CS/ECE 439: Wireless Networking

Fall 2023

GRAINGER ENGINEERING

COMPUTER SCIENCE

Welcome!

- Introduction
  - Who I am: Robin Kravets
  - Where I live: Department of Computer Science
  - What I have taught : 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 341 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 15%
  - You only get out of this class what you put into it!
  - Based on class attendance and participation in discussions
- Class HW (2) 5%
- Presentation of advanced topic 20%
  - In class presentation (20-30 min)
  - Summary of presentation topic
  - Attendance and participation required for group presentations
- Project: team-based, hands-on 45%
  - In-depth study and implementation of a particular problem
- Project Presentation 10%
- Project Evaluations 5%
  - Evaluation of another team's class project

Advanced topics

- For each topic
  - Introduce advanced topics
  - Current technology and research in wireless networking
- Topic Teams = Project Teams
  - Small (1-2 person) teams – Due Sep 9
  - 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)

Class Presentation

- When would this help me?
  - You are working for a company that is exploring a new wireless technology or market
  - You could be asked to prepare a 30 minute presentation to introduce to area
  - You are writing your first paper on a research project you just finished
  - You need to write a short related work section that includes a survey of existing work in the areas relevant to your research

Class Project

- Considerations
  - Concrete outcomes
  - Learn something
- You should have the necessary background to complete the project
  - Do not attempt a project at the physical layer if your only background in this area is just the few lectures in this course.
  - Do not attempt a project that involves kernel or driver hacking if you have limited programming experience.
- The project needs to be feasible
  - Must be reasonable given the time available
  - Access to the necessary infrastructure
- Build a team with diverse skills to cover theoretical and practical topics

Projects

- In-depth study of a particular use of wireless networks
  - 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 22
  - Project Proposal – Team members (1-2), topic, references
- October 13
  - Extended Project Proposal – Progress so far (~5 pages)
- November 10
  - Status Report – Initial demos and results
- Dec 10
  - 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 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.

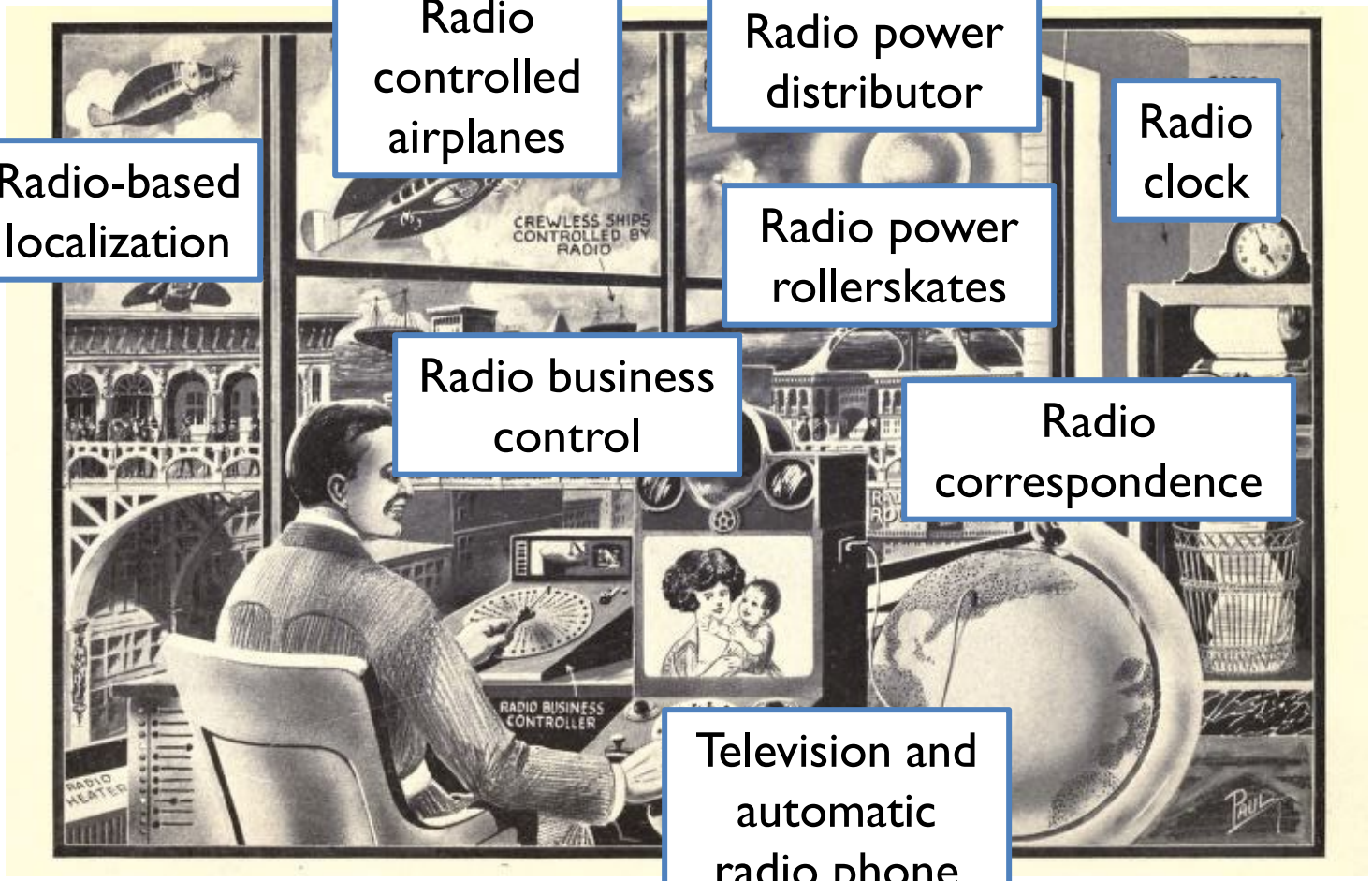
Course Material

- 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

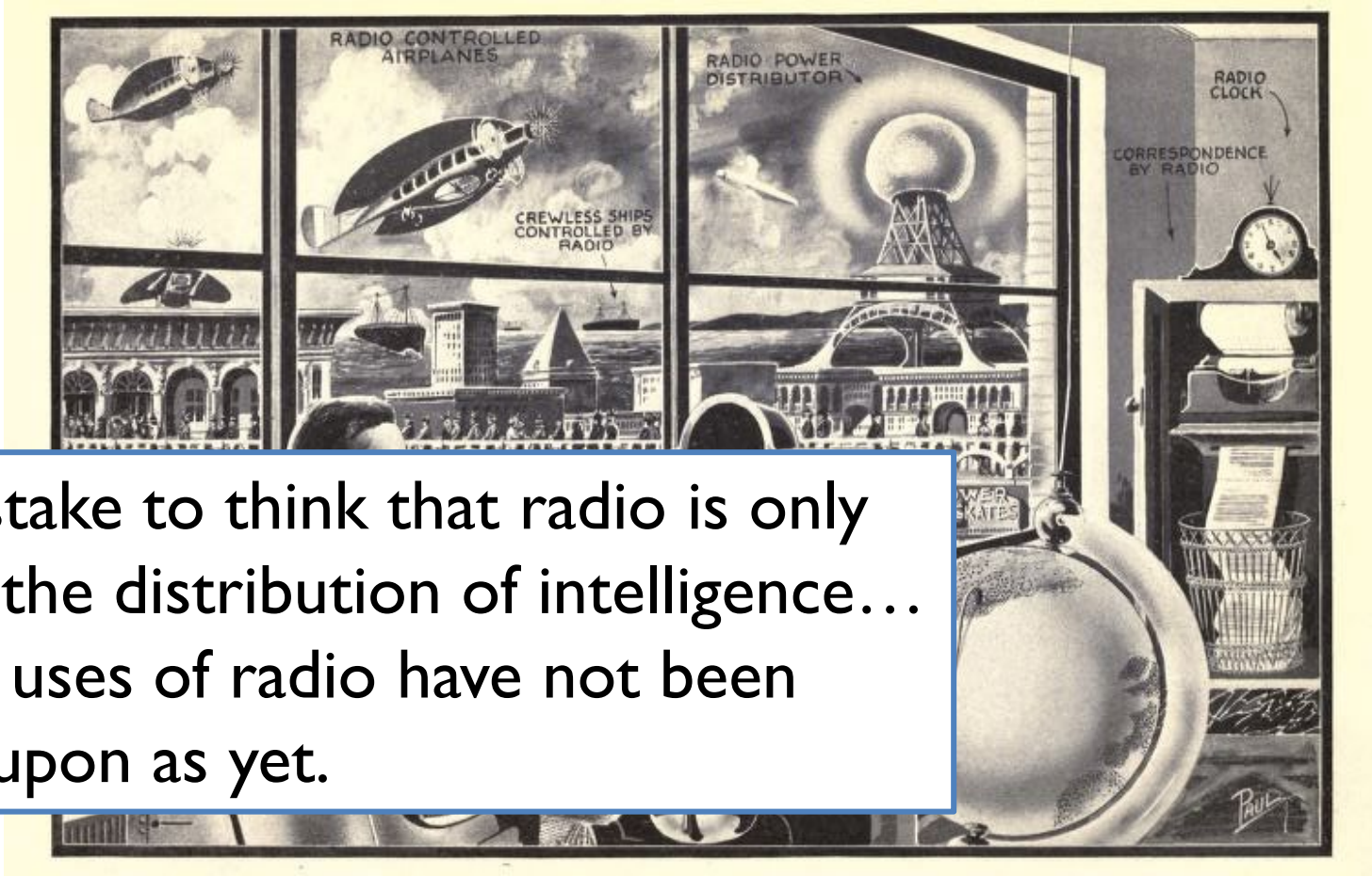
A glimpse of the future

- 1922: "Radio for All", Hugo Gernsback



A glimpse of the future

- 1922: "Radio for All", Hugo Gernsback



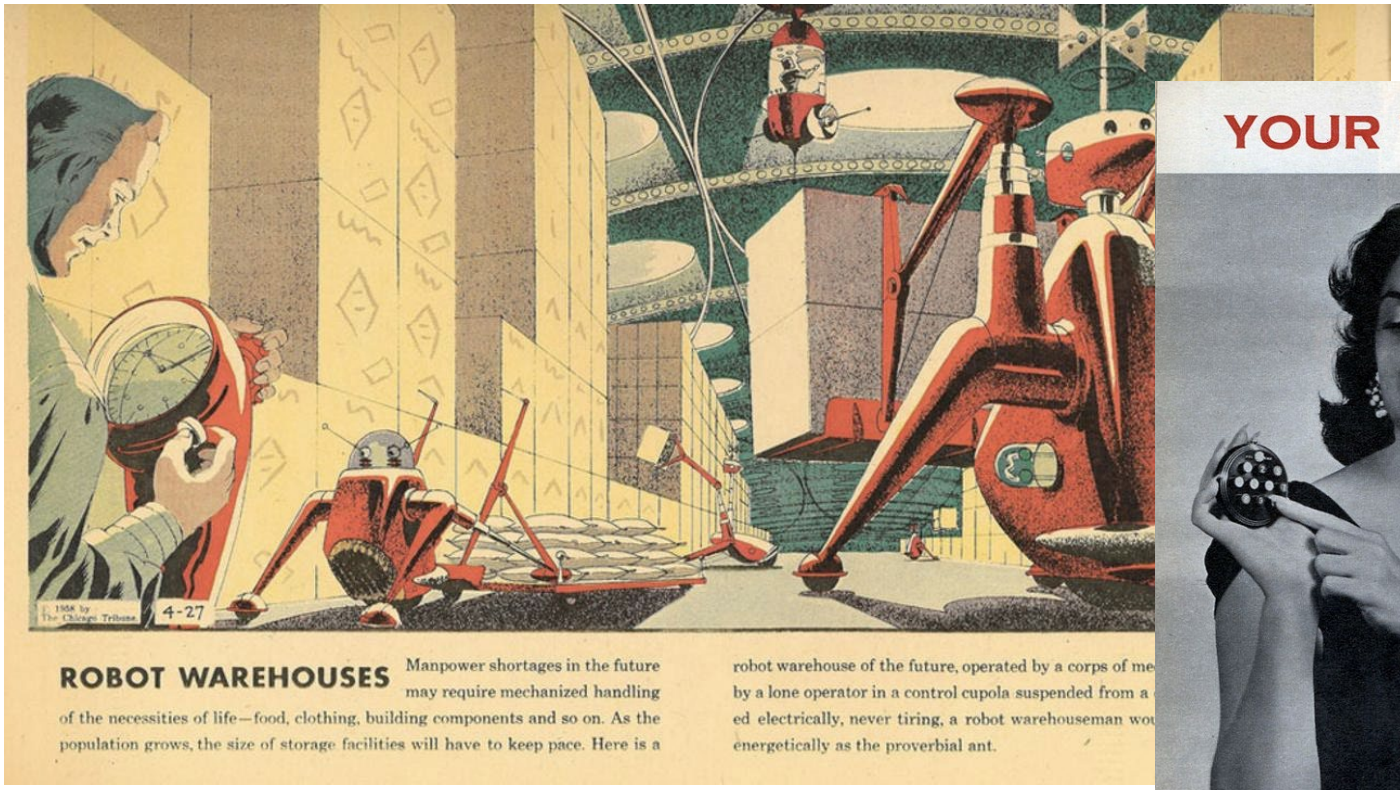
It is a mistake to think that radio is only good for the distribution of intelligence… the great uses of radio have not been touched upon as yet.

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

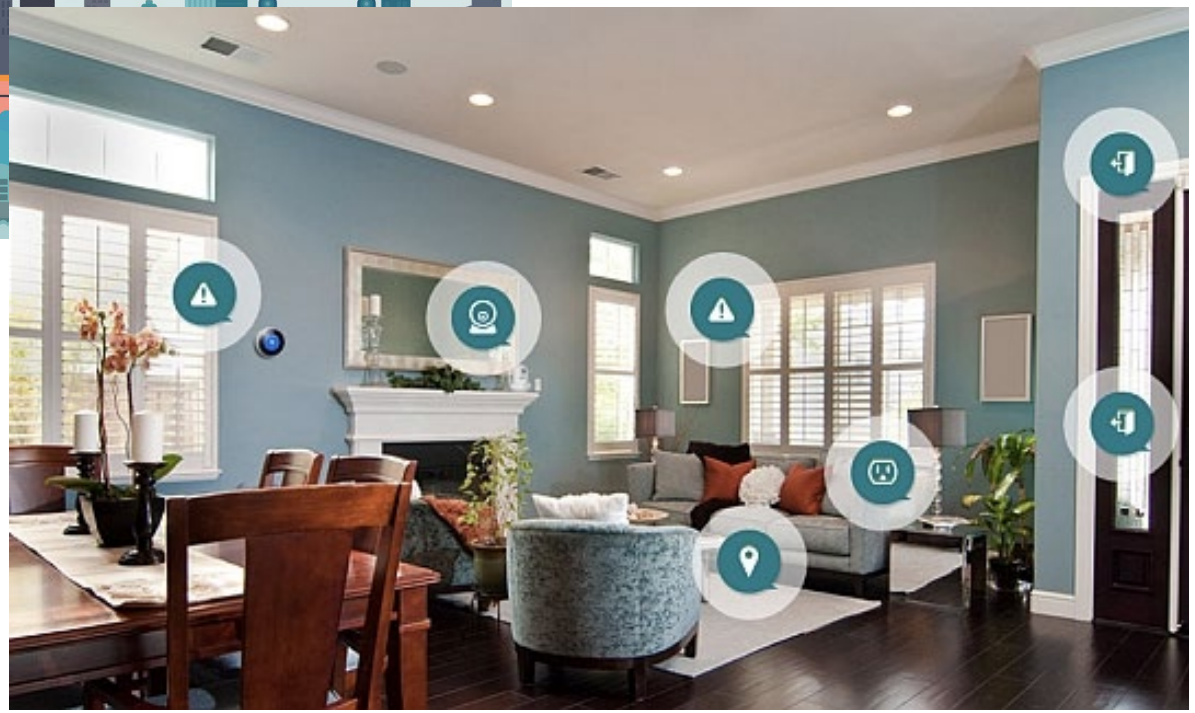
A glimpse of the future

Smart Cities

Smart Homes

The Dream

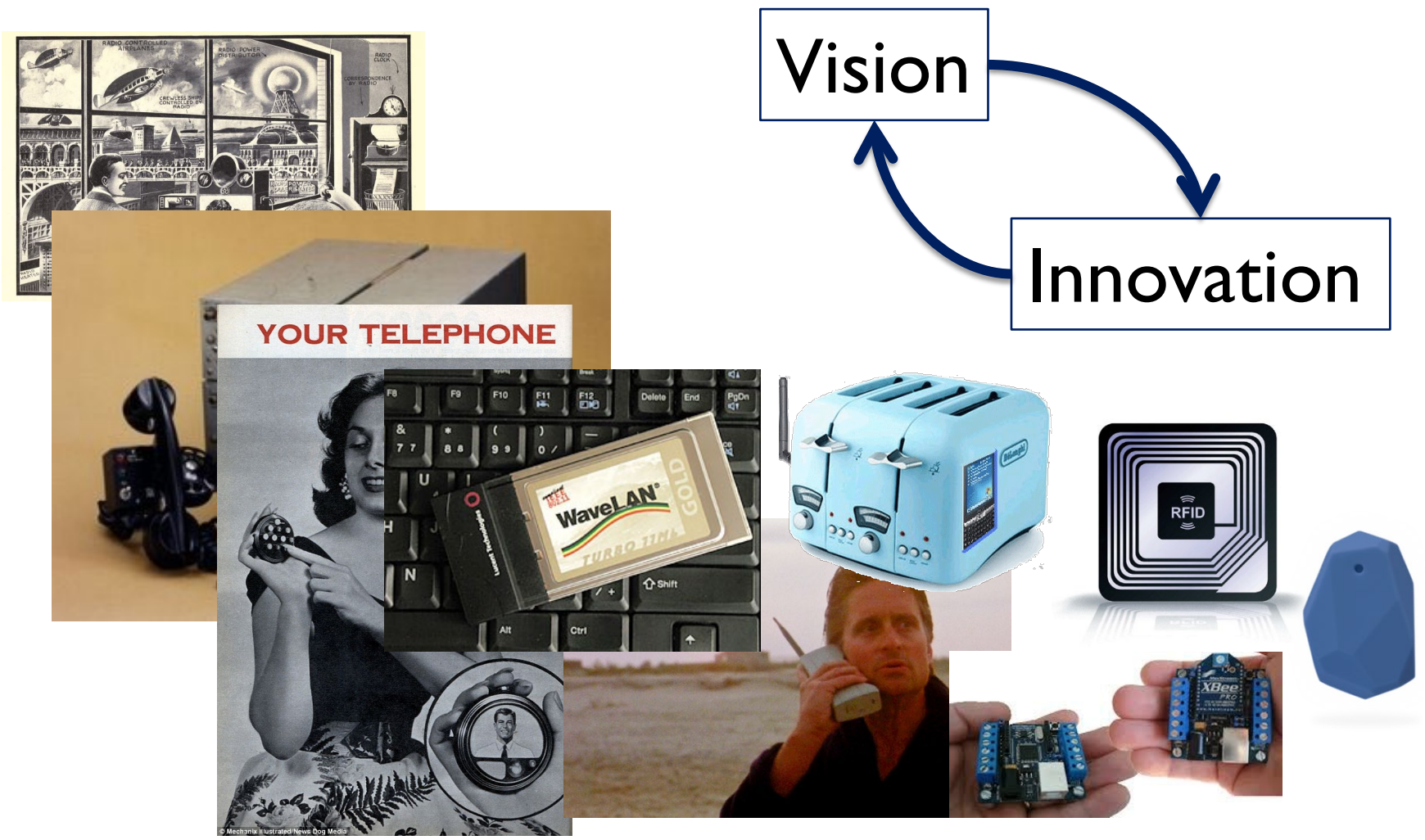
Smart Cities



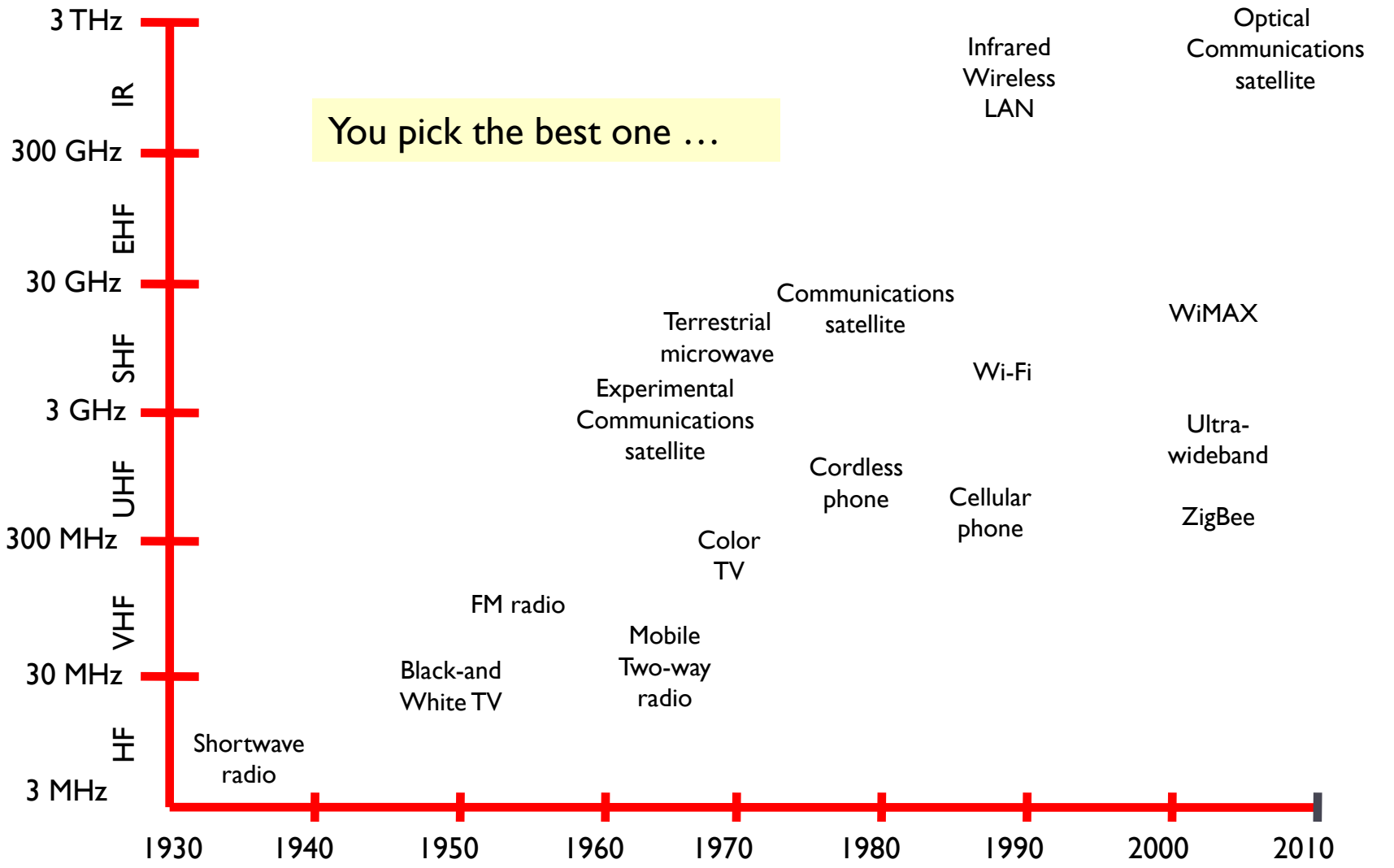
Smart Homes

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

The Road to Ubiquitous Wireless Access

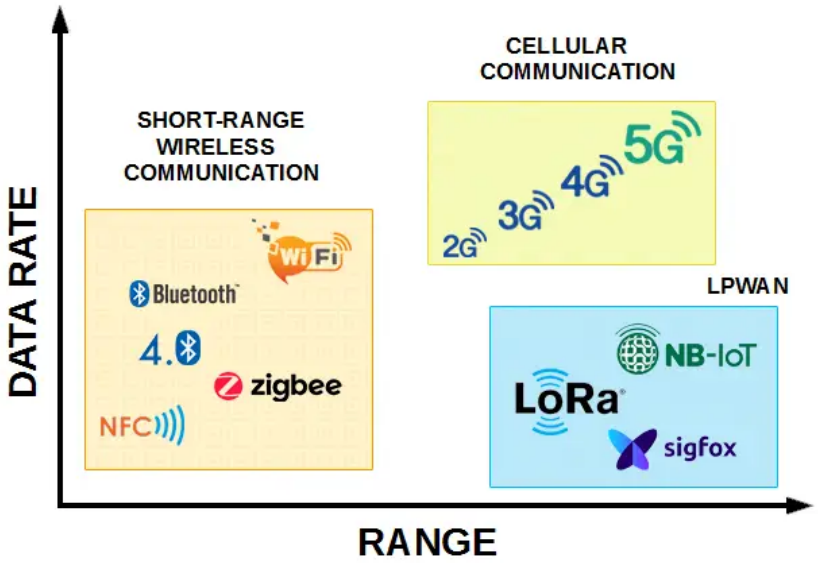


A broad spectrum of Wireless Technologies



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

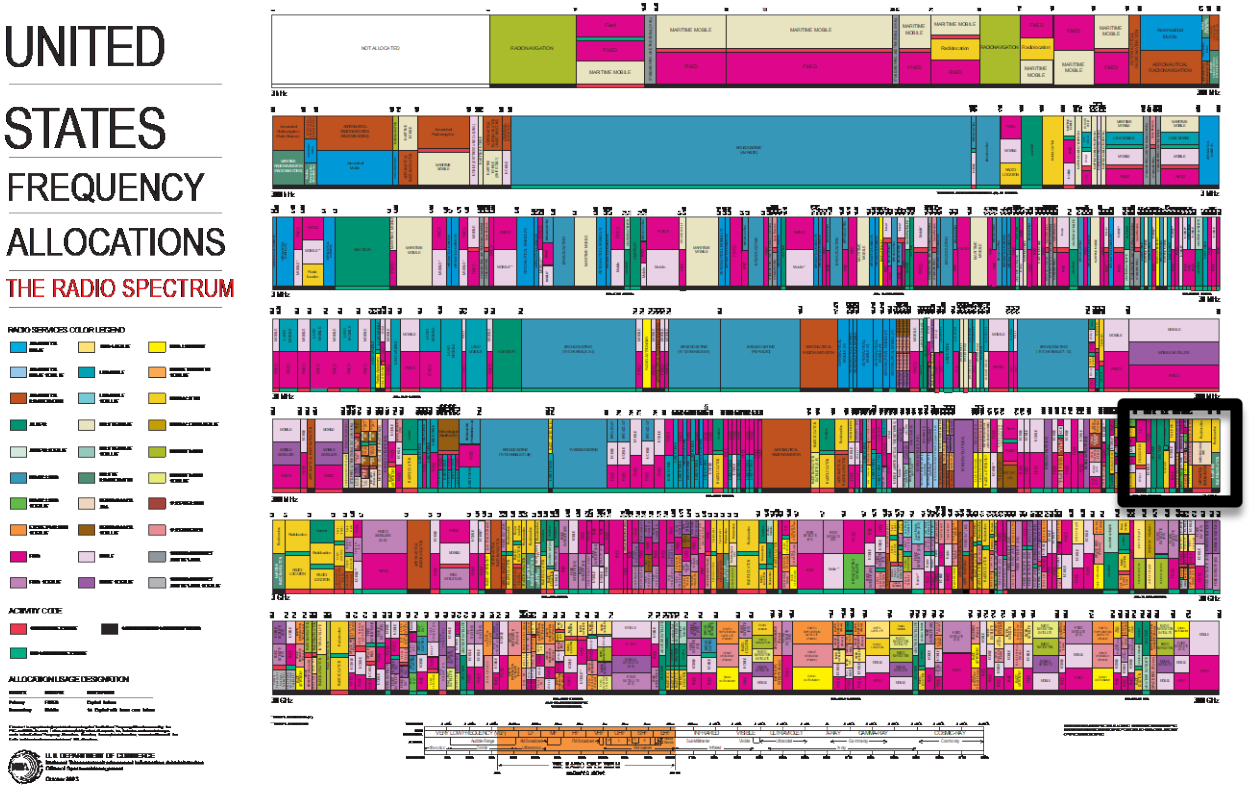


Range

Radio communication

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

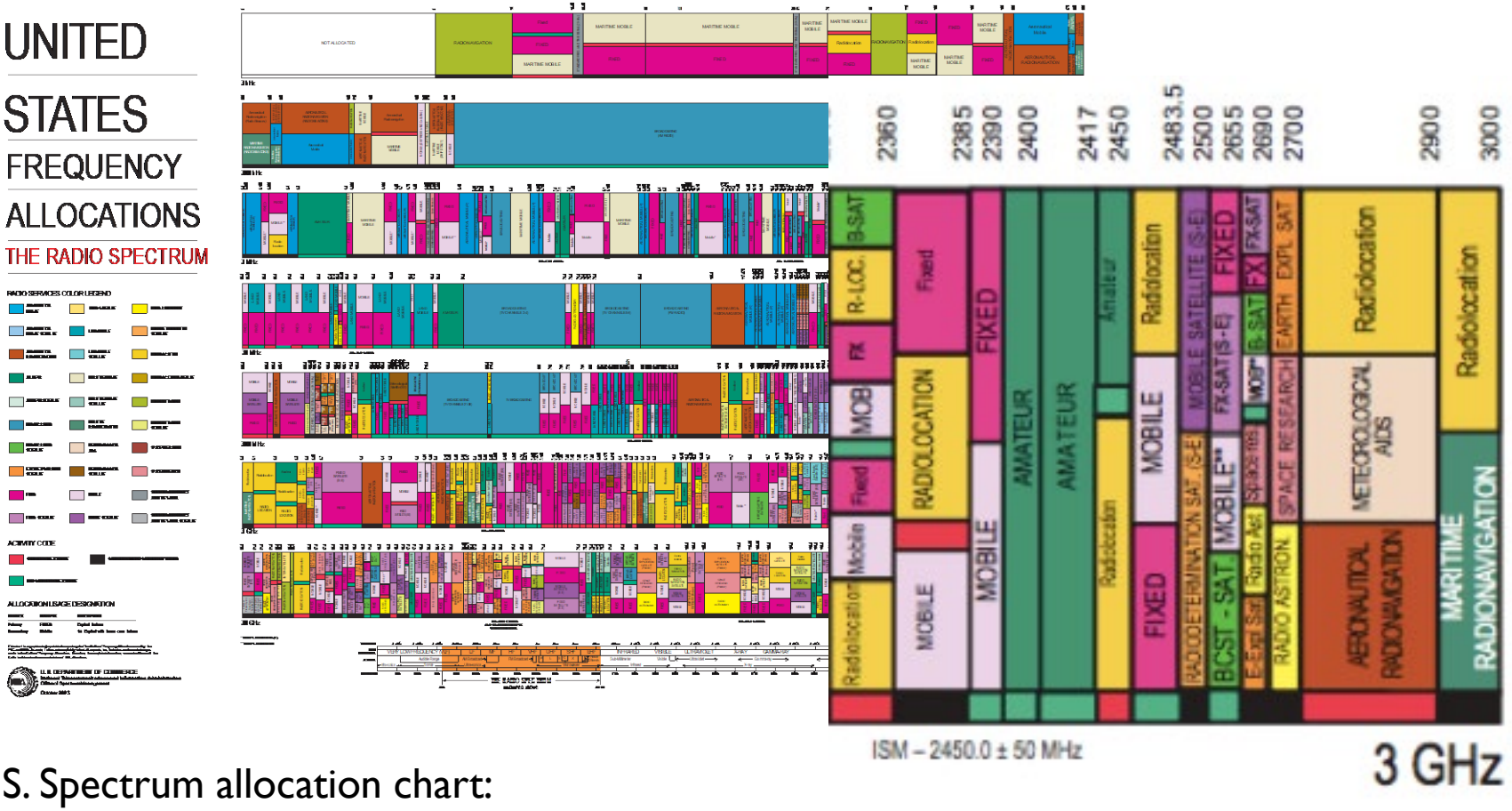
Radio communication



U.S. Spectrum allocation chart:

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

Radio communication



U.S. Spectrum allocation chart:

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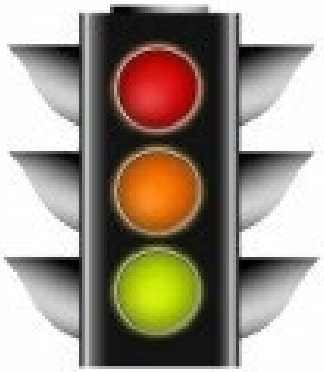
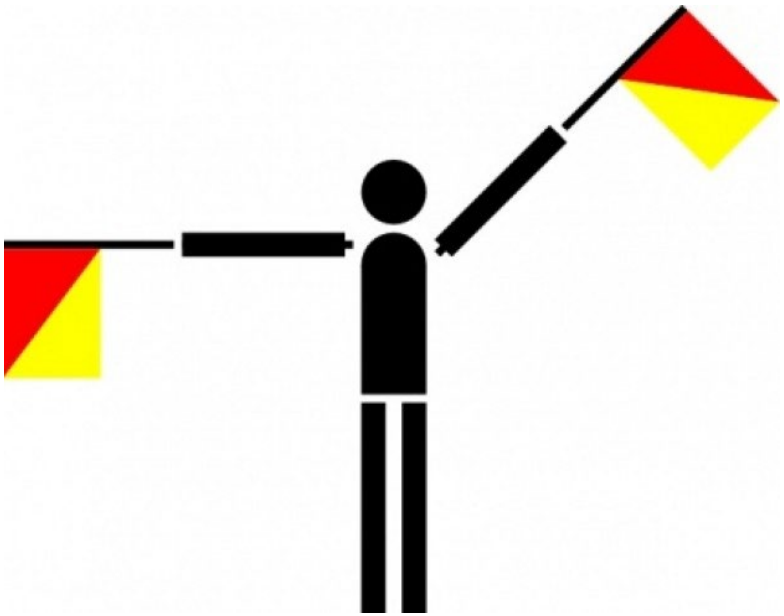
What Makes Wireless Different?

- 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

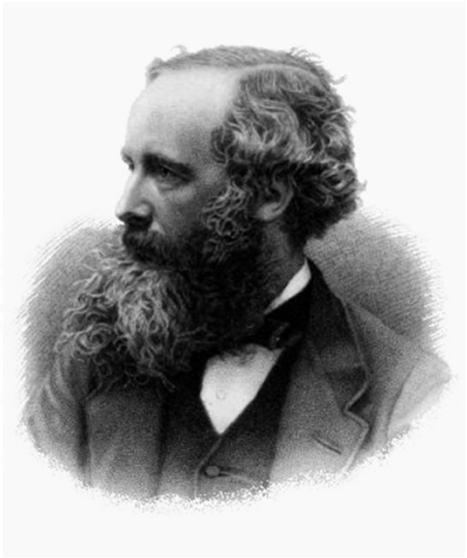
Wireless through the ages …



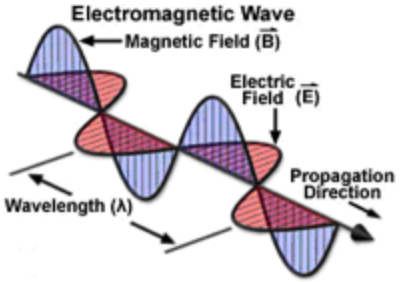


Birth of modern-day wireless communication

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

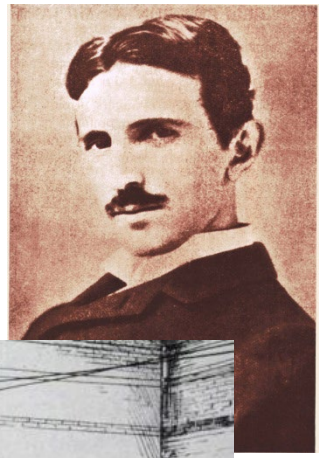


- 1887
  - Hertz proves existence of EM waves

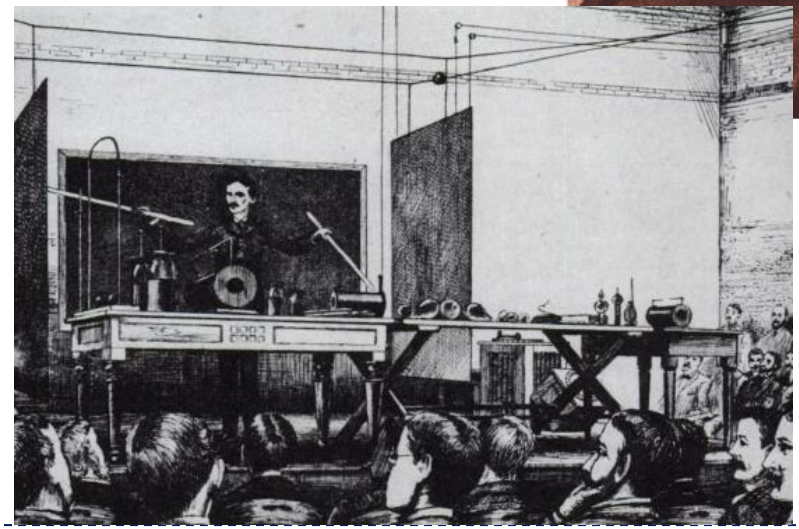


Birth of modern-day wireless communication

- 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

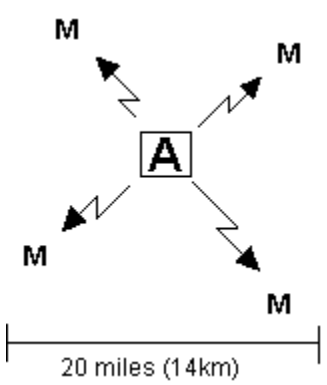
- 1901
  - Marconi: First telegraphic signal traveled across the Atlantic ocean (3,500km/2,200mi).
  - Took another year for it to be bi-directional
  - Used analog signals to transmit alphanumeric characters
- 1914
  - First voice over radio transmission
- 1935
  - Frequency modulation (FM) demonstrated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

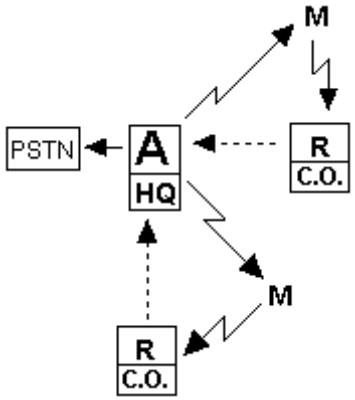
In the beginning …

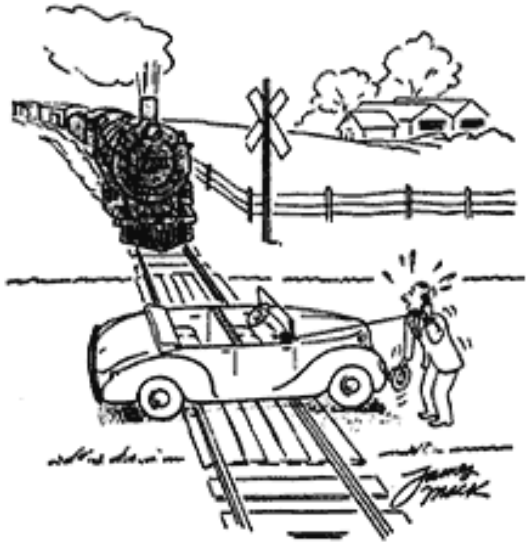
- 1946
  - First interconnection of mobile users to public switched telephone network (PSTN)
  - Operator assisted with 250 maximum users
- Mobile ≠ Portable!
  - First mobile phone weighed 40 Kg!
  - Very bulky and expensive

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

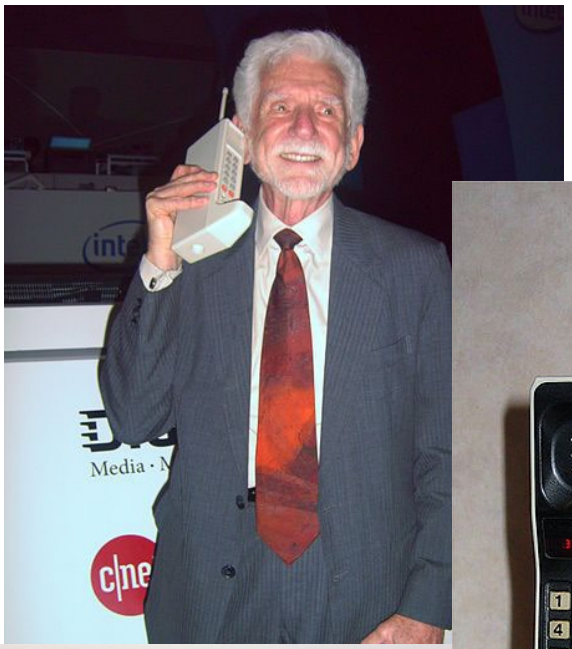
Almost there …

- 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

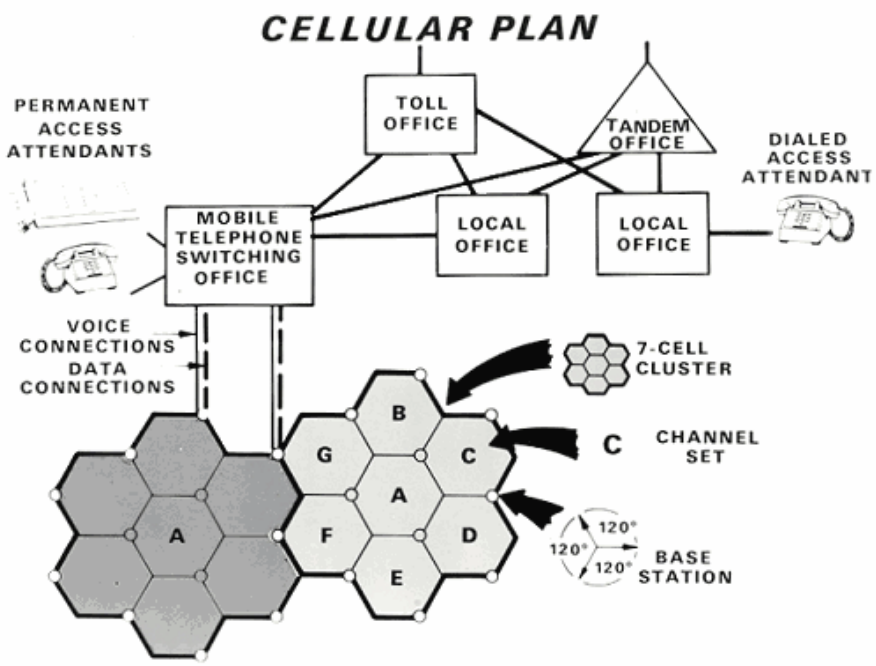
The first cell phone!

- 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: 3G & 4G

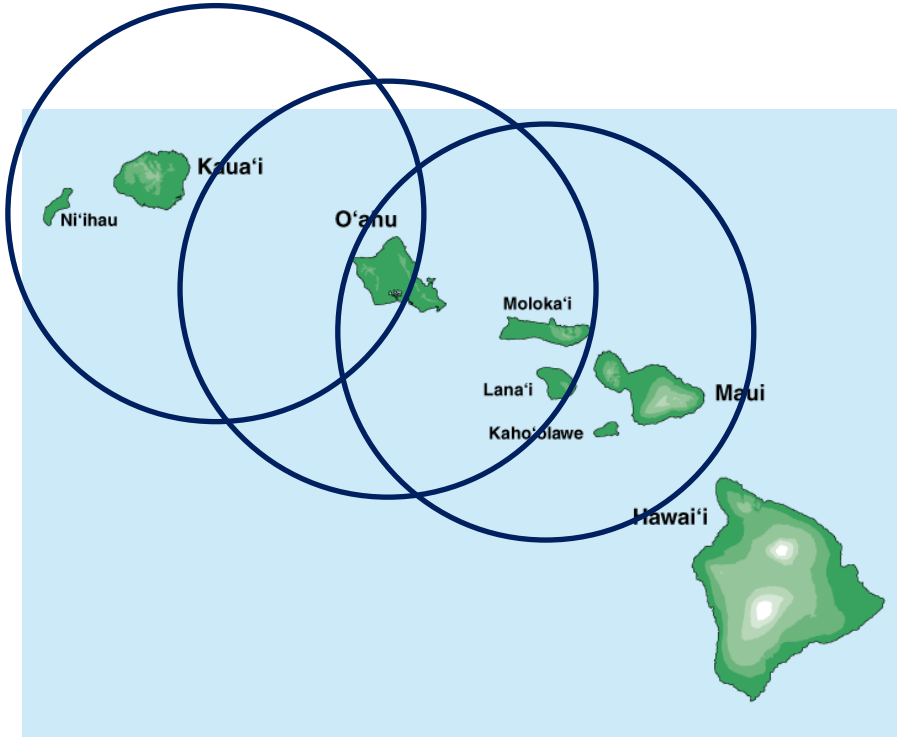
- 3G
  - Service goal: 14 Mbps
  - 2001
    - First commercial WCDMA network in Japan
  - 2002
    - First commercial CDMA2000 1xEV-DO network in South Korea
  - Improvements
    - streaming media (radio and television)
  - End of 2007
    - 295 million subscribers on 3G networks worldwide
- 4G
  - Service goal: 100 Mbps
  - 2008
    - Native IP
      - Mobile WiMAX
      - LTE Advanced
    - OFDMA
    - MIMO
  - End of 2021
    - 5.8 billion 4G subscribers worldwide

Mobile Broadband: 5G & 6G

- 5G
  - Service goal: 10Gbps
  - 2019
    - mmWave: 24 GHz - 54 GHz
    - Massive MIMO
    - Edge computing
    - Beamforming
    - Small cells
  - End of 2021
    - 536 million subscribers on 5G networks worldwide
    - Should reach 1 billion 2 years sooner than 4G!
- 6G
  - Service goals:
    - 1Tbps
    - msec latency
    - Location aware
  - Plans (2030?)
    - Millimeter waves (30 to 300 GHz)
    - Terahertz radiation (300 to 3000 GHz)
    - Small cells
    - Beamforming

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



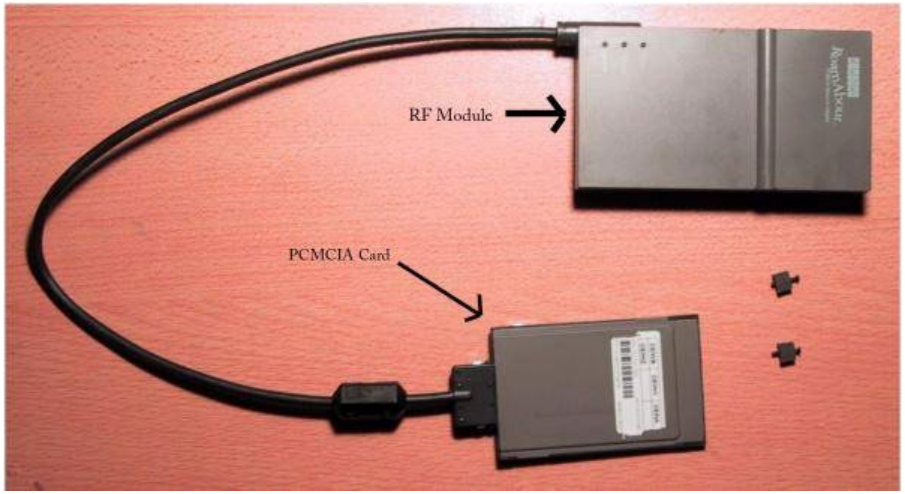
From Aloha comes Ethernet

- 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 …
  - IEEE 802.11 ac, ag …

Integrated Wi-Fi

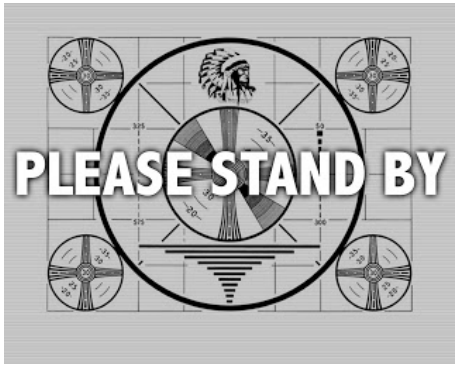
- Antennas placed on the frame of the screen
- Mini-PCI format allows for full integration
- Latest radio technology may feature up to 3 antennas or more!

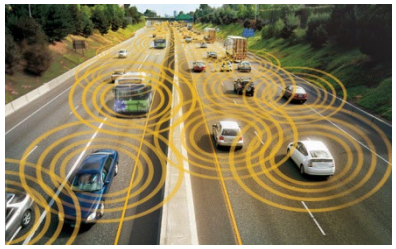
And even more technologies

- Low power wireless
  - Bluetooth
  - ZigBee
  - UWB
  - LoRa
- 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



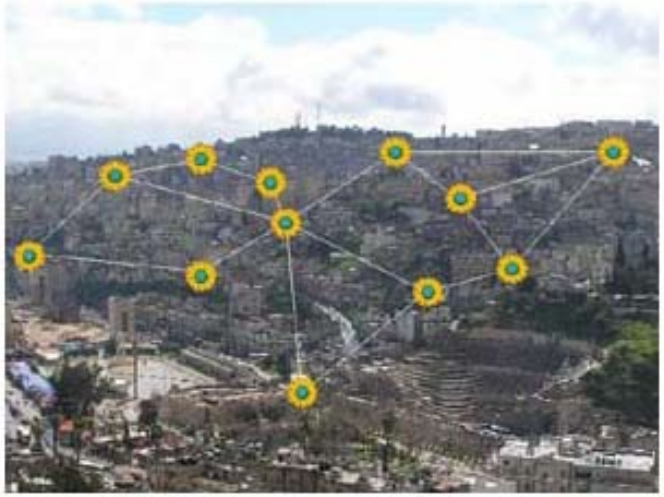


Apps, apps and more apps

- The first killer apps
  - SMS
  - Ring tones
  - Replacement for landlines
- What drives mobile now
  - Videos
  - Gaming
  - Social networking
  - Ecommerce
- Data communication is dominant
  - Always-on connectivity…
  - … while on the move

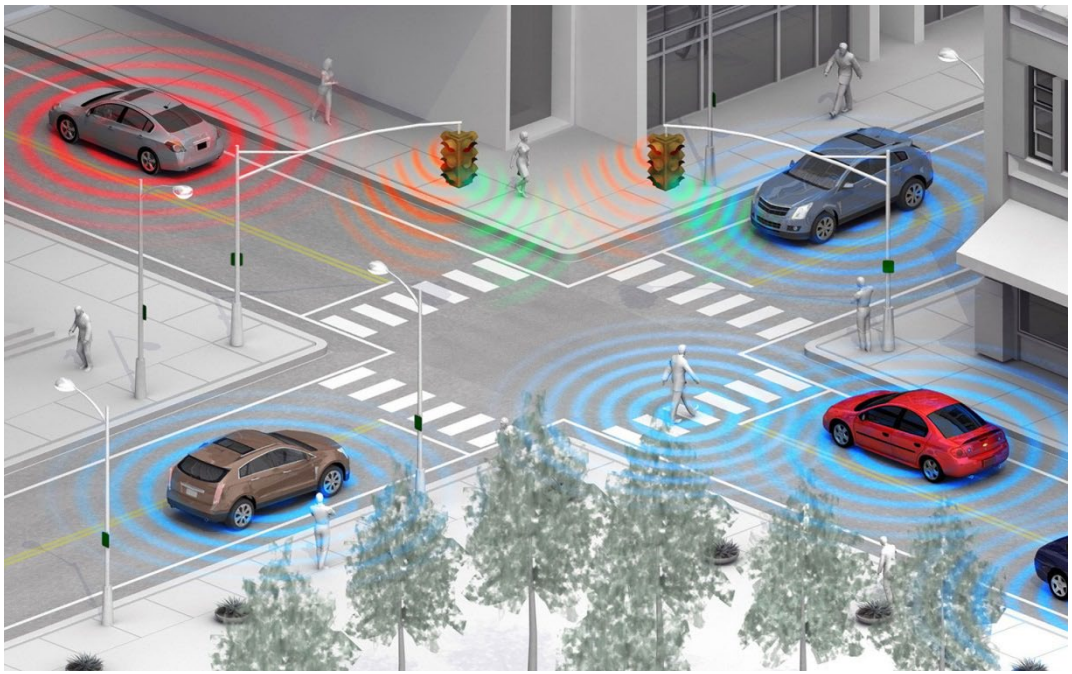
Large scale Wi-Fi access

- Wi-Fi in developing regions

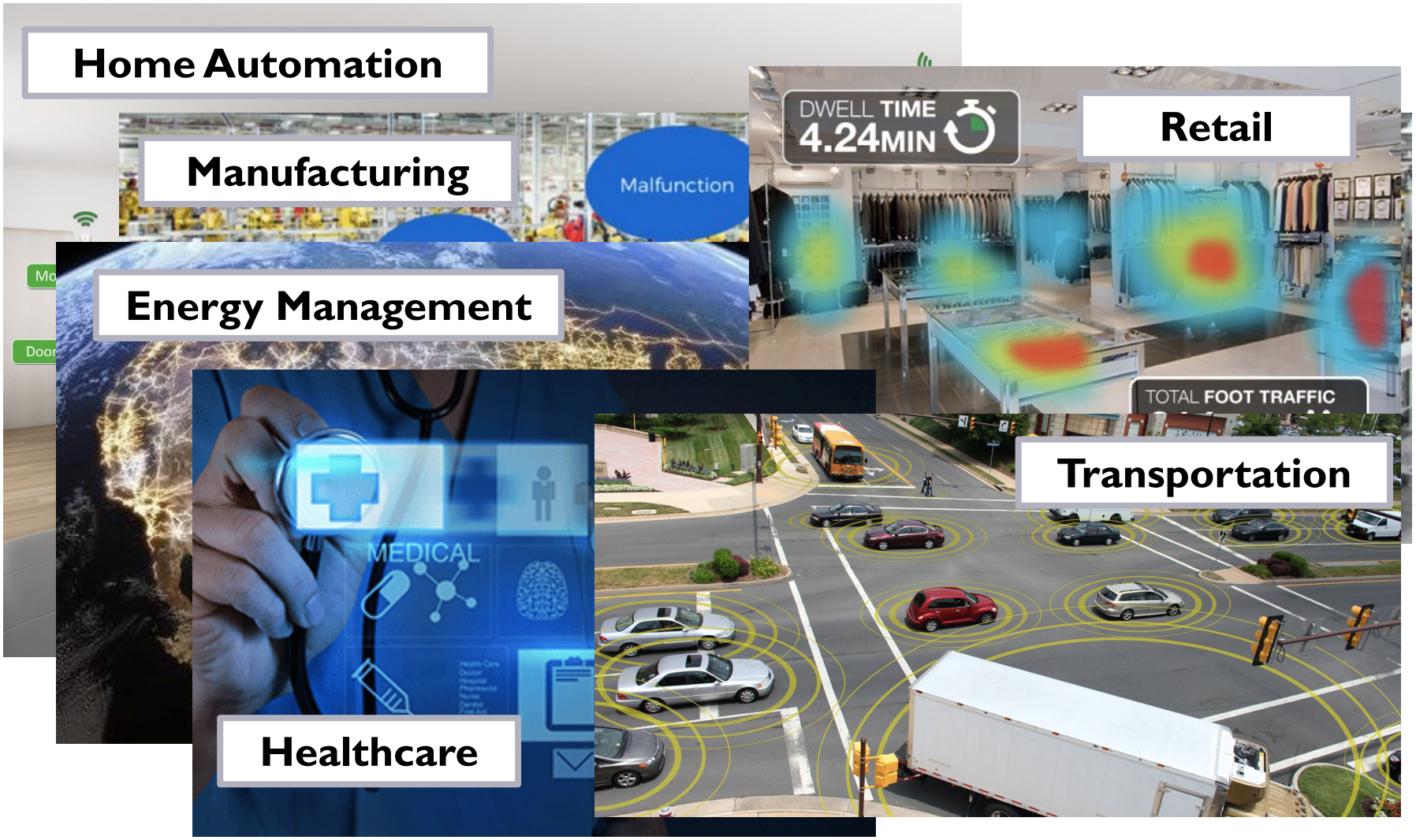


Vehicle-to-Vehicle Communication

- Sensing
- Safety
- Enhanced coverage



Internet of Things

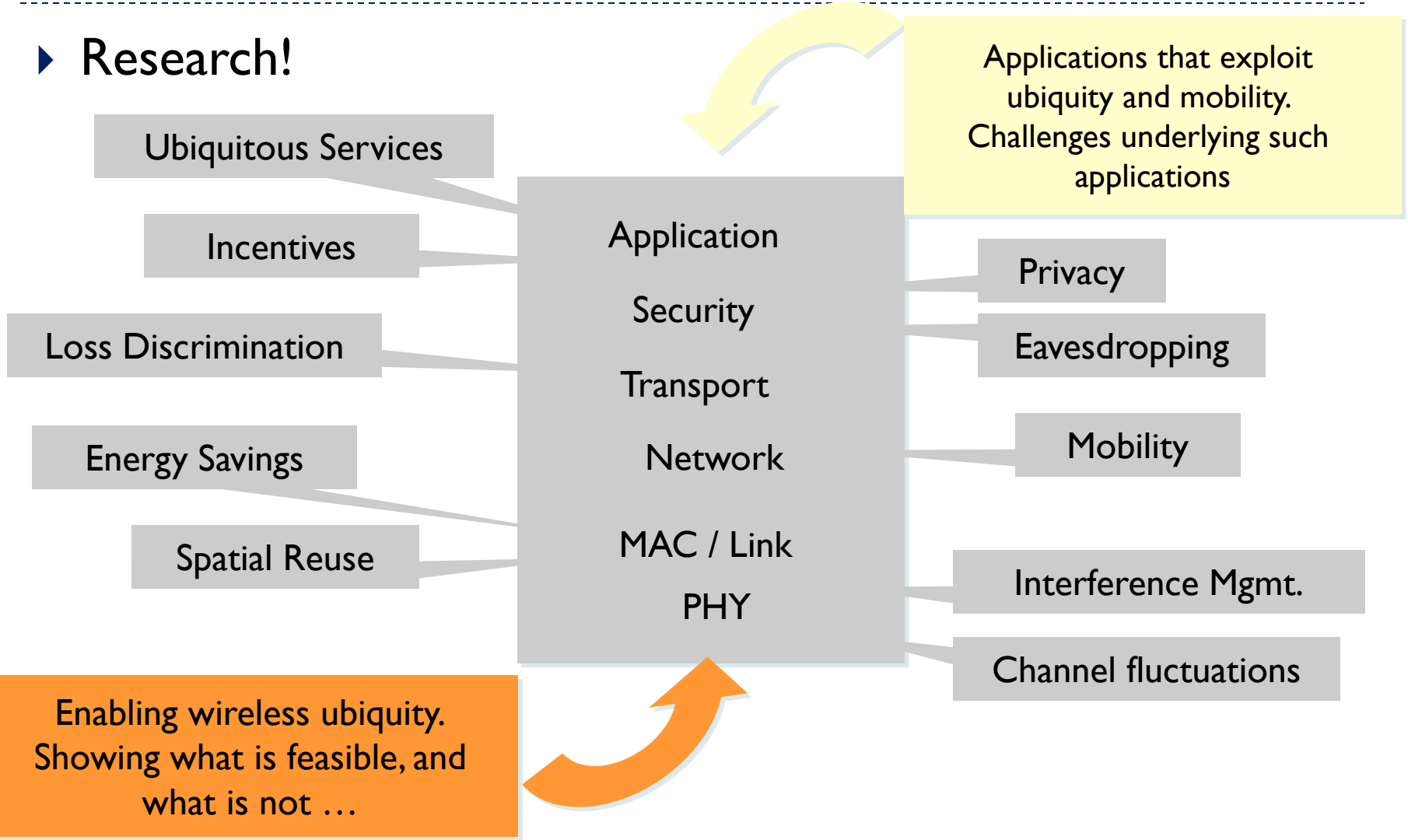


Even more …

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

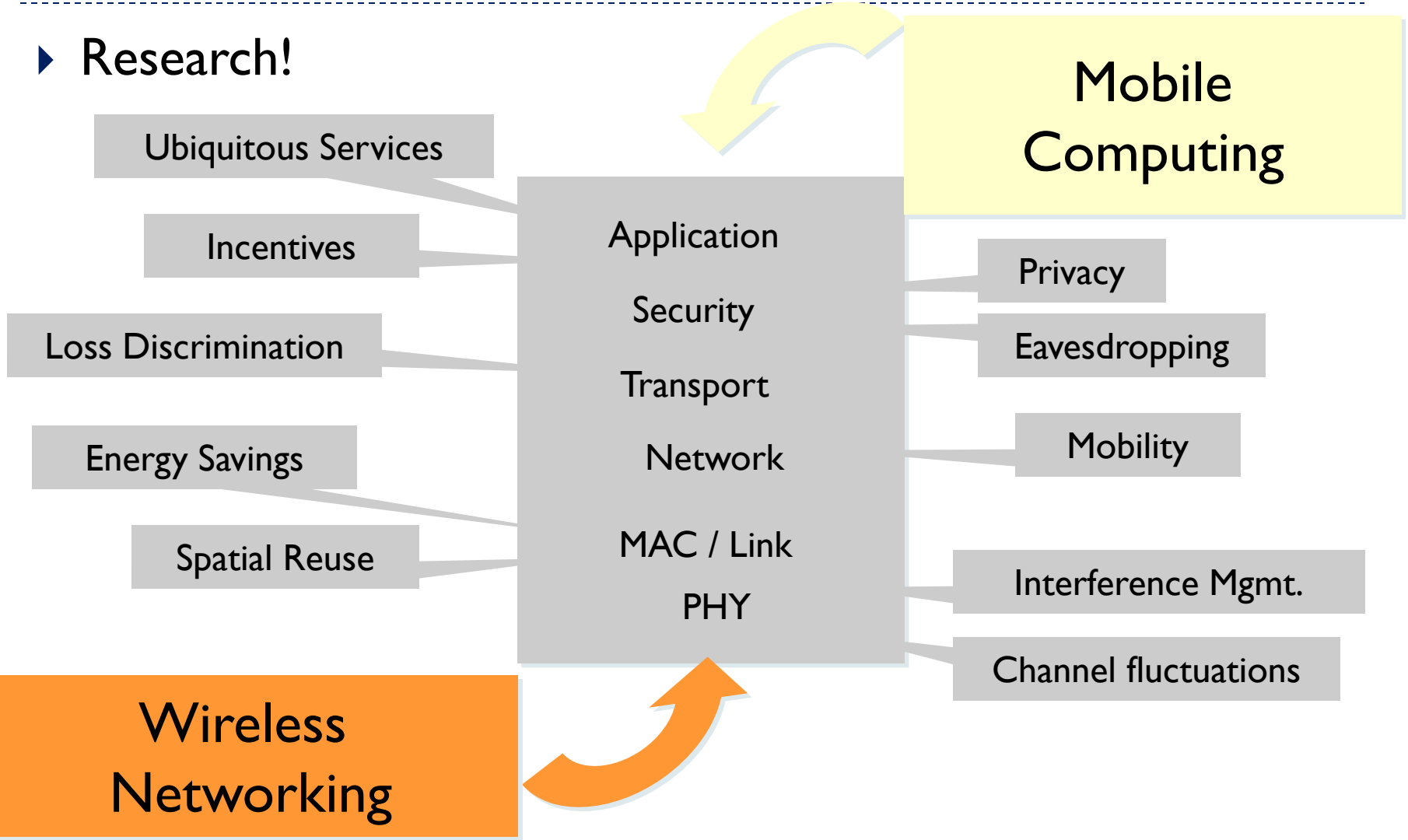
How do we make this all happen

- 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)