



UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN

Microcontroller-based Occupancy Monitoring (MOM)

Team 7

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Microcontroller-based Occupancy Monitoring (MOM)

- Estimates the occupancy of a room or study space
- Analyzes Wi-Fi traffic sent from nearby Wi-Fi enabled devices
- MOM device compiles and estimates occupancy on-device
- Periodically sends occupancy data to the cloud for students to use

Need to find a place to study but don't want to waste time?

The Illinois MOM knows best!

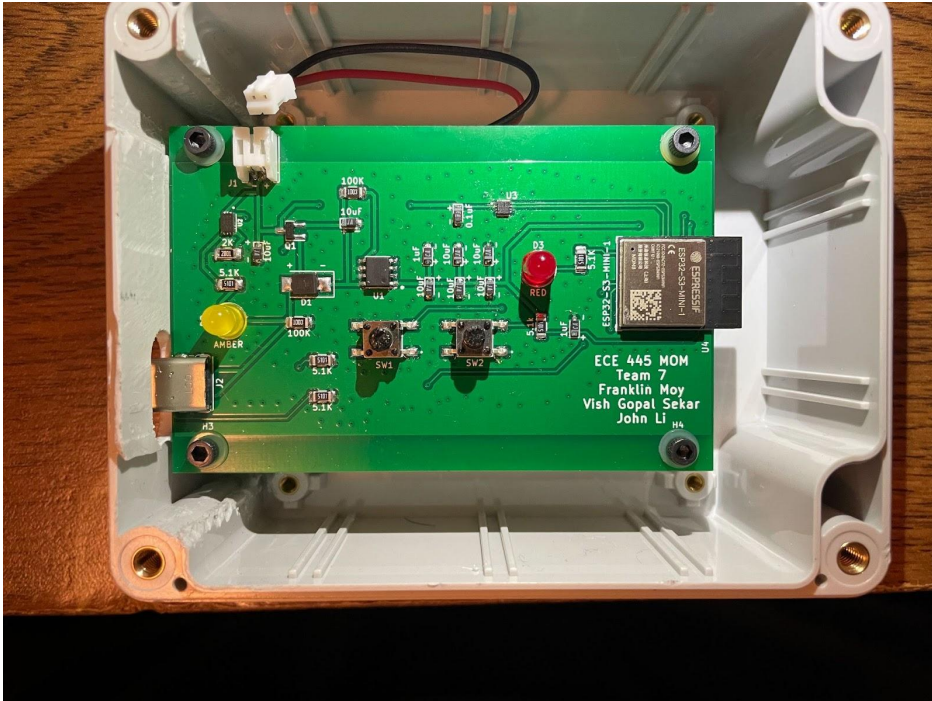
Why do we need MOM?

- Most students have returned to campus
- Increasing number of students studying and working at libraries
- Harder to find a place to study, especially with the closure of UGL
- Students can't afford to waste time just trying to find a place to study
 - Especially true now during finals season



MOM Features

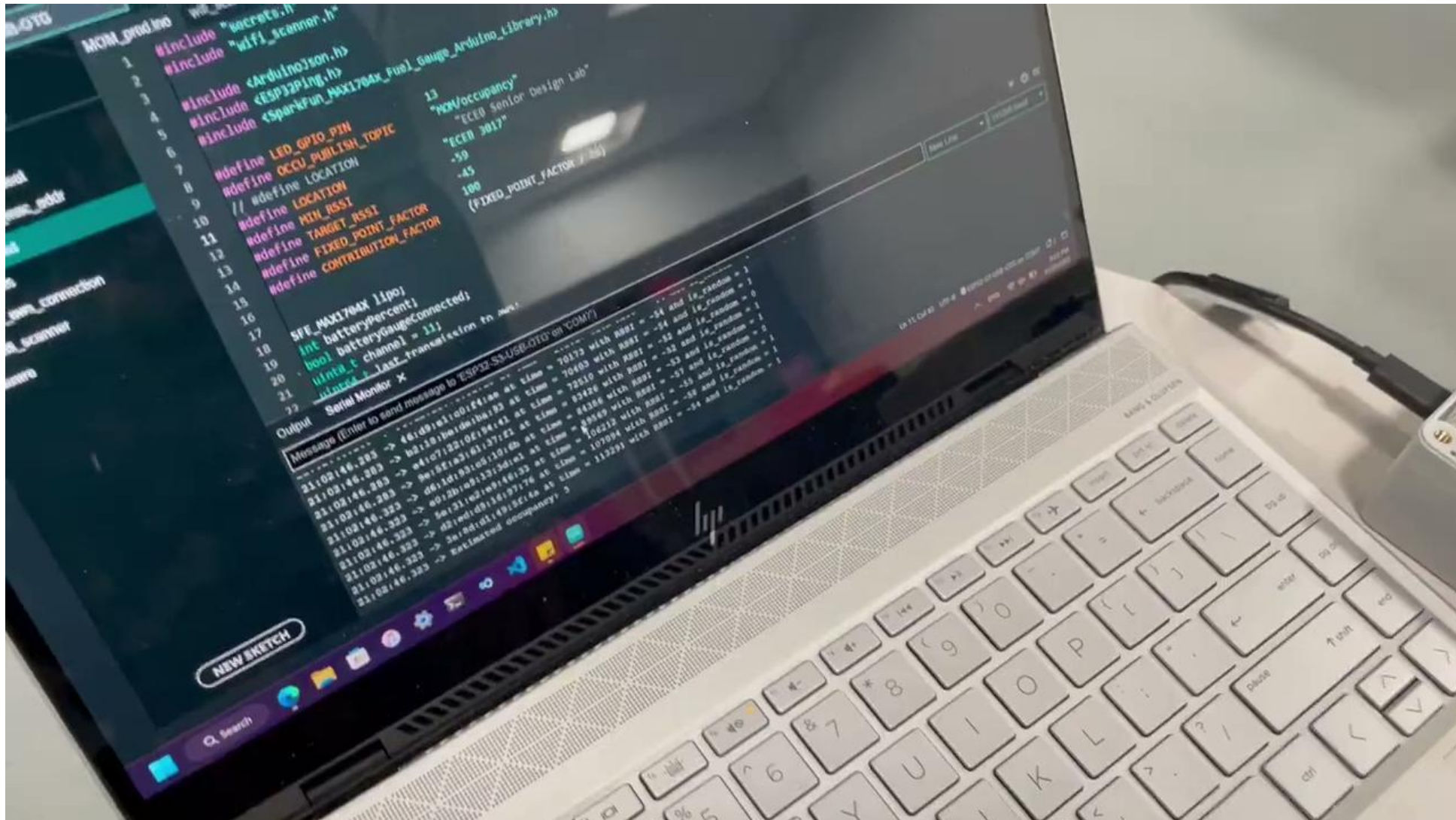
- Deployable in any room or study space with a wall outlet and a strong Wi-Fi connection
- Doesn't need to be put directly on tables in a study space
- Instant switchover to backup Li-Po battery if wall power is interrupted
- Backup battery charges while device is plugged into wall power
- Responsive web application accessible by desktops, laptops, and smartphones



High-Level Requirements

- Estimate occupancy with an accuracy of 80% or higher
- Device can gather data for at least 1 hour when running on battery power
- Device can switch to backup battery instantly after being unplugged from wall power
- Occupancy data is updated every 5 minutes or less

Introduction



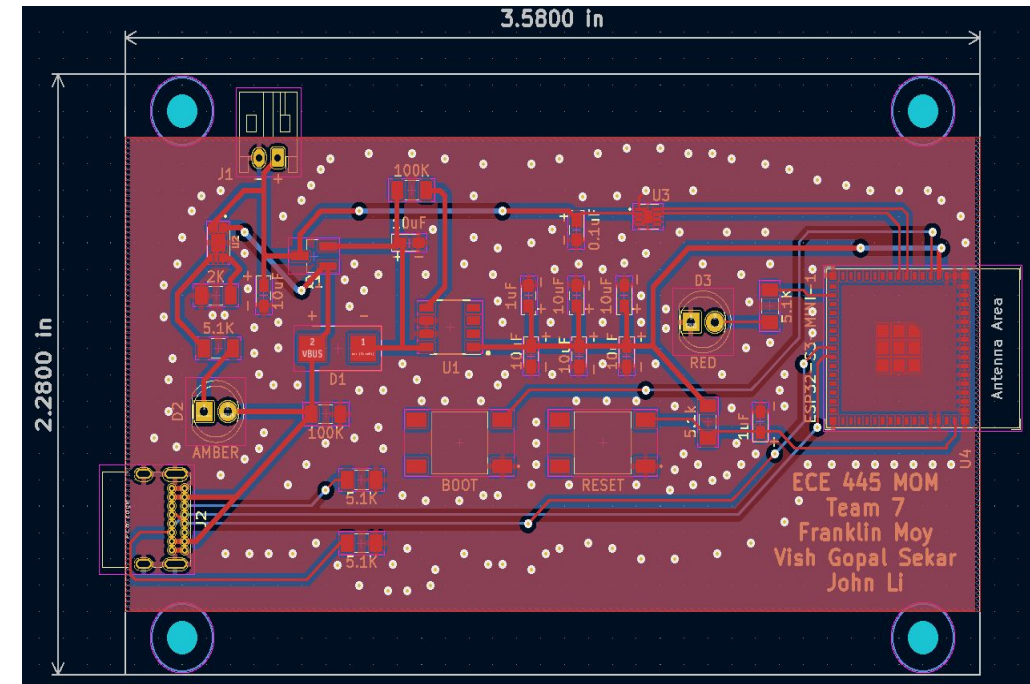


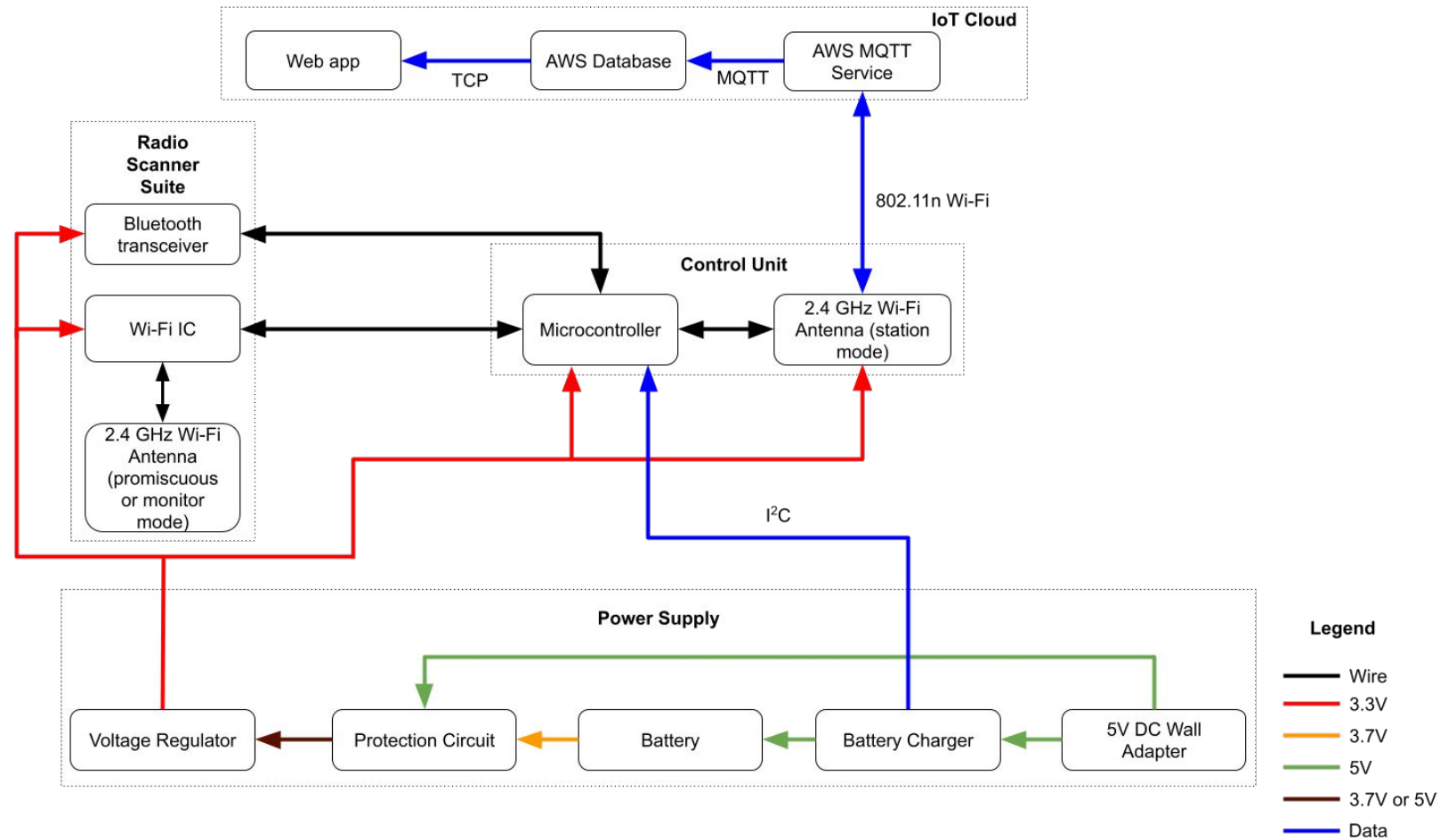
MOM Device Design

Franklin Moy

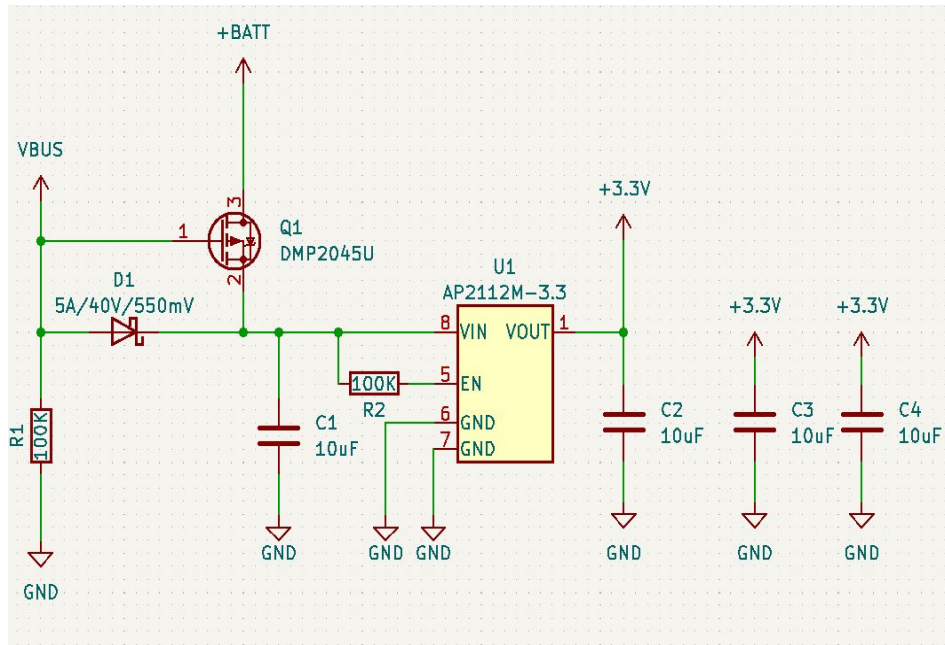
MOM Design

- ESP32-S3-MINI-1 SoC containing microcontroller & Wi-Fi antenna
- USB-C interface to power and program the device
- Instant battery backup switchover for uninterruptible power delivery
- Surface-mount and through-hole footprints for easy hot air and hand soldering





Power Supply Subsystem

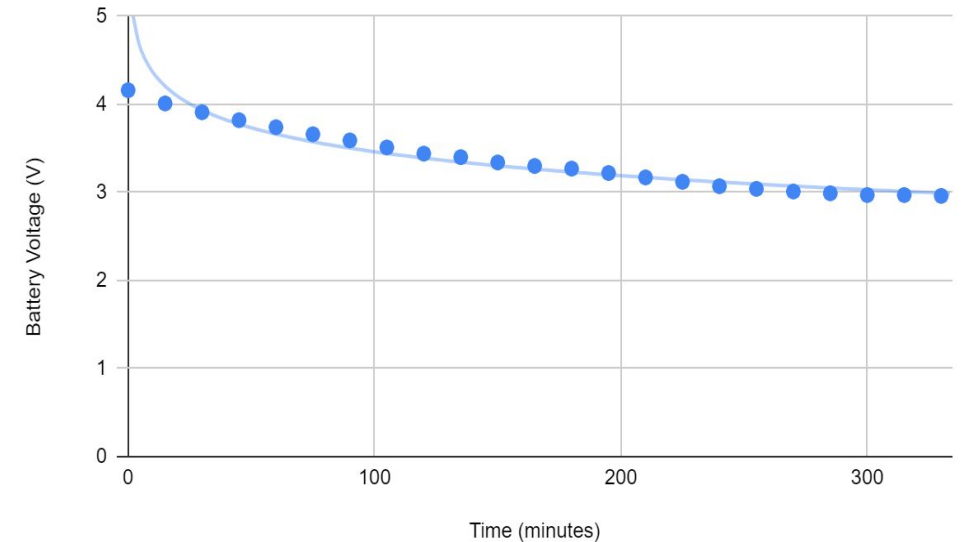


- Wall power delivered over 5V USB
- Li-Po backup battery with 500mAH capacity and average voltage of 3.7V
- Switchover/decision circuit consisting of P-Channel MOSFET
 - Decides between USB and battery power
- Schottky diode to protect USB line
- AP2112 low-dropout 3.3V regulator

Power Supply Requirements

- Instantly switch between battery and USB power
- Output $3.3V \pm 0.3V$ to safely power the microcontroller
- Charge the backup battery to no more than 4.3V in less than 12 hours while connected to wall power
- Backup battery must power the MOM device for at least one hour when the device is unplugged

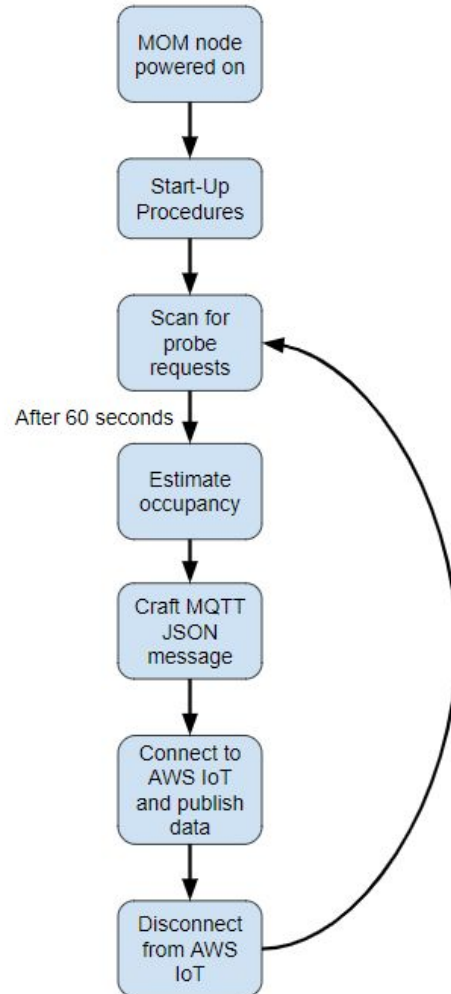
Backup Battery Voltage While Powering MOM device





Occupancy Estimation

Vish Gopal Sekar



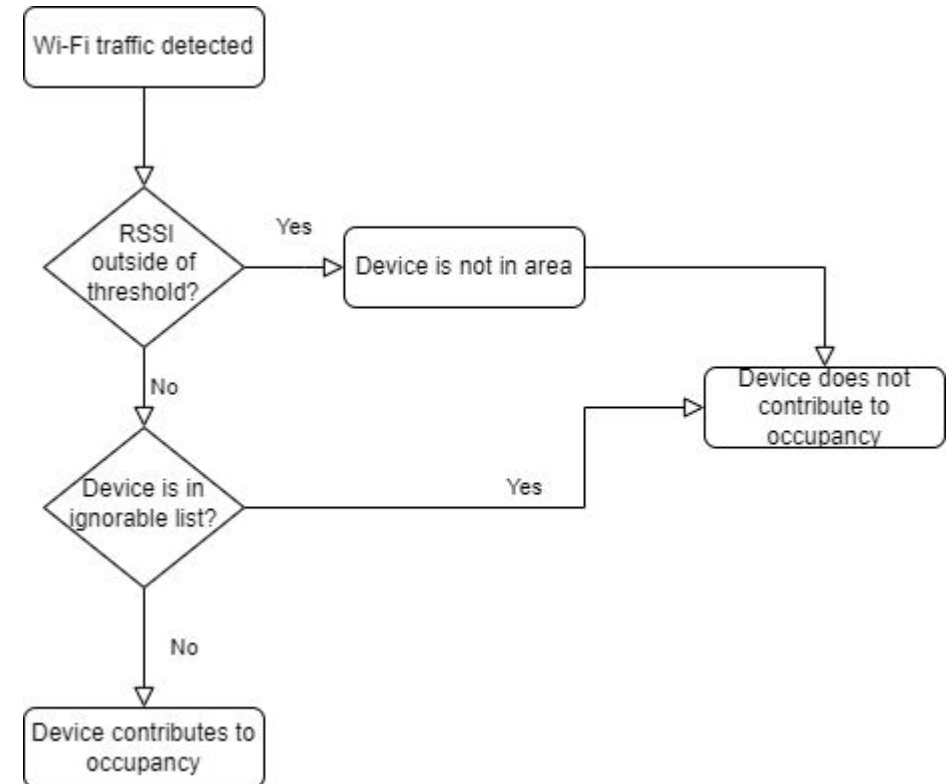
How MOM Estimates Occupancy

- The more Wi-Fi enabled devices in an area, the more Wi-Fi traffic there is
- Consequently, more Wi-Fi traffic in an area means more people
 - L. Oliveira et al. (2019) and many other research publications
- Contribution model using many factors tries to estimate the number of people

Occupancy Factors

Aggregation of multiple factors needed to estimate occupancy:

- Number of Wi-Fi enabled devices seen
- Signal strength of each seen device
- Time when each device was seen
- Size of environment where occupancy is being estimated
- Devices which are part of environment (e.g. Wi-Fi router)



$$RSSI = A - 10n \log\left(\frac{d}{d_0}\right) - X_\sigma$$

$$d = 10^{(A-RSSI) / 10n}$$

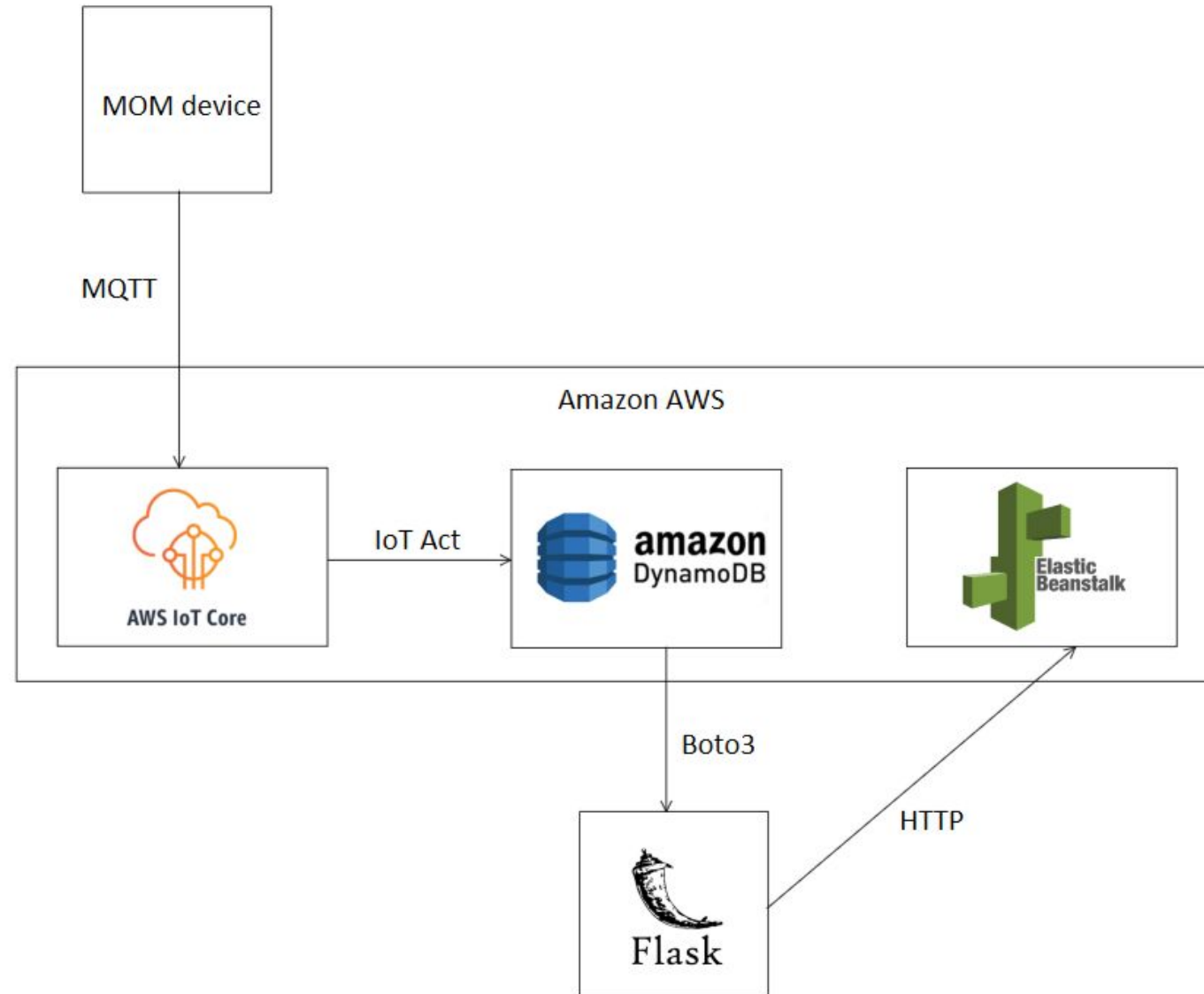
Contributing to Estimated Occupancy

- The stronger the signal, the higher its device's contribution
- The longer it has been since we've seen a certain device, the lower its contribution
- If a device hasn't been seen after a while (TTL expires), then it no longer contributes
- Periodically recalculate the contribution of all recently seen devices



The IoT Cloud


John Li




MOM-Prod
mom-prod.us-east-1.elasticbeanstalk.com (e-v8mjnk8czm)
Application name: **MOM-Prod**


[Refresh](#) [Actions ▼](#)

Health


Ok
[Causes](#)

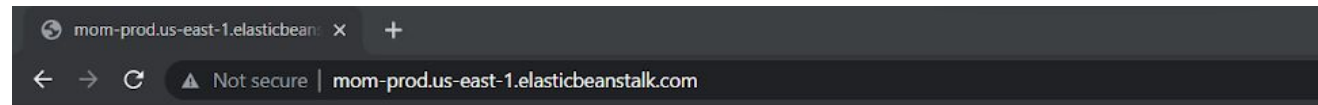
Platform


Python 3.8 running on 64bit
Amazon Linux 2/3.4.1
[Change](#)



The Web Application

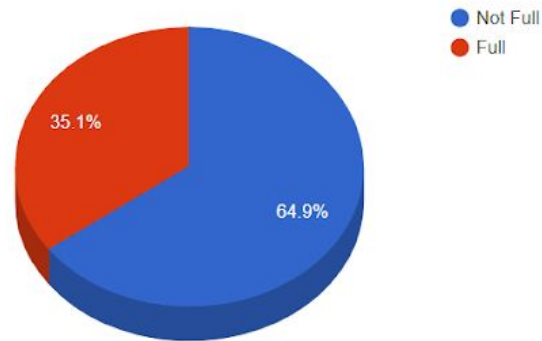
- Needs to be intuitive and fast
- Python Flask backend
- Bootstrap 5 user interface framework
- Deployed on AWS Elastic Beanstalk for public access
- Accessible from any device with a web browser



ECEB Senior Design Lab

Battery: 97 %

Occupancy Data:



Device id: 1

Roughly ~13 occupants in this room

Last Measured: December 05, 2022 ; 12:08:31 PM CT

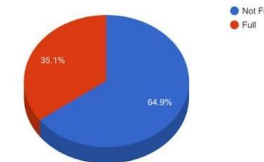
12:37



ECEB Senior Design Lab

Battery: 97 %

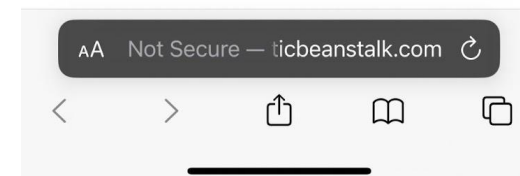
Occupancy Data:



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Conclusion

Successes, challenges, key takeaways, and future work

Successes

- Project was an overall success
- All high-level and subsystem requirements were verified
- Responsive, publicly available web application
- Seamless connection between device and IoT Cloud
- Accurate occupancy estimation from a compact, inexpensive device
 - During the final demo, MOM estimated occupancy with 100% accuracy after the calibration period



Challenges

- Developing an accurate occupancy estimation model that works for both rooms and open spaces
- Accounting for a plethora of factors outside our control
 - MAC address randomization
 - Number of devices per person
 - Inability to distinguish between device types
 - Laptop, Smartphone, Smartwatch, etc.
- Introducing a calibration period to mitigate noise from other areas



What We Learned

- Scanning Wi-Fi traffic is a good way to estimate the occupancy of an enclosed area
- Learned about embedded programming and designing PCBs for IoT
- Practical experience with AWS and hosting a Flask web application



Improvements & Future Work

- Develop a better model to increase occupancy estimation accuracy
 - Existing model is decently effective for getting the relative occupancy
 - Enhanced model would be able to estimate exact occupancy with higher accuracy
- Make more MOM devices and monitor multiple study spaces at once
 - Project was designed with this in mind, even though only one device was made
 - Codebase and cloud infrastructure capable of monitoring multiple spaces



Ethical Considerations

Privacy

- MOM does not read or collect data contained within Wi-Fi packets themselves
- Wi-Fi MAC addresses are public information that cannot be traced to an individual
- Students and others in public spaces have the right to know this monitoring is occurring
 - Also have a right to know how it works



Special Thanks to:

- **Hanyin Shao** for answering our questions and keeping us on track
- **Jason Paximadas** for assisting us in testing the power supply subsystem
- **Gregg Bennett** for helping in the design of the device enclosure
- **Skee Aldrich** for machining the device enclosure



Thank You!

Questions?



The Grainger College of Engineering

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