Experiences Teaching a Wireless for the Internet of Things Course Cooperatively at Multiple Universities

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Agenda

- The “Wireless for IoT” Course
  - Motivation: Why this Course?
  - Course Overview

- The Experience Report
  - Motivation: What’s unique about this Experience Report?
  - Course Design Insights
  - Student Feedback

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IoT is growing rapidly, we need more trained IoT engineers

Projected 100s of billions connected devices by 2030[1]

Requires a new cohort of trained IoT engineers

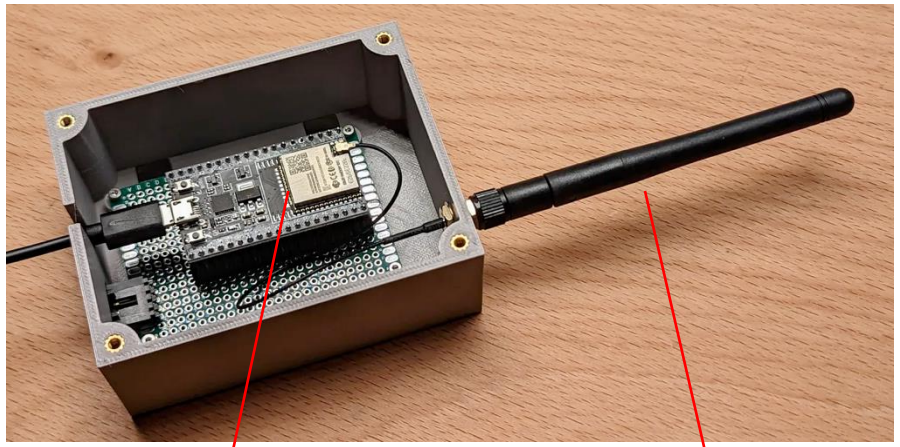
Images AI generated from Microsoft Designer

What entails training a good IoT engineer?

IoT engineers need to know:

1. Embedded systems know-how & programming experience

2. How to analyze and pick an IoT wireless protocol at design time
   - So many wireless protocols with different characteristics
   - Know framework to evaluate tradeoffs and identify best option for use case



(1) Embedded Programming

Bluetooth WiFi zigbee THREAD LoRa ...

(2) Choosing a wireless protocol

Why is training an IoT engineer a difficult pedagogical challenge in CS?

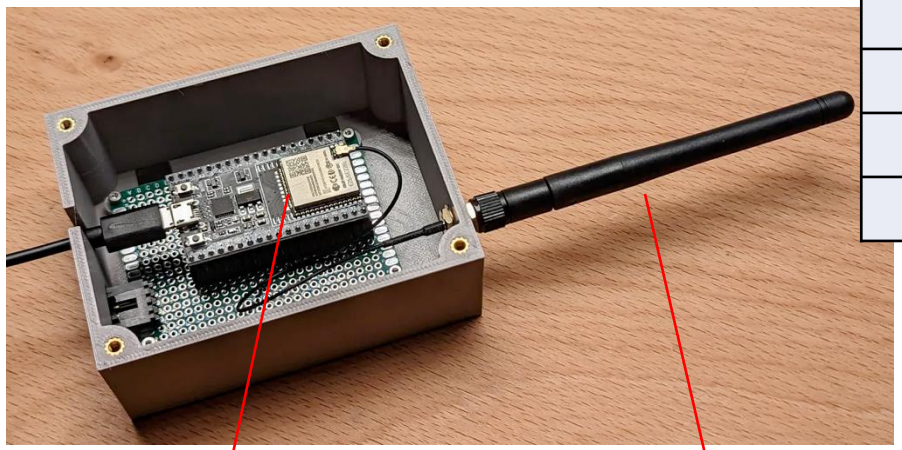
IoT engineers need to know:

1. Embedded systems know-how & programming experience

At the intersection of CS and EE, not very accessible in current CS curricula

2. How to analyze and pick an IoT wireless protocol at design time

- Low-resource nature of IoT => higher coupling between layers
  - Other computing platforms: layers are better abstracted (eg: cloud app)
- Challenge to tackle in CS classrooms as very interdisciplinary



Application
Transport
Network
Data Link
Physical

(1) Embedded Programming

...

(2) Choosing a wireless protocol

Deciding a Wireless Radio and Protocol for your Use Case Major Design decision

- Let's take a look at some of these IoT wireless protocol options:

	Bluetooth Low Energy (BLE)	**LoRaWAN**	**WiFi**
Range	100m (~300ft)	3 miles (4.8 km) urban areas	70m (~230ft)
Throughput	0.27 Mbps – 1.37 Mbps	1 kbps to 20 kbps	450 Mbps – 9.608 Gbps
Transmission Power	8 dBm (6.3 mW)	20 dBm (100 mW)	20–30 dBm (100 mW – 1W)

- Opportunity for students to learn from these tradeoffs!

Train IoT Engineers by Focusing on the Diversity in Wireless Protocols

- New wireless-focused IoT course: Wireless for the Internet of Things (WIoT)

- Focus on wireless and networking aspects of IoT, which enables two things:
  - Students analyze rich design-space tradeoffs as they learn how IoT systems are built
  - Provide a unique, hands-on programming experience for students

- Importantly, not an embedded systems course
  - Accessible for computer scientists, computer engineers, and electrical engineers

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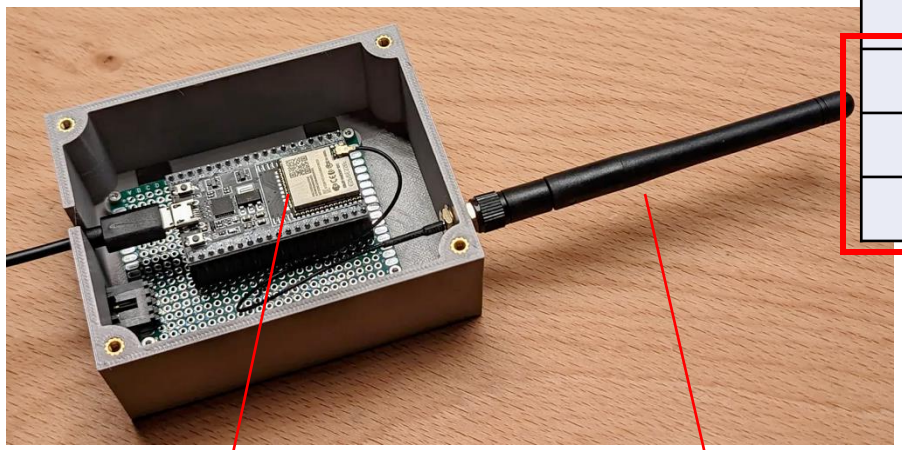
WIoT Course Overview

- Introduce PHY layer and modulation to explain tradeoffs among bandwidth, range, bitrate, and reliability (does not cover math foundation)
- Introduce MAC layer and network topologies to teach pros and cons of different wireless IoT protocols
- Hands-on programming on how to build IoT applications using wireless protocols



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(1) Embedded Programming

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Quick Glance: Course topics

- To explore design space of wireless networks we include course modules on:
  - Point-to-point networks (Bluetooth Low Energy)
  - Mesh networks (IEEE 802.15.4 and Thread)
  - Hub-and-spoke networks (WiFi)
  - Long-range networks (LoRa and 4G/5G cellular)

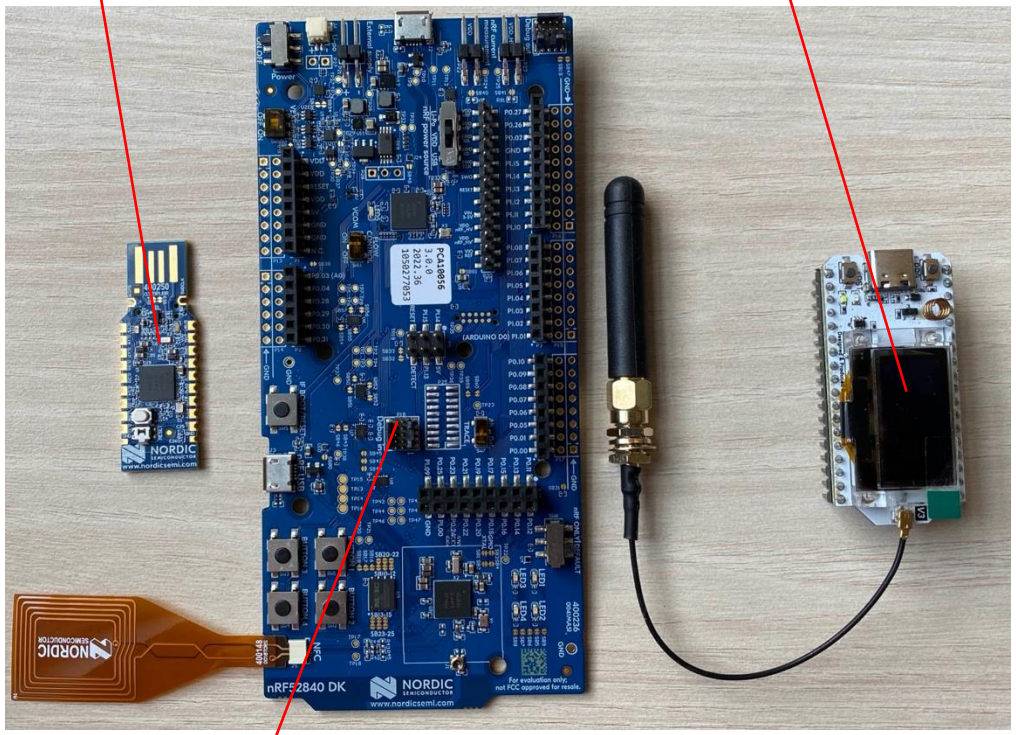
- Introduce topics in lectures
- Reinforce learning with in-class and out-of-class hands-on labs/assignments

- Introduce students to additional specialized wireless protocols:
  - Visible Light Communication (VLC)
  - Citizens Broadband Radio Service (CBRS)
  - Sigfox
  - Cellular IoT (LTE-M and NB-IoT)

Students Work on Similar Hardware to What People Use in the Industry

(2) Nordic nRF52840 Dongle

(3) Heltec WiFi LoRa 32 v3



(1) Nordic nRF52840 Development Kit

(1) Nordic nRF52840 Development Kit ($50)

(2) Nordic nRF52840 Dongle ($10)

- Has support for:
  - Bluetooth & Bluetooth Low Energy (BLE)
  - 802.15.4
  - Thread
  - NFC

(3) Heltec WiFi LoRa 32 v3 ($20)

- Has support for:
  - WiFi
  - LoRa
  - Bluetooth & Bluetooth Low Energy (BLE)

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What is Unique About this Experience Report?

- Presents course design insights and lessons learned teaching WIoT
- Offered 6 times by multiple instructors at 3 R1 universities

	Northwestern		UCSD			UVA
Duration	10-week quarter		10-week quarter			16-week semester
Level	Undergrad	Grad	Undergrad	Grad	Professional Master's	Undergrad
Enrollment (latest offering)	20	13	19	13	7	58
Major	CS: 12 ECE: 6 Other: 2	CS: 3 ECE: 3 Other: 7	CS: 9 CE: 10 EE: 0	CS: 9 CE: 4 EE: 0	CS: 2 CE: 0 EE: 5	CS: 53 CE: 2 EE: 3

- Similar IoT courses exist, but either not with a focus on wireless [1,2], or don't have experience reports [3,4]

1. Farha N. Ali. 2018. Experiences in Teaching the Internet of Things Courses. SIGCSE '18.
2. Hanna Mäenpää et al. 2015. Blending Problem- and Project-Based Learning in Internet of Things Education: Case Greenhouse Maintenance. SIGCSE '15.
3. Peter Steenkiste. 2023. CMU 18-452/18-750: Wireless Networking and Applications.
4. Haitham Hassanieh. 2023. UIUC ECE 439 (Spring 2021): Wireless Networks.

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Focus on Wireless Instead of Embedded Key to Attract More CS Students

- Hands-on learning requires embedded devices but CS students not familiar with embedded systems development
- Make embedded programming accessible
  - Use simpler programming environments like Arduino
  - Use homework and references to bridge gaps in low-level C programming
- Switch focus from embedded to wireless makes lecture-lab separation better
  - Lectures: teach wireless concepts, not embedded programming
  - Labs: student implement learned wireless concepts on actual devices
- Impact: Attracts more CS students, can remove embedded systems experience as pre-req.
  - UCSD, UVA: no specific pre-req., only ‘some upper-level CS systems experience’.
  - But can be enforced too: Northwestern requires embedded systems/computer networking.

Feedback: Attracts more CS students

- Students appreciated that this course was accessible to CS students.
  - “The course did a good job of addressing concepts so people from a wide range of backgrounds could learn. While I was already familiar with access control, packets, some wireless basics like modulation and such, if I hadn’t, I believe I would have picked up that throughout the course.” (Northwestern)

- Students valued the opportunity to learn topics outside of CS
  - “Lots of hands on time with the dev kits gave me, personally, a really fresh experience I hadn’t gotten before and there was a lot I got to learn from it.” (UVA)

  - “I’m honestly kinda surprised it’s listed solely as a CS course just because a lot of the class is about how information is encoded onto radio waves and the physical challenges involved in sending and receiving waves without interference or in ways that are resilient to disturbances. You definitely learn about a lot of cool things, and it would definitely give you enough knowledge to get started doing IoT things.” (Northwestern).

Sharing Hardware Enables Creative Freedom when Designing Labs

- Hardware courses major teaching burdens, esp. when offered at a single university
  - ‘Small’ hardware issues add up, hard to identify due to reduced offering frequency (e.g.: annually)
- When offered across institutions, allows a more aggressive cadence, and shortens time for breaking changes to accumulate
- Our initial assumption: Hardware sharing not essential Turned out to be mostly false!
  - Would reduce overhead, but only if we use same lab assignments
- Every idea, lab, or assignment: immediate starting point for others
  - Allows customization and being more creative: UVA Programming Assignments
  - Eases burden when things do go wrong: LoRa lab

Insight #3

Modularity of topics and Time helped Quarter → Semester/Prof. Master's

- Wireless Protocol: Provides a "grab-bag" of topics
- For the semester offering, we added:
  - Guest Lectures: Invited industry experts and researchers
    - Cutting-edge IoT topics like Wakeup-radio networks, Visible Light Communication, and 4G over Navy channels
- For the Professional Master's program:
  - Four 50 min lectures → One 4 hr. morning session + 4 hr. afternoon session
    - Includes time to complete bulk of lab work in class
  - Do unfinished lab work at home (quarter system already designed that way)

Adaptable to different types of offerings

	Northwestern	UCSD	UVA
Lectures	✓	✓	✓
Labs	✓	✓	✓
Programming Assignments	✓		✓
Homework	✓	✓	✓
Mini Quizzes		✓	✓
Final Exam			✓
Design Project	✓	✓	
Implementation Project			✓
Guest Lectures			✓

Insight #4

Typical Pedagogical Components may Need Tweaking for the Quarter Schedule

- Labs:

UVA (Semester)	UCSD (Quarter)	Northwestern (Quarter)
• Dedicate roughly one in-class session weekly for labs • Multiple TAs and instructors assisting students during the lab		

- Final Project:

UVA (Semester)	UCSD (Quarter)	Northwestern (Quarter)
• Traditional final project towards end of semester • Submit final report, and do a demo		

Feedback: Adaptable to different types of offerings

- Students appreciated utility of the design project and overall effectiveness of the course for the quarter offering
  - “The collaborative aspect of the labs and the solo-focus on the homeworks and final design project was a really good way to approach learning. We learn a lot by discussing and engaging with our classmates, and then we can actually apply what we learned to the homeworks/project.” (UCSD).

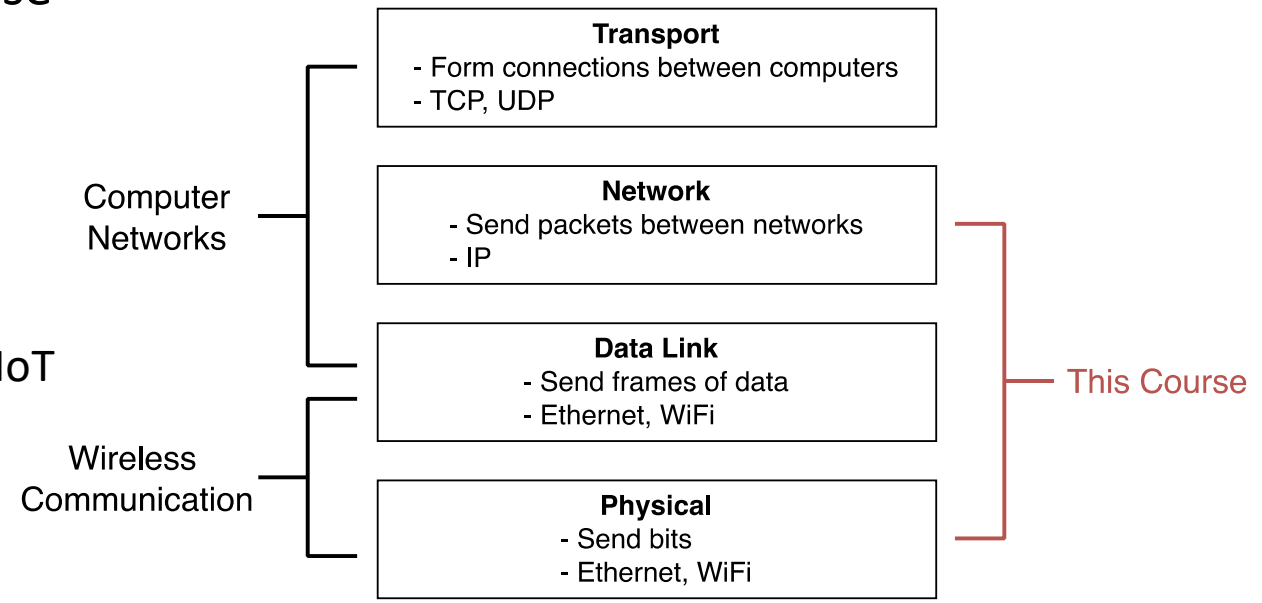
- Students appreciated their learning from the programming assignments, a newly added component at UVA
  - “The lectures were very helpful to provide a baseline, the labs built on this, and then the assignments and homeworks heightened our knowledge.” (UVA)

Applicability to Many Learners

- Bridges many concepts from CS and EE
  - Software engineering of embedded networking stacks
  - Observing physical layer in practice
  - Wireless radio states and low power modes
  - Data formats and endianness
- Interdisciplinary nature of course topics enables flexibility of teaching to various student audiences
  - Suitable to cross-list in CS and EE
- Also suitable to teach at graduate level
  - Since topics likely not explored in practice during undergrad
- Can be adapted to meet various institutional goals and priorities

WIoT Fits Well in a CS Curriculum and Complements Other Courses

- Couples well with a Wireless Communication course
  - WIoT: PHY layer and modulation techniques in action
- Computer Networking typically focus on higher layers
  - WIoT: how those layers can work for IoT and why many IoT protocols don't use them
- Capstone-level Embedded Systems courses sometimes introduce wireless technologies and their high-level APIs
  - WIoT: explains why those APIs are designed as they are



Coverage of topics in the OSI model

Feedback: Bridges CS & EE topic well and valued a diverse classroom

- “Honestly this material should be required for all Computer Engineering majors, it ties together computer science/programming and electrical engineering quite well, learning different ways how wireless communication works.” (UCSD)

- “This should be a main class and not just a special topics elective as the Internet of Things is a huge (part) of EECS in the world of STEM.” (UVA)

- “I like the different skill set, class discussions were diverse as a result and it was interesting to work with different majors for the lab group.” (Northwestern)

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Key Takeaways

- WIoT course fits well in a CS curriculum and aims to train IoT engineers
- It provides a “grab-bag” of topics to choose from, and this modularity provides:
  - Enough continuity that it can be replicated
  - Enough flexibility that it can be adapted
- Key insights to reduce burden on instructors for teaching this course (and maybe other ones with embedded hardware):
  - Explore potential to teach across universities
  - Choose same hardware platforms when teaching at multiple places
- If this sounds exciting, join us as the 4th university to co-teach the course!

Thank you!

- Thanks to:
  - National Science Foundation for funding this work
  - Leo Porter, Associate Teaching Professor (UCSD) for feedback on learning goals
  - Mark Sherriff, Professor, Academic General Faculty, (UVA) for improving overall quality

- Repository of slides, lab materials, homework, mini quizzes, Github repo for labs and assignments available upon request

- Questions?