CharIoT: Final Presentation

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Project Motivation

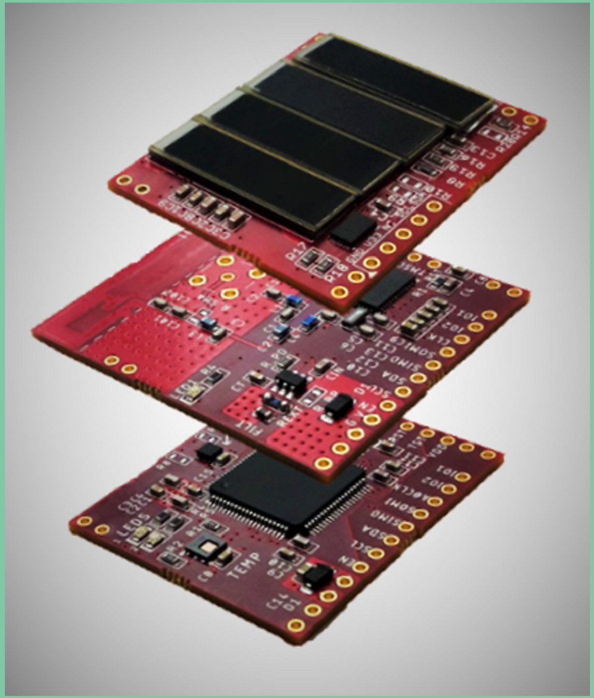
- Increasing demand for IoT devices, but no generic platform exists
- Prior work and new technology:
  - “Smart dust” project at Berkeley in 2001
    - “Autonomous sensing and communication in a cubic millimeter”
    - At the time, Berkeley didn’t have the capabilities
  - System-In-Package (SiP) technology
    - Can combine and shrink down entire systems

- Our task was to create a generalized hardware and software architecture which could ultimately become a SiP
  - Self-powered
  - Wireless
  - Versatile sensing

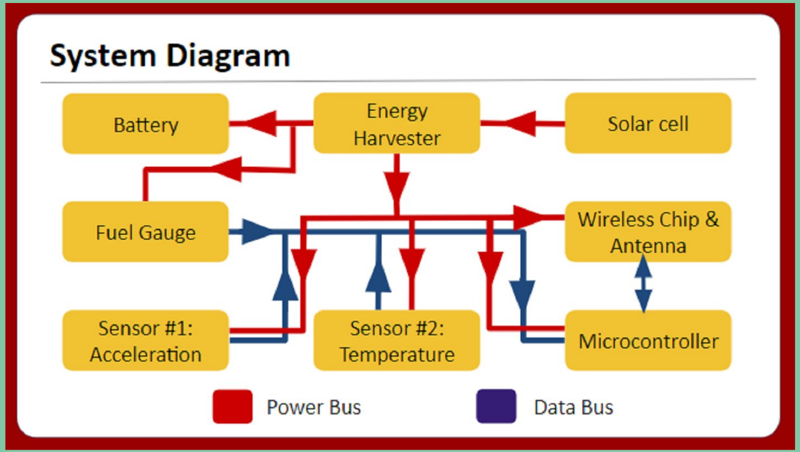
Design Process

- Determined customer needs
  - Modular (easily redesignable)
  - Self-powered/low power
  - Wireless connectivity
  - Compact size
- Picked the best components based on these goals
- First-pass prototype
  - Bought evaluation modules for key components
  - Wrote unit test code
  - Measured power harvesting/consumption
  - Wired components together to verify system functionality
- Second-pass prototype
  - Moved to a PCB design
  - Integrated new communications chip (to enable node-node connections)
- Final prototype
  - Slimmed the design to a smaller form factor
  - Integrated a new sensor (accelerometer)

Final Design



- Small ✓
- Modular ✓
- Self-powered ✓
- Flexible sensing capabilities ✓
- Flexible wireless transmission ✓



Design Specifications

Specification	Points
Design supports SPI, I2C, analog sensors that draw less than 5mA combined	200
Battery can power system for 12 hours without charging.	150
Energy harvester can produce 12mW in direct sunlight.	150
Can sense and/or transmit 12 times throughout a sunny day	100
Wireless Range of at least 5m	200
Design can support different wireless transmitters that include appropriate communications stack and draw less than peak 30mA	200
Maximum footprint size: 50 x 50 x 20 mm (or equivalent volume)	200
Less than $500 to produce a single node (not at production scale)	100

Spec 1: Design supports SPI, I^2C, analog sensors that draw less than 5mA combined

- MSP430FR5994 processor contains:
  - Hardware modules for various serial communication protocols (including SPI, I^2C, UART) ✓
  - Multiple analog to digital converters to support analog sensors ✓
- For final prototype, we used:
  - An SPI module for sending data to the comms chip
  - A shared I^2C bus for communication with the temperature/humidity sensor, the accelerometer, and the fuel gauge.
- We also wrote UART code for the particulate sensor.

- The 5mA combined limit on sensors was just an arbitrary limit to keep sensor power consumption within a reasonable range. Future work could calculate in more detail the limit for a given comms chip.

Spec 2: Battery can power system for 12 hours without charging

- 1 transmit = 8mA current draw, ~5 sec
- Quiescent current= 200uA
- Battery capacity = 100 mAh
- **Can transmit once/hour for 21.7 days without charging ✓**

$$21.7\ Days = \frac{110maH}{\left(8mA * 5s * \frac{1hr}{3600s} + 0.2mA * 1\ hr\right) * \frac{24\ TX}{Day}}$$

Spec 3: Energy harvester can produce 12mW in direct sunlight.

	Sunny	Shade
Solar Cell Current	~36 mA	~2 mA
Solar Cell Voltage	~1.5 V	~1 V
Charge Current	~10 mA	~0.3 mA
Sense & Transmit	Constantly	Every 4 min.

- In direct sunlight, charge current is ~10 mA
- Based on resistor settings, lowest voltage threshold for battery is 3 V

P = IV

P = 10 mA * 3 V

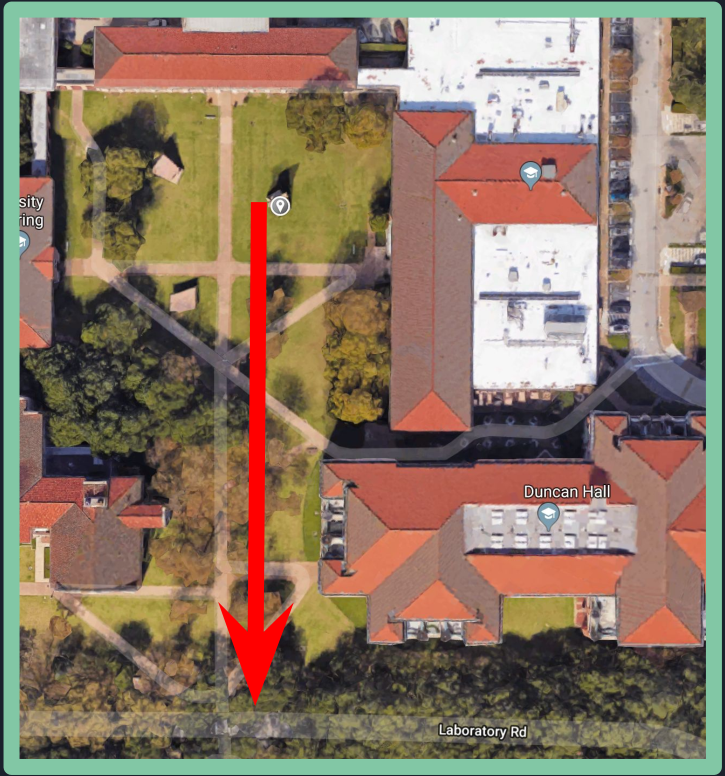
P = ~ 30 mW > 12 mW ✓

Spec 4: Can sense and/or transmit 12 times throughout a sunny day

- While in sunlight, charge current is ~ 10 mA
- To sense and transmit, 8 mA is pulled over ~5 seconds
- About 0.2 mA is pulled when the device is not charging (quiescent current)
- Thus, we can transmit constantly in direct sunlight without draining battery capacity!

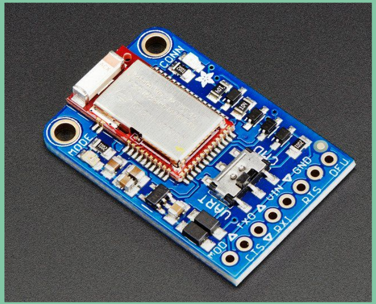
Spec 5: Wireless Range of at least 5m

- We achieved an outdoor wireless range of ~119 m ✅
- We placed a Chariot node on the 90 degree statue in the engineering quad and slowly walked away until we no longer got new data
  - We were able to make it to the edge of the inner loop
- We also attempted an indoor range test in Duncan hall, but the building was not long enough



Spec 6: Design can support different wireless transmitters with peak current draw <30mA

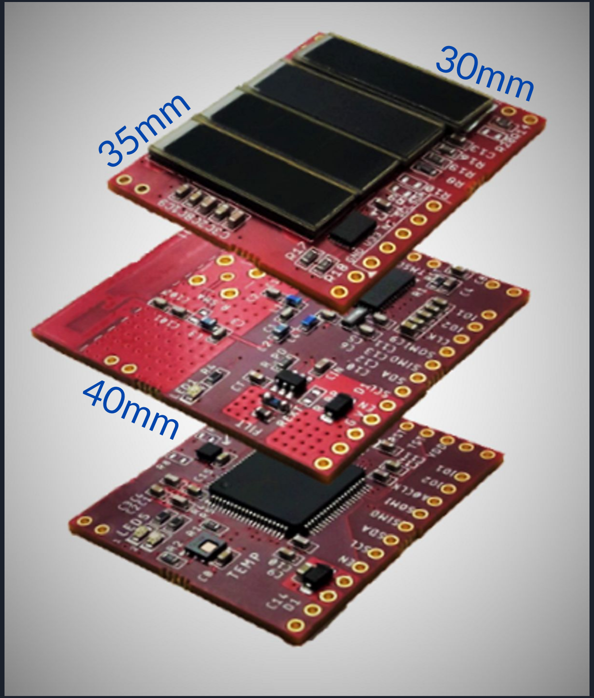
- We used the Adafruit Bluefruit transmitter for our first prototype ✓
- We used the TI CC2652R transmitter for both prototype 2 and 3 ✓
  - The TI CC2652R transmitter has a peak current draw of 16mA



Spec 7: Maximum footprint size: 50mm x 50mm x 20mm (or equivalent volume)

- The PCB design for the showcase prototype had a footprint of 35mm by 40mm, and the entire assembled prototype stands about 20 mm tall ✔

- The comms board is the only PCB which actually is 35mm by 40mm, the sensor and power boards both only have a footprint of 35mm by 30mm



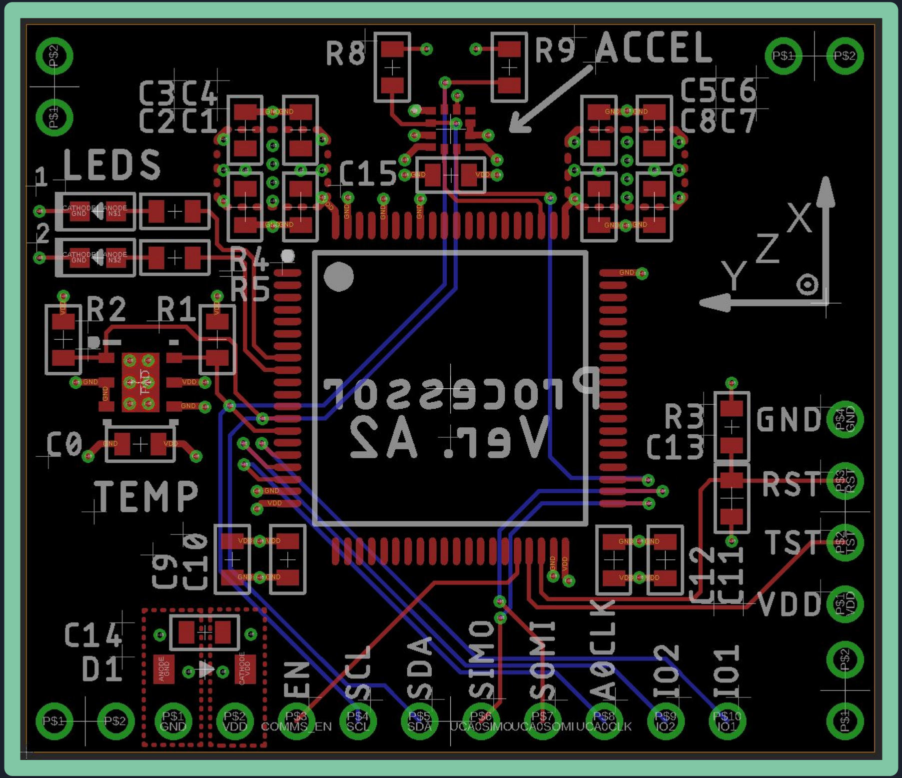
Spec 8: Less than $500 to produce a single node (not at production scale)

- For our showcase prototype, the cost from Macrofab for producing 10 complete prototypes was $199.69 per node.
- Other component costs:
  - Battery = $11
  - Solar Cells = $8
  - Transmitter = $6
  - Passives <$25
- Total: ~$250✅

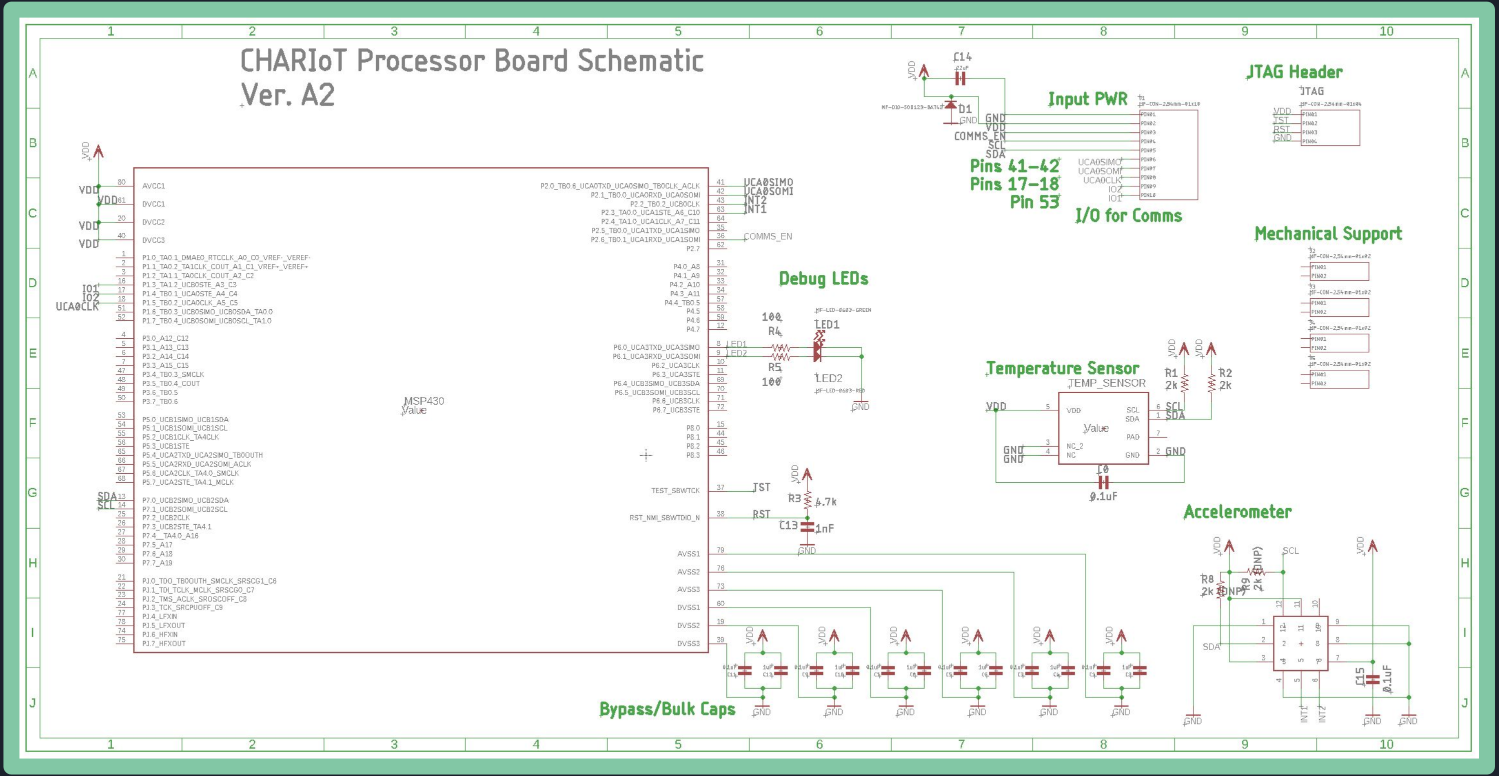
Cycle 4 & 5 Objectives

Objectives	Points
Prototype #3: Design & review Processor/sensor board	150
Prototype #3: Design & review Comms board	200
Prototype #3: Design & review Power board	200
Design Android app for Bluetooth link (Showcase demo)	100
Design & fabricate props for Showcase	100
Design Poster for Showcase	50
Integrate Processor and Comms board for Prototype #2	150
Test Prototype #3	50
Write Accelerometer Code for Prototype #3	100
Prepare Final Documentation	100

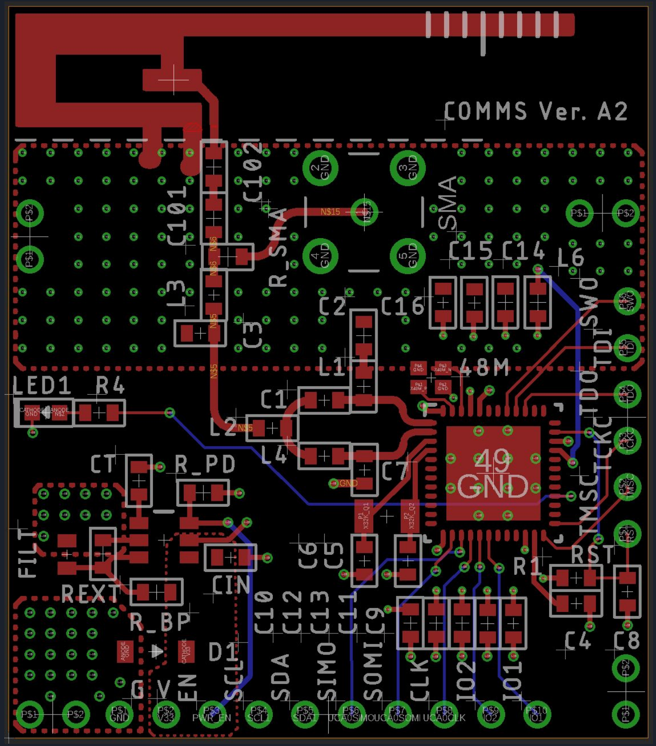
Objective #1: Design & review Processor/sensor board for Prototype #3



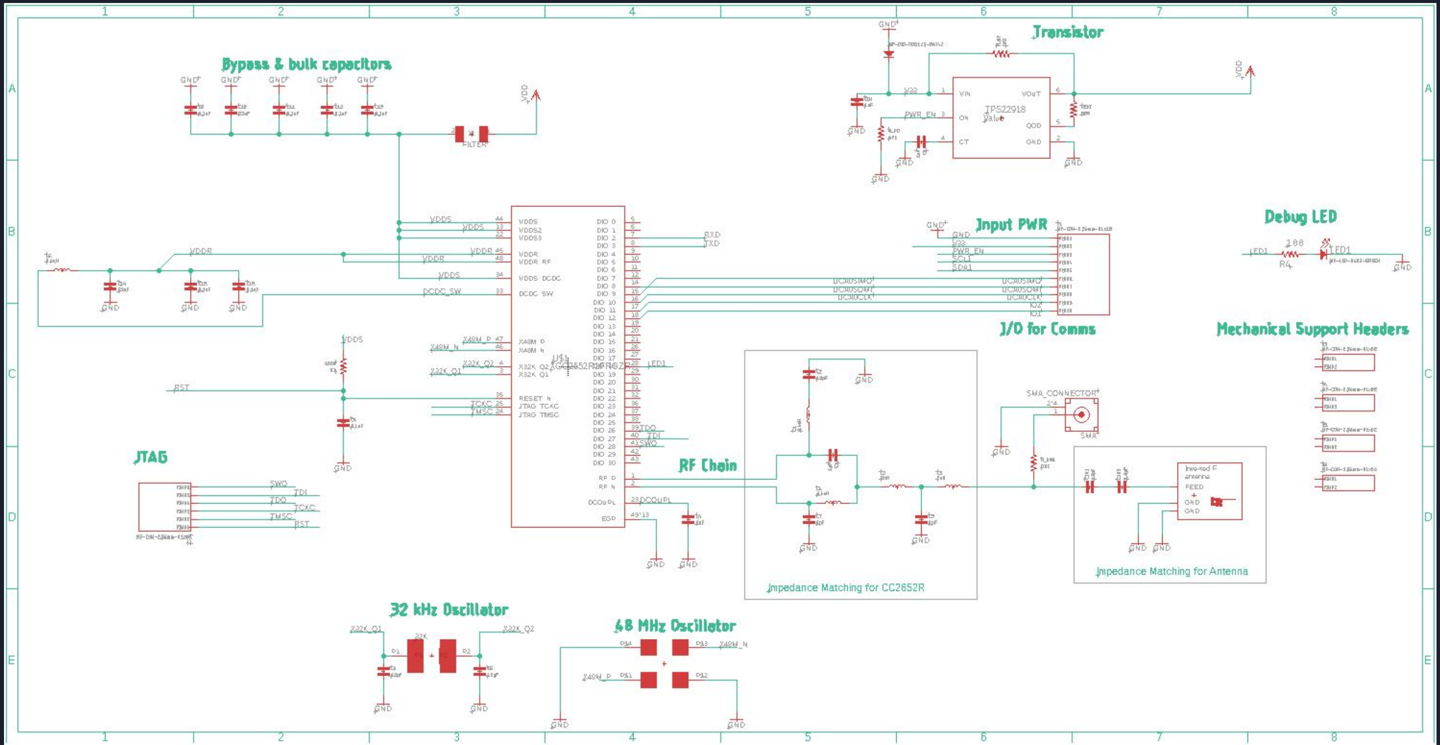
Objective #1: (cont.)



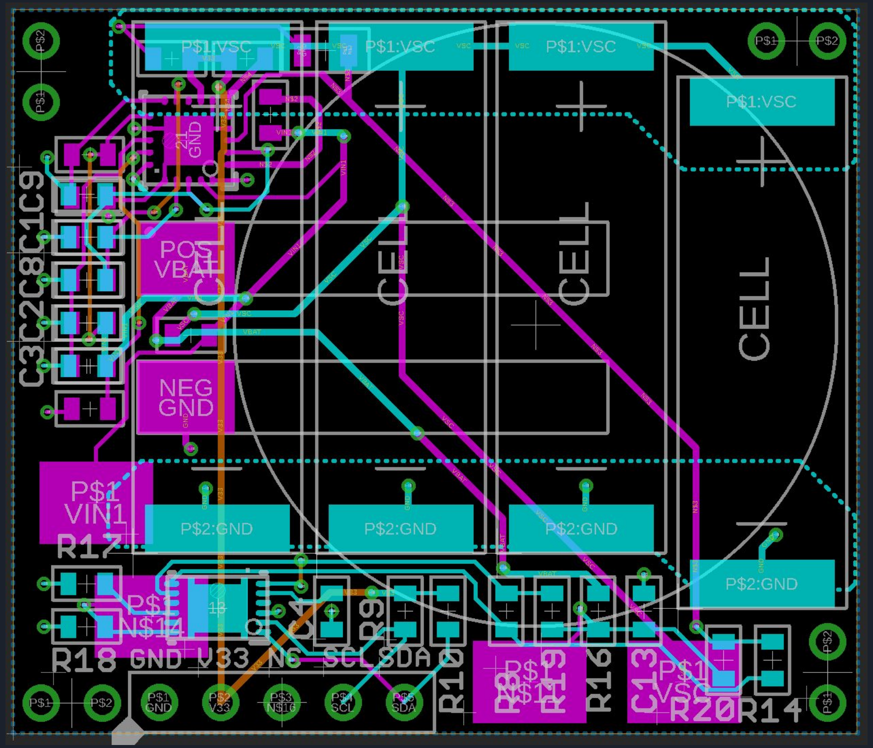
Objective #2: Design & review Comms board for Prototype #3



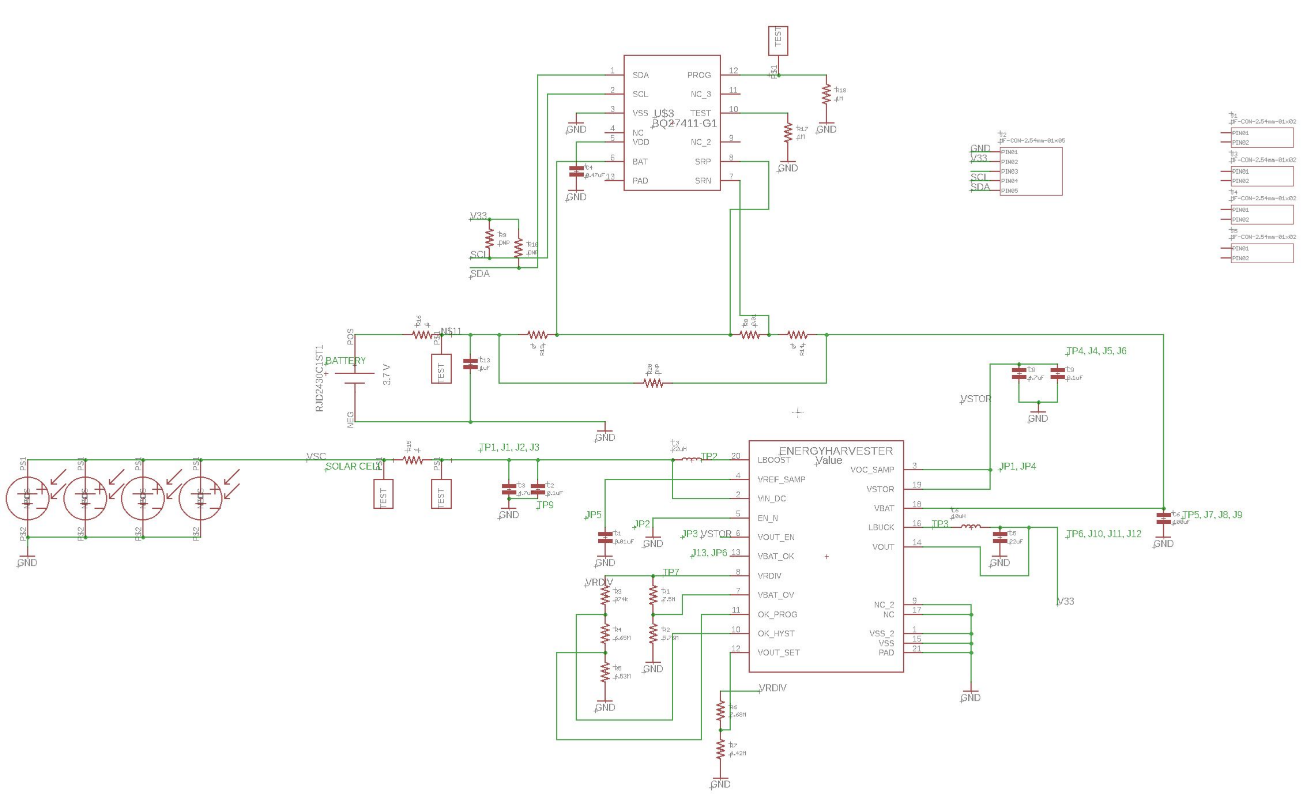
Objective #2: (cont.)



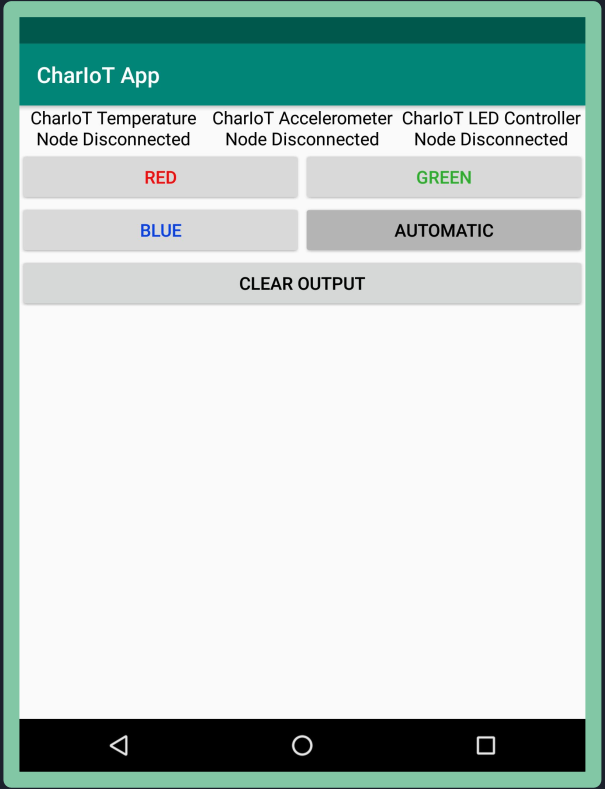
Objective #3: Design & review Power board for Prototype #3



Objective #3: (cont.)



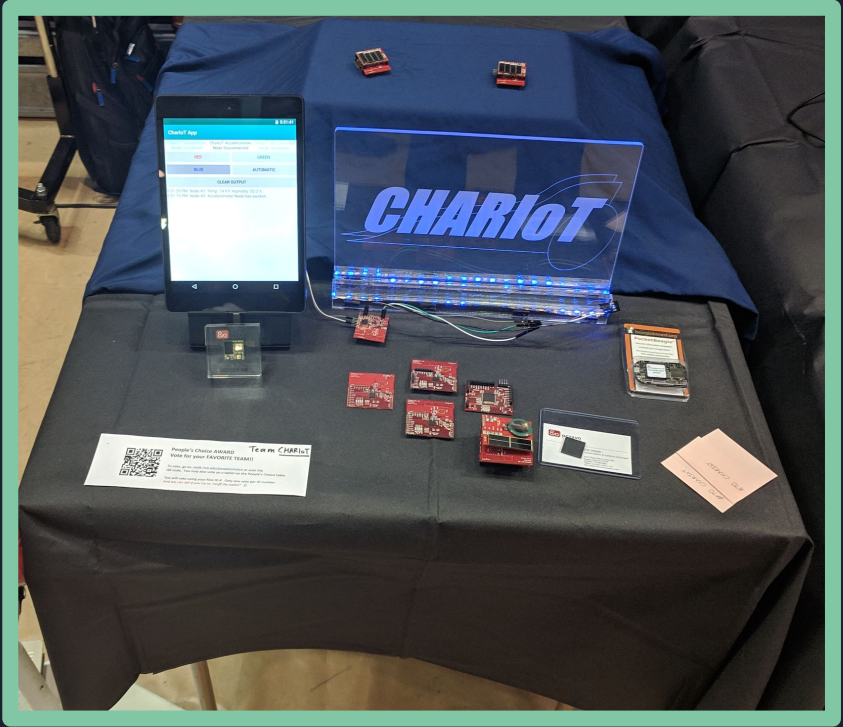
Objective #4: Design Android app for Bluetooth link (Showcase demo)



- ❖ Custom Android app created using Android Studio
- ❖ The app serves as a BLE peripheral device emulating the Nordic nRF UART service, which our nodes recognize and connect to automatically.
- ❖ Created because the app we were using before (Adafruit's Bluefruit app) was a little buggy, and we wanted some custom features for showcase.
- ❖ Receives the raw data bytes from our various nodes and formats and displays the output.
- ❖ In charge of choosing the color value which is sent to the LED controller node for our CharIoT sign.
- ❖ No limits on number of nodes which can be connected at the same time (except for BLE restrictions)

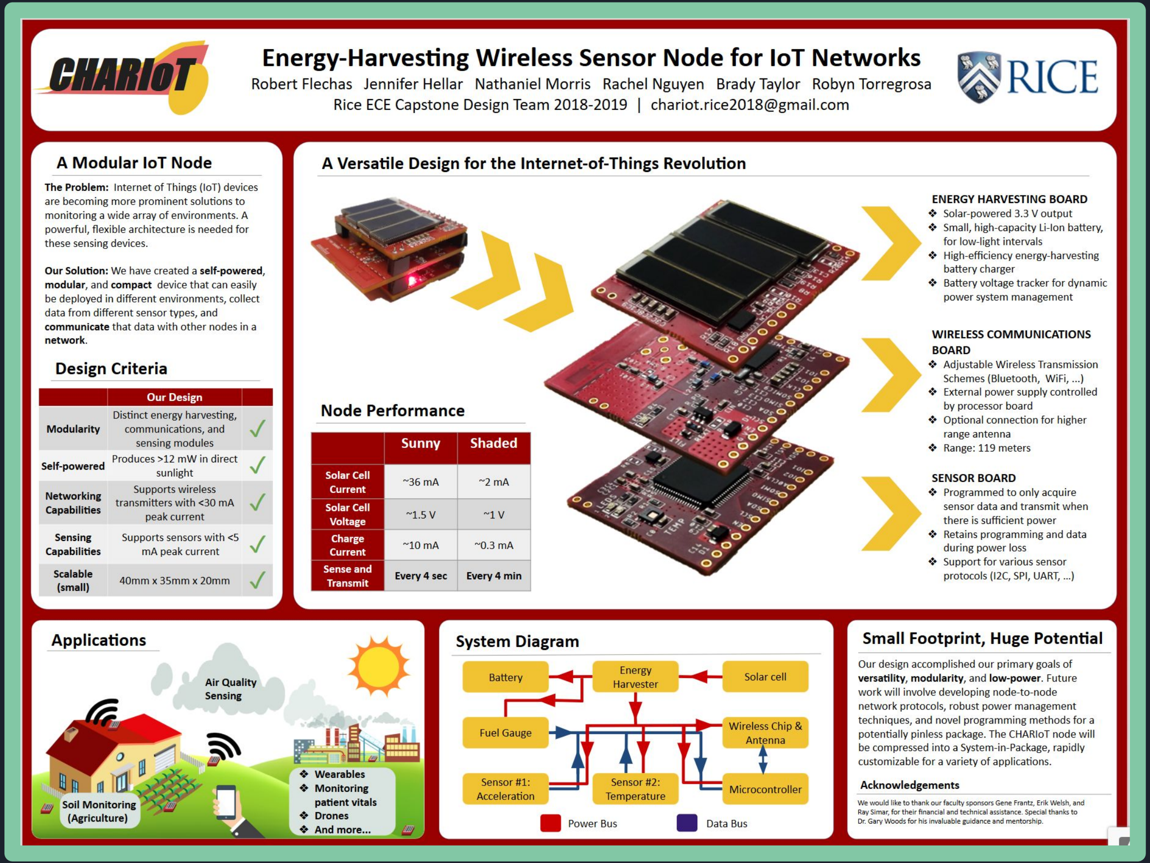
Objective #5: Design & fabricate props for Showcase

“Bobbie” helmet with accelerometer CHARIoT Node



Temp/humidity, accelerometer sensing nodes with Bluetooth controlled LED sign

Objective #6: Design Poster for Showcase



Energy-Harvesting Wireless Sensor Node for IoT Networks

CHARIoT

RICE

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A Modular IoT Node

The Problem: Internet of Things (IoT) devices are becoming more prominent solutions to monitoring a wide array of environments. A powerful, flexible architecture is needed for these sensing devices.

Our Solution: We have created a **self-powered**, **modular**, and **compact** device that can easily be deployed in different environments, collect data from different sensor types, and **communicate** that data with other nodes in a **network**.

Design Criteria

	Our Design	
Modularity	Distinct energy harvesting, communications, and sensing modules	✓
Self-powered	Produces >12 mW in direct sunlight	✓
Networking Capabilities	Supports wireless transmitters with <30 mA peak current	✓
Sensing Capabilities	Supports sensors with <5 mA peak current	✓
Scalable (small)	40mm x 35mm x 20mm	✓

A Versatile Design for the Internet-of-Things Revolution

ENERGY HARVESTING BOARD
- Solar-powered 3.3 V output
- Small, high-capacity Li-Ion battery, for low-light intervals
- High-efficiency energy-harvesting battery charger
- Battery voltage tracker for dynamic power system management

WIRELESS COMMUNICATIONS BOARD
- Adjustable Wireless Transmission Schemes (Bluetooth, WiFi, ...)
- External power supply controlled by processor board
- Optional connection for higher range antenna
- Range: 119 meters

SENSOR BOARD
- Programmed to only acquire sensor data and transmit when there is sufficient power
- Retains programming and data during power loss
- Support for various sensor protocols (I2C, SPI, UART, ...)

Node Performance

	Sunny	Shaded
Solar Cell Current	~36 mA	~2 mA
Solar Cell Voltage	~1.5 V	~1 V
Charge Current	~10 mA	~0.3 mA
Sense and Transmit	Every 4 sec	Every 4 min

Applications

Air Quality Sensing

Soil Monitoring (Agriculture)

- Wearables
- Monitoring patient vitals
- Drones
- And more...

System Diagram

Battery
Energy Harvester
Solar cell
Fuel Gauge
Wireless Chip & Antenna
Sensor #1: Acceleration
Sensor #2: Temperature
Microcontroller
Power Bus
Data Bus

Small Footprint, Huge Potential

Our design accomplished our primary goals of **versatility**, **modularity**, and **low-power**. Future work will involve developing node-to-node network protocols, robust power management techniques, and novel programming methods for a potentially pinless package. The CHARIoT node will be compressed into a System-in-Package, rapidly customizable for a variety of applications.

Acknowledgements

We would like to thank our faculty sponsors Gene Frantz, Erik Welsh, and Ray Simar, for their financial and technical assistance. Special thanks to Dr. Gary Woods for his invaluable guidance and mentorship.

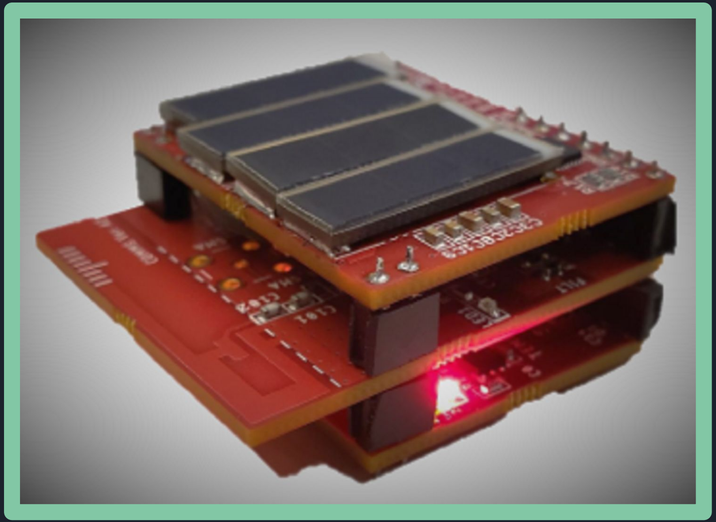
- ❖ Received feedback on poster design (Dr. Tracy Volz)
- ❖ Added “Applications” section to give context to problem space

Objective #7: Integrate Processor and Comms board

- This involved setting up the SPI communication on both the MSP430 and the comms chip, as well as setting up the MSP430's control of power to the comms chip.
- Designed a custom simple SPI transaction scheme to transmit the required data back and forth between the MSP430 and the comms chip.
- We had some issues getting the SPI data bus to be stable for more than one SPI transaction, but we were able to get around this in the end by saving all pertinent data to FRAM then resetting the MSP430 between every SPI transaction.

Objective #8: Test Prototype #3

- Power board: produces 3.3 V and charges battery in direct sunlight ✓
- Comms board: successfully transmits and receives wireless data to and from tablet ✓
- Sensor board: Temp/Accel sensors gather data and send to comms board ✓
- Produced a working demo with multiple independent prototype #3 ✓

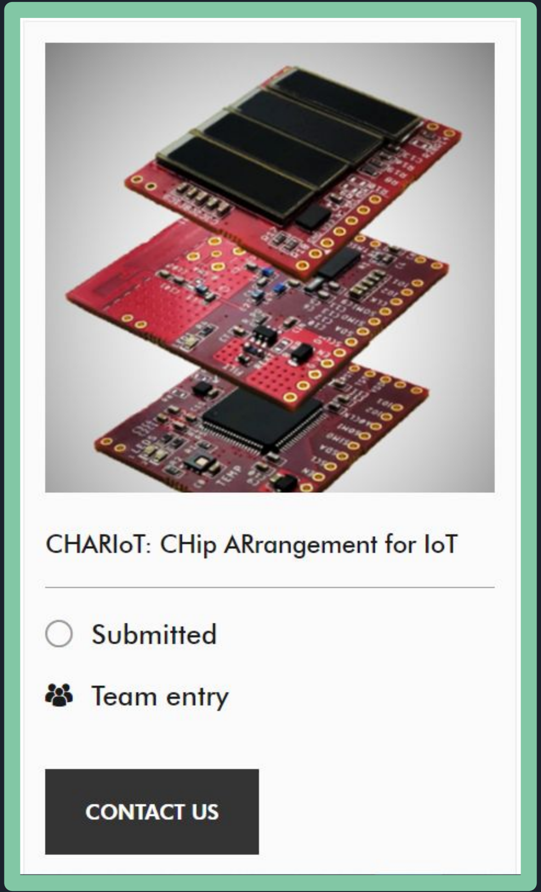


Objective #9: Write Accelerometer Code for Prototype #3

- Initially wrote data to a register in the accelerometer and read data back out in order to verify proper I2C communication
- Wrote values to registers to set up the accelerometer for our demo
  - Interrupt triggered on pin based on slope of measured acceleration in any axis of motion
  - Modified threshold and acceleration ranges to get appropriate sensitivity
- Configured pin on MSP430 to read incoming interrupt
- Wrote functions to turn off the accelerometer & reset it (low power functionality)
- Put all this code in its own source code file with a header

Objective #10: Prepare Final Documentation

- We are currently writing a final report (with commented code) and an ethics write-up (each)
- These will be submitted before the last day of finals ✔
- Sponsor meeting on Thursday ✔
- Submitted our project to the James Dyson Award Competition (an inventor’s challenge)



Demonstration


ITS OVER...
ITS FINALLY OVER...
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