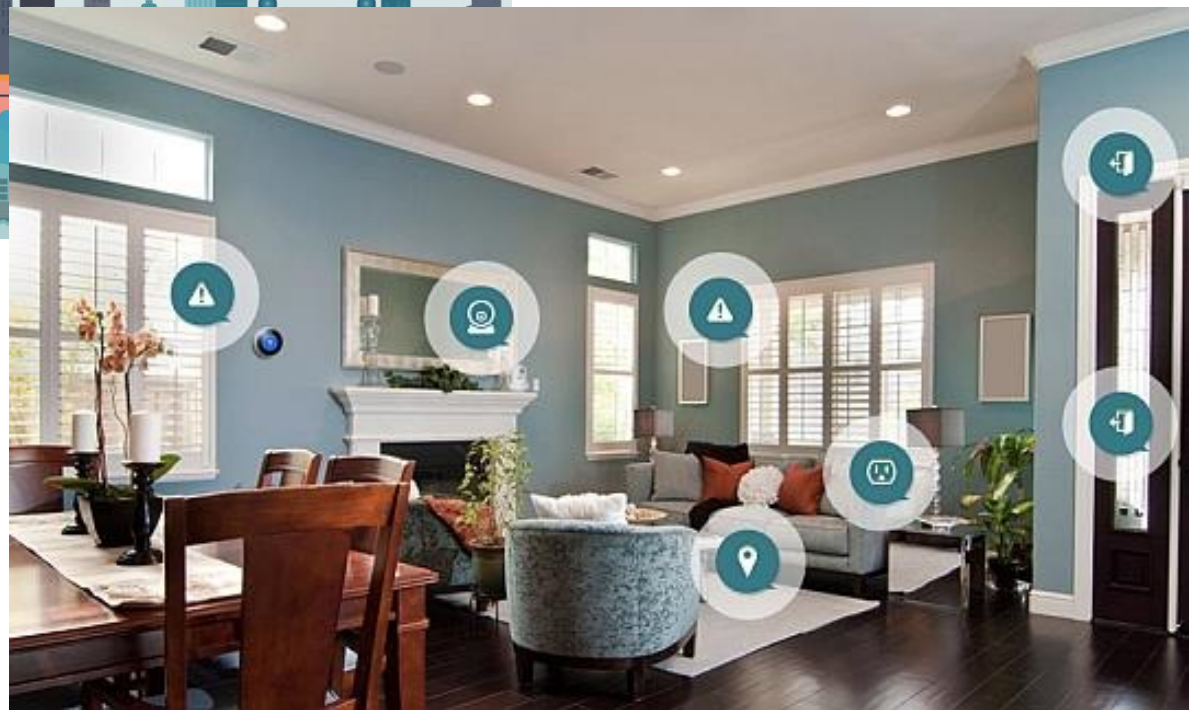


Smart Cities

Smart Homes

# The Dream

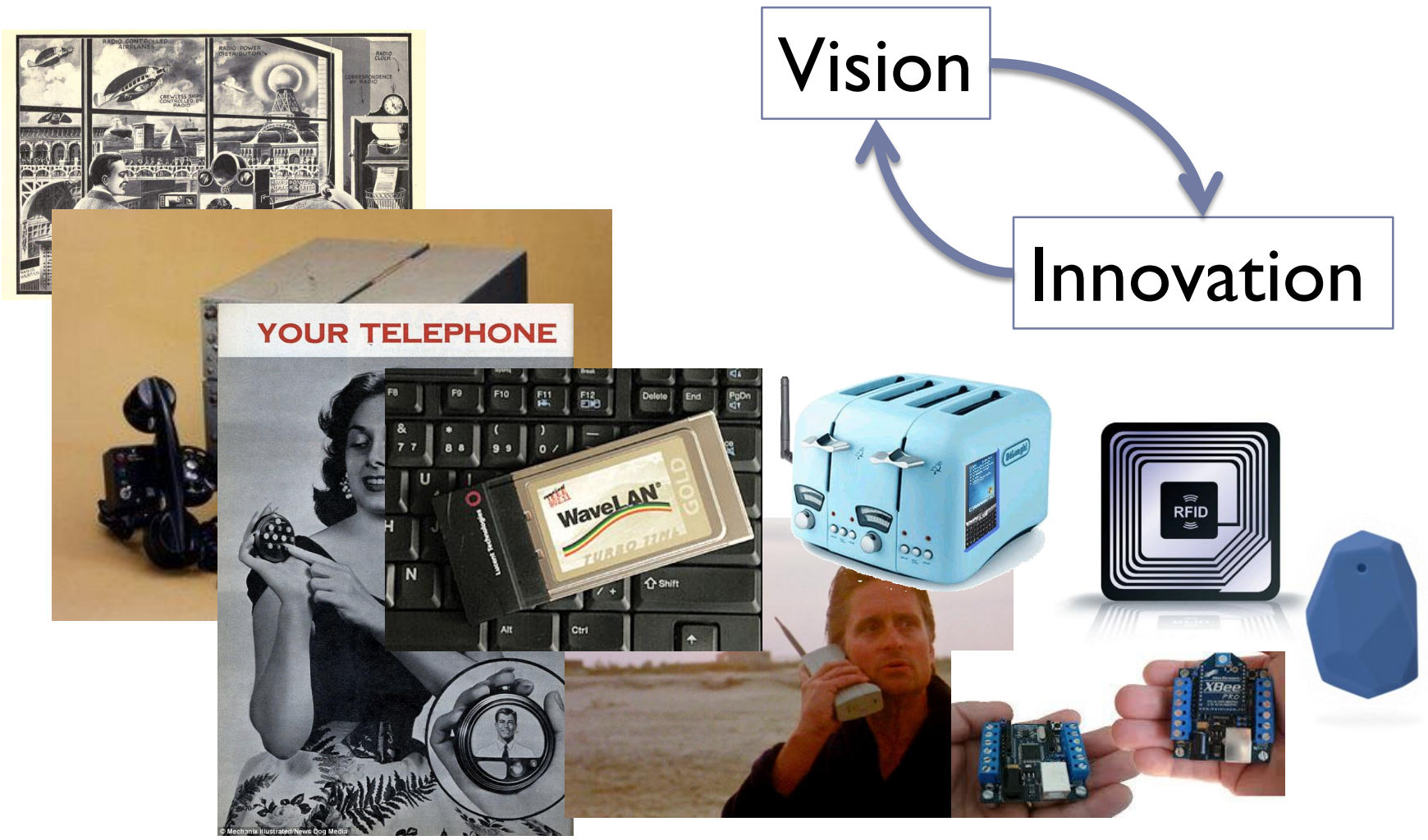
Smart Cities



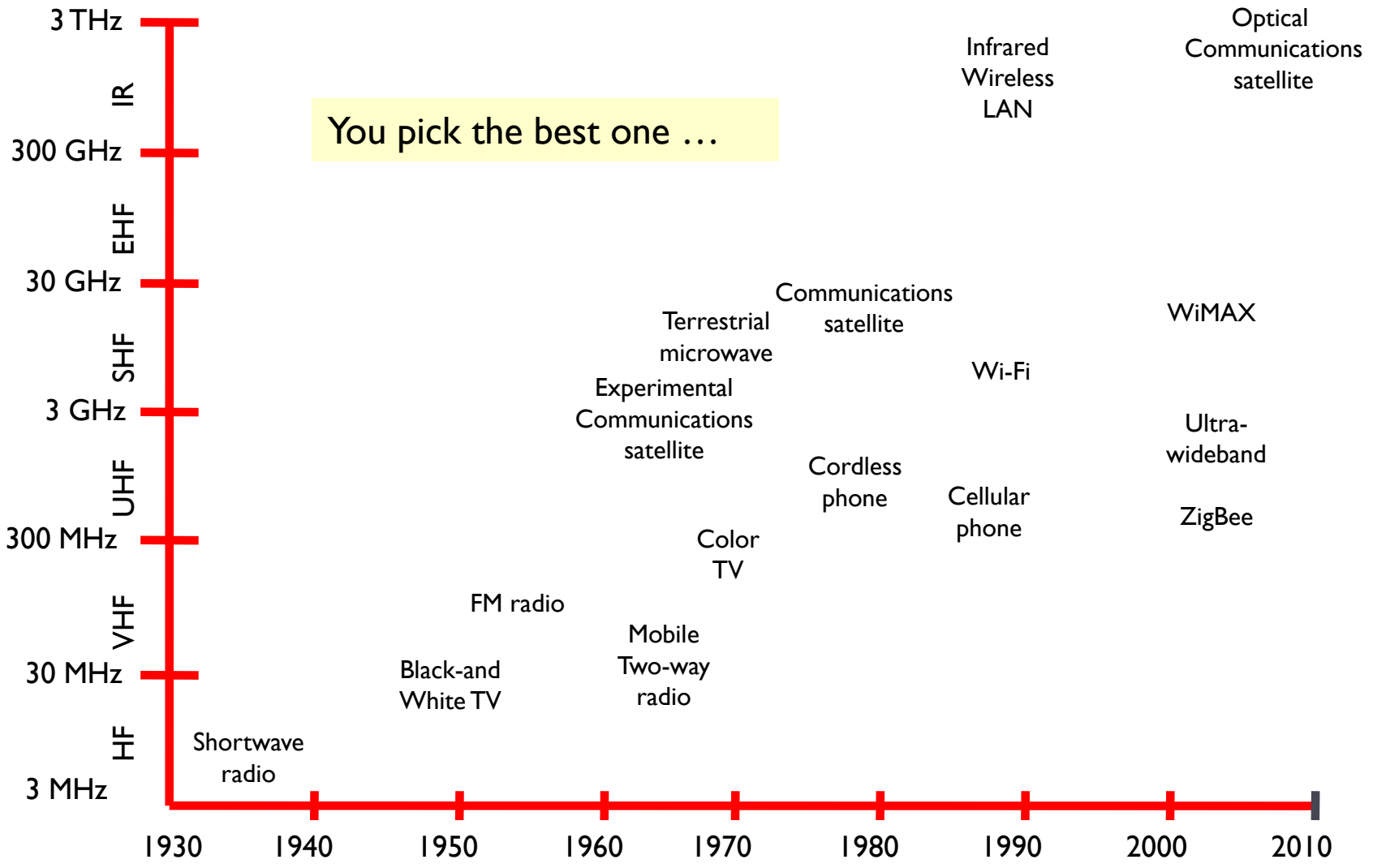
Smart Homes

**Are we there yet and why is it taking so long?**

# The Road to Ubiquitous Wireless Access

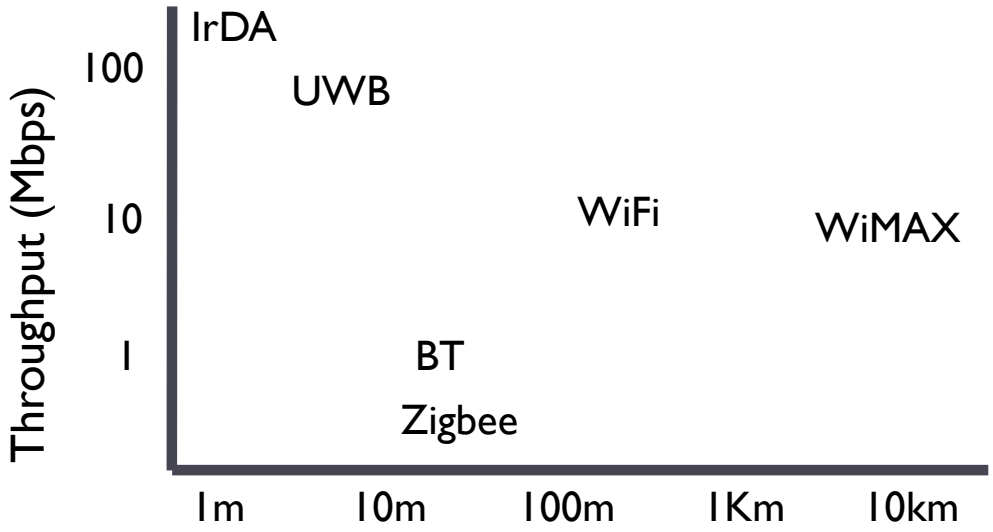


# A broad spectrum of Wireless Technologies



# Diversity is king

- Diverse application requirements
  - Energy consumption
  - Range
  - Bandwidth
  - Mobility
  - Cost
- Diverse deployments
  - Licensed vs. unlicensed
  - Provisioned vs. unprovisioned
- Diverse characteristics
  - Signal penetration
  - Frequency use
  - Cost
  - Market size
  - Age, integration



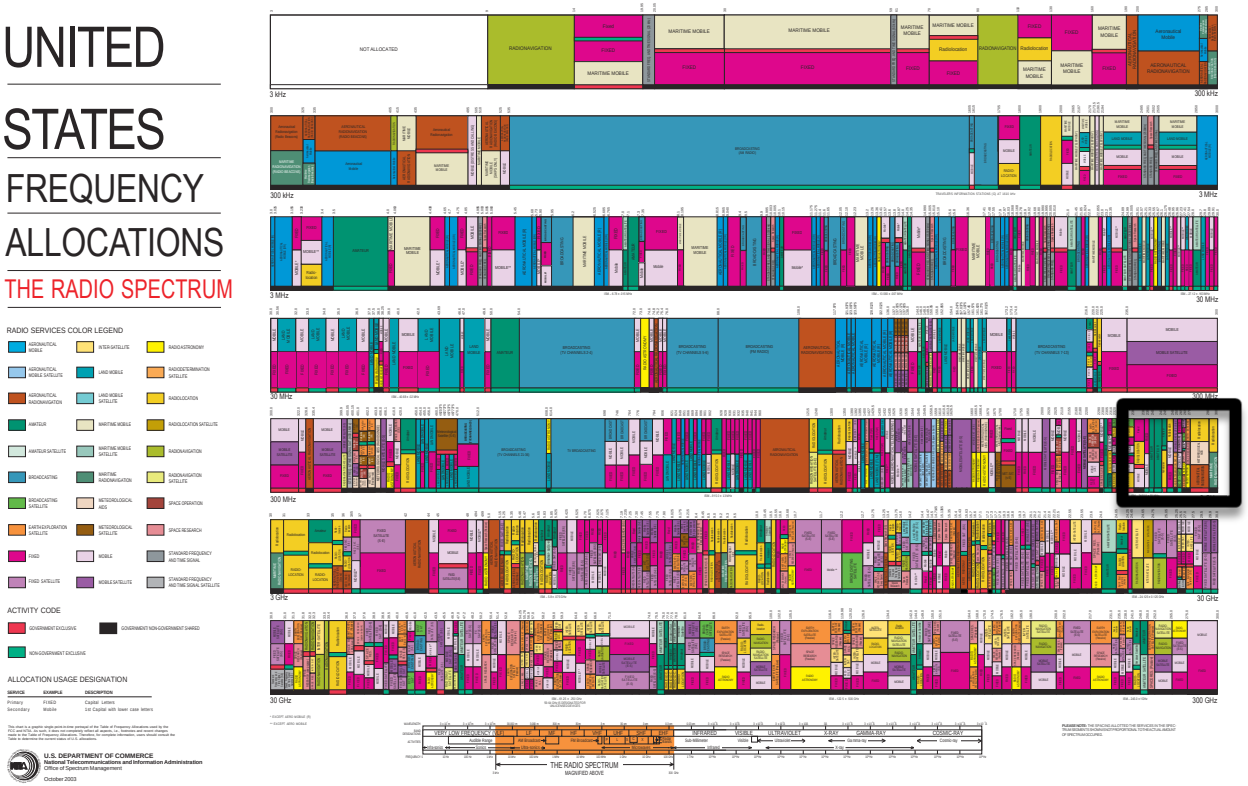
# Radio communication

- Limited spectrum
  - Must be shared among the various applications
- Spectrum access
  - Typically regulated by the government





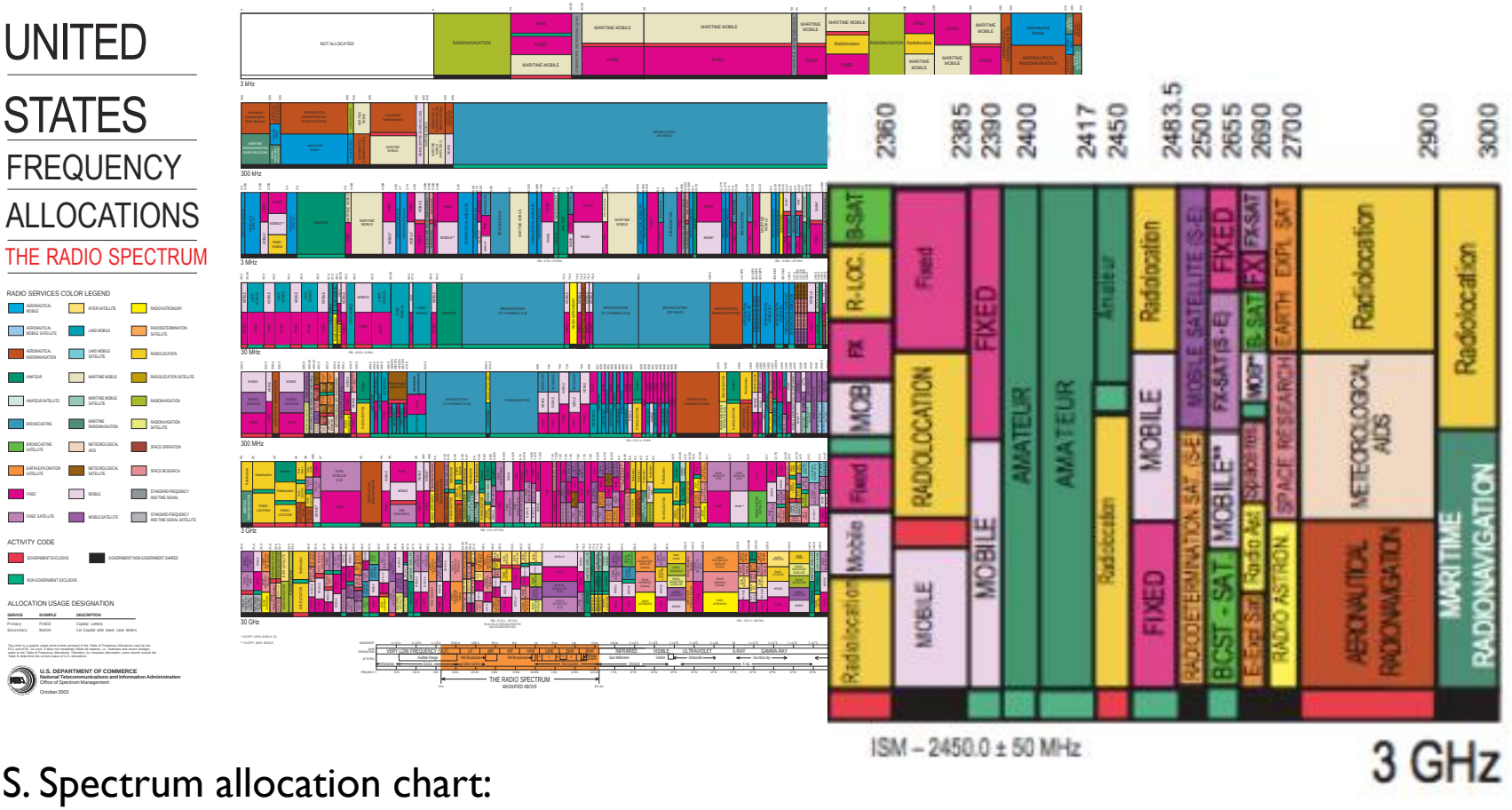
# Radio communication




U.S. Spectrum allocation chart:

http://www.ntia.doc.gov/osmhome/allochrt.pdf

# Radio communication




U.S. Spectrum allocation chart:

http://www.ntia.doc.gov/osmhome/allochrt.pdf

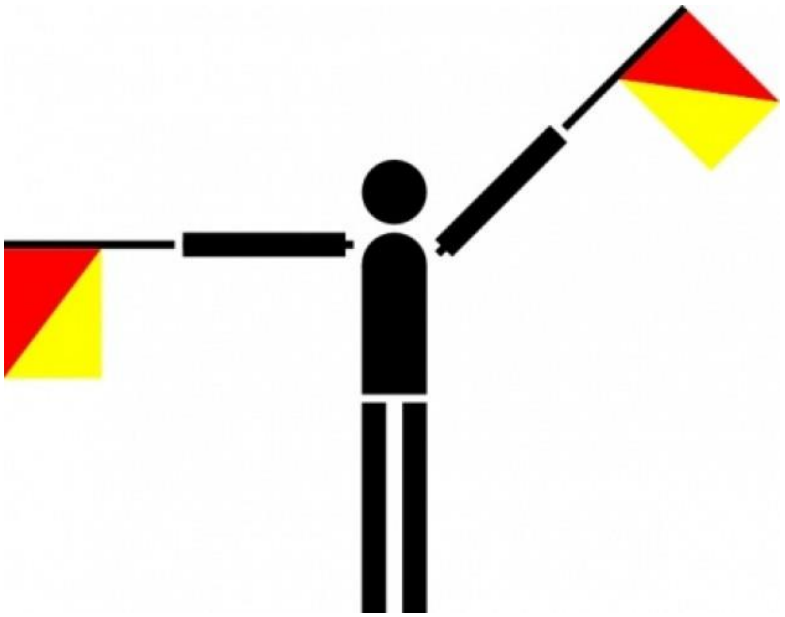
# What Makes Wireless Different?

- Absence of wires facilitate mobility
- Signal attenuation
- Spatial reuse
- Diversity
  - Multi-user diversity
  - Antenna diversity
  - Time diversity
  - Frequency diversity
- Wireless devices often battery-powered
  - Need to conserve energy
- Broadcast medium
  - Easier to snoop on, or tamper with, wireless transmissions





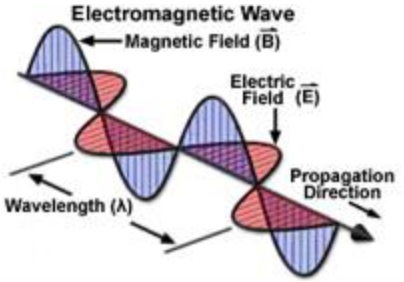
# Wireless through the ages …



# Birth of modern-day wireless communication

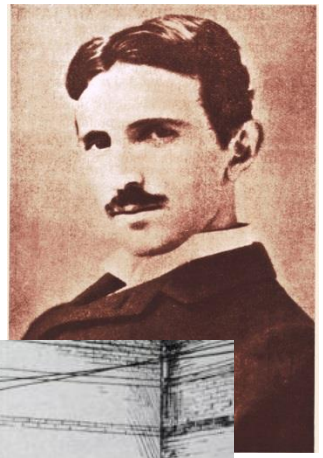
- 1867
  - Maxwell predicts existence of electromagnetic (EM) waves

- 1887
  - Hertz proves existence of EM waves

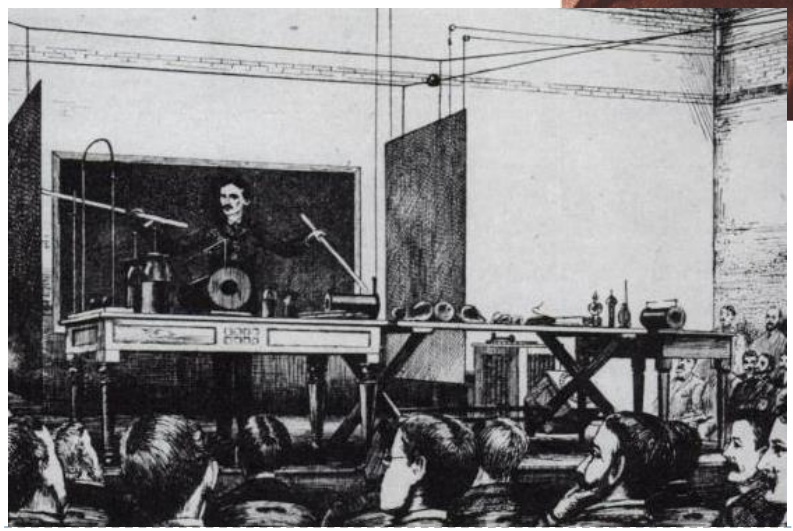


# Birth of modern-day wireless communication

- 1896
  - Wireless telegraph invented by Guglielmo Marconi
  - Awarded the Nobel Prize in 1908!



- 1893
  - Tesla credited with first radio communication

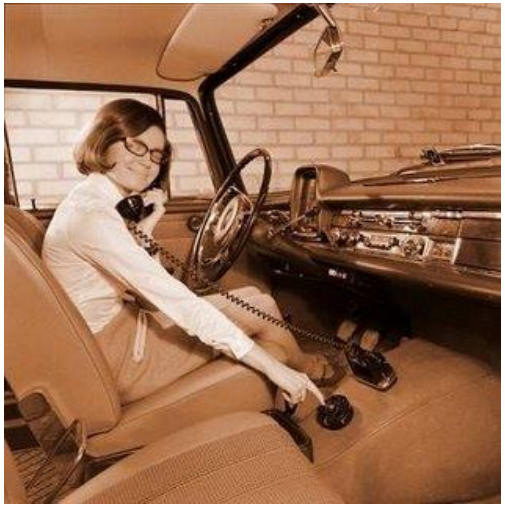


# Birth of modern-day wireless communication

- 1901
  - Marconi: First telegraphic signal traveled across the Atlantic ocean (3,500km/2,200mi).
  - Took another year for it to be bi-directional
  - Used analog signals to transmit alphanumeric characters
- 1914
  - First voice over radio transmission
- 1935
  - Frequency modulation (FM) demonstrated by Armstrong

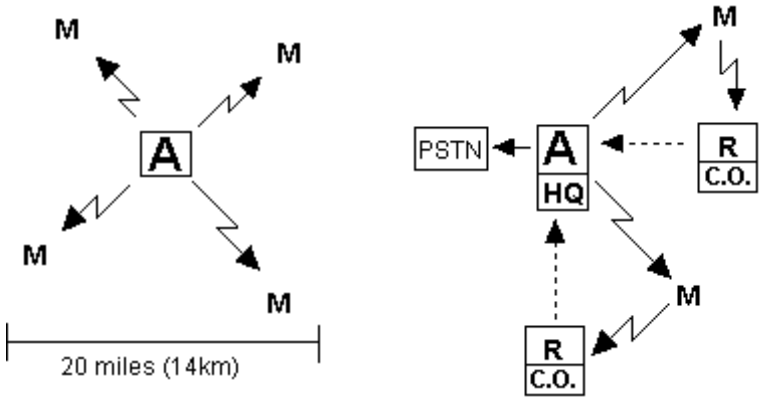
# In the beginning …

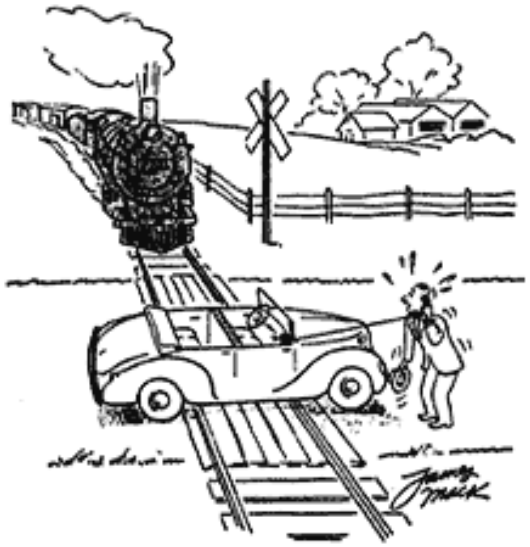
- 1946
  - First interconnection of mobile users to public switched telephone network (PSTN)
  - Operator assisted with 250 maximum users
- Mobile ≠ Portable!
  - First mobile phone weighed 40 Kg!
  - Very bulky and expensive



# Mobile Telephone System (MTS)

- 1946
  - 3 channels for all the users in the metropolitan area
    - Later more licenses were added bringing the total to 32 channels across 3 bands
- October 2, 1946
  - Motorola communications equipment carried the first calls on Illinois Bell Telephone Company's new car radiotelephone service in Chicago
  - Few radio frequencies available → service quickly reached capacity



*"Hello, Mr. Bunting, I've changed my mind– I'll take that accident policy!"* April, 1948

# Who needs one anyway?

- The FCC commissioner Robert E. Lee
  - "mobile phones are a status symbol"
  - "Every family might someday believe that its car had to have one!"
  - "frivolous use of spectrum"
  - "It's not going to be something you and I put in the car to call home and say we're on the way home for dinner!"





# From global to cellular

- 1947
  - Donald H. Ring outlined the idea in a Bell labs memo
  - Split an area into cells with their own low power towers
  - Each cell would use its own frequency

- An idea before its time
  - Existing technology could not handle the "extreme" processing needs!
  - Handoff for thousands of users
  - Rapid switching infeasible – maintain call while changing frequency





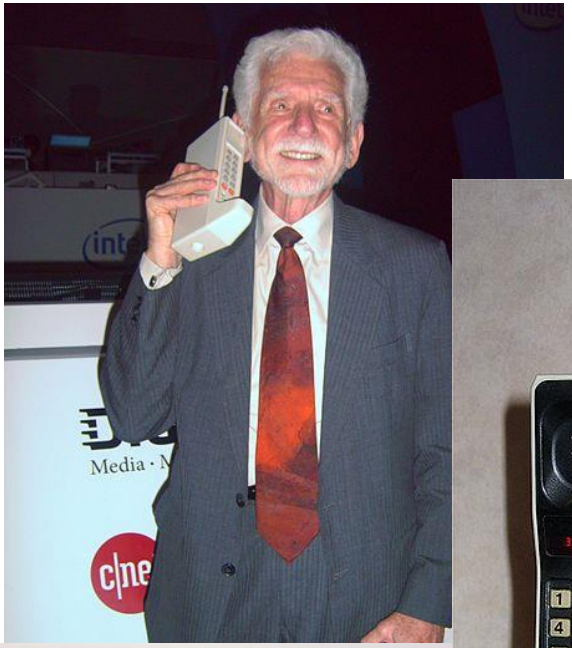
# Almost there …

- 1947
  - William Shockley, John Bardeen, and Walter Brattain invented the transistor

- But true mobile coverage was still out of reach
  - A mobile phone needs to send a signal – not just receive and amplify
  - The energy required for a mobile phone transmission still too high for the high power/high tower approach – could only be done with a car battery

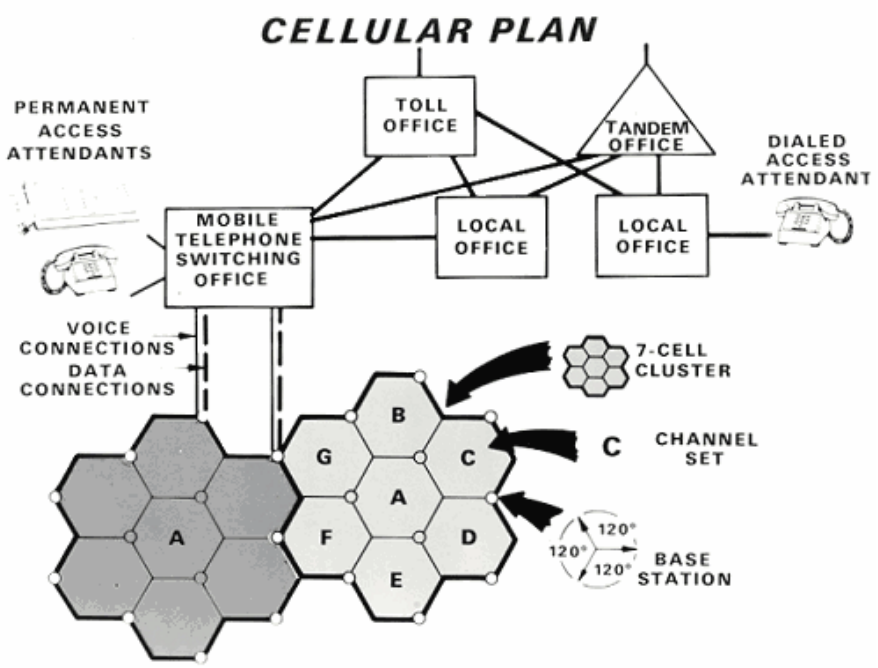
# The first cell phone!

- Prototype
  - Dr. Martin Cooper of Motorola made the first publicized handheld mobile phone call on April 4, 1973
- Production
  - 10 years (1973-1983) and $100 million to develop!
- DynaTAC8000X
  - 2 pounds
  - 30 mins of talk time
  - 8 hours of standby
  - LED display for dialing or recall 30 phone numbers
  - $3,995!



# Analog Cellular: 1G

- 1978
  - AMPS – Advanced/Analog Mobile Phone System
  - First complete cellular system (not handheld) deployed in the suburbs of Chicago
  - 10 1-mile radius cells
  - 135 custom-designed car phones
- Limitations
  - Unencrypted
  - Vulnerable to eavesdropping
  - Susceptible to "cloning"
  - Frequency-division multiple access (FDMA) required significant amounts of wireless spectrum




Used for On*Star until ~2010!

# Digital Cellular: 2G

- 1991
  - First GSM network in Finland
  - Digital, circuit-switched network optimized for full duplex voice telephony
  - Expanded to include data communications
    - Circuit-switched transport
    - Packet data transport via GPRS (General Packet Radio Services) and EDGE (Enhanced Data rates for GSM Evolution or EGPRS).





# Mobile Broadband and Beyond: 3G & 4G

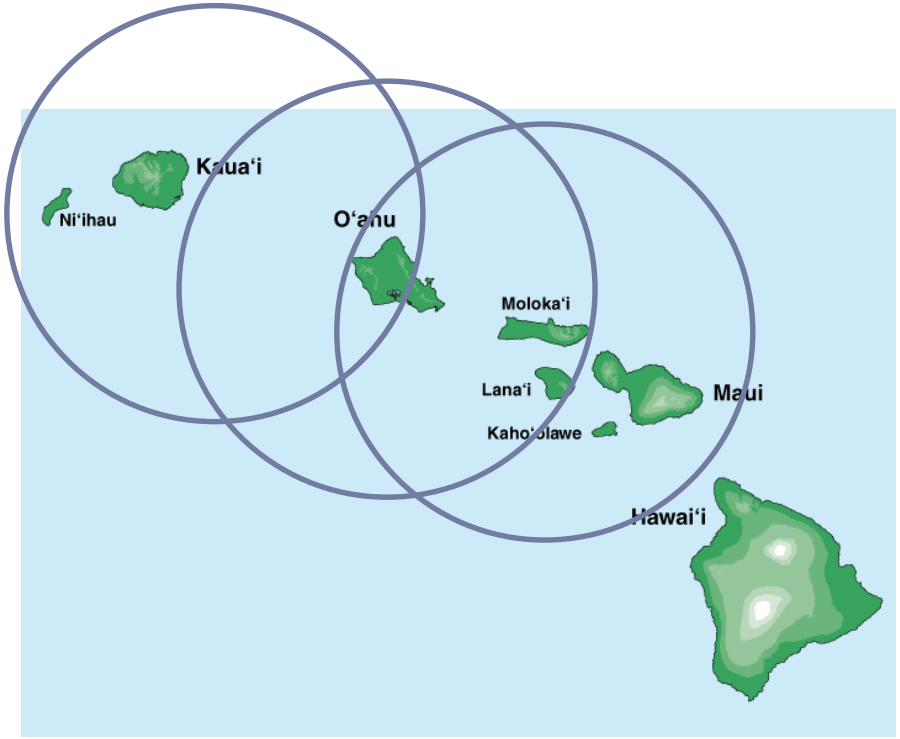
- 3G
  - Minimum service: 200 Kbps
  - 2001
    - First commercial WCDMA network in Japan
  - 2002
    - First commercial CDMA2000 1xEV-DO network in South Korea
  - Improvements
    - streaming media (radio and television)
  - End of 2007
    - 295 million subscribers on 3G networks worldwide
- 4G
  - Service goal: 100 Mbps
  - 2008
    - Native IP
      - Mobile WiMAX
      - LTE





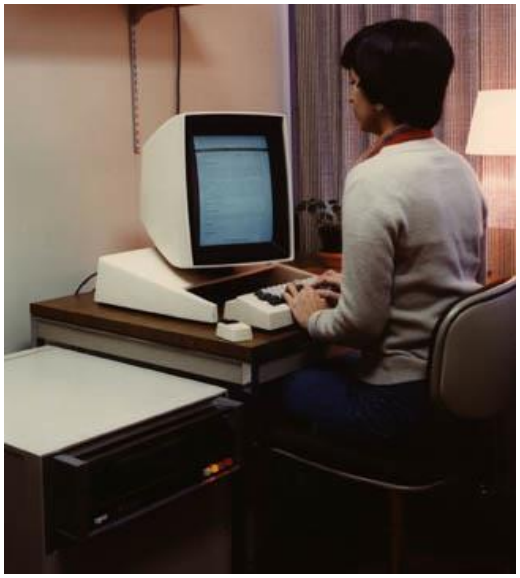
# In the meantime …

- 1971: Aloha Packet Radio Network
  - Norm Abramson left Stanford to surf
  - Set up first data communication system for Hawaiian islands
  - Hub at U. Hawaii, Oahu
  - Two radio channels:
    - Random access: for sites sending data
    - Broadcast for hub rebroadcasting data



# From Aloha comes Ethernet

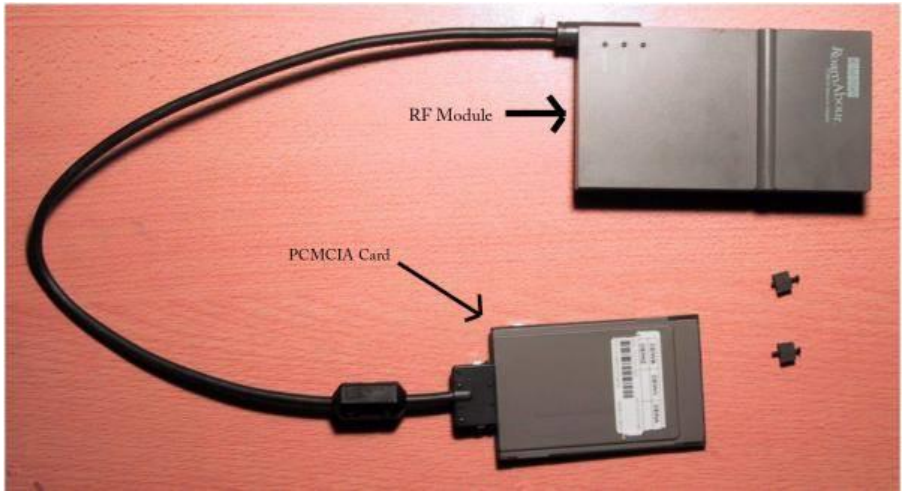
- Ethernet
  - Developed by Xerox PARC, 1974
  - Standardized by Xerox, DEC and Intel in 1978
  - Later, IEEE 802.3 standard
  - Fast Ethernet (100 Mbps) - IEEE 802.3u standard
  - Switched Ethernet now popular
- Numerous standards with increasing bandwidth over the years
  - 10 Mbps – 100 Mbps – 1 Gbps – 10 Gbps



Xerox Alto, first machine networked with Ethernet

# From Ethernet comes Wi-Fi!

- 1986
  - Wireless alternative for Ethernet and Token Ring
- 1995
  - FCC released ISM band for unlicensed use
  - WaveLAN
    - 900 MHz ISM band
    - 1 & 2 Mbps
- 1997
  - IEEE 802.11
    - DSSS
    - 2.4 GHz
    - 1 & 2 Mbps




# The growth of Wi-Fi

- 1999
  - IEEE 802.11a
    - OFDM
    - 5.8 GHz
    - 54MBps
- 2003
  - IEEE 802.11g
    - OFDM
    - 2.4 GHz
    - 54MBps
- 2009
  - IEEE 802.11n
    - MIMO
    - 2.4 GHz and 5 GHz
    - 54 Mbps to 600 Mbps


- And more to come
  - IEEE 802.11 ac, ag …

# Integrated Wi-Fi

- Antennas placed on the frame of the screen
- Mini-PCI format allows for full integration
- Latest radio technology may feature up to 3 antennas or more!

# And even more technologies

- Low power wireless
  - Bluetooth
  - ZigBee
  - UWB
- No power wireless
  - RFID
- What's next?


# Wireless communication is a tool

- How do we use it?
- Emergency broadcast systems
  - Restricted communication
- Device to infrastructure
  - Internet access, phone calls
- Device to device
  - Sensor networks, vehicular networks, mobile social networks



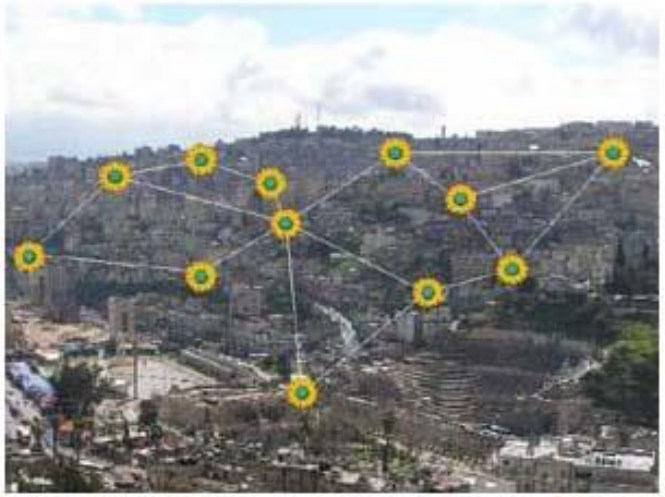
# Apps, apps and more apps

- SMS
  - The first killer app
- Ring tones
- Games
- Social networking
- Replacement for landlines


- Data communication now dominant
  - Always-on connectivity…
  - … while on the move

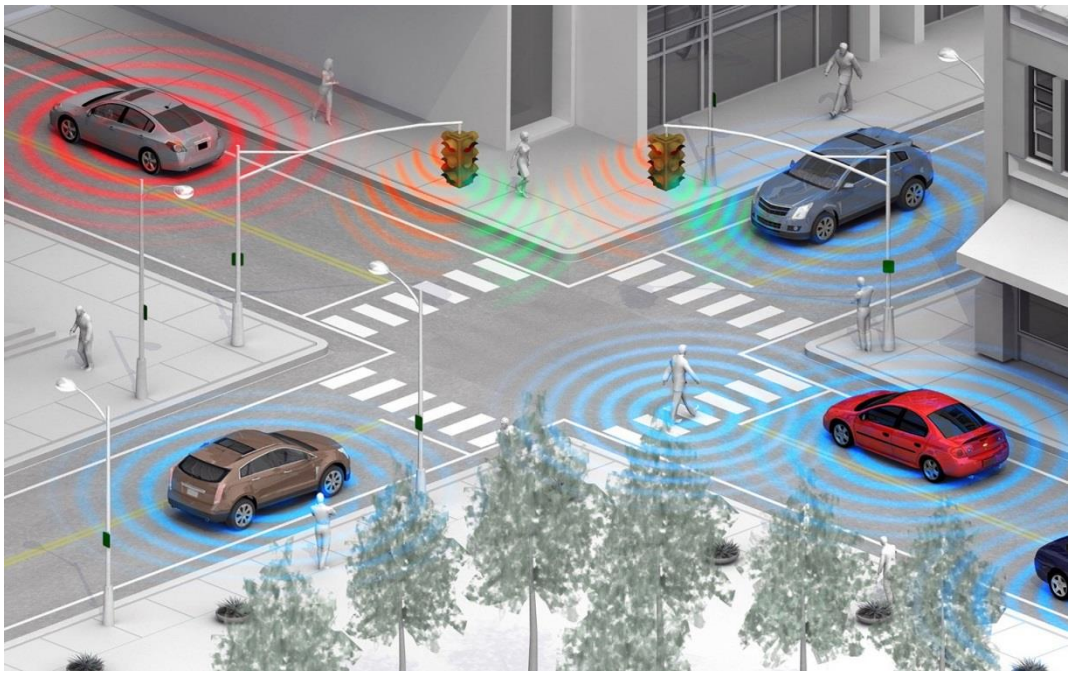
# Large scale Wi-Fi access

- Wi-Fi in developing regions

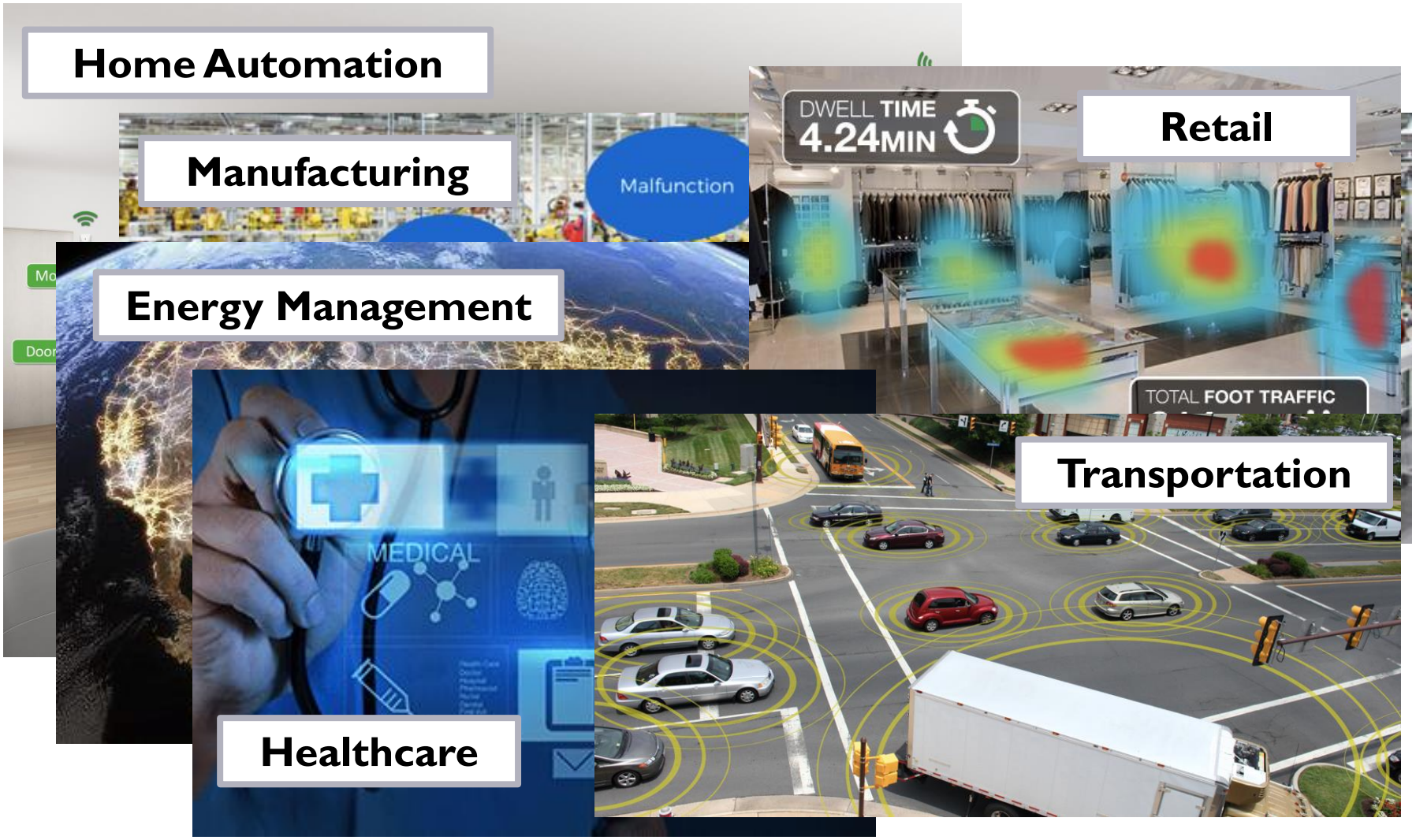


# Vehicle-to-Vehicle Communication

- Sensing
- Safety
- Enhanced coverage



# Internet of Things

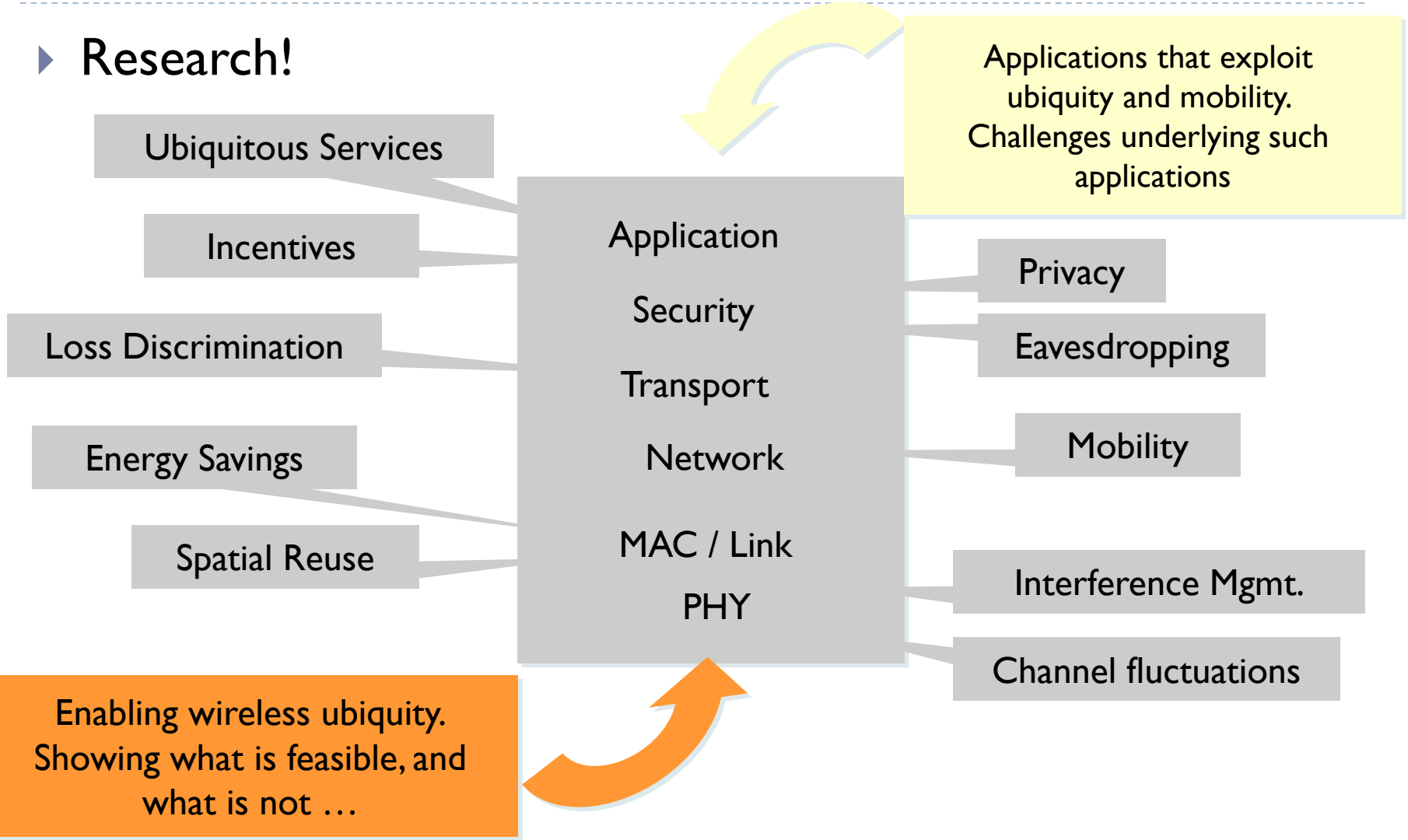


# Even more …

- 60 GHz for in-home entertainment
- Software defined radios
- Ultra Wideband (UWB)
- LoRa

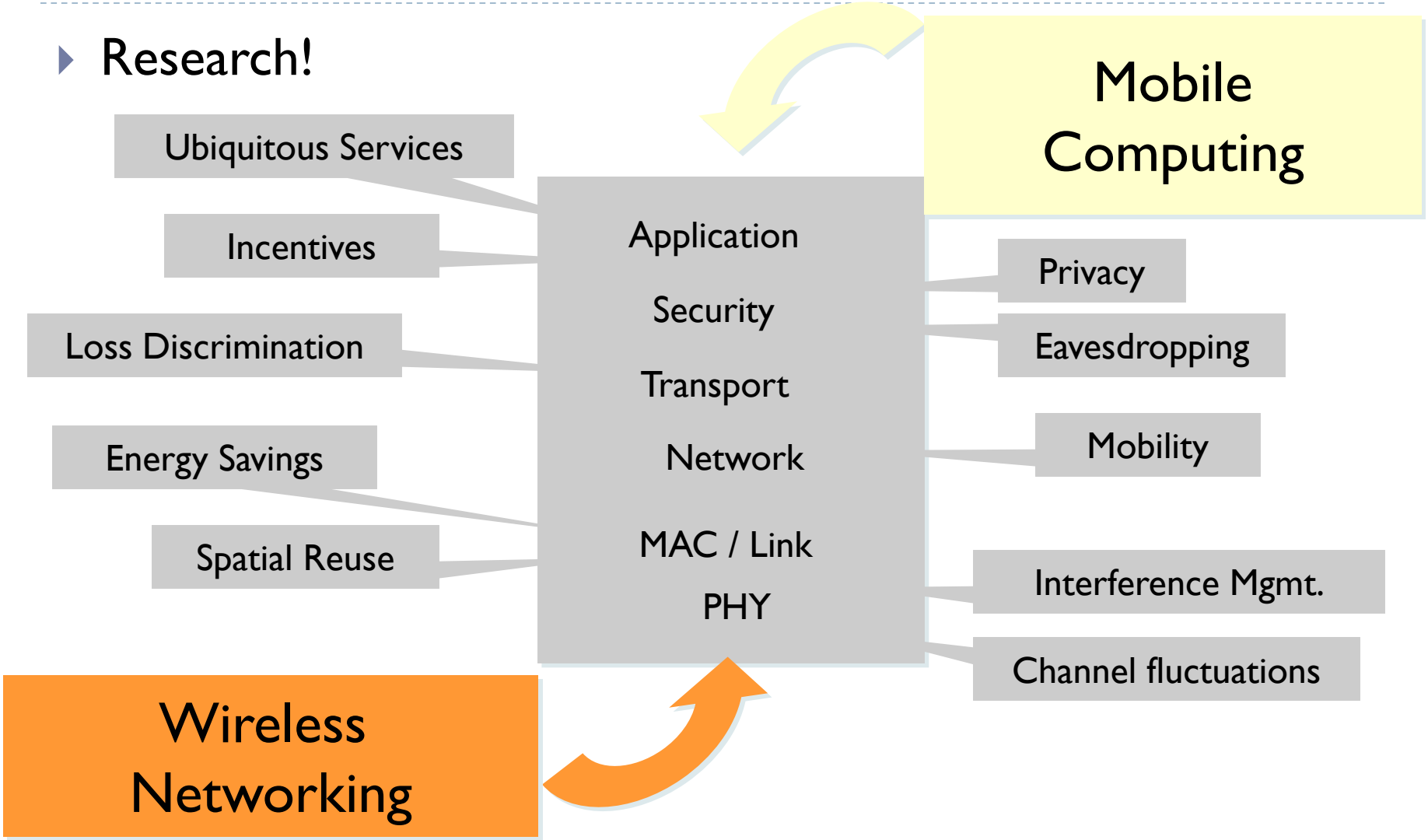
# How do we make this all happen

- Research!



# How do we make this all happen

- Research!



# At the End of this Course …

- You should understand
  - Physical layer (radios, rate, antennas, channels)
  - MAC protocols (who gets the chance to talk)
  - Cross-Layer protocols (interference cancellation, OFDM …)
  - Routing (path selection algorithms and issues)
  - Reliability (wireless congestion control, rate control)

  - Applications (social networks, personal networks, P2P networks)
  - Sensing Systems
    - Localization (extracting the location of a device)
    - Mobility (how it helps and disrupts communication)
    - Interfaces (phones are more than communication devices)
    - Privacy (how to protect a user from being tracked)

  - Energy-awareness (how it percolates various network functions)
  - Capacity (what is feasible, what are performance bounds)