Wireless and Communication in the Internet of Things

We will start ~1:05 today, but promptly at 1:00 in the future

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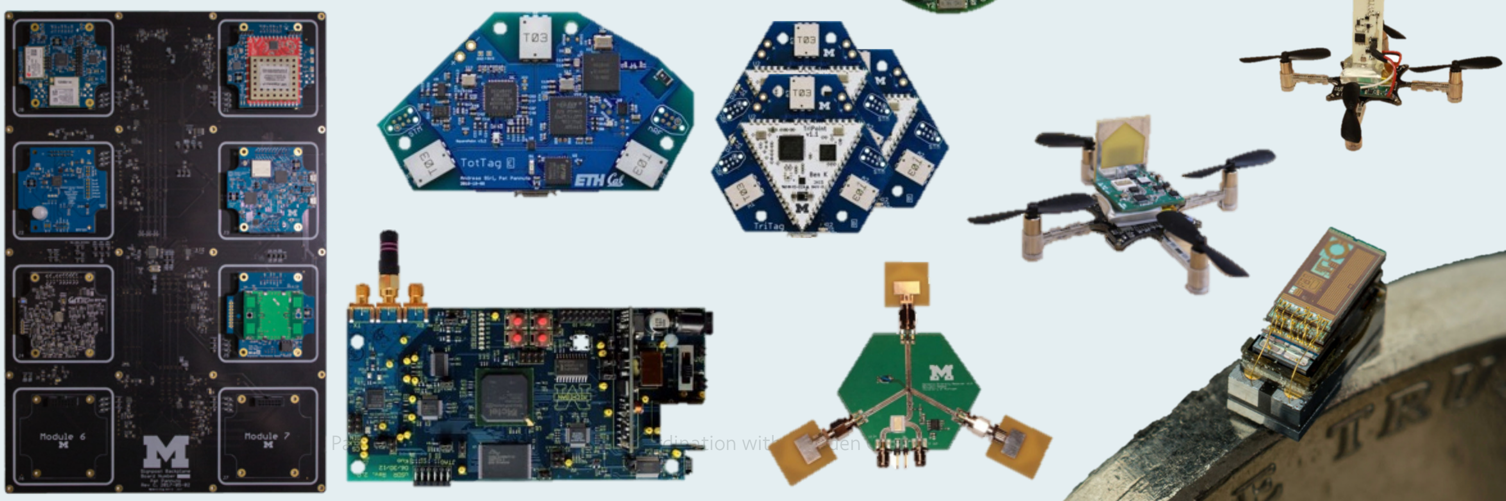
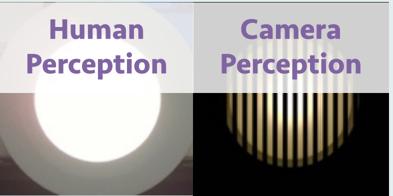




Today's Goals

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

Welcome to CSE190/291!
Wireless and Communication for the Internet of Things [WxIoT]

- ~45 students (25 undergrad; 20 graduate)
  - Many different backgrounds and interests
- This is an experience- and design-oriented course
  - Experience comes from labs (45% of grade)
  - Design comes from written assignments (15% HW, 30% Final = 45% of grade)
  - Lectures give you the foundation to understand what you are doing and how to make design decisions
    - Minute-Quizzes keep you honest on lecture material (10% of grade)

Quick Logistics

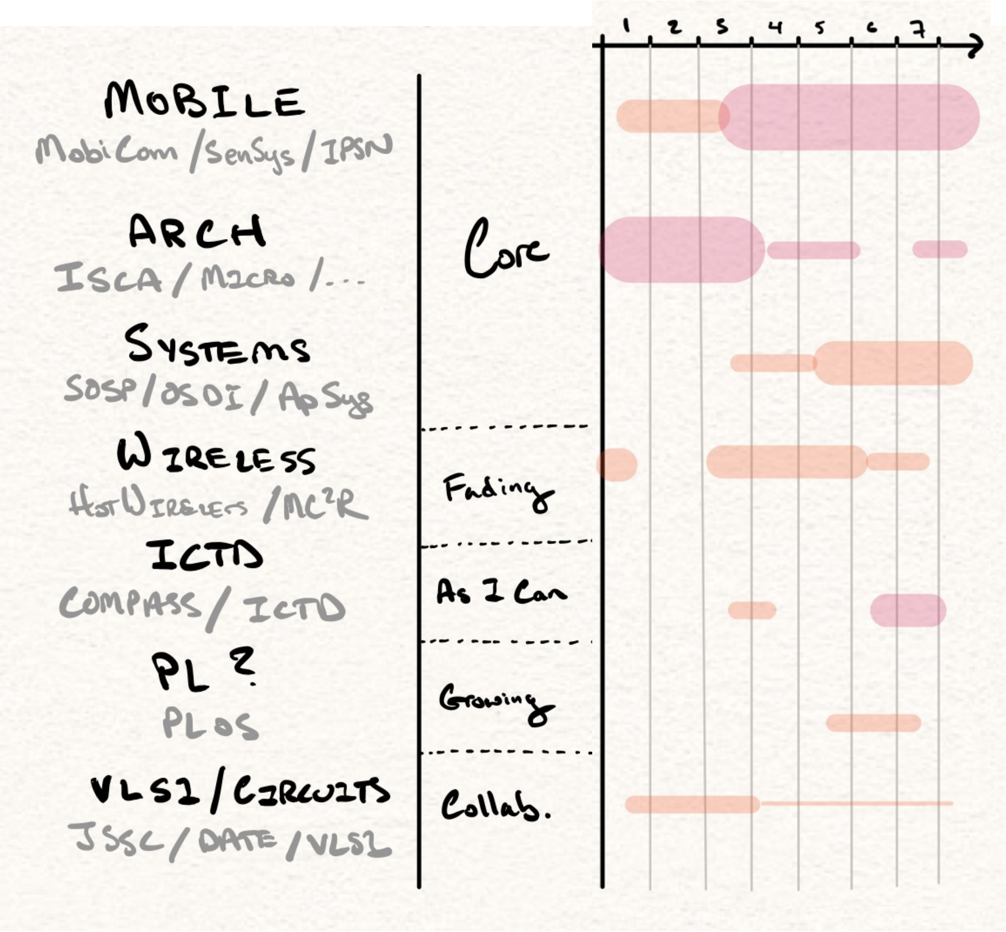
- Everything is on the course website
  - https://patpannuto.com/classes/2022/fall/wireless-iot/
  - ^This is also the homepage in Canvas
- This is an advanced course
  - Target is senior-level undergraduate, or early-career graduate students
- This is also a new / experimental course
  - Please bear with us, we're scaling up this quarter and trying new things
- We will use Gradescope to submit stuff
- We will use Piazza for a message board

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



Journal Conference Workshop

Outline

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

Perspective of this course

- This class is about wireless protocols
  - For a specific domain: the Internet of Things

- So we'll spend some amount of time discussing the Internet of Things and embedded systems

What is the IoT anyway?

- Seriously: let’s define “Internet of Things”

Discussion: what is the Internet of Things?

1. Name a few Internet of Things devices

2. What are the qualities that designate those devices at “IoT”?

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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?

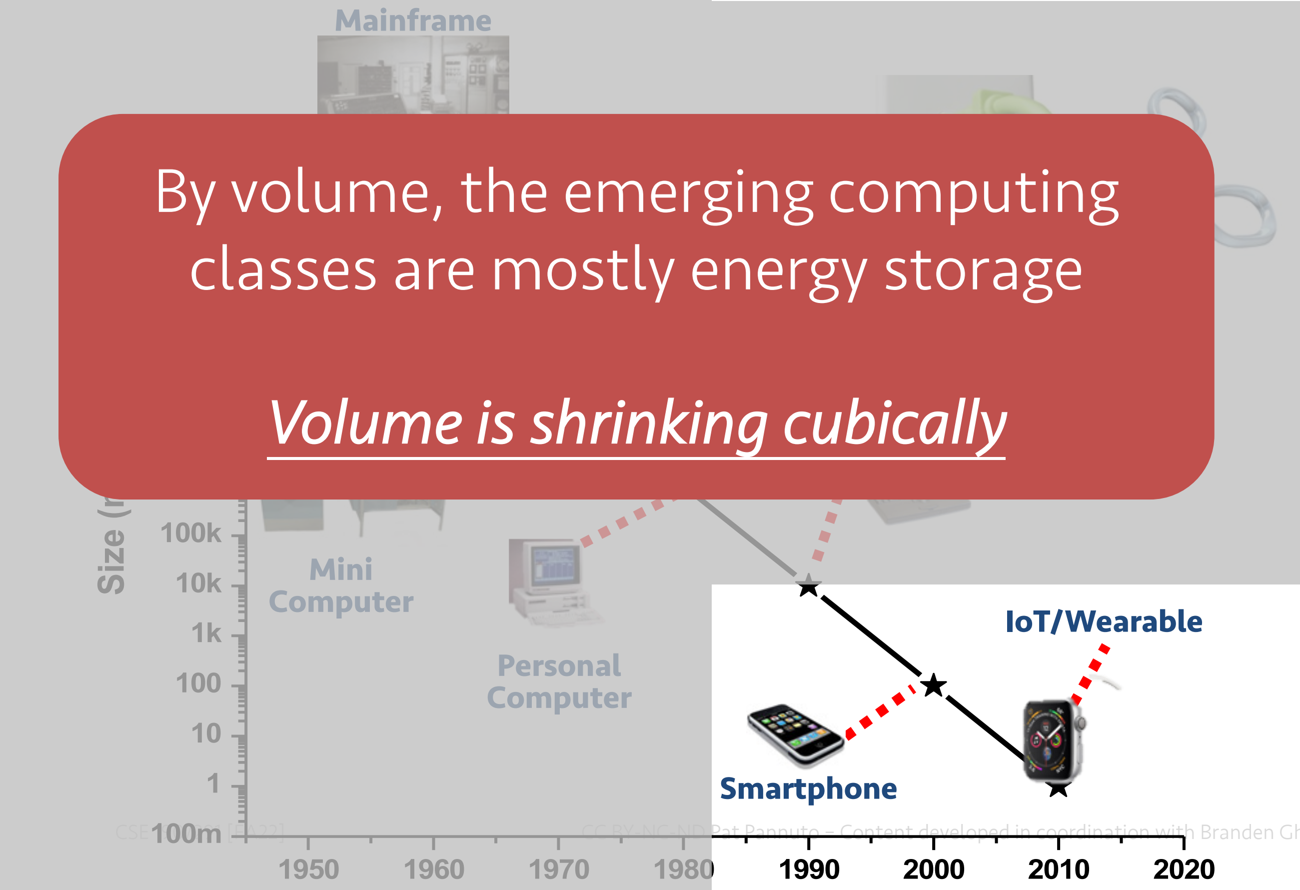
The two hardest things in embedded systems / IoT are *power* and *communication*

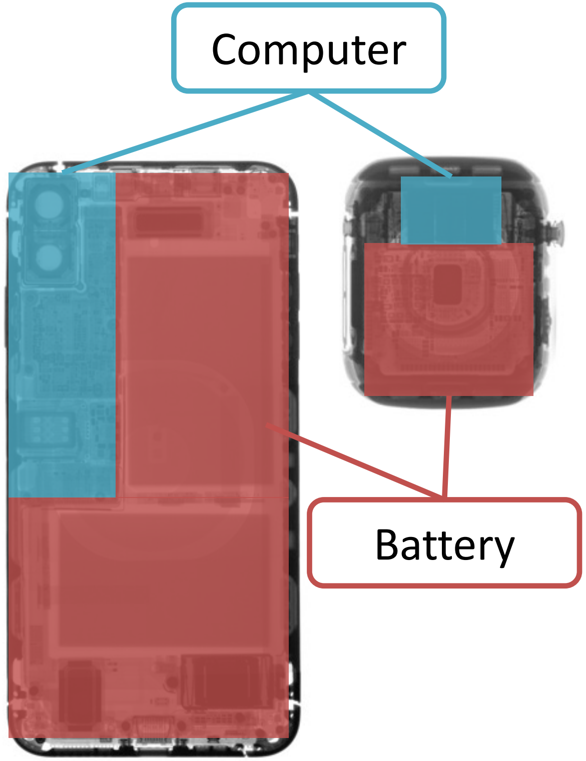
- This class is about wireless technologies
  - For resource-constrained systems, such as the IoT
- We will focus on the tradeoffs between technologies
  - How they balance differing constraints
    - Power, spectrum, complexity, etc.
  - And the technical foundations of these designs and differences

Energy is *the* defining constraint of emerging technologies

By volume, the emerging computing classes are mostly energy storage

Volume is shrinking cubically





Pat's Take on the Internet of Things

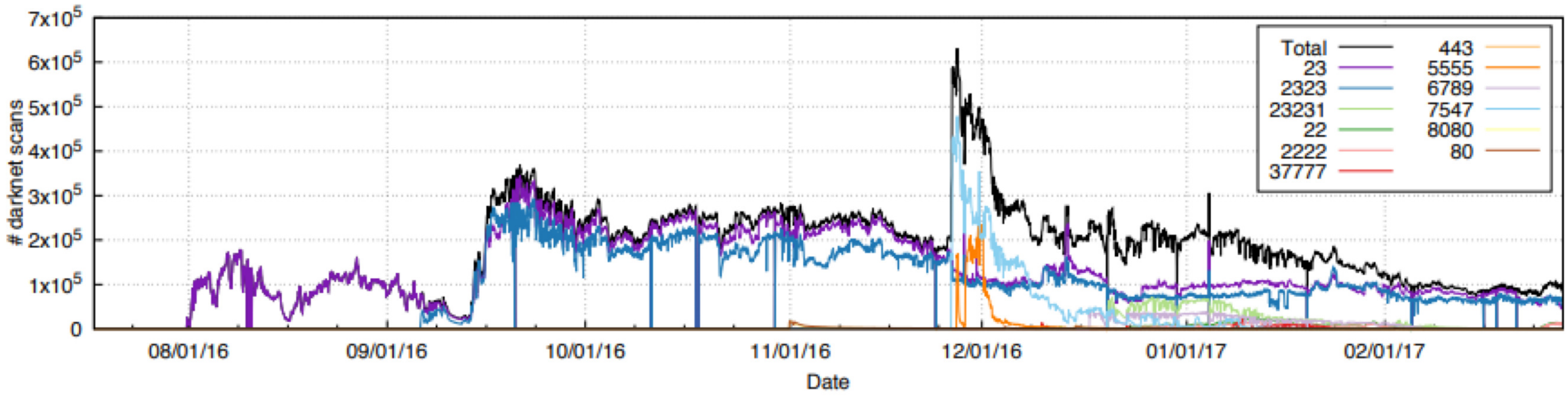
- Pretty literal
- My early grad school essays described the "last inch" problem
- Now I often say "expanding the reach of digital world"
- For me, it is about 'networked' 'things'
  - Which implicitly adds some computational capacity

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

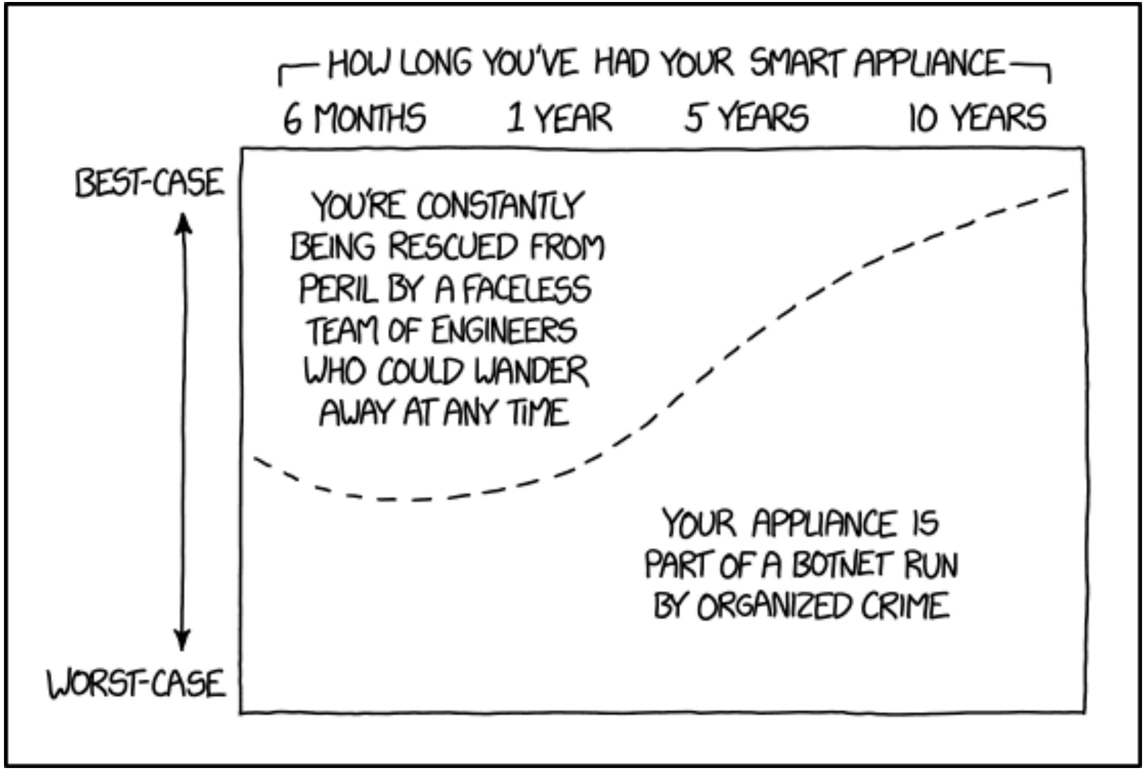
Warning: Internet of Crap

Internet of Insecure Crap



- Mirai botnet (2016)
- Takes control of up to 600,000 insecure connected devices
  - IP-attached cameras, DVRs, routers, printers
- Used to DoS websites

Break + xkcd



https://xkcd.com/1966/

Outline

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

General course structure

- Mondays and Wednesdays
  - Lecture and discussion about IoT communication technology
- Fridays
  - Labs
- **WARNING:** This starts to shift around a bit starting week 6
  - I tried pretty hard to make the agenda easy to read, but please be mindful
  - I'll also (try to remember to) send reminders

Asking questions

- Class and office hours are always an option!
  - Office hours by demand. I promise to meet!!

- Piazza
  - Post questions
  - Answer each other's questions
  - Find lab partners
  - Information from the course staff
  - Post private info just to course staff

- Discord?

Collaboration?
Experiential bits – Yes, please!

- This is an experience- and design-oriented course
  - Experience comes from labs (45% of grade)
    - This part is *highly collaborative*
    - You cannot talk to each other too much, *help each other out in the labs*
    - **One Rule:** *Hands on your own keyboards*
      - Don't copy/paste stuff
      - Don't do things for someone else, *explain how* to do it
      - (As a team) write up your pre-labs, post-lab reports with all your own work

Collaboration?
Design pieces – That's all just you

- This is an experience- and design-oriented course
  - Design comes from written assignments (15% HW, 30% Final = 45% of grade)
    - These you must do *on your own*
      - You can *talk* to others, but don't write anything down or look at anything they have written down
    - Guiding rule: Start from a blank piece of paper to prepare your final submission

Labs

- Semi-guided efforts of getting wireless communication working on real hardware
  - Wireshark
  - Bluetooth
  - 802.15.4
  - WiFi
  - LoRa

Pre-Labs

- Absolutely essential to success in lab
- Lab time is limited (just one hour!)
  - Must have pre-lab complete before lab to make lab successful
- Pre-labs are due by the start of lab, no exceptions, no make-ups

In-Lab

- Semi-directed activities
  - Some parts you will be expected to figure out
  - <u>Help each other!</u>
  - There are (aggressive) time estimates for each part, if you're falling far behind the estimates, *get help*
- Be sure to save your work as you go along
  - The lab guide will try to remind you

Post-Lab / Lab Writeup

- Each lab has a post-lab assignment, two parts inside
  - Report on your lab activities
  - Some extra questions related to lab activities
- Generally, due one week after the final in-class lab session

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At 20:00 US/Pacific (8:00 PM)

Access to the lab?

- You can come into the lab if it is not currently in use when convenient
- We will host our office hours in the lab
- The door code is in Canvas

- We are sharing the lab with Prof. Schulman's CSE 190A
  - Like us, they have a mixture of lecture days and lab days
  - It meets MWF, 10–11 and generally has office hours MWF, 11–12

- During non-class hours, will be a *mix* of students – be nice! ☺

What’s a Design Final?

- More on that later in the term
- Homework will give you some preparation and experience

- *There is no final exam for this course*

Mastery Grading

aka: no, there is not a curve

- My goal is to teach you the material and for everyone to learn it
- I am most successful if everyone in class *earns* an A

A+	A	A-	B+	B	B-	C+	C	C-	D
>96.7	[93,96.7)	[90,93)	[86.7,90)	[83.3,86.7)	[80,83.3)	[76.7,80)	[73.3,76.7)	[70,73.3)	[60,

- You earn in four categories:
  - 45% Labs
  - 30% Design Assignment (Final Exam)
  - 15% Homework
  - 10% Minute-Quizzes
- If you exceed the maximum in a category, %age over max is halved

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aka: no, there is not a curve

- My goal is t… …o learn it
- I am mo…

A+	A	…	C-	D
>96.7	[93,96.7)	…	[70,73.3)	[60,

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  - 45% Lab…
  - 30% Des…
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  - 10% Minut…
- If you exceed t… …a category, %age over max is halved

GIANT CAVEAT

This is a new class, so things may have to adjust some

Hey, what about that mini-quiz thing you snuck in there?

- Lecture will begin with a "minute-quiz”
- These will be (very) short and will cover material from the prior lecture, or possibly pre-lab, lab, post-lab, homework or other assignment
- You should not need to study or worry about these – if you were there and paying attention, you'll be prepared

- Correct quizzes earn 1%/ea, incorrect quizzes earn 0.5%/ea
  - Not counting today, there are **19** more lecture sessions
  - Everything >10% counts for half (i.e. max possible 14.5%)

Questions, Concerns, Confused?

- *Please*, go read the actual Syllabus

Wireless and Communication in the Internet of Things

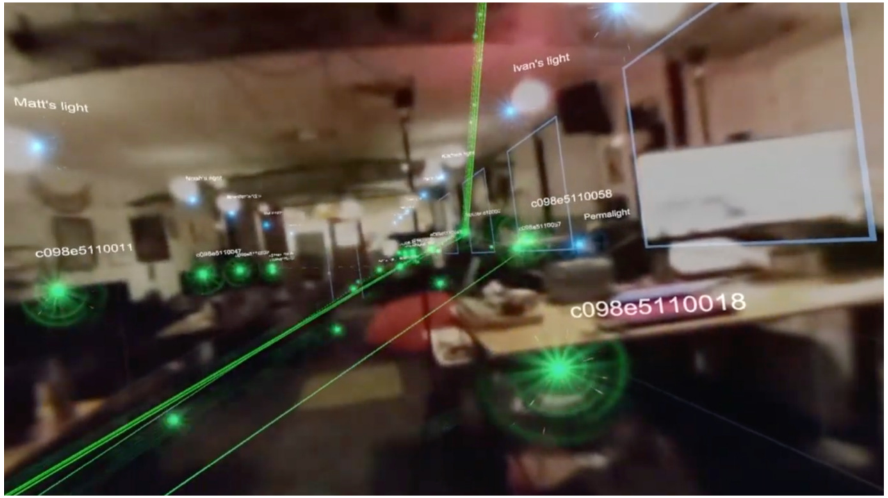
Home | Syllabus | Agenda | Labs

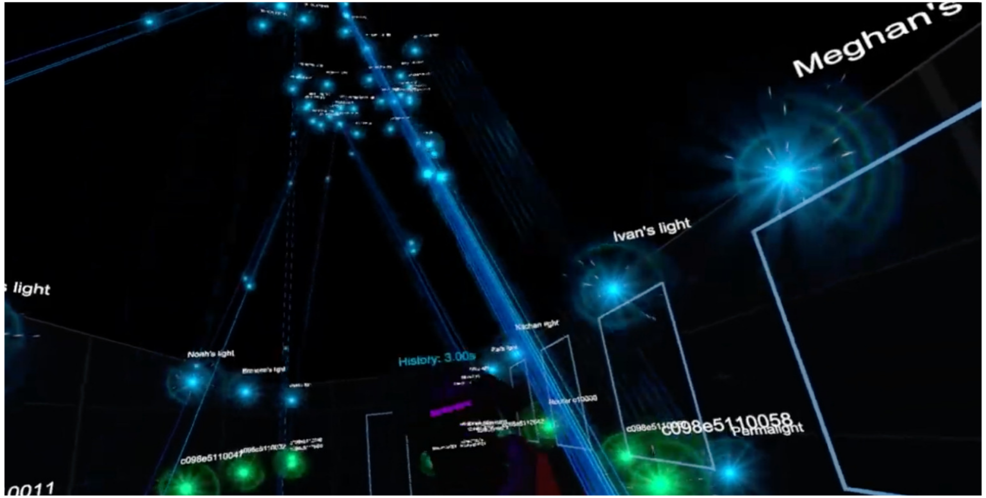
Syllabus

- Course Staff
  - What should you call me?
  - What should I call you?
  - TA - Nishant Bhaskar
- Prerequisites
- Textbook & Other Resources
- Schedule
  - (A?)Sychronous?, Remote?, Recordings?
- Grading
  - 10%: Minute-Quizzes
  - 45%: Labs
    - Pre-Labs
    - Post-Lab Reports

Break+Video

Wireless Network Visualization (Dr. Meghan Clark – UC Berkeley)
https://www.youtube.com/watch?v=KLOdp54_qJ4





Outline

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

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
- Non-RF wireless
  - Infrared communication
  - Ultrasonic communication
- 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!

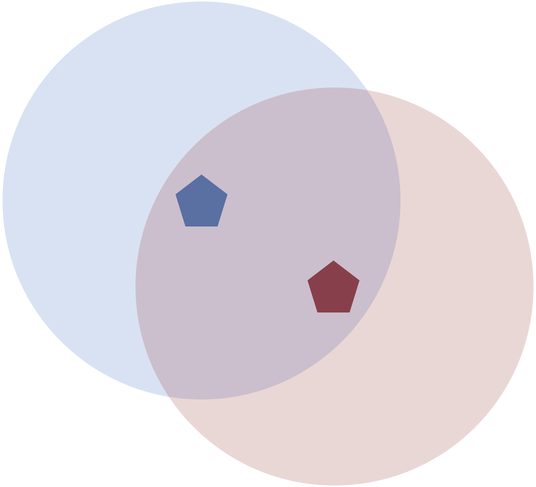
- Wired networks are constant, reliable, and physically isolated
  - Ethernet has the same throughput minute-to-minute
  - Bits sent through Ethernet or USB are (usually) received

- 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

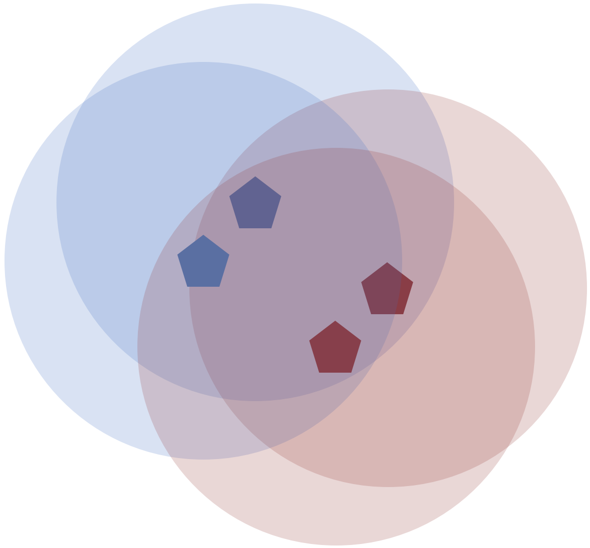
- Wired communication has signals confined to a conductor
  - Copper or fiber
  - Guides energy to destination
  - Protects signal from interference

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



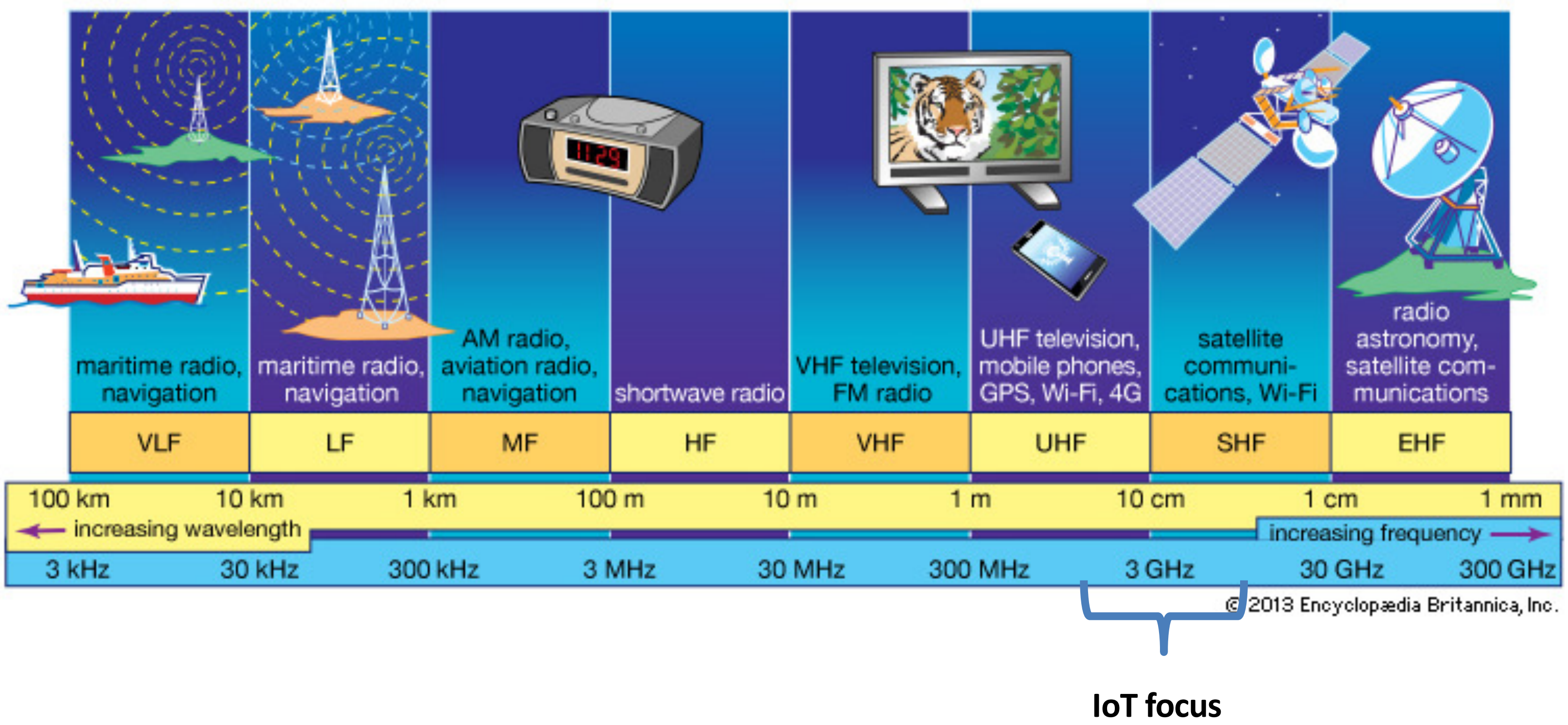
Increasing network capacity is challenging

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

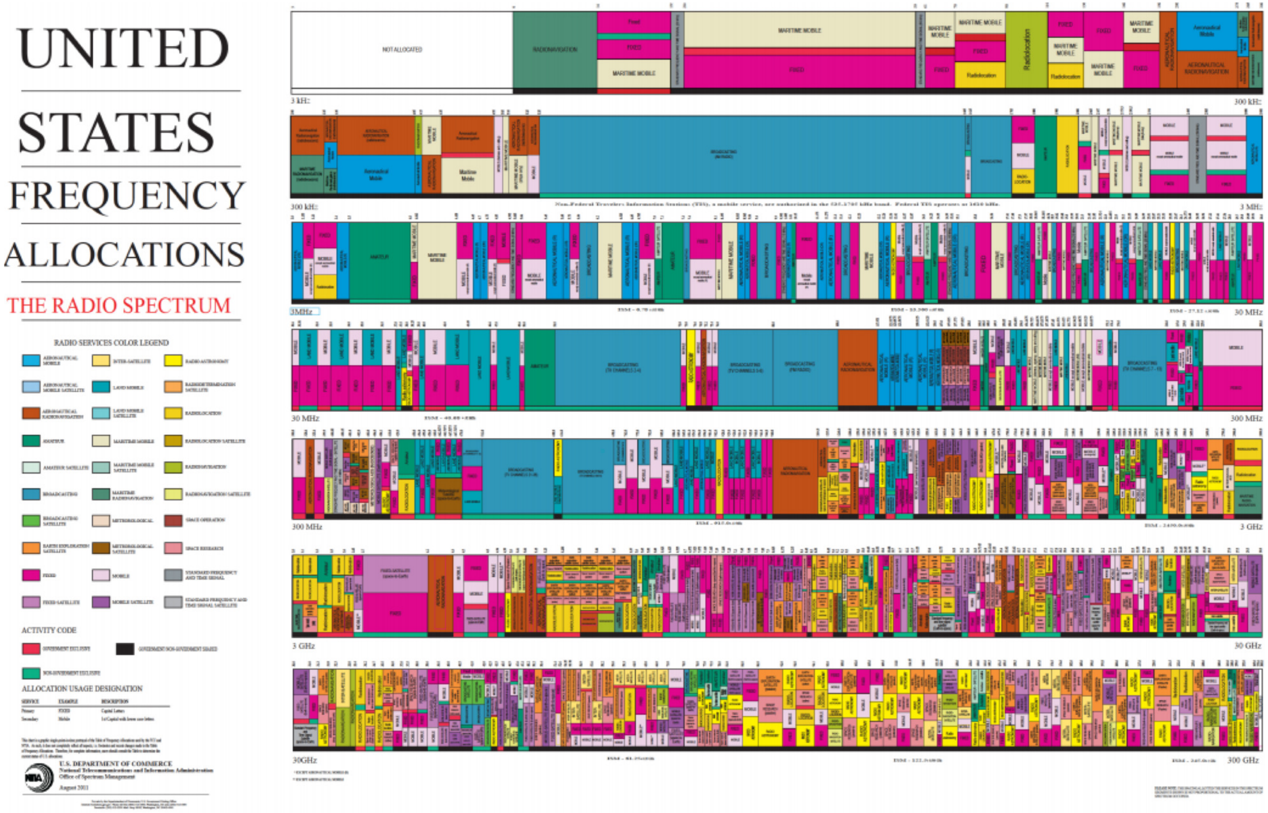


- Wireless networks are harder
  - Adding more links just increases interference
  - Need to expand to different frequencies

RF communication

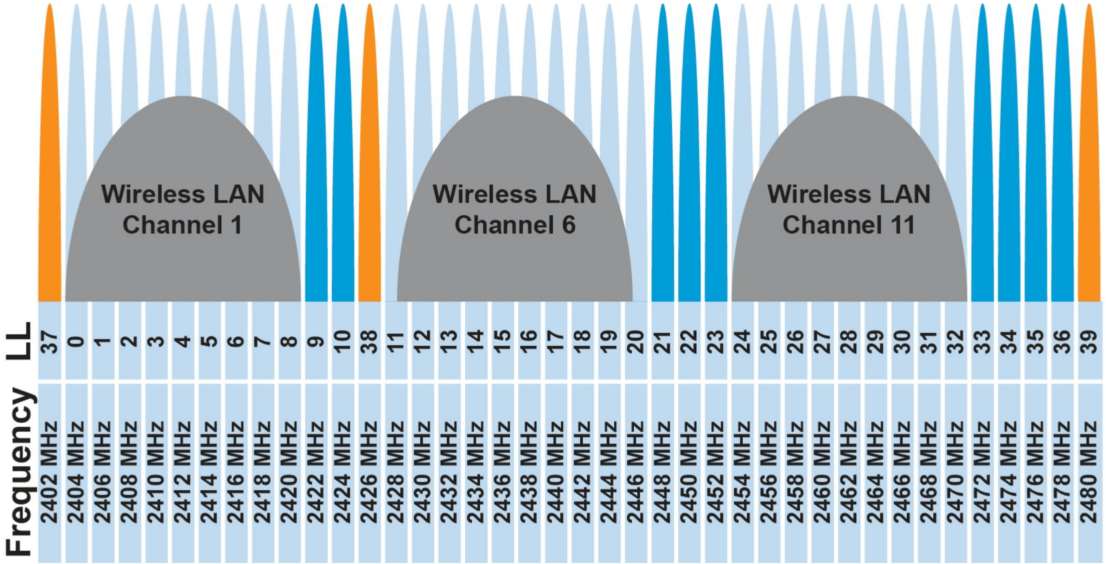


Wireless spectrum is allocated to specific uses



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

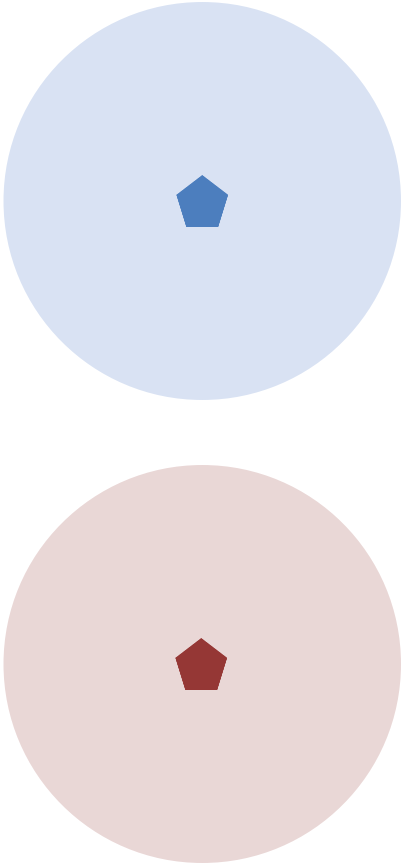


Model of RF communication

- 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 a decent chunk of CSE123 in one week

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Out now!

Homework 1, due in one week