CSE 291: Wireless and Communication in the Internet of Things

We will start ~2:05 today, but promptly at 2:00 in the future

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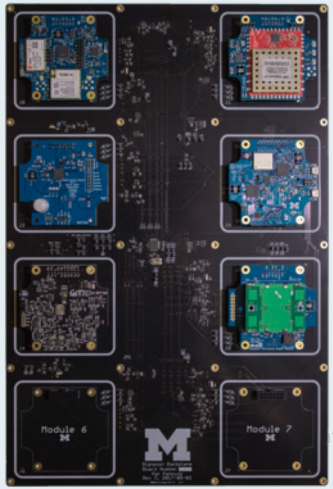
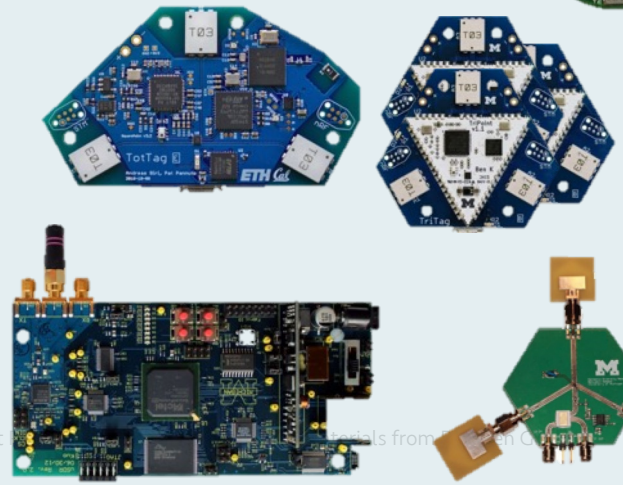
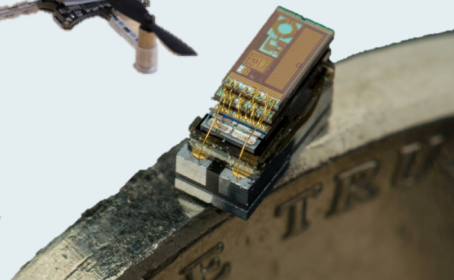






Today's Goals

- Overview of the course
- Introduction to the Internet of Things
- Introduction to wireless communication

Welcome & Logistics

- Everything is on the course website
  - https://patpannuto.com/classes/2022/winter/cse291/
  - ^This is also the homepage in Canvas
- We will use Gradescope to submit stuff when relevant
- We will use [Slack ? Piazza ? Canvas Forum ? Nothing ?] for a message board
- This is a graduate course
  - No exam
  - Occasional paper reading
  - Small weekly-ish lab assignment
  - Smaller capstone project
- This course expects discussion, interactions, and questions
  - Please webcams on [if you can] while remote
  - No Zoom planned after week 2; could be talked into Zoom option M/W, not F (labs have HW)

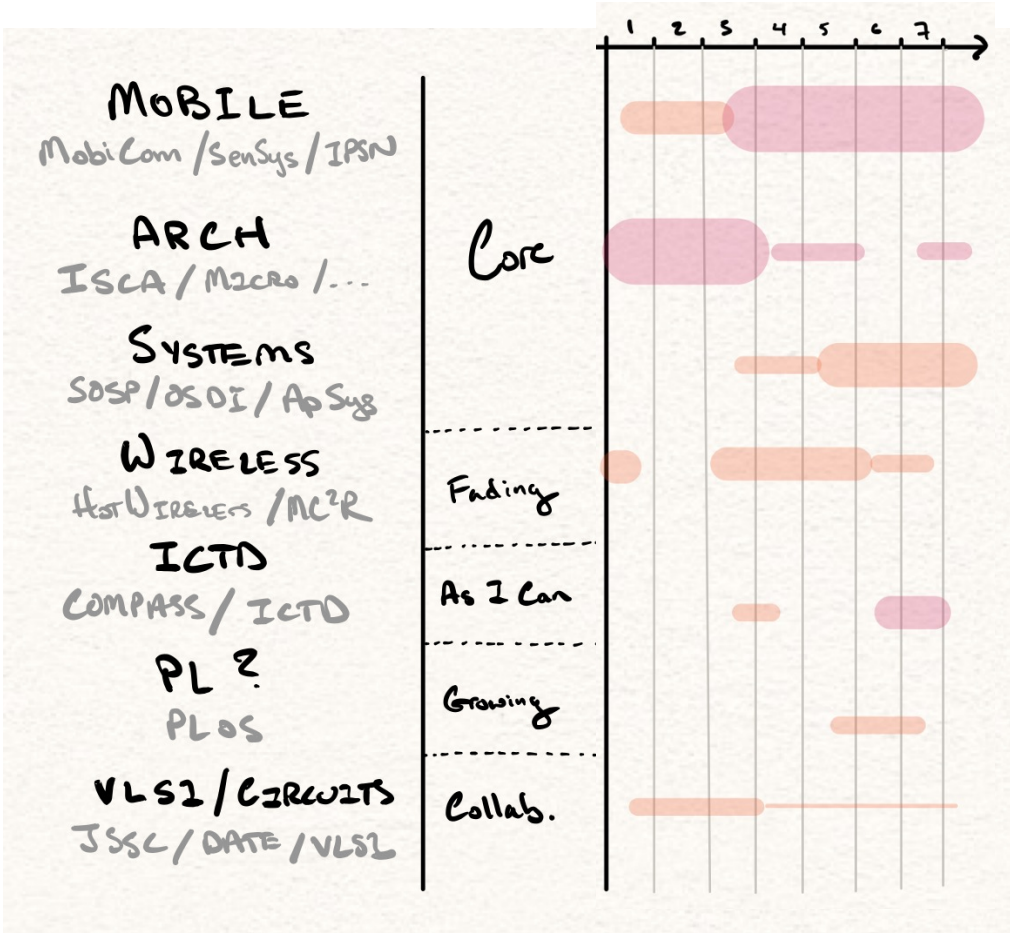
Hi, I'm Pat
(they/them)

- Originally from Michigan
- BSE CE, MSE CS from U of M
- PhD in EECS from UC Berkeley
- I work in "embedded systems"

→

- I thrive when abstractions break
  - Resource constrained computing

- Interstitial / highly collaborative
  - 40 co-authors
  - 9 institutions
  - 4 continents



Outline

- Internet of Things
- Course Overview
- Overview of wireless networks

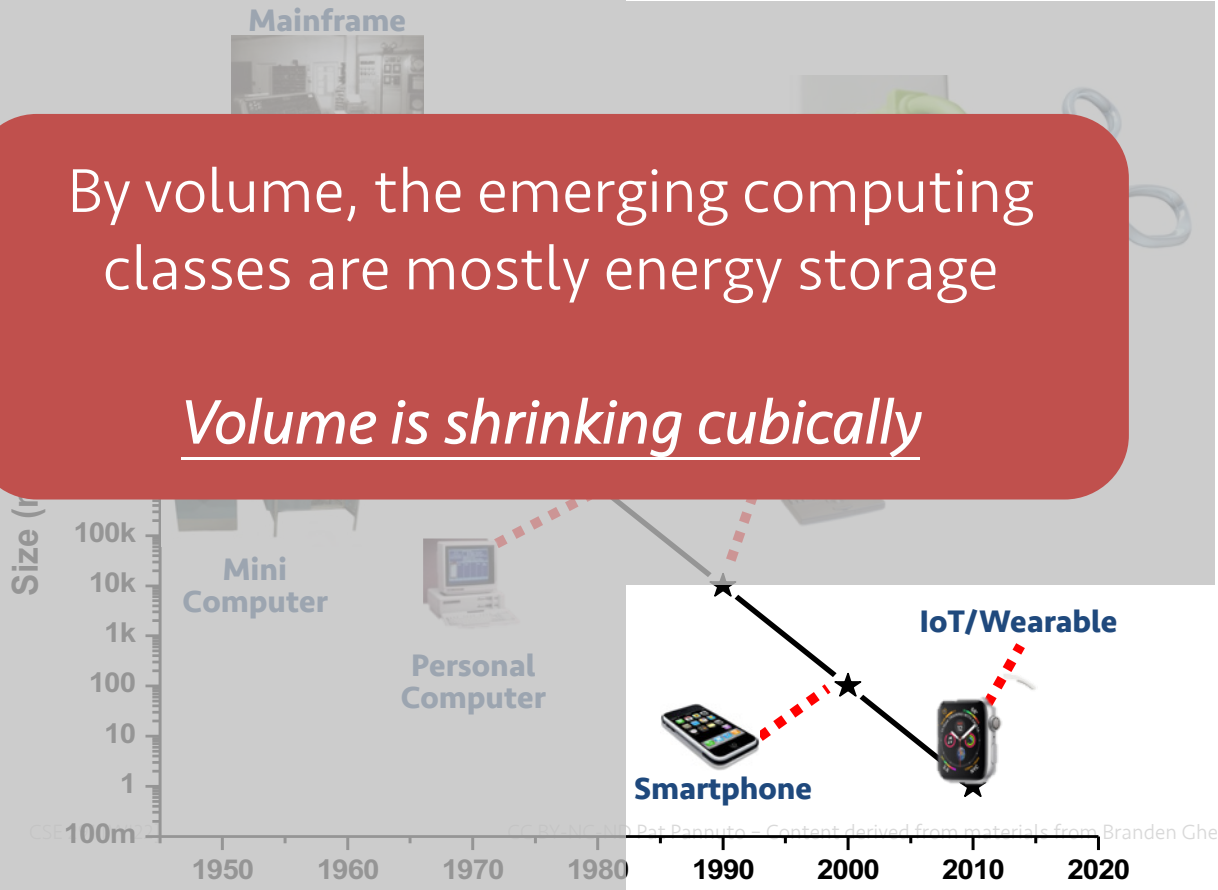
The two hardest things in embedded systems / IoT are *power* and *communication*

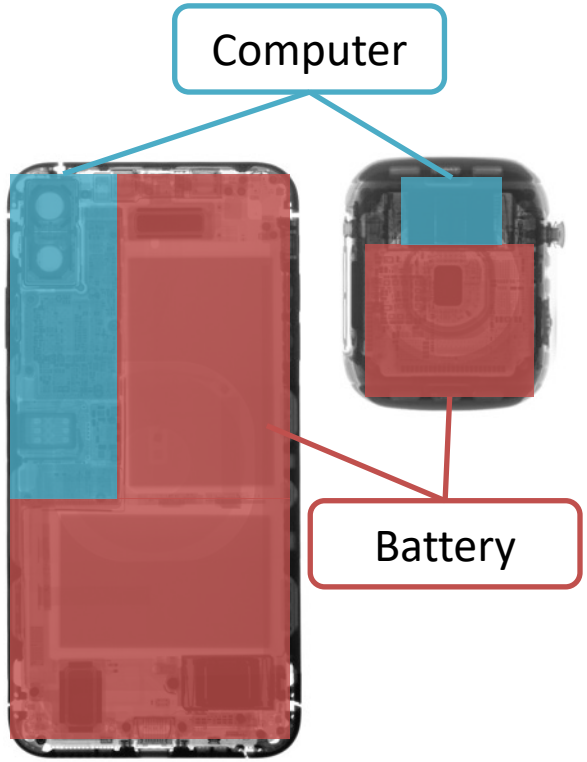
- This class is about wireless technologies
  - For resource-constrained systems [the IoT]
- We will focus on the tradeoffs between technologies
  - How they balance differing constraints [power, spectrum, complexity, etc]
  - And the technical foundations of these designs and differences

Energy is *the* defining constraint of emerging technologies

By volume, the emerging computing classes are mostly energy storage

Volume is shrinking cubically





What is the IoT anyway?

- Seriously: let's define "Internet of Things"

Thought experiment on capabilities

- What if the Nest thermostat was powered by…
  - a desktop: 8-core x86-64 processor, 32 GB RAM, 1 TB SSD
  - a laptop?
  - an iPad?
- Would that still count as IoT?
- Why don't we see "desktop IoT" in practice?

"Google Nest Hub"

Thought experiment on energy

- IoT devices include a mix of batteries, wall power, (and energy-harvesting)

- Why do we put so much focus on systems with batteries?
  - Why do they need batteries?

Pat's Take on the Internet of Things

- Pretty literal
- My early grad school essays described the "last inch" problem
- Now I often say "expanding the reach of digital world"
- For me, it is about 'networked' 'things'
  - Which implicitly adds some computational capacity
    - [Though not always? Backscatter sensors break this definition…]

Branden's take on the Internet of Things

- Key features
  - Computation
    - Local to the device
    - With some capability for arbitrary compute and storage
  - Connectivity
    - Almost certainly wireless
    - Likely Internet, possibly local
  - Interaction
    - Sensing or Actuation
- Secondary features
  - Low energy
  - (Relatively) Low cost

Content derived from materials from Branden Ghena

Outline

- Internet of Things
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General course structure

- Mondays and Wednesdays
  - Lecture and discussion about IoT communication technology
- Fridays
  - Labs and projects

Grading

- 65% Participation during the quarter
  - Discussion / questions / engagement on M/W
  - Lab / reports on or from F
- 35% Final project

- No exams or homework or participation points
  - The point of in-class material is to teach you and prepare you for projects
  - Come because you want to learn it

Labs

- Semi-guided efforts of getting wireless communication working on real hardware
  - LoRa
  - BLE
  - Thread
- In a perfect world we would also do something with WiFi, cellular radios, and probably backscatter
  - Would need additional hardware
  - And extra time that we don't have this quarter

Lab grading

- Submit *something* on Gradescope
  - "Prove to me that you did this lab"
  - Point me at public Github code. Include pictures of debug output/network visualization. Discuss what did/didn't work.
  - NOT a formal lab writeup
  - When you work in groups, put all the names at the top and each of you submit copies of the same thing (just logistically easier for me)

- Playing this pretty loose since it's a small, experimental class
  - There's always a chance something in labs *won't* work

Final “Project”

- Trying something different, and invite you to try something different
- Tap into your inner hacker/maker/artist/creative and build/do/make/create something interesting — take a risk, have some fun
  - Build an ‘advisor-tracker’ that detects my wearables and alerts my students to look productive before I open the door to their office
  - It’s winter quarter? Crochet a scarf with a complete LoRa packet waveform [maybe just the payload, no one is tall enough to wear the preamble…]
  - Wither 2G? Drive around San Diego county, can you find any active 2G networks? What are they being used for?
  - Find a community group that needs data on something; can you build something useful that might help measure something important [quick-build bike counter? Wearable UV dosimeter? Ambient noise monitor / cheap SPL montior?]
- Reasonable budget available, plus any HW we use in the labs

Project Proposals

- Due at 2pm, Wednesday February 2nd
  - That's the middle of Week 5, halfway through the quarter
  - Note: Not much time after week 10 before showtime

- Start thinking about ideas now

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Bluetooth Low Energy

- Bluetooth Classic was good for enabling device to device communication
  - But not particularly fast or low energy
- Bluetooth Low Energy was developed to improve this
  - Focuses on low-energy interactions
  - Much lower throughput that Bluetooth
- Supported by hardware devices already in smartphones
  - Humans can interact directly with nearby devices!!

802.15.4 & Thread

- 802.15.4 is a low-energy physical layer
  - Radio chips have been widely available for 15-20 years
- *Significant* amounts of sensor network research have focused on building layers on top of 802.15.4
  - Access control layers
  - Network layers
- Thread is a selection of these possibilities to make a network
  - Uses IPv6 networking!!

WiFi (802.11)

- Ubiquitous wireless communication
  - High energy requirements for high throughput communication
- Now accessible through relatively low power radios
  - ESP32, Electric Imp, and company
  - Still significantly more effort than BLE or Thread
- IoT devices can use the same WiFi that's already available
  - No need for additional infrastructure!!

LPWANs (Low-Power Wide-Area Networks)

- How do we collect data from city-scale deployments?
  - There's an unmet need for long-range, but low-throughput networks
  - Existing cellular technologies focus on human requirements

- Still a brand new space (relatively)
  - Unlicensed-band technologies in last decade: Sigfox and LoRaWAN
  - Cellular technologies in last half-decade: LTE-M and NB-IoT

- Focus on long-range, low-energy, low-throughput
  - One gateway can cover an entire city!!

Extras

- Extremely active research areas

- Backscatter
  - Insanely low-energy communication
  - Enables energy-harvesting indoor devices

- Localization
  - How do we find all this stuff?
  - And how do devices determine where they are relative to each other?

- Other topics are possible if desired. Tell me what focus you want.

Why use wireless?

- There are no wires!

- No need to install and maintain wires
  - Reduces cost
  - Simplifies deployment – place devices wherever makes sense

- Supports mobile users
  - Move around office, campus, city
  - Move devices around home

What is hard about wireless?

- There are no wires!

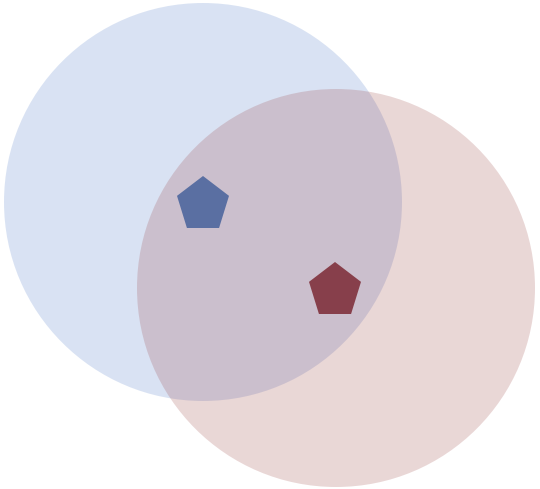
- Wired networks are constant, reliable, and physically isolated
  - Ethernet has the same throughput minute-to-minute
  - Bits sent through Ethernet or USB are (usually) received

- Wireless networks are variable, error-prone, and shared
  - WiFi throughput changes based on location and walls
  - Signals from nearby devices interfere with your signals
  - Individual bits might flip or never be heard at all

Wireless is a shared medium

- Wired communication has signals confined to a conductor
  - Copper or fiber
  - Guides energy to destination
  - Protects signal from interference

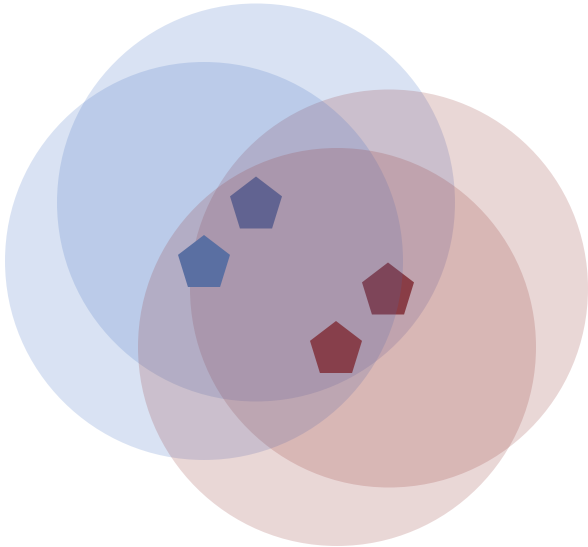
- Wireless communication is inherently broadcast
  - Energy is distributed in space
  - Signals must compete with other signals in same frequency band



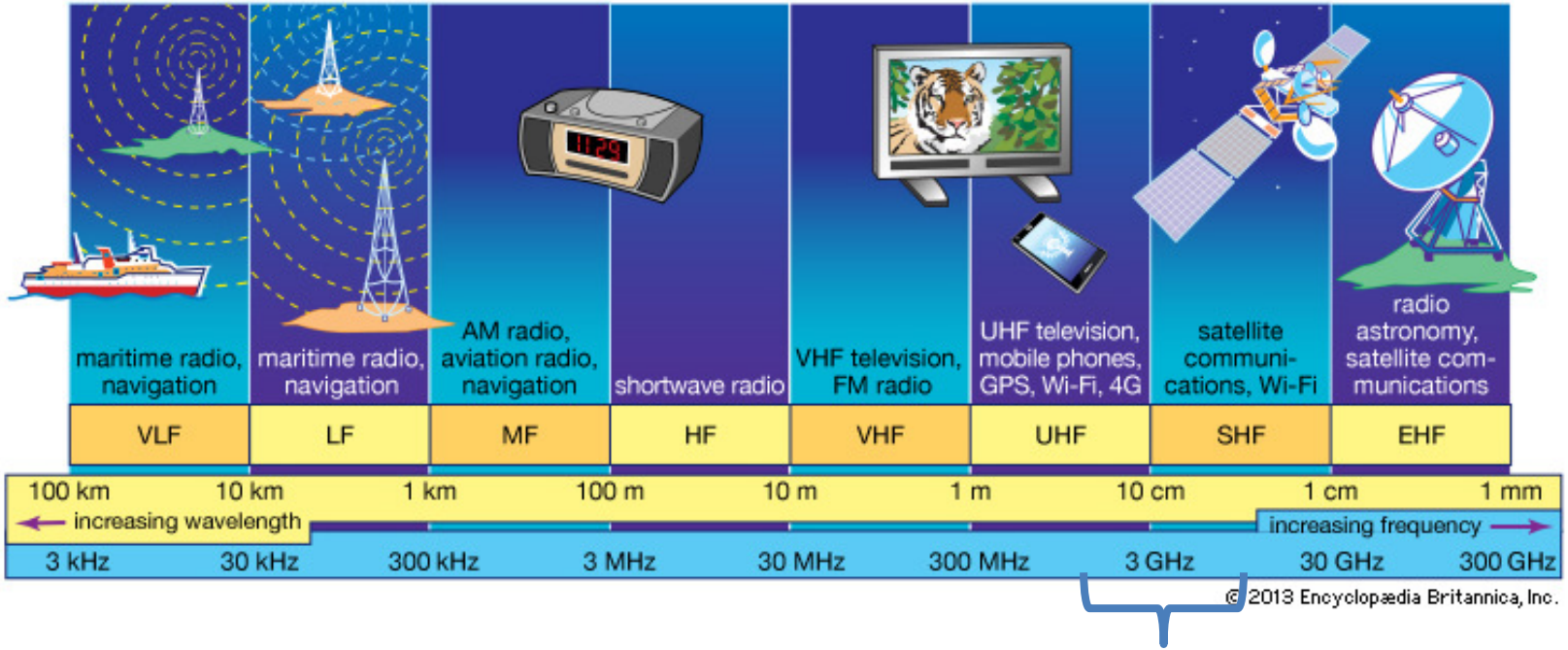
Increasing network capacity is challenging

- Wired networks just add more wires
  - Buses are many signals in parallel to send more data

- Wireless networks are harder
  - Adding more links just increases interference
  - Need to expand to different frequencies

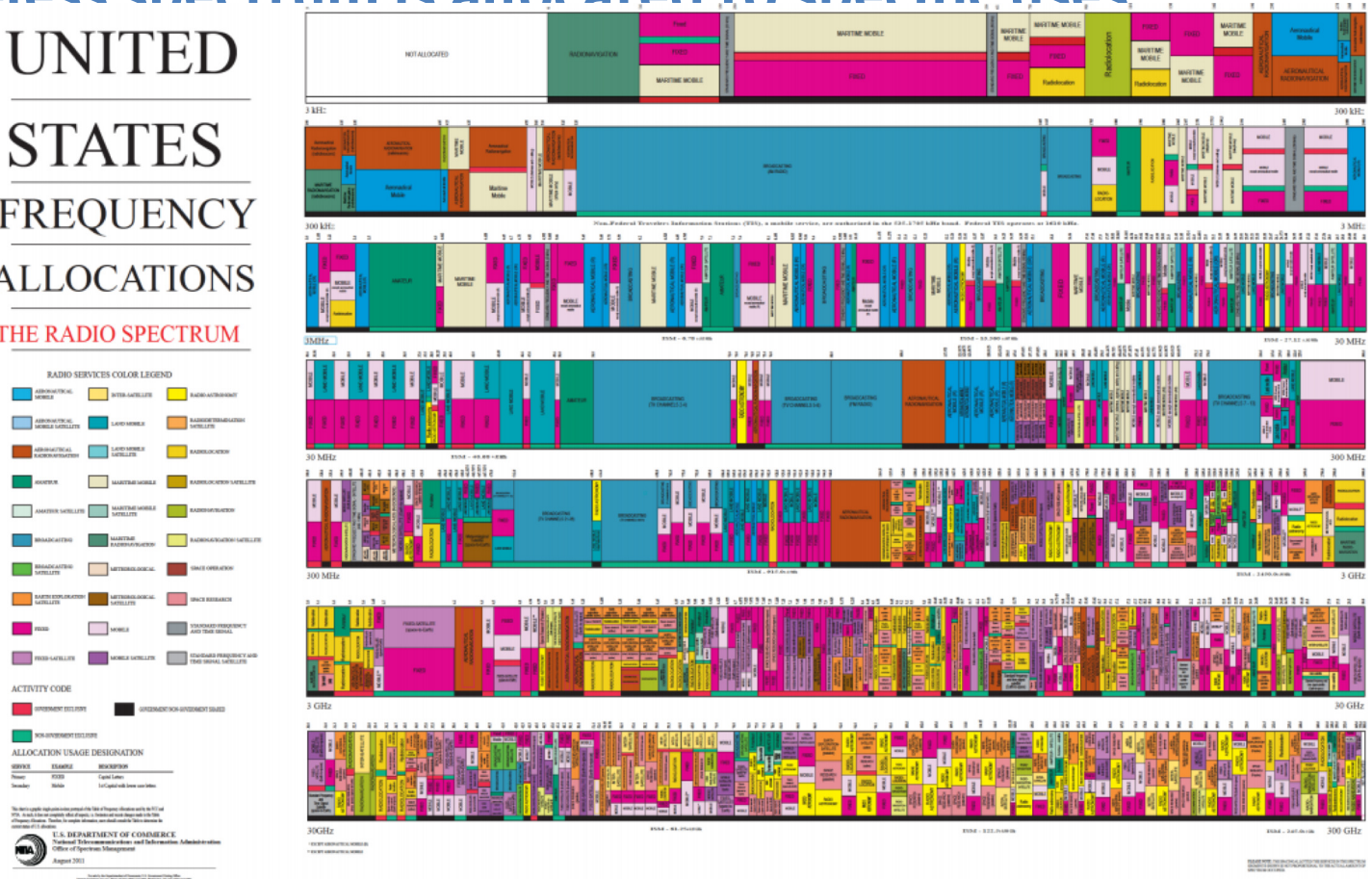


RF communication



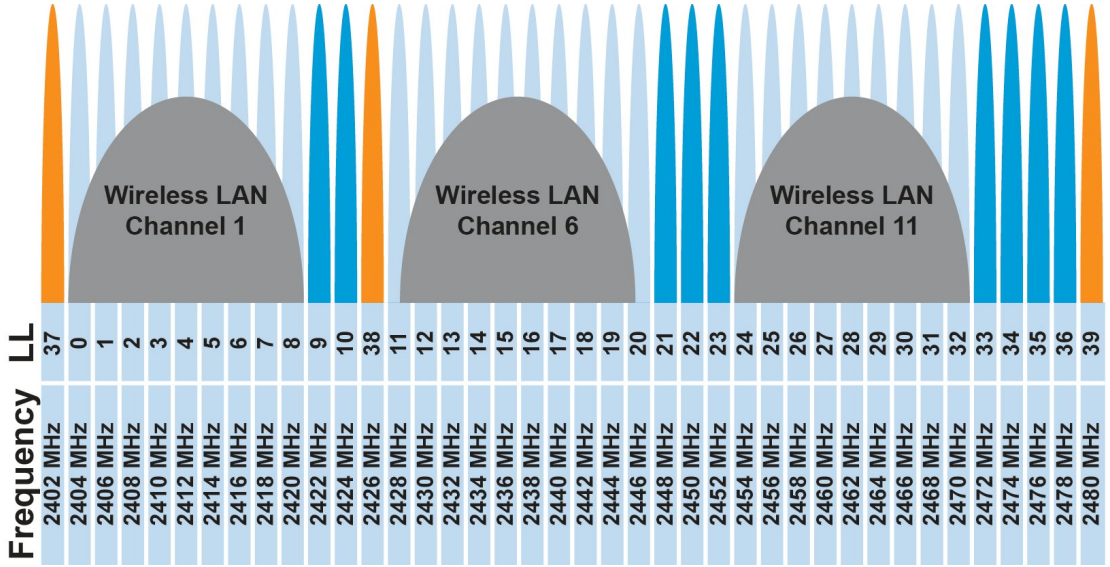
IoT focus

Wireless spectrum is allocated to specific uses



Unlicensed bands are where IoT thrives

- 902 MHz – 928 MHz
  - LPWANs
- 2.4 GHz to 2.5 GHz
  - WiFi, BLE, Thread
- 5 GHz
  - Faster WiFi
- Cellular uses licensed bands

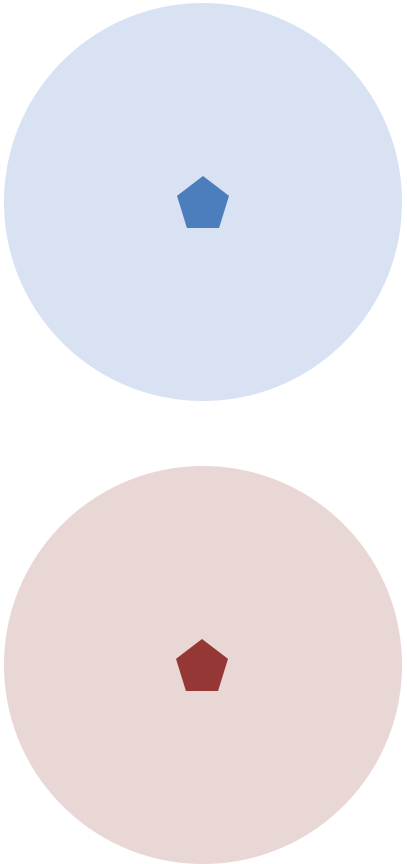


Model of RF communication

- Energy that radiates spherically from an antenna

- Attenuation with distance
  - Density of energy reduces over time, distance
  - Signal strength reduced, errors go up

- Two key features
  - Error rates depend on distance
  - Spatial reuse of frequencies



Next Time: How does the Regular ol' Internet work?

- Aka Pat tries to speedrun most of CSE123 in fifty minutes