Lecture 01
Introduction

CS397/497 – Wireless Protocols for IoT

Branden Ghena – Spring 2022

Materials in collaboration
with Pat Pannuto (UCSD)

COVID Update - Spring 2022 Edition

- Masks in class are no longer mandatory
  - You’re still welcome to wear one if you want, but I won’t make you
  - I’ll still be wearing one

- If you are sick, do not come to class
  - We will be flexible with deadlines as necessary
  - Lectures are being recorded automatically

Welcome to CS397/497!

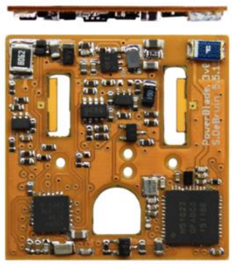
- ~37 students (25 undergrad, 12 grad)
  - Lots of different backgrounds and interests

- This is going to be like a graduate course
  - No exams!
  - Occasional paper reading
  - Majority of your grade is the final project

- This course is based on discussion and questions
  - Expect to attend classes, ask questions, and interact with others
  - You're hopefully here because you want to be and want to learn

Branden Ghena (he/him)

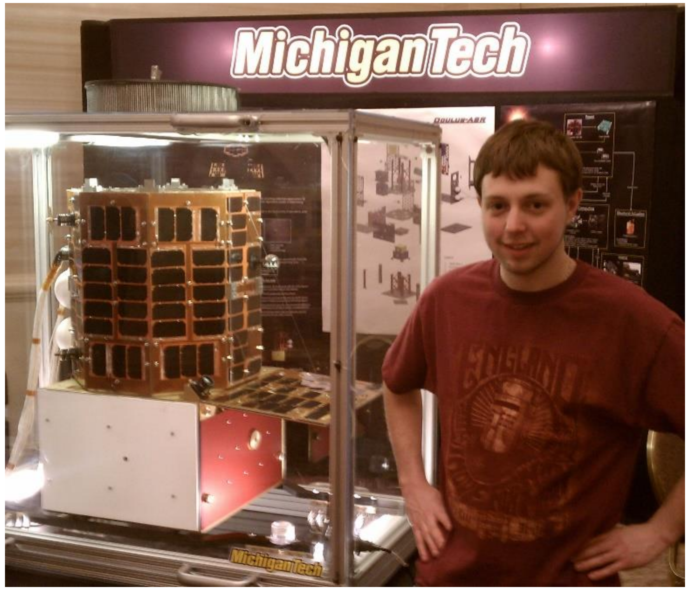
- Assistant Faculty of Instruction
- Education
  - Undergrad: Michigan Tech
  - Master's: University of Michigan
  - PhD: University of California, Berkeley
- Research
  - Resource-constrained sensing systems
  - Low-energy wireless networks
  - Embedded operating systems
- Teaching
  - Computer Systems
    - CS211: Fundamentals of Programming II
    - CS213: Intro to Computer Systems
    - CS343: Operating Systems
    - CE346: Microprocessor System Design
    - CS397: Wireless Protocols for the IoT



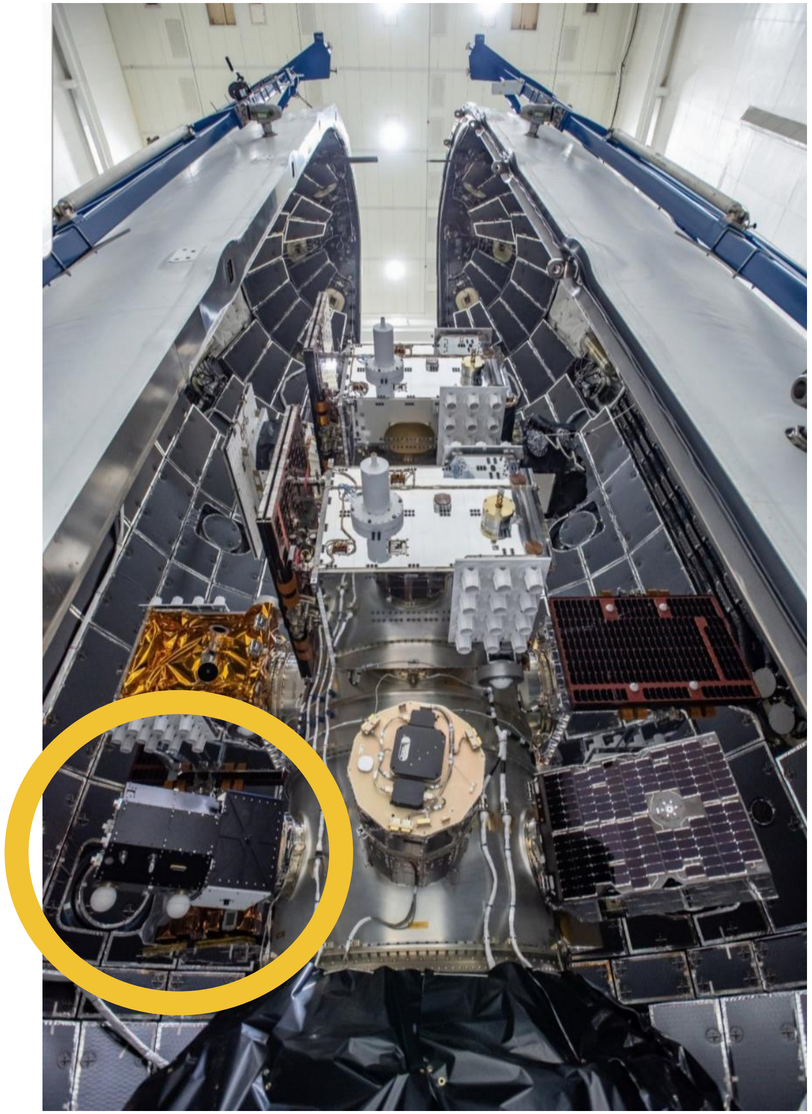
Things I love

Undergraduate: satellite radios and computers

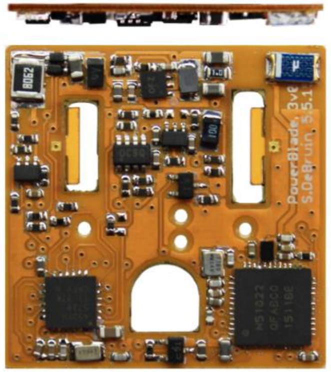
Oculus -Sat Uplink Command Budget:	NOTE:		Oculus -Sat Version: 2.4.1	Date Data Last Modified: 2011 October 12
Parameter:	*Value:*	*Units:*	*Comments:*	
Ground Station:				
Ground Station Transmitter Power Output:	50.0	watts	This value is transferred from "Transmitters" W/S, Cell [E15].	
In dBW:	17.0	dBW	Transmitter power expressed in dB above one watt	
In dBm:	47.0	dBm	Transmitter power expressed in dB above one milliwatt	
Ground Stn. Total Transmission Line Losses:	3.3	dB	This value is transferred from "Transmitters" W/S, Cell [I33]	
Antenna Gain:	16.3	dBi	This value is selected at "Antenna Gain" W/S, Cell [E11]	
Ground Station EIRP:	30.0	dBW	Ground Station Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]	
Uplink Path:				
Ground Station Antenna Pointing Loss:	0.3	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and transferred f	
Gnd-to-S/C Antenna Polarization Losses:	3.0	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from C	
Path Loss:	141.5	dB	Lp = 22 + 20LOG(D/l); Transferred from "Orbit & Frequency" W/S	
Atmospheric Losses:	1.1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]	
Ionospheric Losses:	0.7	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]	
Rain Losses:	0.0	dB	This value should be estimated by the link model operator and place into Cell [	
Isotropic Signal Level at Spacecraft:	-116.6	dBW	This is the signal level received in space in the vacinity of the spacecraft using	

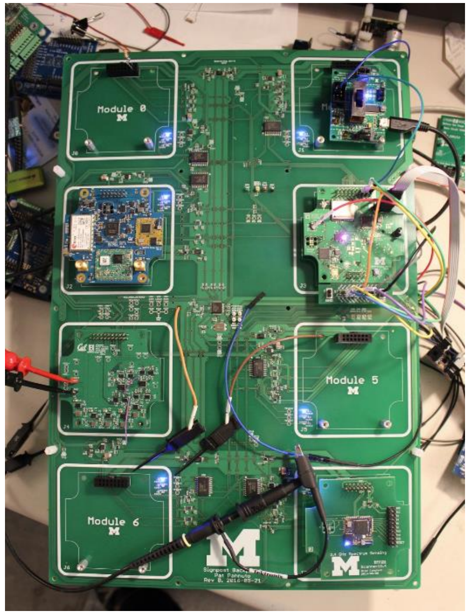


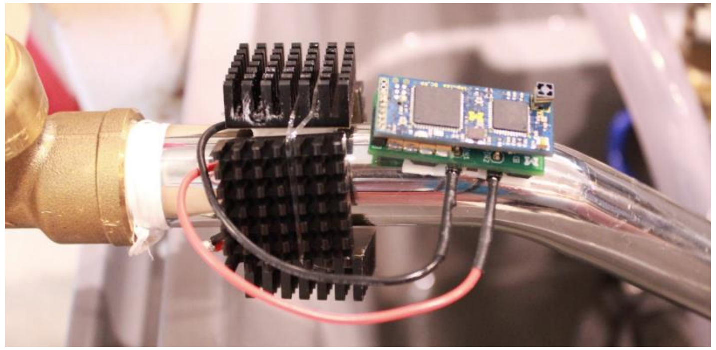
- How the heck are you supposed to learn this stuff?



Grad school: resource-constrained embedded systems







- Most interesting to me: the interfaces
  - Hardware and software
  - Applications and OS
  - Communication
- Again: learn by doing
  - With significant assistance from my peers

Faculty: now I can choose what to teach!

- Goal: provide classes that teach more advanced embedded systems topics
  - Hopefully, generally useful to other nearby domains of CS and ECE too!

- Result: this course!
  - Course goals: make students familiar with a number of different wireless protocols and their tradeoffs
    - Practical hands-on experience with some networks
    - Open-ended project where students can choose their specific focus

Today's Goals

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

Outline

- Who and Why
- **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

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 an entire desktop?
  - 8-core x86-64 processor, 32 GB RAM, 1 TB SSD
- Would that still count as IoT?
- Why don’t we see that in practice?

Thought experiment on capabilities

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Cost

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?

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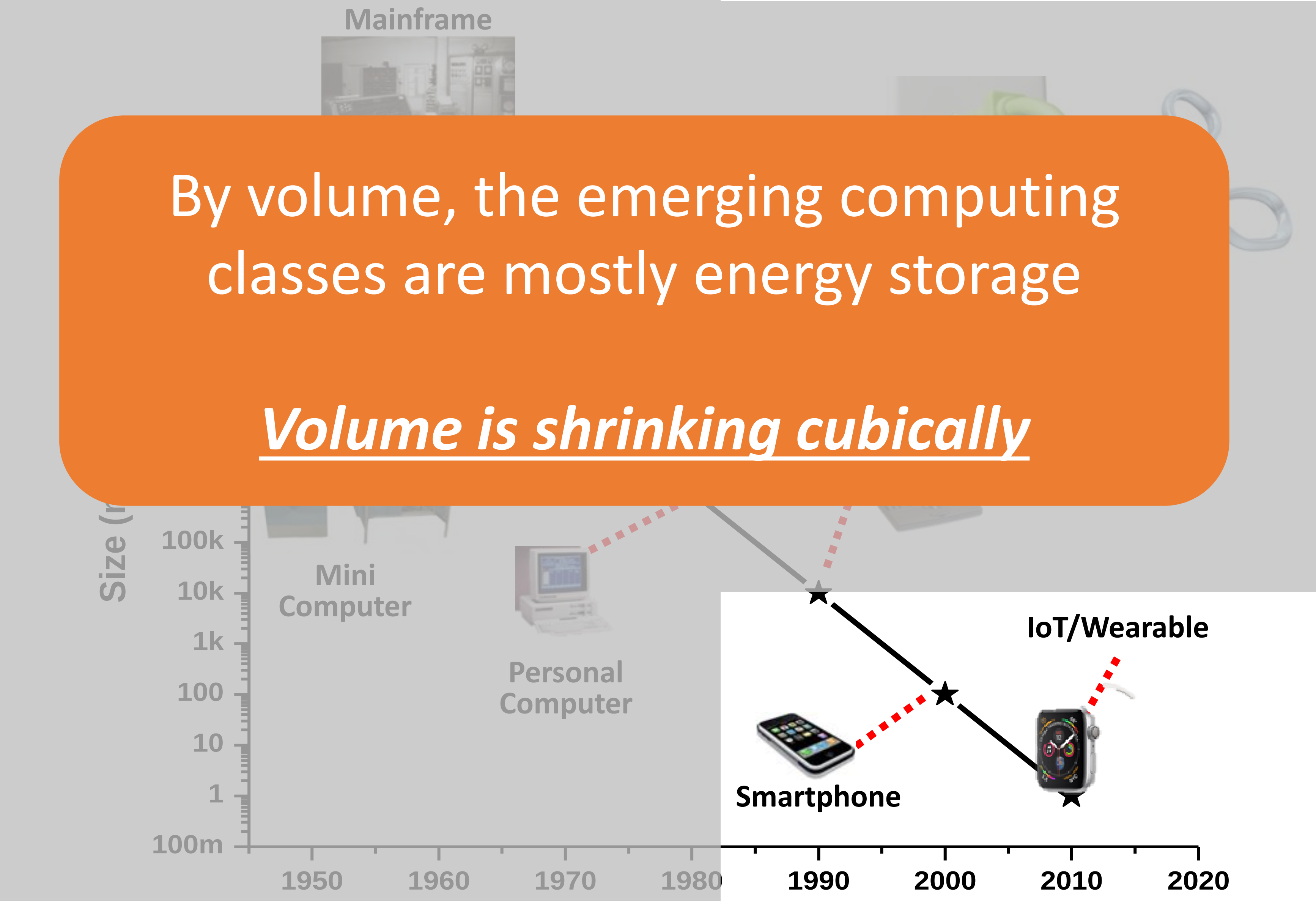
Deployability

Largest IoT challenges: *power* and *communication*

- This class is about wireless technologies
  - For resource-constrained systems, such as the IoT

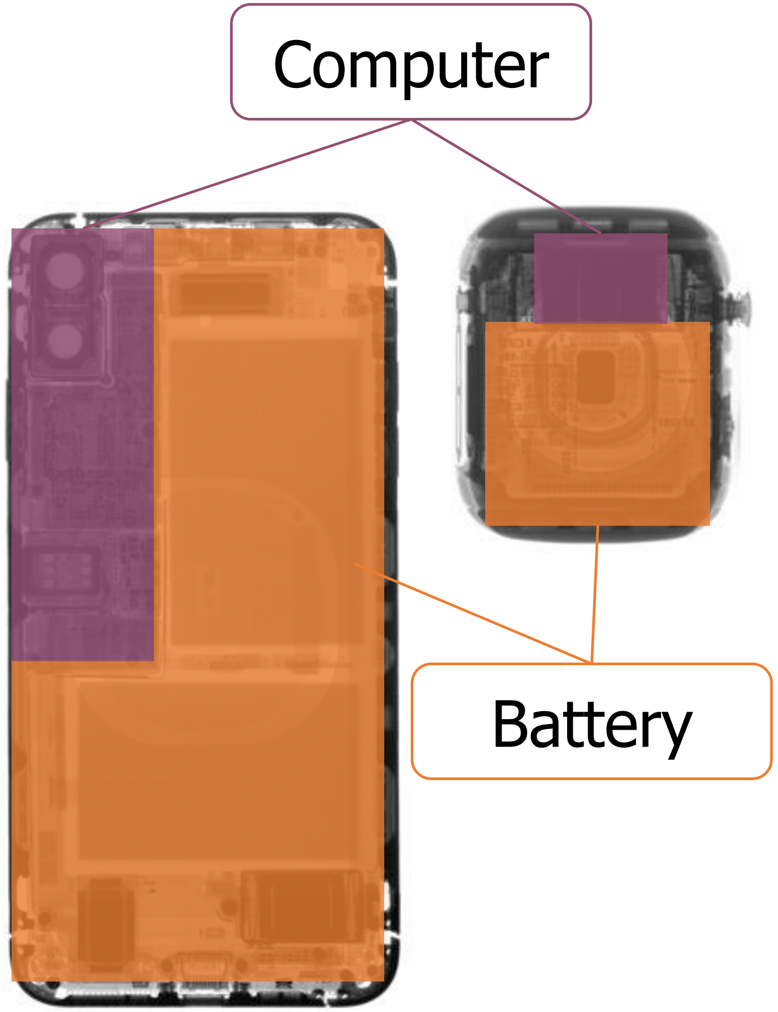
- We will focus on the tradeoffs between technologies
  - How they balance differing constraints
    - Power, spectrum, complexity, etc.
  - And the technical foundations of these designs and differences

Energy is *the* defining constraint of emerging technologies



By volume, the emerging computing classes are mostly energy storage

Volume is shrinking cubically



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

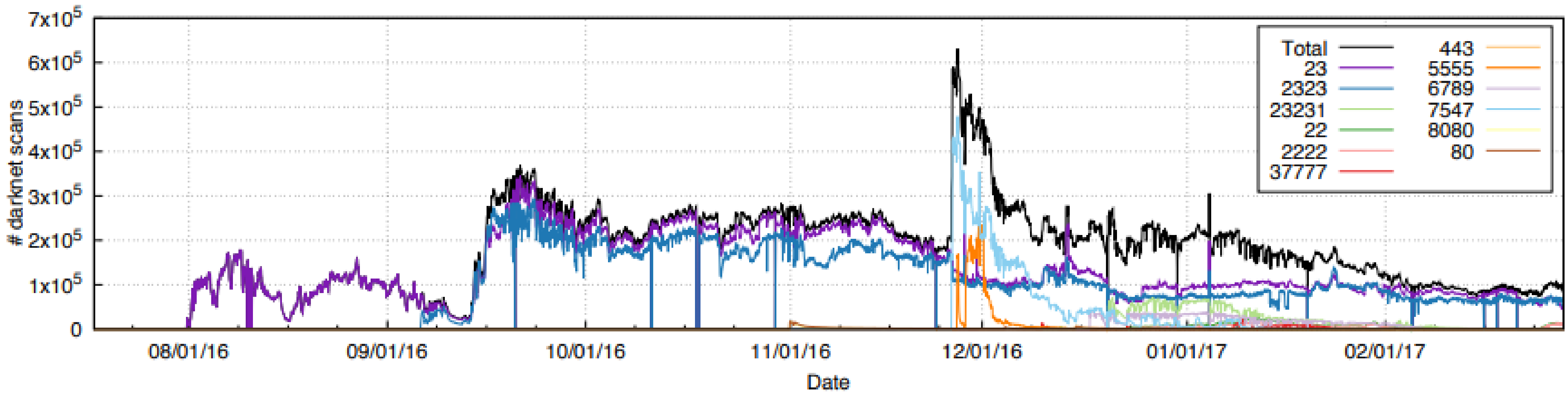
Pat Pannuto’s take on the Internet of Things

- His early grad school essays described the “last inch” problem
  - Now he often says “expanding the reach of digital world”
- For him, it is about ‘networked’ ‘things’
  - Which implicitly adds some computational capacity
    - [Though not always? Backscatter sensors break this definition…]

Assistant Professor, UC San Diego
https://patpannuto.com/

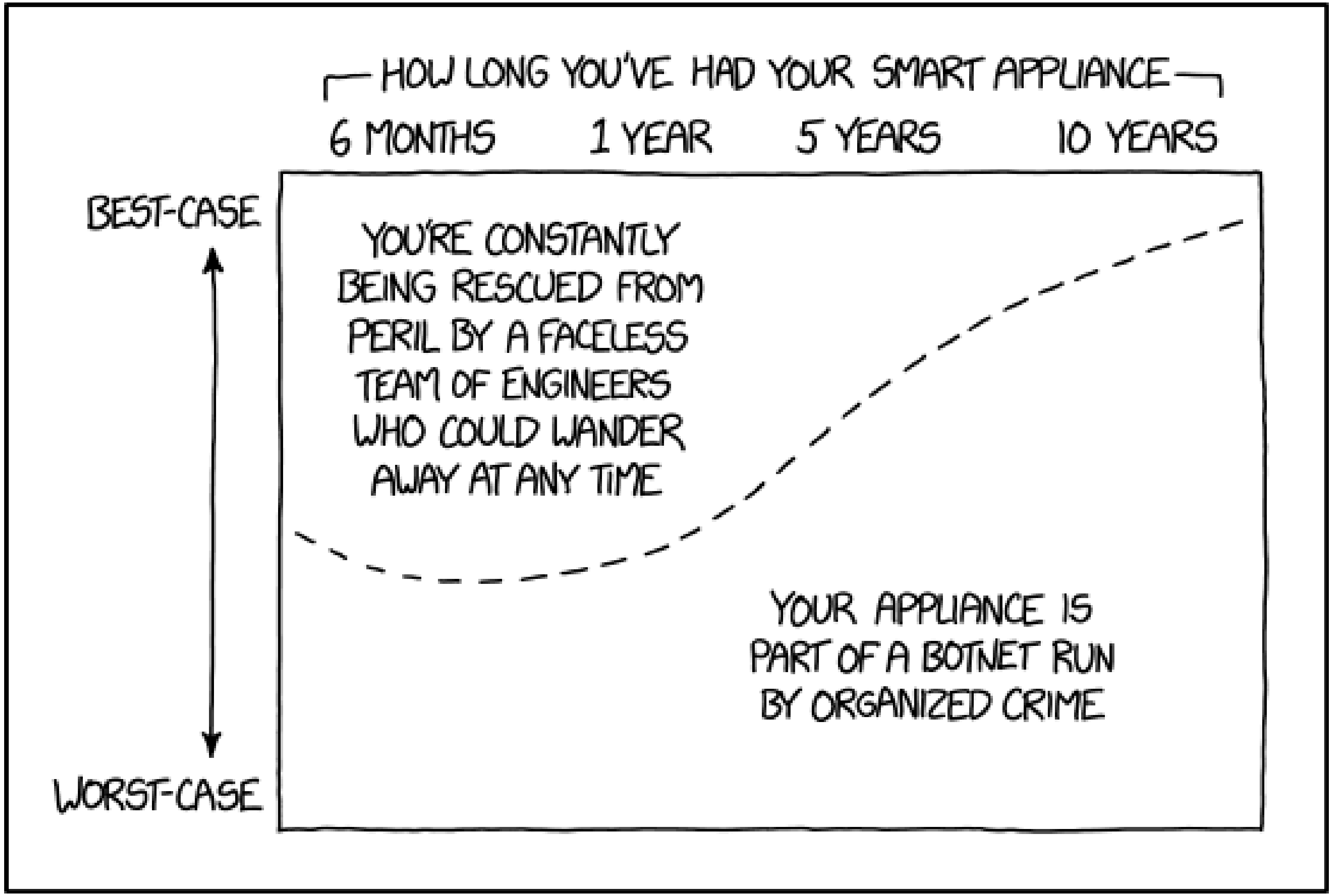
Warning: Internet of Crap

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/

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Asking questions

- Class and office hours are always an option!
  - Office hours by demand. I promise to meet!!
- Campuswire: (similar to piazza)
  - Post questions
  - Answer each other's questions
  - Find lab partners
  - Information from the course staff
  - Post private info just to course staff
- Please do not email me! Post to Campuswire instead!
  - I'll be updating roster again a few times

Grading

- Seriously, 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

- 35% Lab projects
  - Likely 7 of these, divided equally

- 65% Final project
  - 10% Proposal
  - 05% Update Meeting
  - 10% Presentation
  - 10% Paper
  - 30% Project Quality

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Labs

- Practice interacting with and considering networks

- Sometimes getting real hardware working
  - BLE Scanning/Advertising, BLE Connections, OpenThread Lab

- Sometimes analysis and designing
  - Wireshark, WiFi Analysis, Cellular Cost, Sensor Network Design

- Might be able to start these in-class, but likely will be done outside of class
  - Can definitely be done in small groups (up to three students)
  - Some will require it (due to hardware availability)

Lab grading

- Around one page submission on canvas
  - “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.
  - Possibly answer some questions and write up thoughts.
  - **NOT** a formal lab writeup

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

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Project

- Classic grad school “do a project”

- Come up with something you’re interested in exploring that is linked to the topics of class
  - Definitely acceptable to overlap with research or other classes
  - Work in small groups of 2-4 students

- This is your chance to decide what you’re actually interested in and to guide your own learning
  - Expectation is that you’ll do a serious deep dive into it

Project proposals

- Proposals due Friday, April 22nd
  - Three weeks from tomorrow
  - Want to provide plenty of time to work on the project
  - And also to order hardware if necessary

- Start thinking about project ideas and finding partners now
  - Preferably two-four people. One or Five+ would need justification.

- I am very happy to talk about ideas during office hours
  - Goal is that we'll have talked about it at some point *before* you submit the proposal

Project ideas

- Analyze and optimize a deployed network
  - Measure throughput, packet loss, or latency, etc.
  - Determine how to improve network for an application use case
- Implement and evaluate a modified network protocol
  - Change something about the specification of an existing protocol
  - Measure the effect that it has on a deployment
- Implement software library for a protocol
  - Especially for anyone that took CE346
  - Implement BLE Advertisements or 802.15.4 on top of Microbit

Project ideas

- Simulate a wireless network
  - Accurately predict throughput, energy, latency, etc.
  - Could be done in any language or platform (e.g. NS-3)

- Visualize network performance
  - Provide tools for understanding and debugging performance
  - Real-time or historical snapshot

- Many other possibilities. Don’t feel limited by these!

Hardware for projects

- Talk to me about your needs, and I might have ideas or things to lend out that will help
  - I’ve got lots of random stuff on hand, as does Josiah Hester

- We have *some* budget for ordering project hardware
  - Talk to me about what your project needs would be
  - Make sure that hardware *is* actually purchasable

Project presentations and report

- Presentations will be the last week of classes
  - During lecture Tuesday and Thursday
  - (may revise this based on the number of groups)

- Reports will be due during exam week
  - Up to 6 page “workshop paper” writeup

Break+Video

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

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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 5 years: Sigfox and LoRaWAN
  - Cellular technologies in last 2 years: LTE-M and NB-IoT

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

Extras

- This space is very much still an area of active research

- 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!
  - Reach out and tell me what you want to learn about

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!

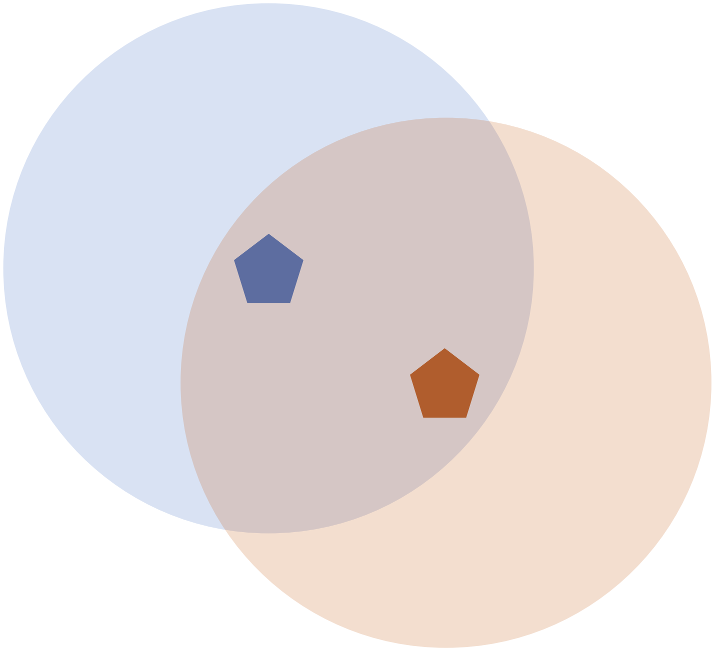
- Wired networks are constant, reliable, and physically isolated
  - Ethernet has the same throughput minute-to-minute
  - Bits sent through Ethernet or USB are (usually) received

- 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

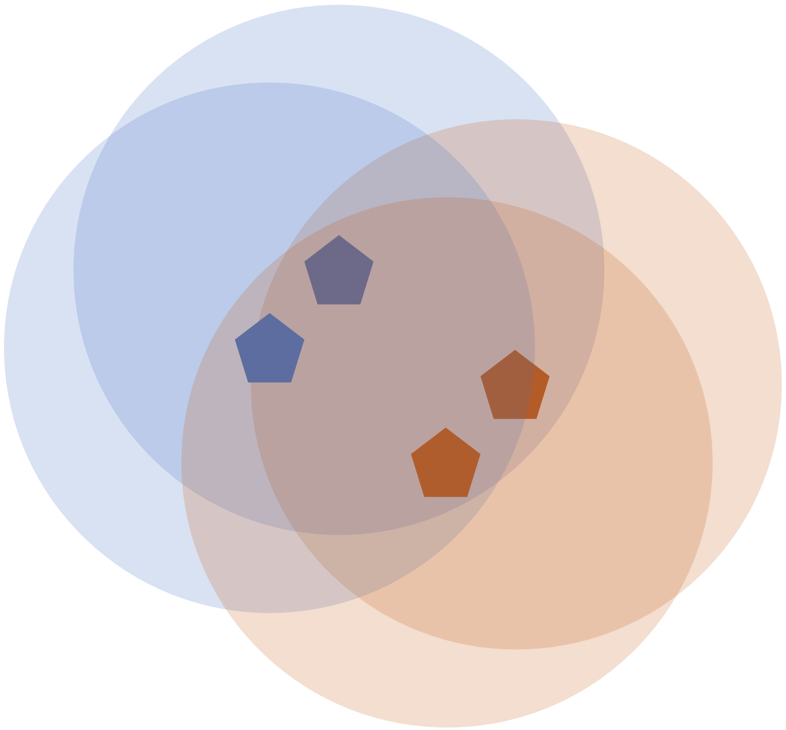
- Wireless communication is inherently broadcast
  - Energy is distributed in space
  - Signals must compete with other signals in same frequency band



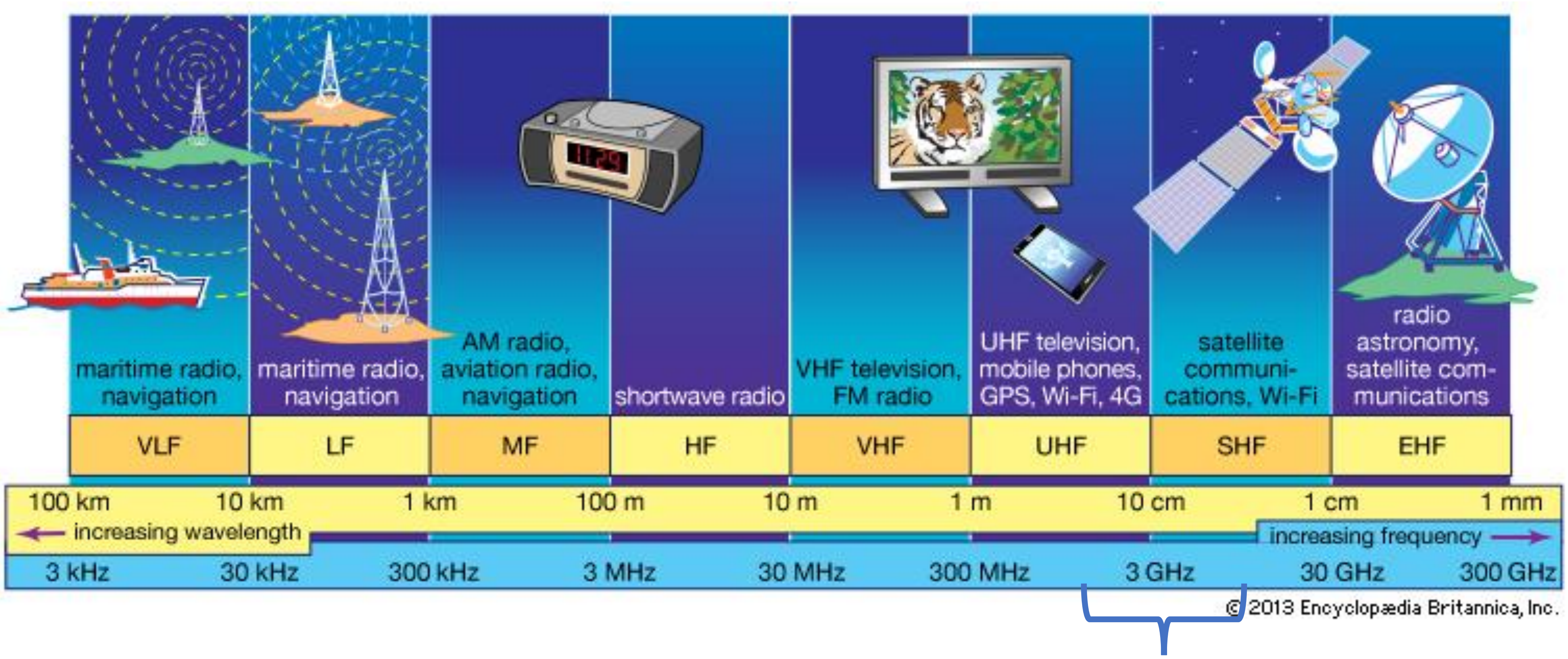
Increasing network capacity is challenging

- 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

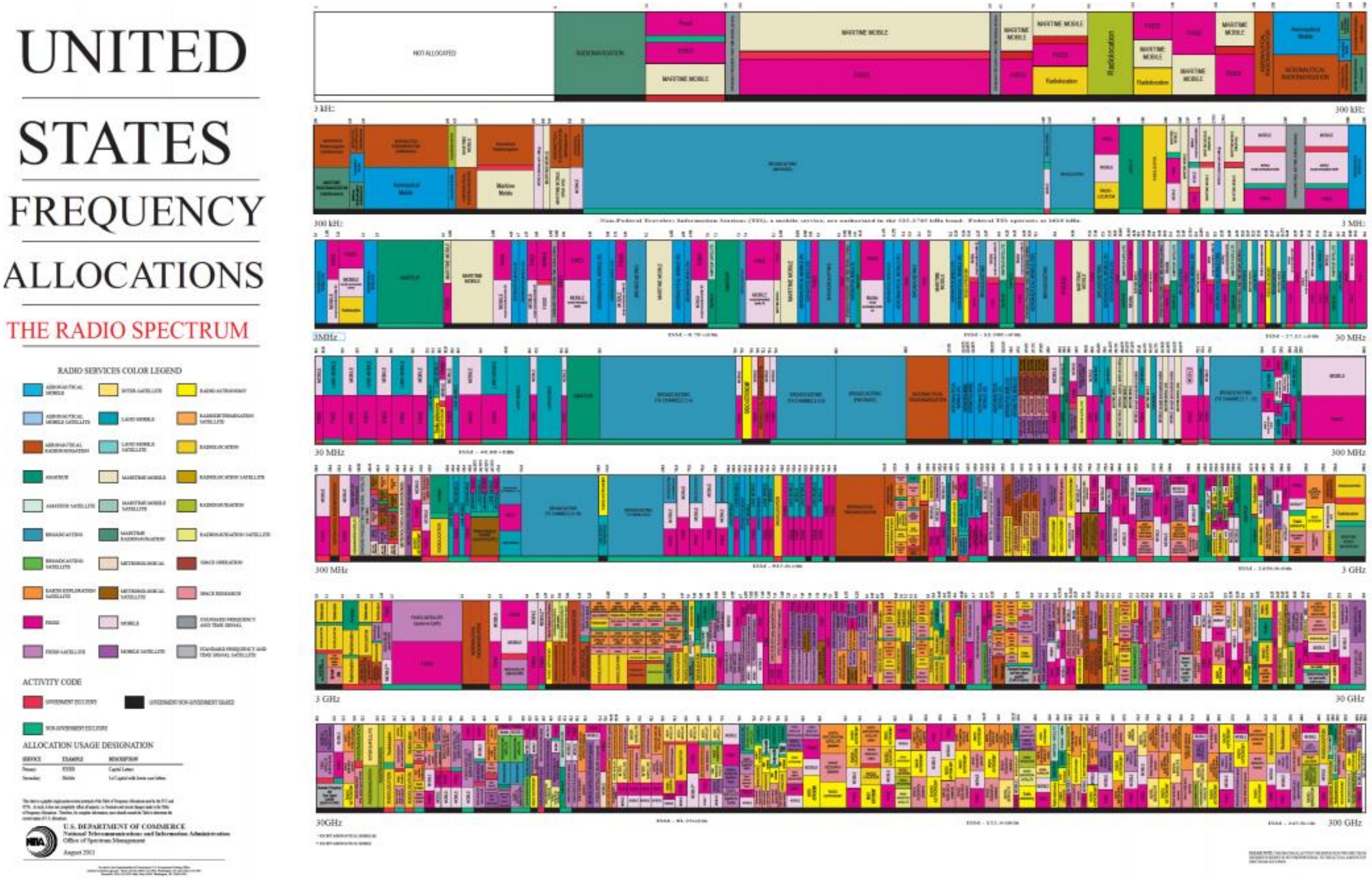


RF communication



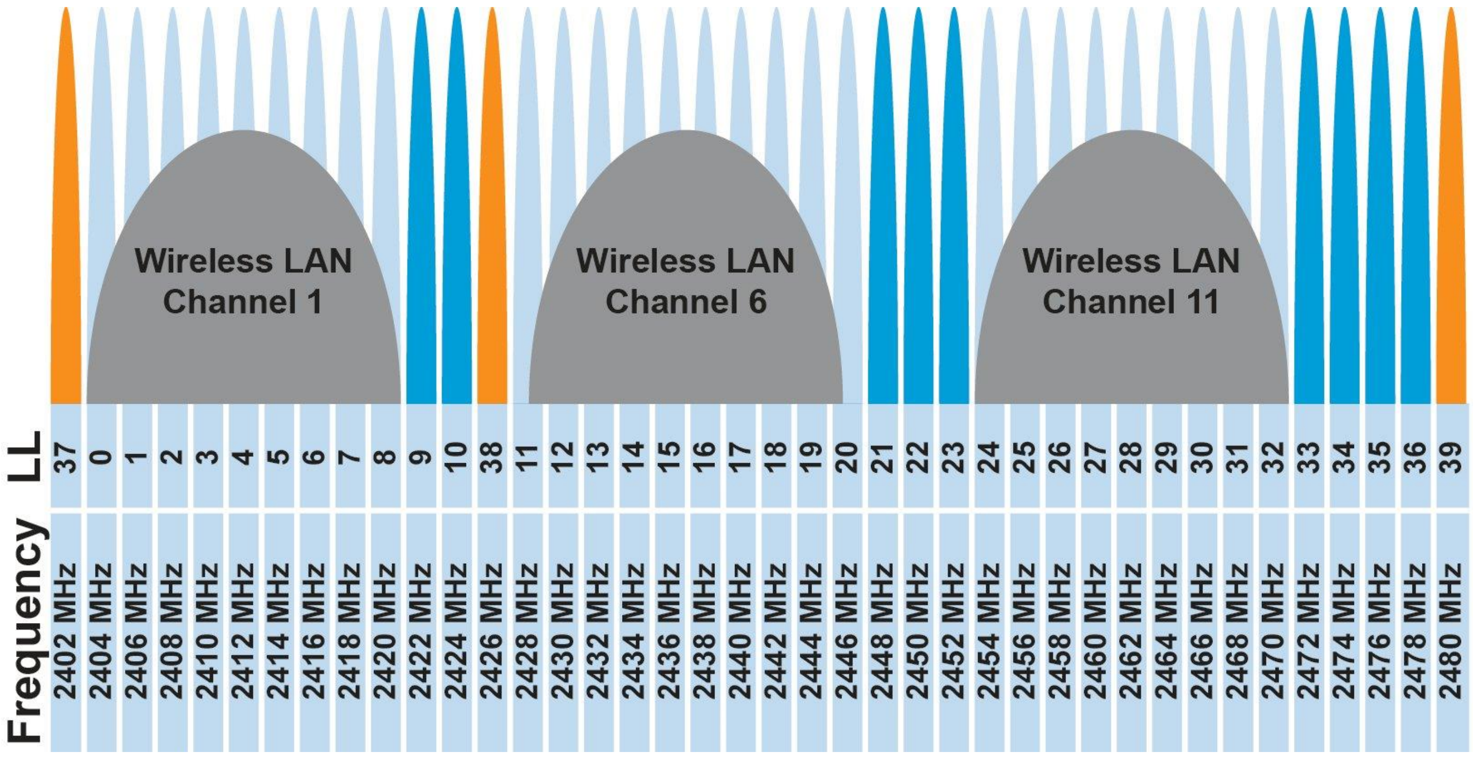
IoT focus

Wireless spectrum is allocated to specific uses



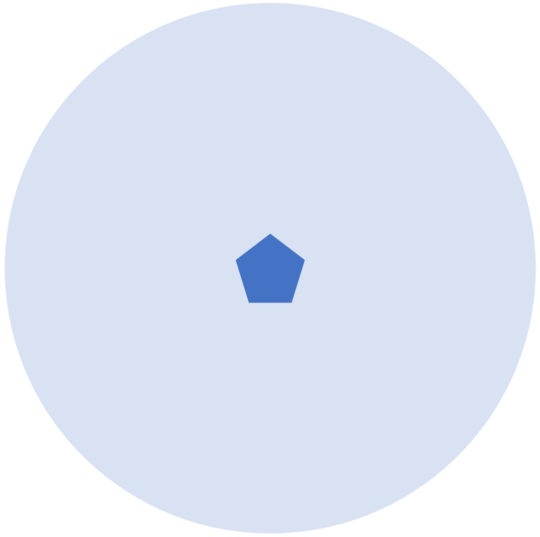
Unlicensed bands are where IoT thrives

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



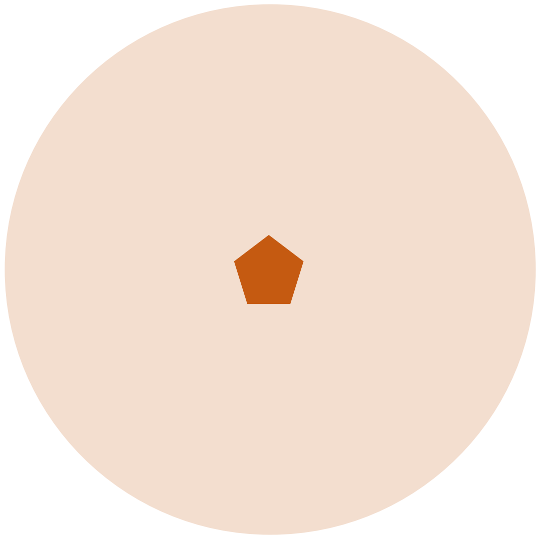
Model of RF communication

- 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



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