# 18-452/18-750
# Wireless Networks and Applications
## Lecture 1: Course Organization and Overview

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**http://www.cs.cmu.edu/~prs/wirelessS24/**



# Outline

- Goals and structure of the course
- Administrative stuff
- Internet basics
- Course content
- Why an entire course on wireless?
- A bit of history of wireless (context)

- Please ask questions!

# Goals of the Course

- Learn about the unique challenges in wireless networking
  - » Starting point is "regular" wired networks
  - » But the physical layer is very different!
- Gain an understanding of wireless technologies at the physical and datalink layers
  - » Physical layer: the focus is on concept + difference from wired
  - » Datalink protocols: focus on features specific to wireless
- Impact of wireless on the rest of the protocol stack
- Get some hands-on experience in working with wireless networks and devices
  - » Measurements of a wireless network
  - » Implementing wireless protocols, algorithms



# Lectures

- Introduction
  - » What is the course about?
  - » A very quick overview of networking
- Physical layer concepts (~5)
  - » Conceptual – this is not a wireless communications course!
- LANs and WiFi (~6)
- Cellular networks (~4)
- Other technologies; PAN, RFID, NFC, …. (~5)
- GPS, localization, sensing (~3)
- Deployments: sensor networks, ad hoc, …

# Projects

Two hands on projects

1. Measurement project to improve your understanding of wireless link properties
   - » Measure signal strength and other signal properties
   - » How do they relate to the physical context?
   - » Individual project this semester
2. Design, implement and evaluate some wireless protocol, algorithm or system
   - » Dealwith the unpredictable nature of wireless links, mobility
   - » Multi-phase projects: start small and work your way up to larger networks or systems
   - » Define your own project
   - » Teams of 2 students



# Survey Presentations

- Present a survey of a particular wireless topic to the class
  - » Basically a short lecture
  - » Done in teams of 2 students
- Survey content is based on research papers
  - » Pick from a list of topics or define your own topic
  - » Initial set of papers provided for the topics on the list
- Goals are:
  - » Learn about a specific topic in depth
  - » Develop critical thinking skills
  - » Improve your presentation skills

# Graduate versus Undergraduate Course Numbers

The course content is the same, but they are separate courses:

- Some questions on the tests are different
- Different levels of expectation for projects and surveys, e.g., more aggressive, evaluation
- Final grades are curved separately
- The expectation is that students sign up for the course number that matches their status
  - » Let the instructor know if you are an UG signing up for the grad sections, e.g., as an ECE IMB student
- 18-452 is a Software Systems area course
- 18-750 is part of Wireless Systems concentration



# Prerequisites

- The course assumes you have taken an "Introduction to Computer Systems" course
  - » For example, based on the O'Hallaron and Bryant book
- We will also build on basic networking and signals concepts but the course includes introductory material on these topics
- Programming experience needed for project
  - » Often: C/C++ or other language, depending on project
- Course should be accessible to students with a broad range of backgrounds, but …
- I don't know you, so please ask questions when something is not clear!

# More Specifically …

- For undergraduates – 18-452
  - 18-213 or 15-213: Introduction to Computer Systems
- For graduates – 18-750
  - 15-513/18-613 or …
  - Equivalent: a basic understanding of how computer systems work both inside the box (CMU, memory, IO, ..) and across boxes (familiarity with networking)
  - If you have a degree in computer science or computer engineering, you should generally be ok
  - Please talk to me if you have concerns



# Grading

Grade distribution:

- Homeworks: 10%
- Project 1: 5%
- Project 2: 25%
- Survey: 10%
- Midterm: 20%
- Final: 30%

# Where to Look for Things

- The course web page is your primary source for information
  - Lecture schedule and slides
  - Office hours, contact information, …
  - Deadlines for homeworks, surveys, and projects
  - Handouts
- Piazza: questions on homeworks, Project 1
- Gradescope: used for some assignments
- Canvas: solutions assignments and grades
  - Also provides info on how to access Gradescope and Piazza
- Midterm and final: in person and in class



# Lecture Format

- The recitation slots will be used for lectures early in the semester
  - The number of lectures will remain the same
- Moving lectures earlier in the semester has several advantages:
  - Reduced class schedule in the second half of the semester when your workload is often higher, e.g., course projects
  - It may help in picking survey and project topics
  - A tentative lecture schedule is on the web page
- The lecture slot duration is 1hr 50 min
  - Usual lecture duration for a 12 unit course is 80 min
  - The plan is to stick close to that

# More Administrative Stuff

- Lectures are Mo/Wed 2:00pm – 3:50pm EST
  - But lectures will typically be ~80 minutes, which is the typical lecture duration for a 12 unit course
- Recitations are Fr 12:30pm -1:50pm EST
  - Only 80 minutes
- Course admin: Michele Passerrello – HH 1112
  - Appointments: Tracy Farbacher (CSD)
- Teaching assistant: Sofia Martins
- Syllabus has more details on course policies



# Textbook and Readings

- "Introduction to Wireless Networking and Its Impact on Applications"
  - https://link.springer.com/book/10.1007/978-3-031-27466-4
  - Free to CMU people – must be authenticated (Andrew)
  - Based on the course but does not include all the material – lectures have more depth and cover more topics
- Optional: "Wireless Communication Networks and Systems", Corry Beard and William Stallings, Pearson, 2015
- Optional: "Wireless Communication", Andreas Mulisch, Wiley, 2023
  - Both books provide more depth on the course material

# Collaboration

- Traditional rules of collaboration apply
  - » https://www.cmu.edu/policies/student-and-student-life/academic-integrity.html
- You must complete individual assignments and tests by yourself
  - » The use of AI tools such as ChatGPT constitutes unauthorized assistance
- You are expected to collaborate with your partner in the team-based projects
- It is acceptable and encouraged to help fellow students with generic problems
  - » E.g. where to find documentation, use of tools, ..
  - » You must give proper credit when reusing material





# CMU's Disability Services Office and CAPS are Great

- I follow do what the Disability Services office decides, no questions asked
  - » I don't need to know why you need accommodations
- Please email me a copy of the accommodations sheet for us
  - » I am also notified directly by their office
- CAPS - Counseling and Psychologic Services
  - » They are not just for people with severe mental health troubles
  - » They are a useful resource for anybody who is stressed or needs to talk to someone

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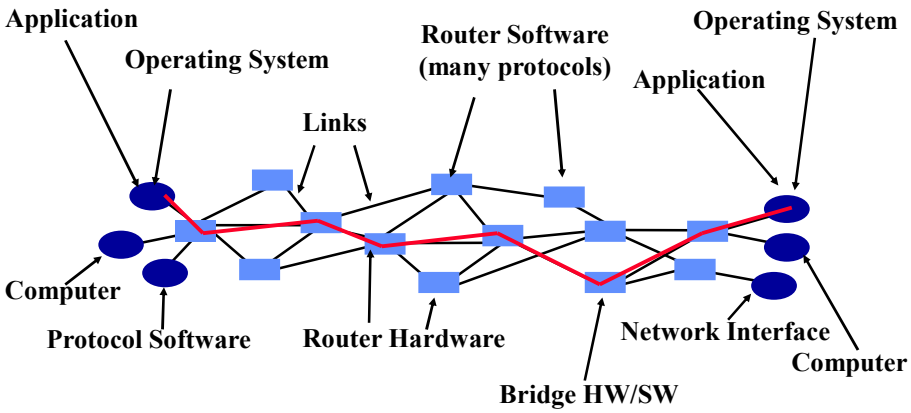
# The Internet is Big and Has Many, Many Pieces

**How do you design something this complex?**



# What Pieces Do We Need?

Module:

- We need to be able to send bits
  - » Over wired and wireless links
  - » Based on analog signals

Physical

- We really want to send packets
  - » Statistical multiplexing: users can share link
  - » Need addresses to deliver packets correctly

Datalink
Network

- Communication must be reliable
  - » But the network will lose or corrupt packets
  - » Must recover from these errors

Transport

- You need applications and services
  - » Otherwise: who cares?

Application

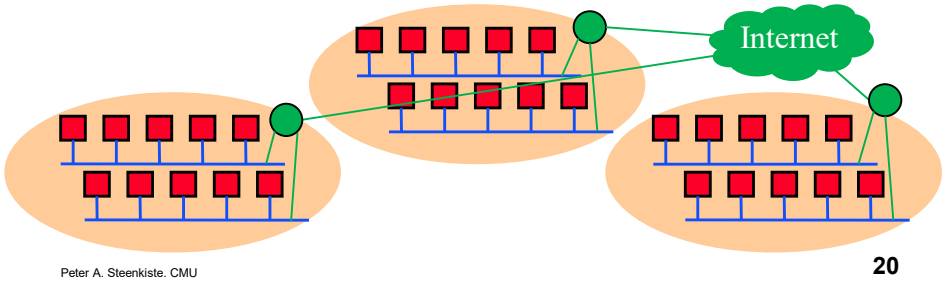




# Two Hosts Exchanging Packets can be Easy or Hard

Scaling up

- Two or more hosts talk over a wire (bits) — Physical
- Groups of hosts can talk at two levels
  - » Hosts talk in a network is homogeneous in terms of administration and technology — Datalink
  - » Hosts talk across networks that have different administrators and technologies — Internet
- Differ in physical and admin properties, scale



# A Bit More Detail

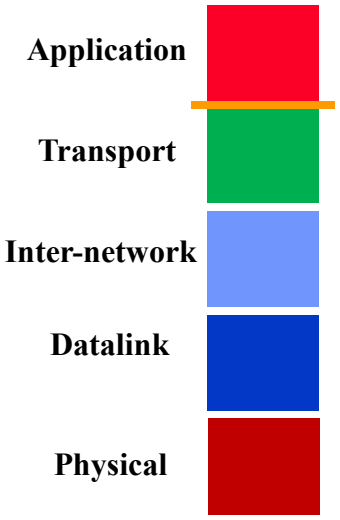
- Physical layer delivers bits between the two endpoints of a "link"
  - » Copper, fiber, wireless, visible light, …
- Datalink layer delivers packets between two or more hosts in a local area network
  - » Ethernet, WiFi, cellular, …
  - » Best effort service: should expect a modest loss rate
  - » "Boxes" that connect links are called bridges or switches
- Network layer connects multiple networks
  - » The Inter-net protocol (IP)
  - » Also offers best effort service
  - » Boxes that forward packets are called routers

Scaling up the network





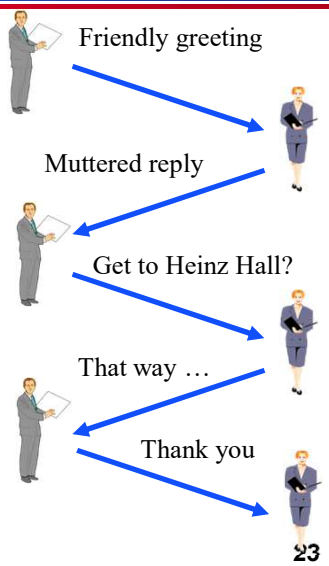
# Our Internet So Far




- The Internet as five modules that are stacked as a set of layers
  - » More on this later
- Five layers is nice, but …
  - » What about communication?
- We need protocols!
- Protocol modules within each layer jointly support end-to-end communication

# Protocol Enable Communication

- An agreement between parties on how communication should take place.
- Protocols must define many aspects of the communication.
- Syntax:
  - » Data encoding, language, etc.
- Semantics:
  - » Error handling, termination, ordering of requests, etc.
- Protocols at hardware, software, *all* levels!
- Example: Buying airline ticket by typing.
- Syntax: English, ascii, lines delimited by "\n"



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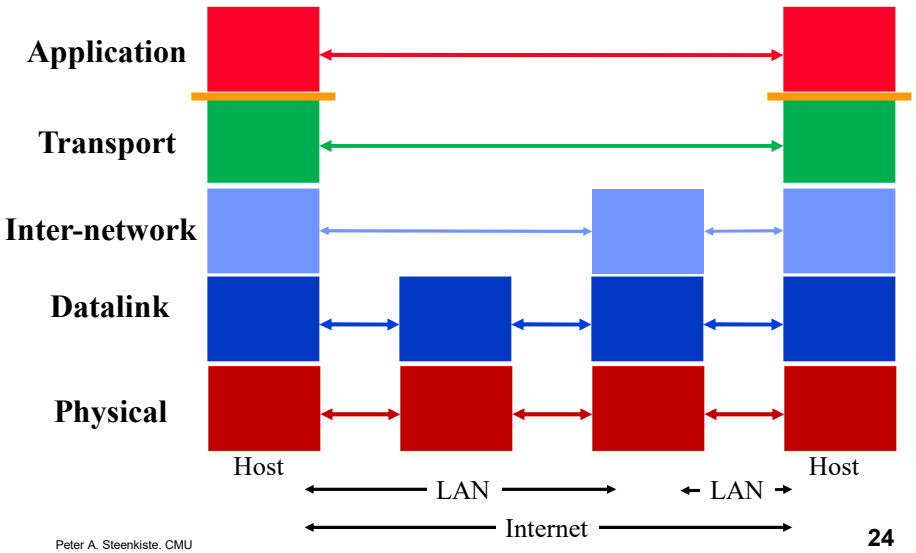
# Protocol and Service Levels



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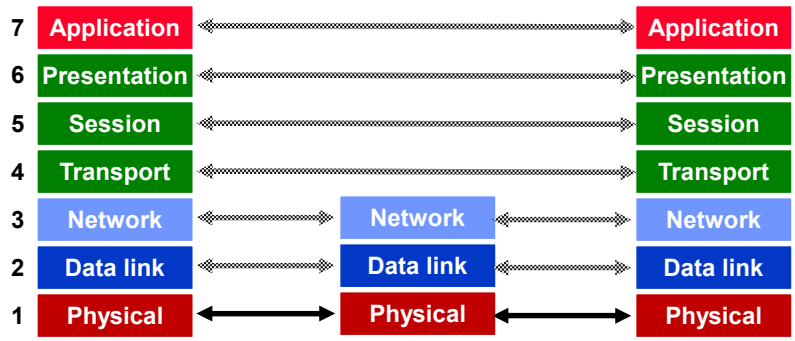
# The ISO Layered Network Model

**The Open Systems Interconnection (OSI) Model.**



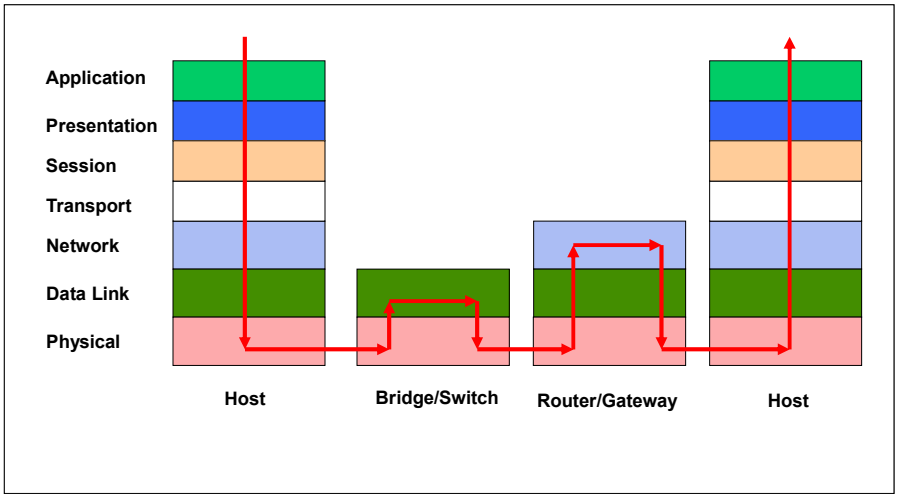





# OSI Functions

- **(1) Physical: transmission of a bit stream.**
- **(2) Data link: flow control, framing, error detection.**
- **(3) Network: switching and routing.**
- **(4) Transport: reliable end to end delivery.**
- **(5) Session: managing logical connections.**
- **(6) Presentation: data transformations.**
- **(7) Application: specific uses, e.g. mail, file transfer, telnet, network management.**

# Life of Packet



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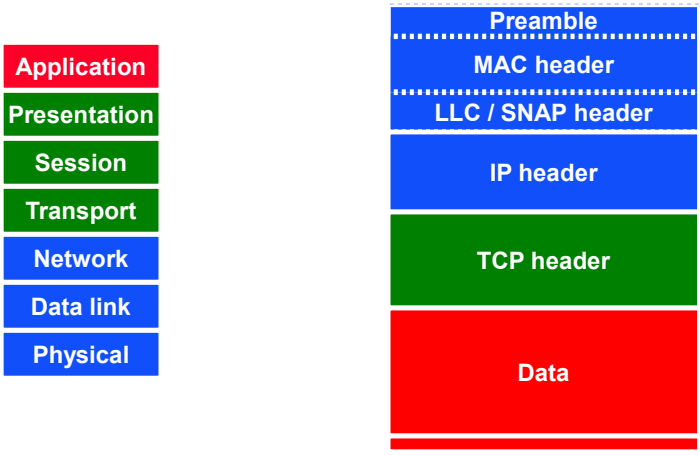
# A TCP / IP / 802.11 Packet



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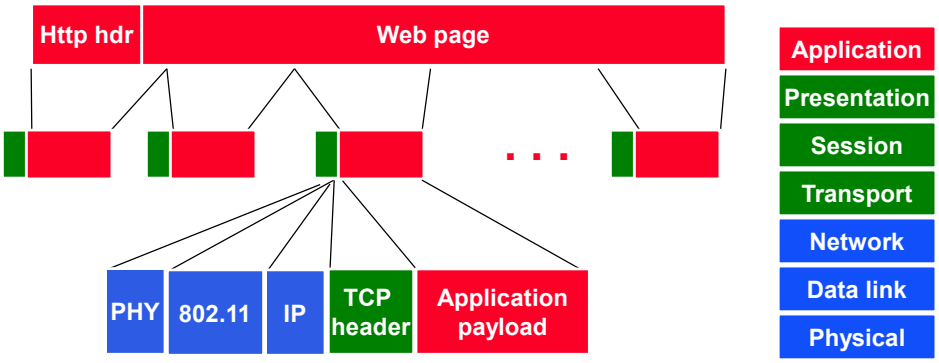
# Example: Sending a Web Page








# OSI Motivation

- **Standard approach of breaking up a system in a set of components with well defined interfaces, but components are organized as a set of layers.**
  - » **Only horizontal and vertical communication**
  - » **Components/layers can be implemented and modified in isolation without affecting the other components**
- **Each layer offers a service to the higher layer, using the services of the lower layer.**
- **"Peer" layers on different systems communicate via a protocol.**
  - » **higher level protocols (e.g. TCP/IP, Appletalk) can run on multiple lower layers**
  - » **multiple higher level protocols can share a single physical network**

# Benefits of Layered Architecture

- Significantly reduces the complexity of building and maintaining the system.
  - » Effort is 7 x N instead of $N^7$ for N versions per layer
- The implementation of a layer can be replaced easily as long as its interfaces are respected
  - » Does not impact the other components in the system
  - » Different implementation versus different protocols

True For Wireless?

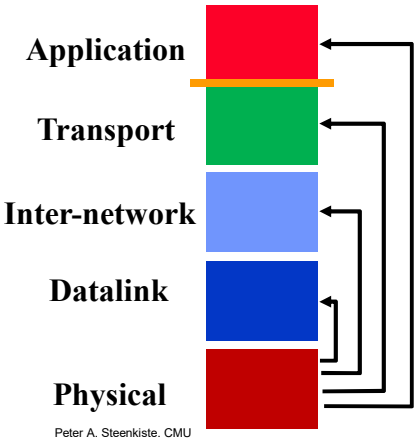
- In practice: most significant evolution and diversity at the top and bottom:
  - » Applications: web, peer-to-peer, video streaming, games, ..
  - » Physical layers: new types of copper, optical, wireless,
  - » The Internet Protocol in the "middle" is hard to change!





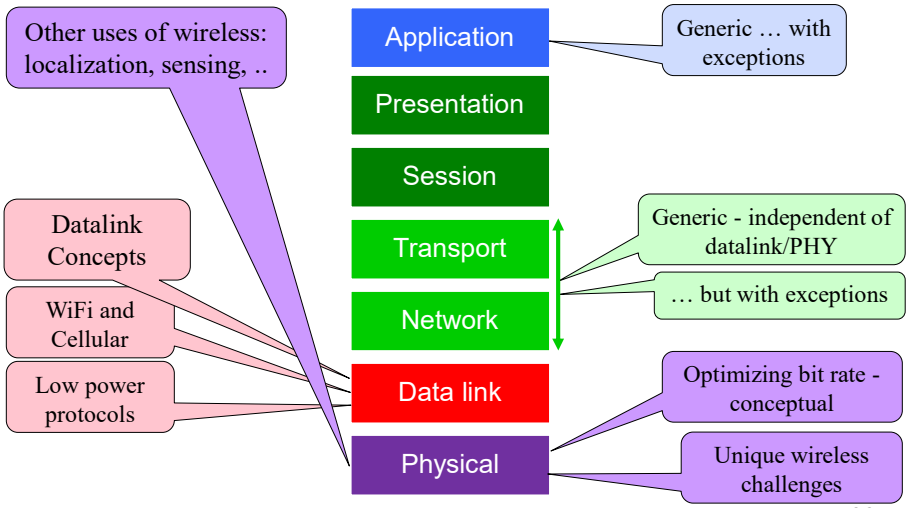
# Impact of the Physical Layer

**Wires: reliable and predictable** ⟺ **Wireless: error prone and variable**




- Packet losses and variable delay and bandwidth
- Disconnections
- Mobility: IP addresses change
- Must manage complex PHY to perform error control
- Sophisticated modulation & coding, bit rate adaptation

# What is Covered?








# Scope of Wireless Covered in the Course

- **Significant depth on two technologies**
  - **WiFi (unlicensed spectrum) and cellular (licensed spectrum)**
  - **Optimize performance with high spectrum efficiency**
  - **Sophisticated protocols to fight physical layer challenges**
- **Other wireless communication technologies**
  - **RFID/NFC, low-power, sensor networks, …**
- **Wireless deployments**
  - **Infrastructure WiFi, ad hoc, sensor networks, vehicular, ..**
- **Other applications of wireless**
  - **GPS, Wifi for localization, dynamic spectrum access, …**
  - **Diverse set of topics covered in the surveys**

# Course Material

- Most slides were prepared by the course instructor
- Some slides contain material from other sources
  - » Previous co-instructors have contributed slides
  - » Some figures are taken from the textbook
  - » Some lectures contain material from other sources





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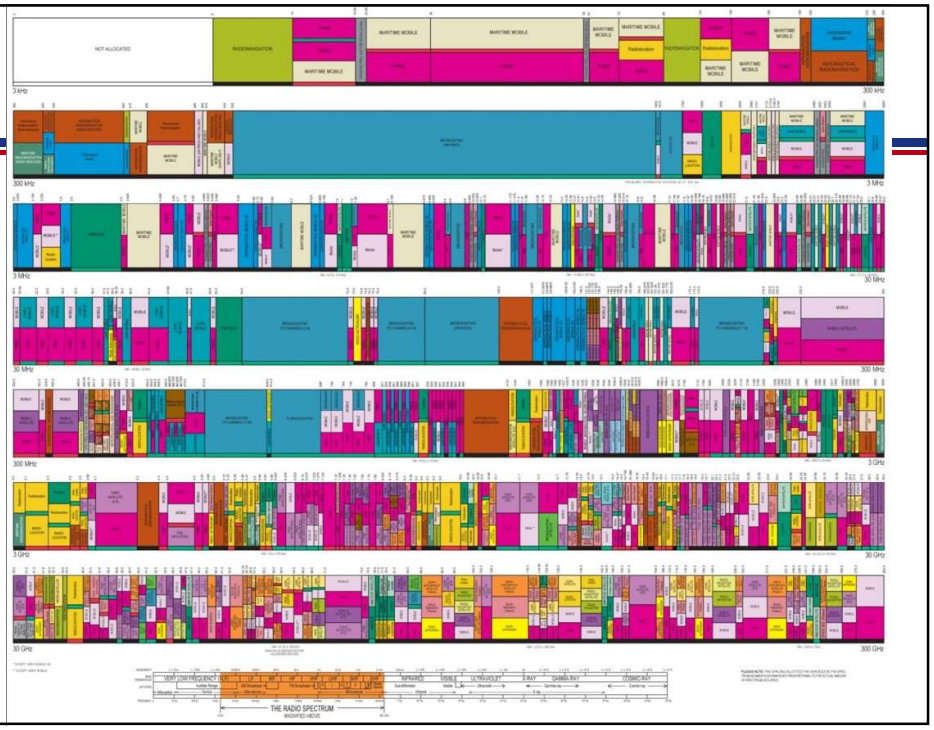

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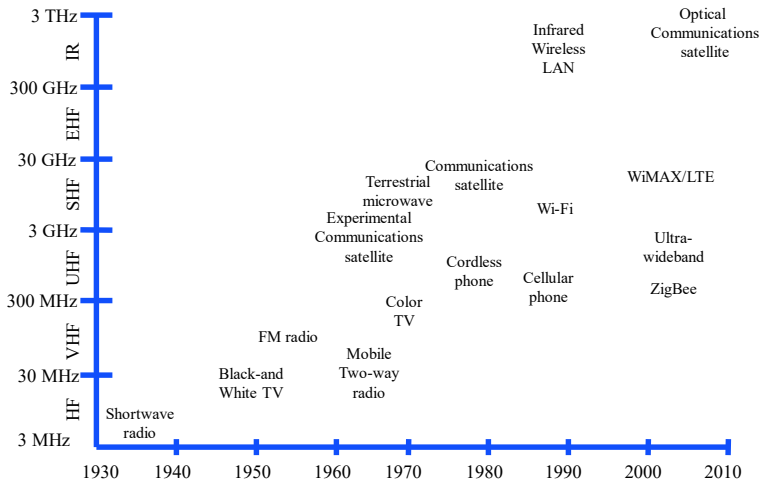
# Spectrum Shared by Many Users

- **Spectrum allocated by FCC and NTIA**
- **Two types of spectrum bands:**
  1. **Licensed spectrum: exclusive access to an organization**
     - **Federal agencies, broadcast TV, first responders, …**
     - **Commercial, e.g., cellular operators**
  2. **Unlicensed spectrum: everyone can use it with appropriate equipment, e.g., WiFi, zigbee, …**
- **Other trends:**
  - » **Technology improvements have allowed us to use higher frequency bands over time**
  - » **Many bands have low utilization**
  - » **Older bands often use very inefficient technologies**

# Wireless Technologies

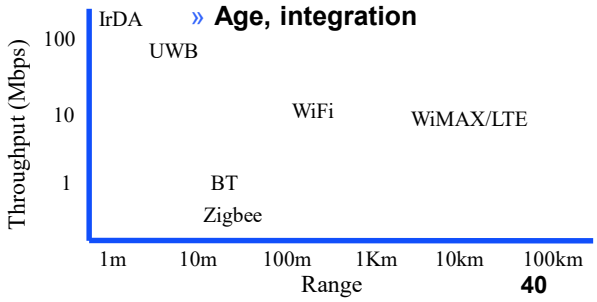







# Why so many Technologies?

- **Diverse application requirements**
  - » **Energy consumption**
  - » **Range**
  - » **Bandwidth**
  - » **Mobility**
  - » **Cost**
- **Diverse deployments**
  - » **Licensed versus unlicensed**
  - » **Provisioned or not**
- **Technologies have different**
  - » **Signal penetration**
  - » **Frequency use**
  - » **Cost**
  - » **Market size**
  - » **Age, integration**



# Application Trends in Wireless

- Early days: specialized wireless networks
  - » Broadcast TV and radio, voice calls, data, ..
  - » The same was true for wired networks
- Today: single network for diverse apps
  - » Phones, tables, and laptops all run similar applications
  - » Everything runs over the Internet (= data)
  - » The edge of the Internet is increasingly wireless
- Wireless is expanding in new domains
  - » Originally: support nomadic and mobile users
  - » Sensor networks, body area networks, RFID, …
  - » Emerging: sensing, backscatter, energy harvesting, ...
- Future?



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# Some History…

- Tesla credited with first radio communication in 1893
- Wireless telegraph invented by Marconi in 1896
- First telegraphic signal traveled across the Atlantic ocean in 1901
- First "cell phone" concept developed in 1946
  - » FCC allocated spectrum in the 70s
  - » 1G commercial service in the early 80s (analog)
  - » New generation every 10 years
- GPS project started in 1973, complete in 1995
- WiFi technology developed in the 1990s
  - » After FCC opened up 900MHz, 2.4 and 5.8GHz bands in 1985