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Electrical Engineering

Remote Soil Moisture Monitoring

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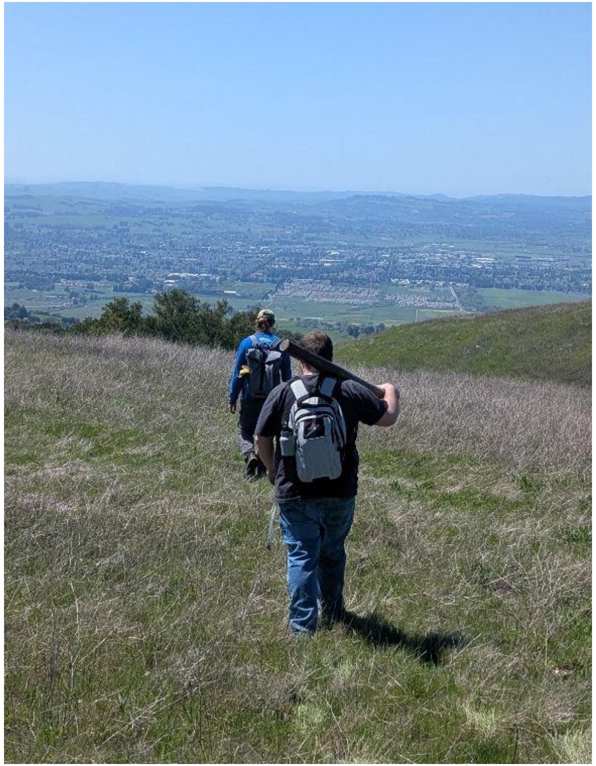
Overview

- Problem Statement, Value Proposition, Existing and Definitions and Proposed Solution
- Marketing and Engineering Requirements
- System Overview
- Scalability
- Challenges and Risks
- Tests and Results
- Schedule
- Budget and Materials
- Supporting Courses

Problem Statement

The Center of Environmental Inquiry (CEI) desire a system to collect, and transfer sensor data from a remote part of the Fairfield Osborn Preserve (FOP) to the Education Center. The clients need to be able to control sensors remotely, and be able to see the data visualized. There is a lack of infrastructure in place to allow cost effective data collection, being limited to manual data collection.



Value Proposition

Our LoRaWAN network helps the CEI schedule and collect data remotely; avoiding manual data collection in remote areas of the FOP. It allows an increase in productivity with the same amount of work done by the end user and unlike existing solutions to the problem, it does not require a recurring fee for an LTE connection to operate.

The system is able to be expanded in the future for further measurements.

Deployed Node

Existing Solutions

The meter.me product line uses long-range, low-power communication methods such as LoRa. However, they implement proprietary data management services and sensor connections, making it an expensive and inflexible solution. They also offer features that are not desired by our client (LTE) that add additional costs.

Definitions

LoRa is a robust modulation technique based on Chirp Spread Spectrum that is able to decode signals at very low power levels, even below the noise floor.

LoRaWAN is a MAC and Network layer protocol that offers end to end encryption

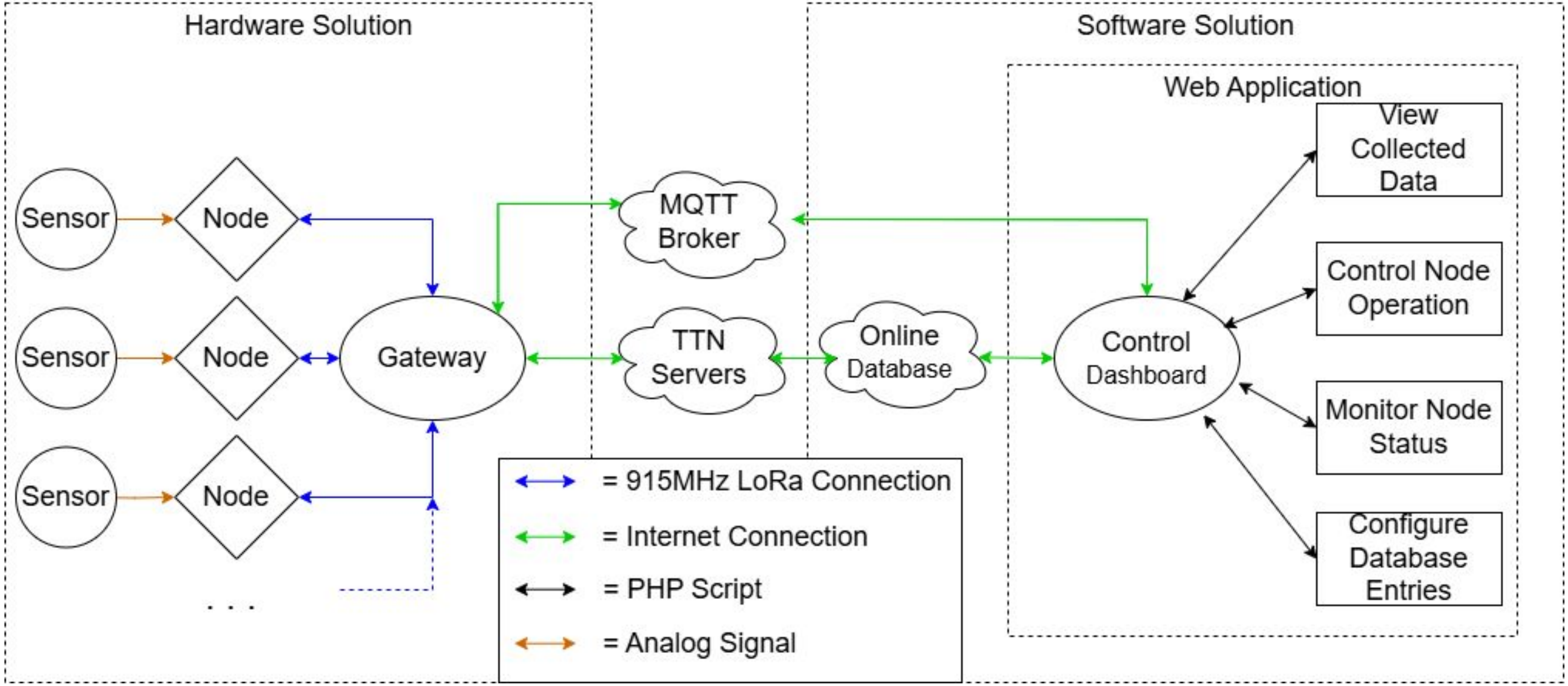
Nodes are enclosed devices containing a microcontroller, LoRa transmission module, battery, and other necessary control equipment and transmission equipment.

Sensors are separate devices that are interfaced with each Node. Sensor types include soil moisture sensors and temperature sensors.

A **Gateway** receives LoRa transmissions from the Nodes and relays that information to the cloud. It also broadcasts updates to all Nodes.

The **System** includes the Gateway, Nodes, and all Sensors.

Our Solution



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Marketing Requirements

System Overview

1. **Node Support:** The system must support a minimum of six Nodes.
2. **Range:** Nodes must operate within a 0.75-mile radius of the Gateway.
3. **Autonomy:** Nodes must function autonomously for three years under normal operating conditions (sensor readings and broadcasts to the Gateway every 15 minutes).
4. **Durability:** The system must be resistant to water, dust, and potential damage from animals.

Marketing Requirements

Data Collection and Management

5. **Data Collection Frequency:** The data collection rate must be adjustable via the user dashboard, up to a maximum frequency of once every 15 minutes.
6. **Data Updates:** The data upload rate must be adjustable via the user dashboard, up to a maximum frequency of once per data point collected.
7. **Data Reliability:** Sensor data must be accurate and reliable.
8. **Data Storage:**
    a. Sensor data must be temporarily stored on each Node in the event of communication failure.
    b. Aggregated data must be retained on the Gateway for as long as necessary.

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Marketing Requirements

User Interface and Dashboard

9. **Accessibility:** Users must have easy access to collected data through a visualization dashboard.
10. **Battery Monitoring:** Node battery status must be viewable via the dashboard.
11. **Connection Monitoring:** Node connection status must be displayed on the dashboard.
12. **Location Tracking:** The location of each Node must be accessible through the dashboard and must be able to be changed via the dashboard.

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Marketing Requirements

Deployment and Maintenance

13. **Relocatable Nodes:** Nodes must be designed to allow for relocation after initial deployment.
14. **Documentation:** The system must include a user manual detailing the normal operations of the system as well as how to maintain it in case of issues.

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Engineering Requirements

System Overview

1. The system must allow communication between a minimum of six Nodes and the Gateway and allow the addition of 4 more Nodes in the future. (MR1)
2. **Communication must be reliable, with less than 10% packet loss when the Nodes are installed at locations not exceeding 0.75 miles away from the Gateway in hilly forested terrain such as that present on the Preserve. The LoRa signal must have a SNR of greater than -20dB as that is the lowest signal level that can be decoded by our Gateway. (MR2)**

Engineering Requirements

System Overview

3. **Nodes must be able to operate continuously for three years, given data collection once every 15 minutes, data transmission once every 15 minutes, and with an average battery consumption of no more than 2.5 mAh in a day of operation. (MR3)**
4. The Nodes must meet IP67 rating to survive weather conditions, and external wires must be resistant to damage from animals through the use of shielding and conduit. (MR4)

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Engineering Requirements

Data Collection and Management

5. **The Nodes must sample data from their sensors autonomously at a frequency that users can change remotely through the dashboard, up to a maximum frequency of once every 15 minutes with a margin of +/- 1 minute. (MR5)**
6. The system must autonomously upload data collected from the Nodes to a publicly accessible dashboard website at a frequency (minimum once per day) that users can change remotely through the dashboard. (MR6)
7. The moisture sensors used must be calibrated before installation, with a calibrated range measuring water tension from 10 to 75 centibars. Error must not exceed +/- 6 CB, two times the max error of the reference device. (MR7)
8. If data sent to the Gateway is not acknowledged with a message back it must be stored in nonvolatile memory on the Node to ensure it is not lost. (MR 7)

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Engineering Requirements

Data Collection and Management

9. The data stored on the Node’s nonvolatile memory must be transmitted to the Gateway when the connection is restored between them. (MR 8)
10. The data is aggregated by the Gateway and must be uploaded to a website hosting the dashboard, in addition it must be saved locally to a removable storage medium connected to the Gateway. (MR8)
11. Data stored on the removable storage device must be updated with data gathered even if the connection with the website is lost. When the connection is reestablished, it must be uploaded to the server. (MR8)
12. **The communication between the Nodes and Gateway must be bidirectional to allow for verification of data receipt and reconfiguration. (MR 6)**

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Engineering Requirements

User Interface and Dashboard

13. **The data collected from the sensors must be available to users as a graph on the dashboard. The graphs must be able to show individual data from single Nodes as well as aggregated data from all of them. (MR9)**
14. **The battery status of all of the Nodes must be available to users as graphs on the dashboard to allow for monitoring of the battery level remotely. (MR10)**
15. Battery status must be recorded with data collection from the sensors and be transmitted to the Gateway at the scheduled times. (MR10)
16. The status of the connection between the Nodes and the Gateway must be available to users of the dashboard. If data is not transmitted from a Node when it was expected, the Node will be flagged as having been disconnected. (MR11)

Engineering Requirements

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User Interface and Dashboard

17. The status of the connection between the Nodes and the Gateway must be available to be monitored by users of the Dashboard, recording the last time a message was received from each Node. (MR11)
18. The Nodes must be able to be shown at their location on a map to allow users to easily tell which Node's data corresponds to the location of the Nodes as they were installed. (MR12)

Engineering Requirements

Deployment and Maintenance

19. **The location of each Node must be stored in the database of connected Nodes and be able to be changed by users of the dashboard to allow for reuse of devices and moving them while preserving the data. (MR13)**
20. **The Nodes must be able to be installed by users with minimal tools and knowledge required to allow for easy reuse, movement, or expansion of the system. (MR13)**
21. The Nodes must be able to indicate to users installing them that they are connected to the network without requiring users to look at the dashboard or any other devices. (MR13)
22. The system must have documentation made available to users including instructions on how to install Nodes, how to troubleshoot connection issues, and how to use the dashboard to access and manipulate data. (MR14)

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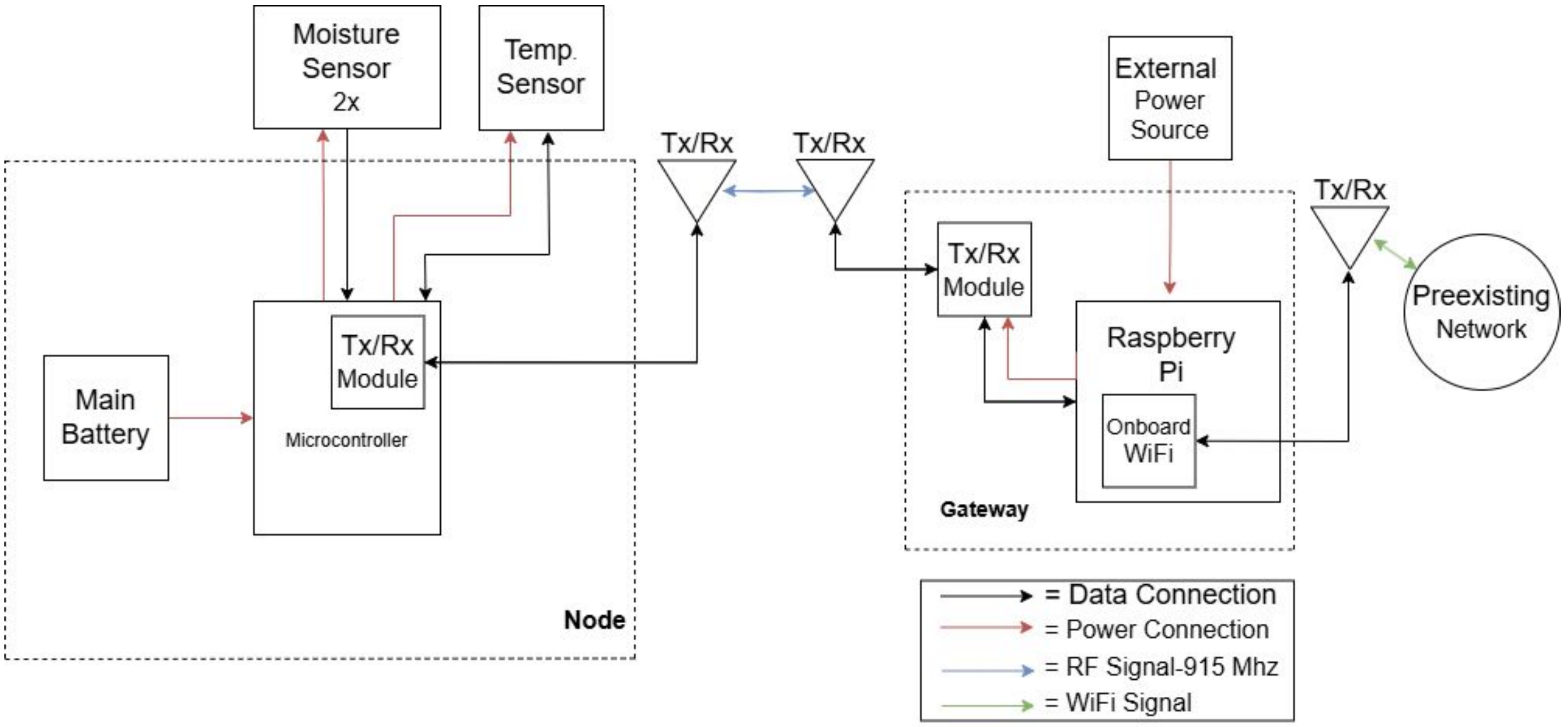
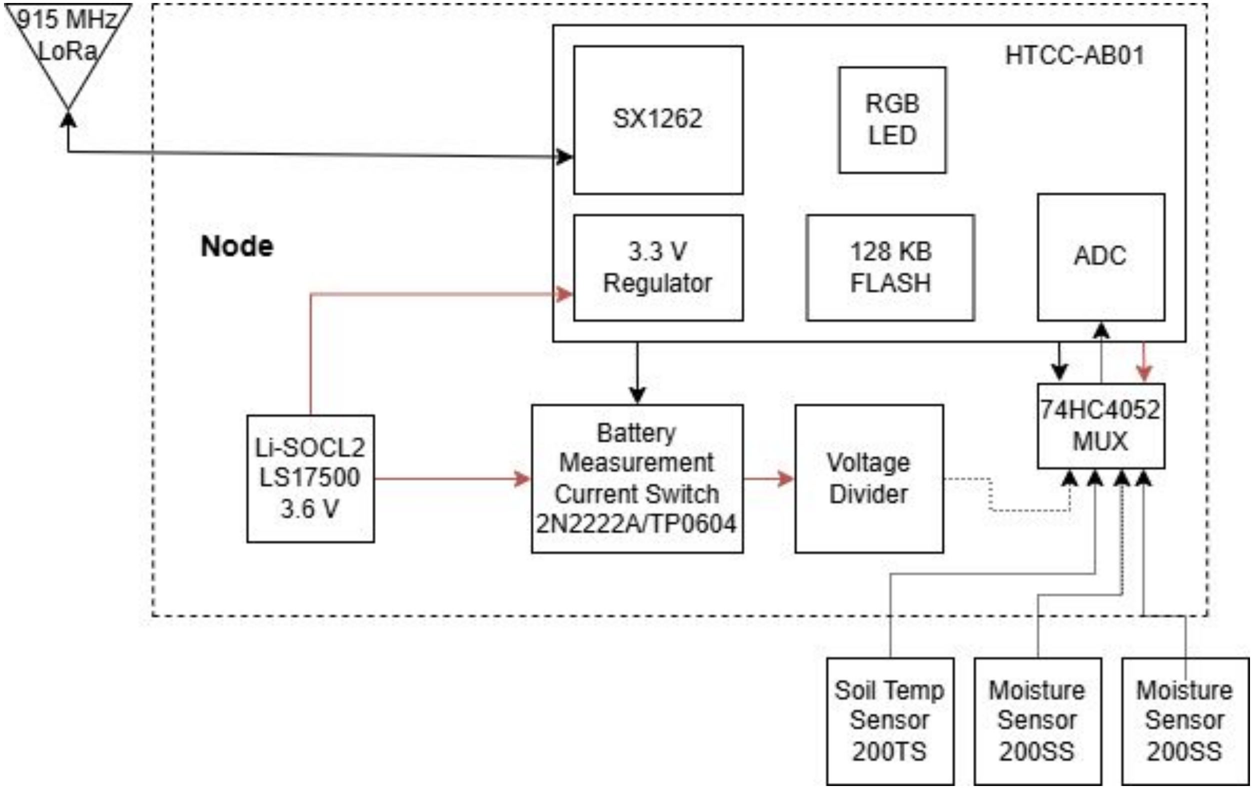
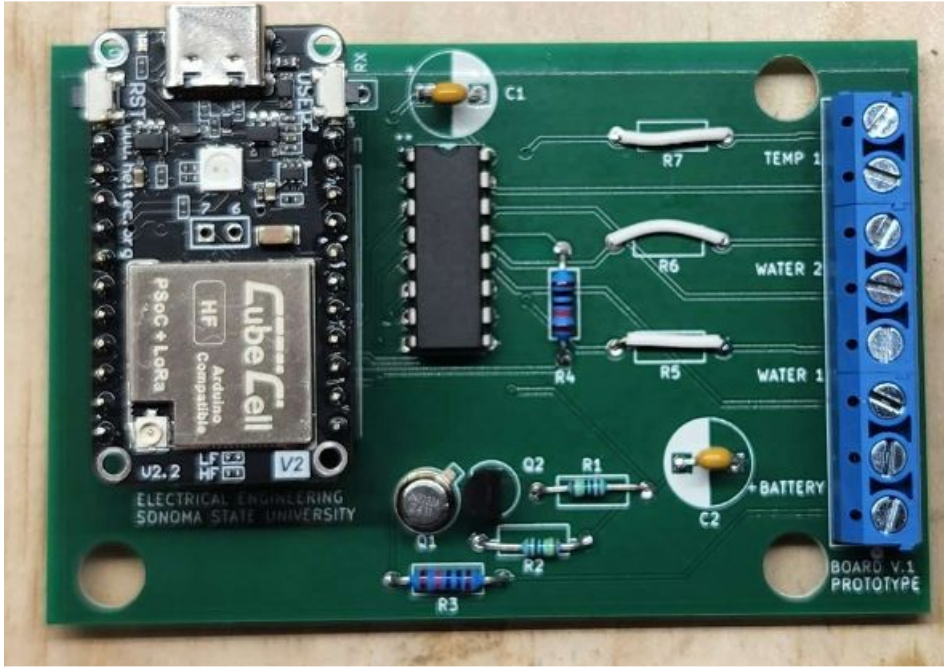
System Block Diagram: Node to Gateway



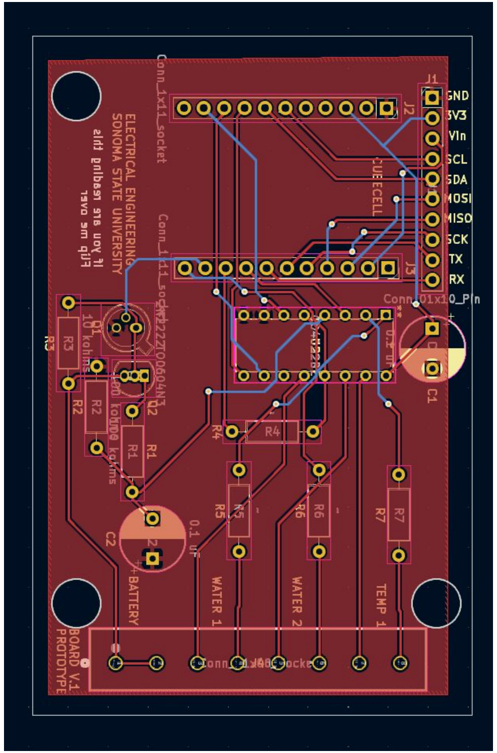
Hardware Block Diagram: Node



Hardware: Node PCB



Populated PCB



PCB Routing

Sensor Hardware

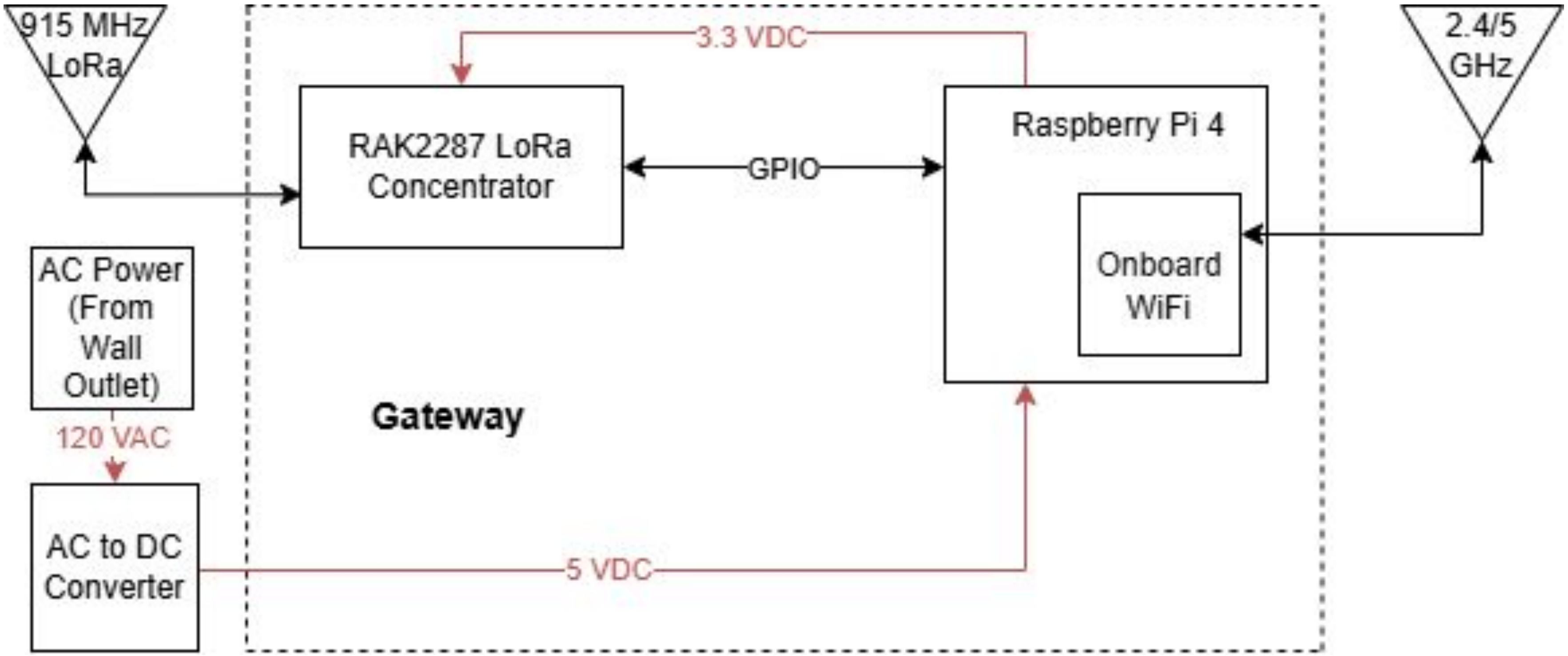
Irrometer 200SS Soil Moisture Sensor-

- OUTPUT: Variable resistance from 550Ω to 32000Ω
- TOTAL RANGE: 0 to 239 centibar (kPa) of water tension
- CALIBRATED RANGE: 10 to 75 centibar of water tension
- Compared to Watermark Tensiometer to confirm calibrated range

Irrometer 200TS Soil Temperature Sensor-

- OUTPUT: Variable resistance from 180Ω to 1 MΩ
- TOTAL RANGE: -50 °C to 150 °C
- CALIBRATED RANGE: 0 °C to 100 °C
- Compared to FLUKE IR Thermometer (+/- 0.5 °C)

Hardware Block Diagram: Gateway



Hardware: Gateway

RAK2287

Implemented Gateway

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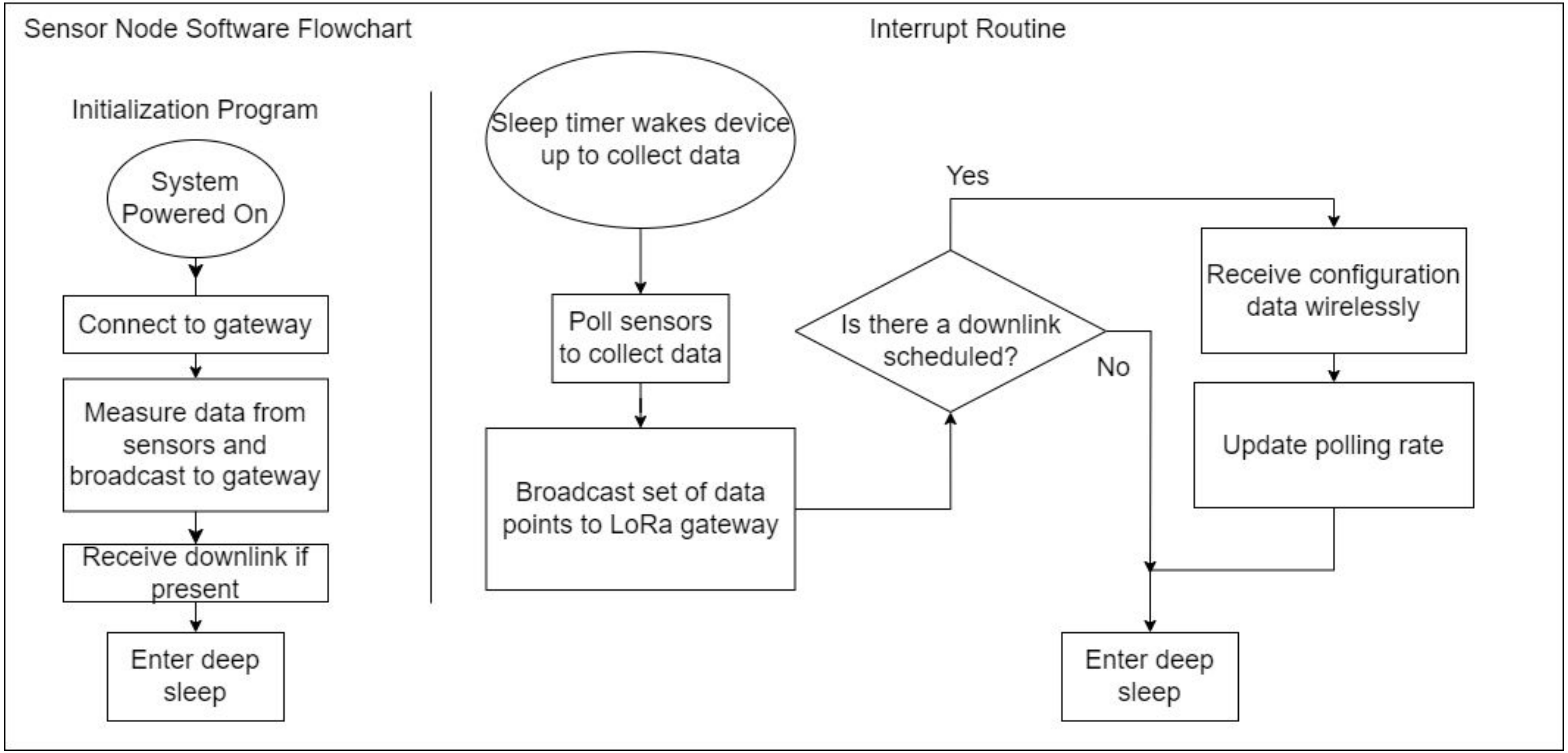
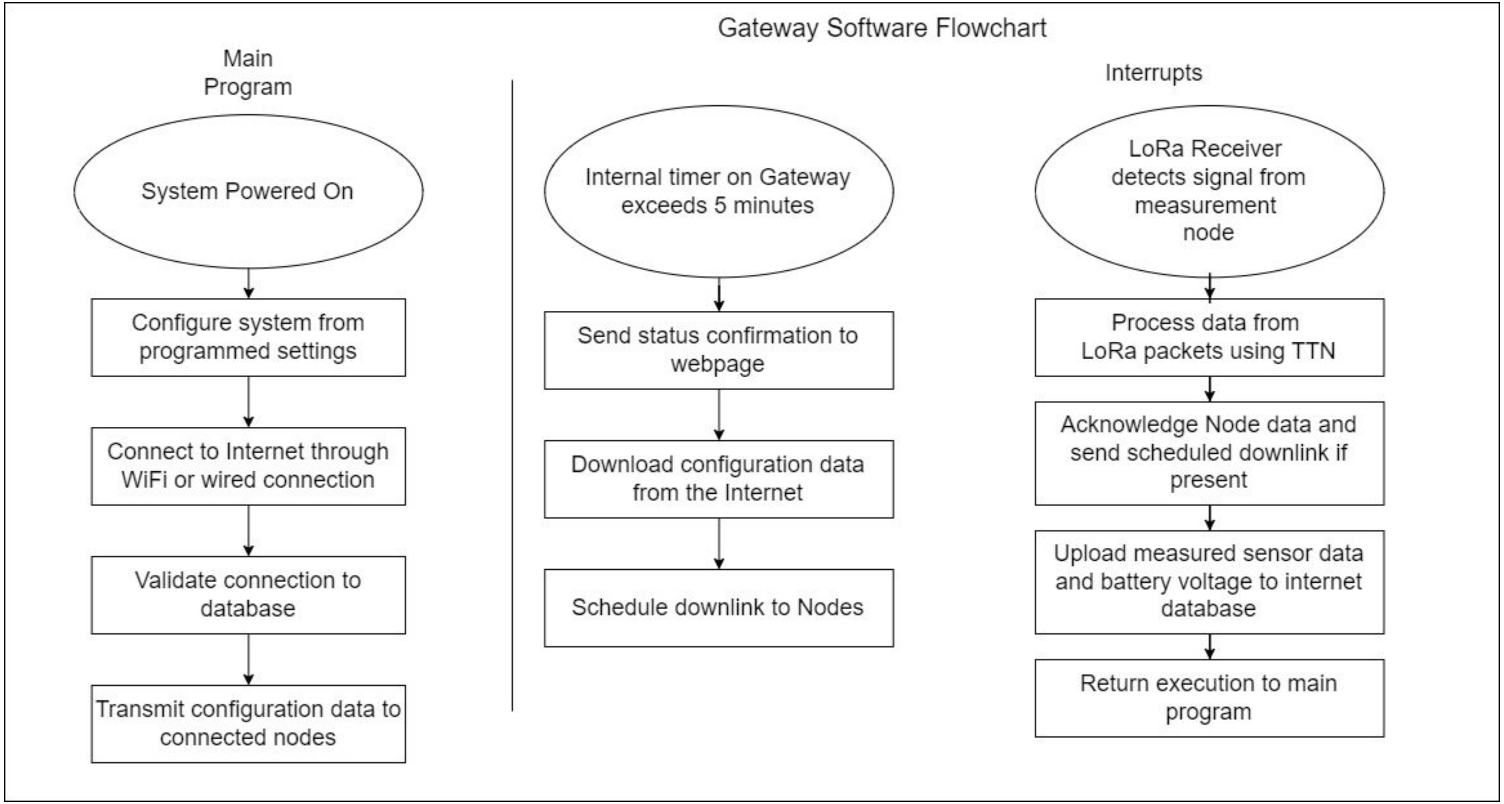
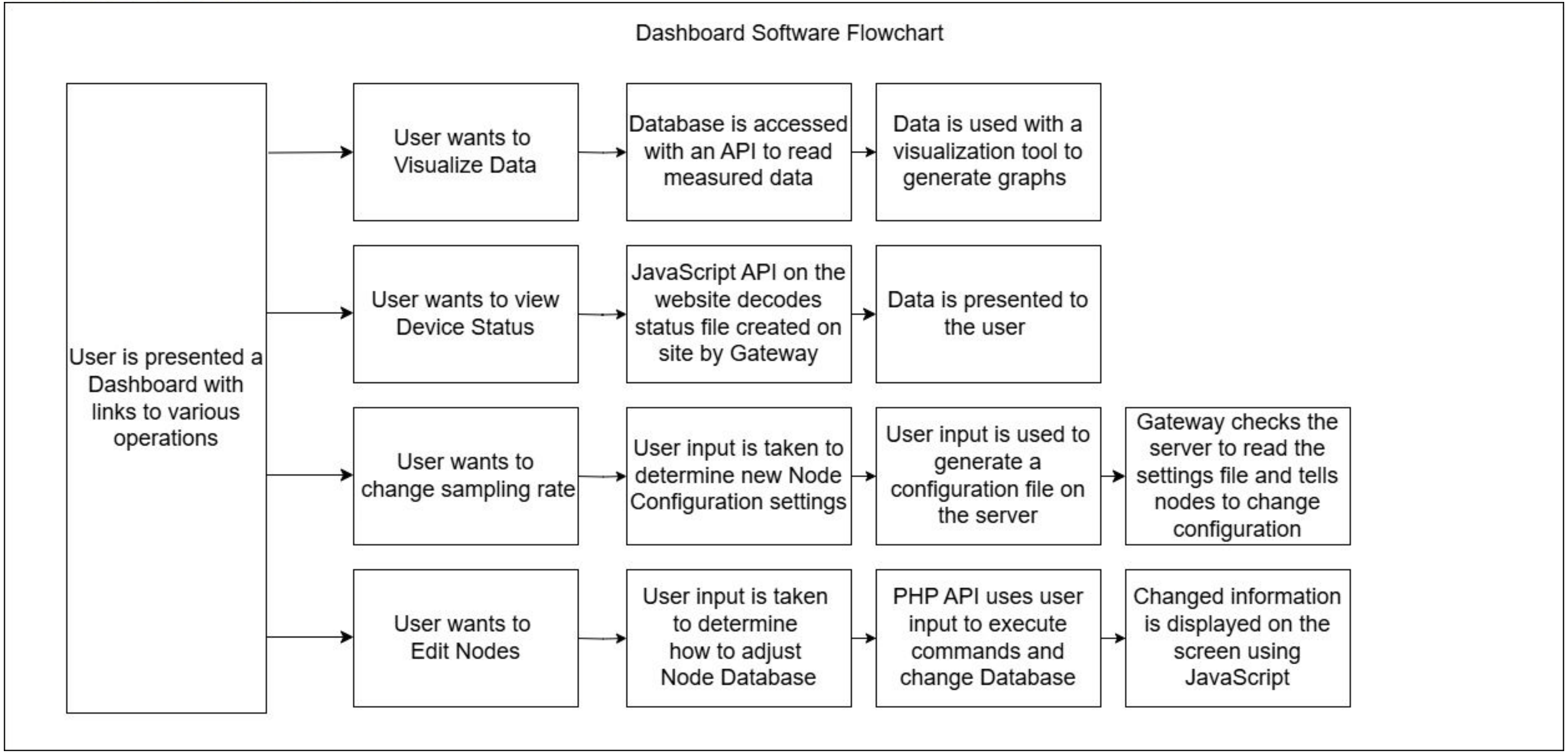
Sensor Node Software Design



Gateway Software Design



Server Software Design



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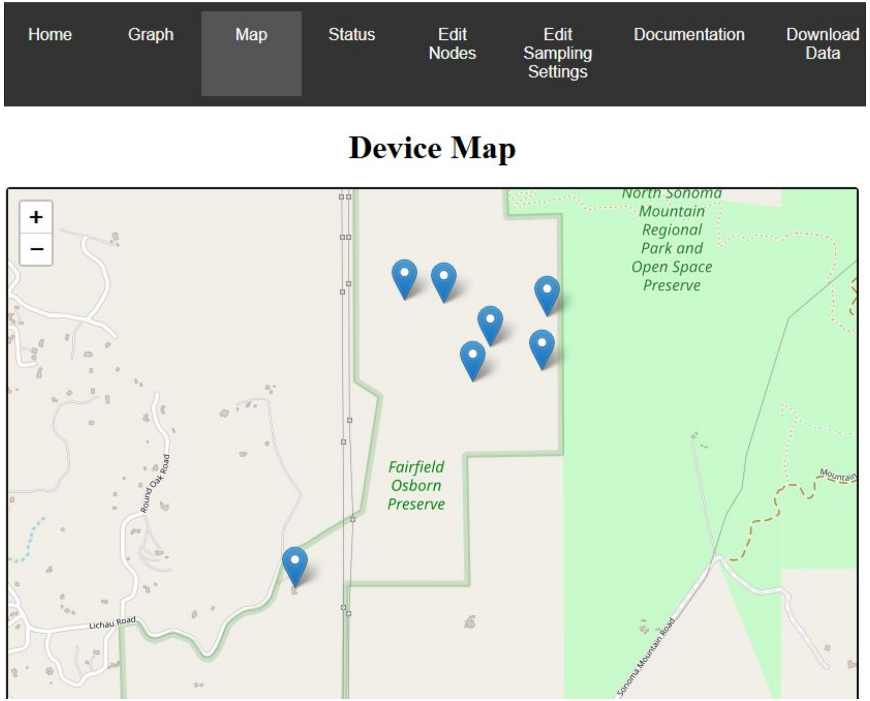
Server Software Design

Graph Page

Map Page



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Matrix: Communication Methods

Raw Scores				Normalized Weighted Scores		
Criteria	LoRaWAN	BLE Nano	LTE	**LoRaWAN**	BLE Nano	LTE
Cost	4	2	1	0.364	0.222	0.125
Range	4 (10 km)	3 (0.1 km)	5 (20 km)	0.250	0.250	0.250
Power Consumption	2 (100 mA)	3 (20 mA)	2 (100 mA)	0.222	0.300	0.222
Transfer Speed	2 (27 kbps)	3 (2 Mbps)	5 (200 Mbps)	0.167	0.231	0.333
Ease of Use	3	2	2	0.300	0.222	0.222
Score				1.303	1.225	1.153

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Matrix: Microcontroller

Raw Scores				Normalized Weighted Scores		
Criteria	ESP32-C3	STM32F401	HTCC-AB01	ESP32-C3	STM32F401	**HTCC-AB01**
Cost	3 ($8)	4 ($6)	5 ($5)	0.250	0.333	0.417
Program Memory	4 (4000 KB)	3 (256 KB)	2 (128 KB)	0.444	0.333	0.222
Sleep Current	2 (5 uA)	5 (2.4 uA)	3 (2.5 uA)	0.200	0.500	0.300
ADC/IO	4	4	1	0.444	0.445	0.111
Ease of Use	4	3	3	0.400	0.300	0.300
Score				1.739	1.911	1.350

Matrix: Gateway Hardware

Raw Scores			Normalized Weighted Scores	
Criteria	Dragino LG308	Raspberry Pi	Dragino LG308	**Raspberry Pi**
Cost	3 ($350)	3 ($200)	0.500	0.500
Power Usage	2 (12W)	3 (5W)	0.400	0.600
Onboard Computing	2	4	0.333	0.667
Ease of Use	5	2	0.714	0.286
Score			1.948	2.052

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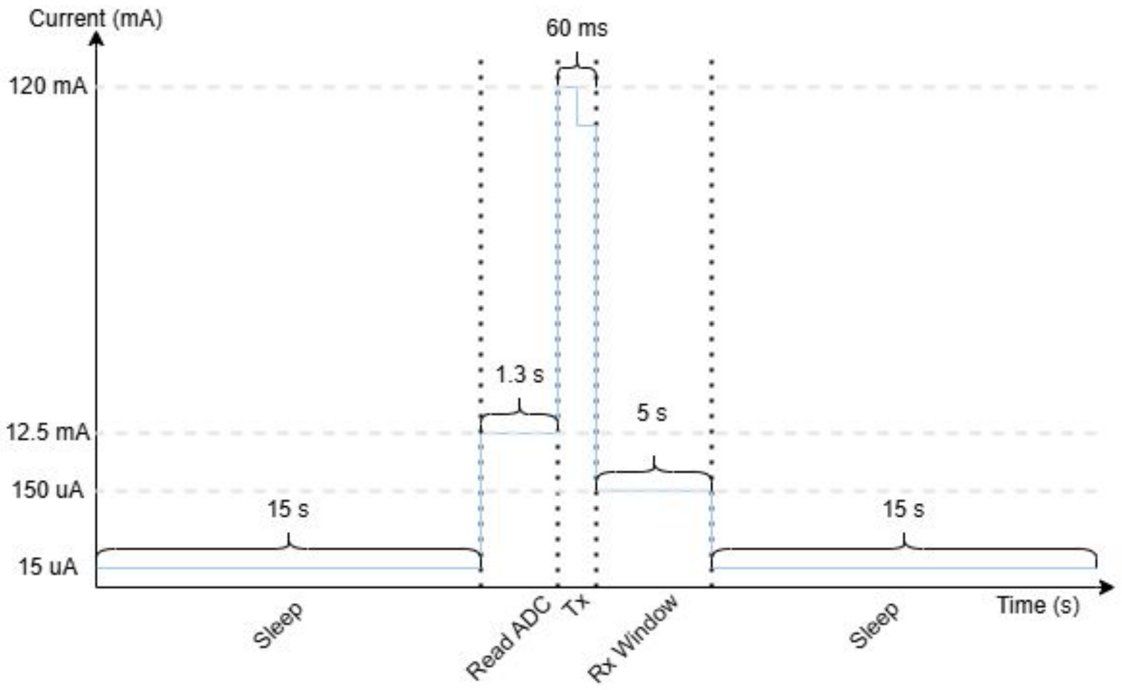
Theory: Power Consumption



The amount of current drawn by the Nodes depends on what the Node is doing.

Transmitting data causes far more current draw than reading the sensors or waiting to receive data.

The sleep routine that runs between measurements causes very little current draw.

Power Consumption

Battery Capacity

By taking the current draw of components multiplied by the time active we can determine the amount of Ah used in a single measurement then the amount in one day:

$$I_{Day} = (I_{TX} + I_{RX} + I_{ADC} + I_{Sleep}) \times N_{Measurements} = 2.303 \text{ mAh}$$

Using this calculation we determine the Ah needed for a year of operation:

$$I_{year} = I_{day} \times 365 = 0.841 \text{ Ah}$$

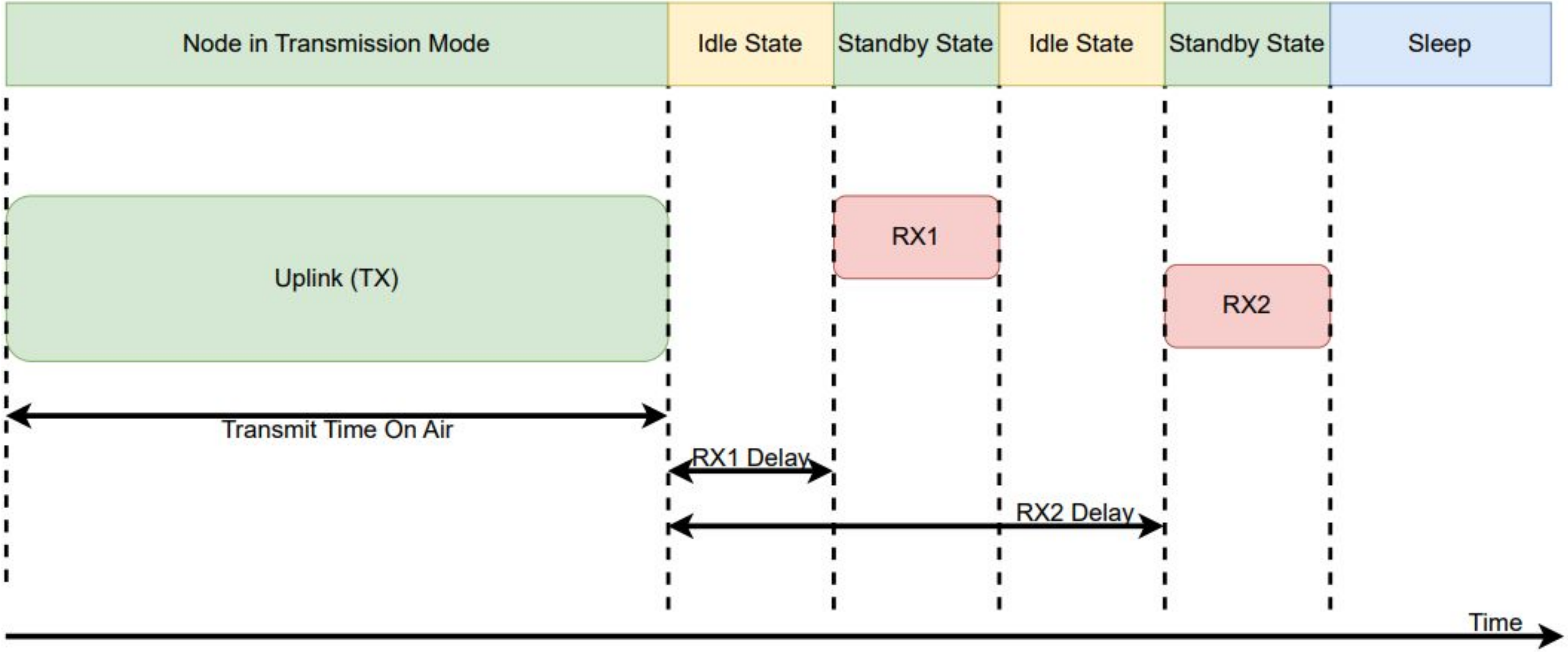
To be conservative with our estimates, we included an additional energy loss factor of 50%:

$$I_{year} = 0.841 \text{ (Ah)} \times (1+ 0.5) = 1.226 \text{ Ah}$$

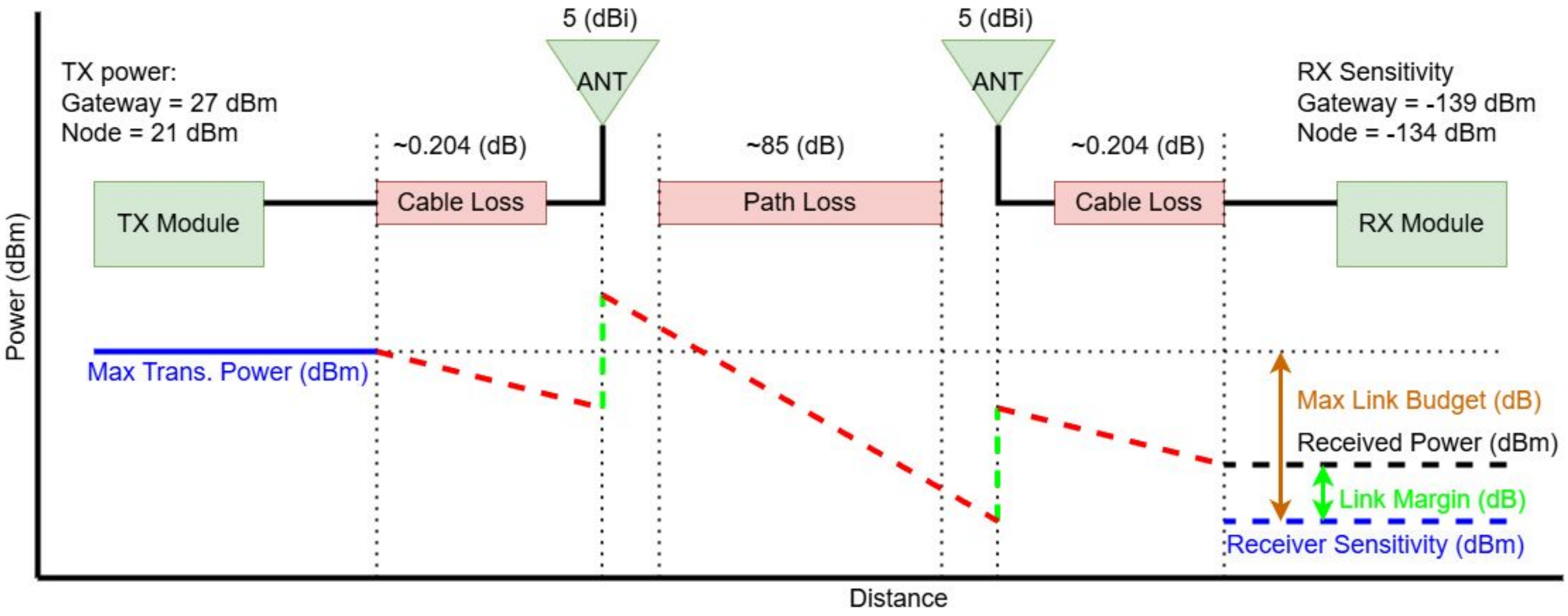
Taking this into consideration, a battery with a 3.6 Ah capacity will last just under 3 years:

3.6 (Ah) / 1.226 (Ah) = 2.93 years or 1072 days

Theory: LoRa Class A



RF Link Power Budget



Max Link Budget = Max Trans. Power - Lowest Receiver Sensitivity

Received Power = Trans. Power + Gains - Losses

Link Margin = Received Power - Receiver Sensitivity

Scalability

Scalability Concerns:

- Cost for additional devices with multiple sensors is out of budget
- Desired locations for new devices may be outside of the range of the Gateway
- Additional devices would eventually hit a limit when they can’t avoid transmitting at the same time, interfering with each other’s signals
- Increasing the complexity of the devices would require larger batteries or more robust microcontrollers
- Additional devices on TTN requires paid plan

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Theory: Scalability

Max Number of Supported Nodes:

$$\mathbf{Node_{MAX} = T_{available} / (T_{airtime} \times M)}$$

Where:

- $T_{available}$ depends on Gateway Duty Cycle, Number of Channels, and Time.
- $T_{airtime}$ depends on Spread Factor, Channel BW, Payload size
- **M** is messages per hour

Worst Case:
1% Duty Cycle, 8 Channels, 0.37s airtime (SF10, 125 kHz Channel BW, 22 Byte Packets), 4 messages per hour.

$$\mathbf{Node_{MAX} = (0.01 \times 3600 \times 8) / (0.37 \times 4) = 194\ Nodes}$$

Challenges

Challenges we anticipated:

- Finding a cost effective wireless communication method that can transmit up to 0.75 miles in environments with elevation changes and heavy tree cover
- Ensuring data is not lost in transmission from Node to Gateway or from Gateway to server
- Getting a housing device and external components that can withstand the environment on the Fairfield Osborn Preserve

Challenges we didn't anticipate:

- The difficulty and time it would take to implement local storage on the Nodes
- The Gateway does not have access to data gathered with the internet disconnected because of limitations in the TTN service
- We were unable to implement MQTT from the webpage like we had wanted; this was caused by limitations of our web host.

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List of Tests to Complete

Test Number	Test Objective	Related ER	Status	Notes
FT-1	LoRa 915 MHz Range Test	ER2	Complete	Some locations need additional height to ensure transmission
FT-2	Connect TTN server to our database and website	ER6	Complete	

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List of Tests to Complete

Test Number	Test Objective	Related ER	Status	Notes
FT-3	Create web application for user interface	ER6	Complete	Details will change as project progresses
FT-4	Test communication from Gateway to Nodes	ER4	Complete	Connect Node to serial monitor and print received data

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List of Tests to Complete

Test Number	Test Objective	Related ER	Status	Notes
FT-5	Testing Device Enclosure	ER2	Complete	The devices are currently installed on site being tested
FT-6	Moisture Sensor Calibration Test	ER7	Complete	Water tension & temperature compensation

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List of Tests to Complete

Test Number	Test Objective	Related ER	Status	Notes
FT-7	Testing interruptions of Gateway service Testing LED status indicator	ER21	Complete	
FT-8	Verifying reported ADC values aligns with measured	ER7	Complete	

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List of Tests to Complete

Test Number	Test Objective	Related ER	Status	Notes
ST-1	Test Device Comm. with Web Server	ER4,ER6	Complete	
ST-2	Parameter Change for Nodes	ER4	Complete	Sleep duration must be updated on downlink

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List of Tests to Complete

Test Number	Test Objective	Related ER	Status	Notes
ST-3	Power Consumption and Battery Life	ER2	In-Progress	Dependent on frequency of data collection & transmission
ST-4	Full Autonomy Test		In-Progress	The Nodes are installed and their autonomous behavior is being recorded

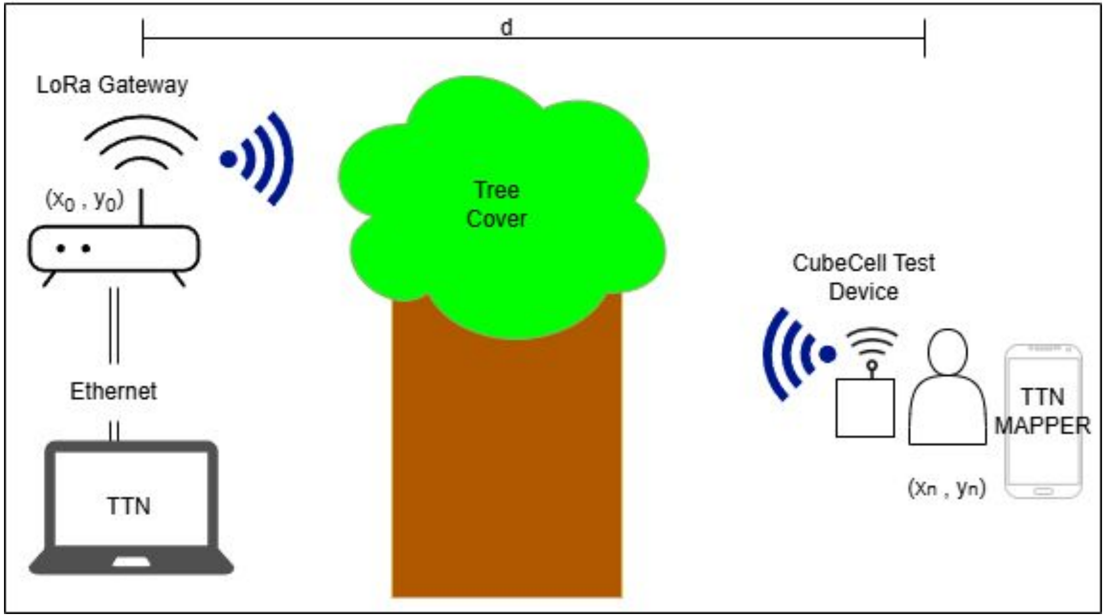
Completed

Function Test 1 (ER2)

Purpose:

- Verifying that the Gateway is able to receive data from the Nodes when installed in the locations on site with no packet loss and received signal to noise ratio of over -20 dB which is the physical limit for LoRa

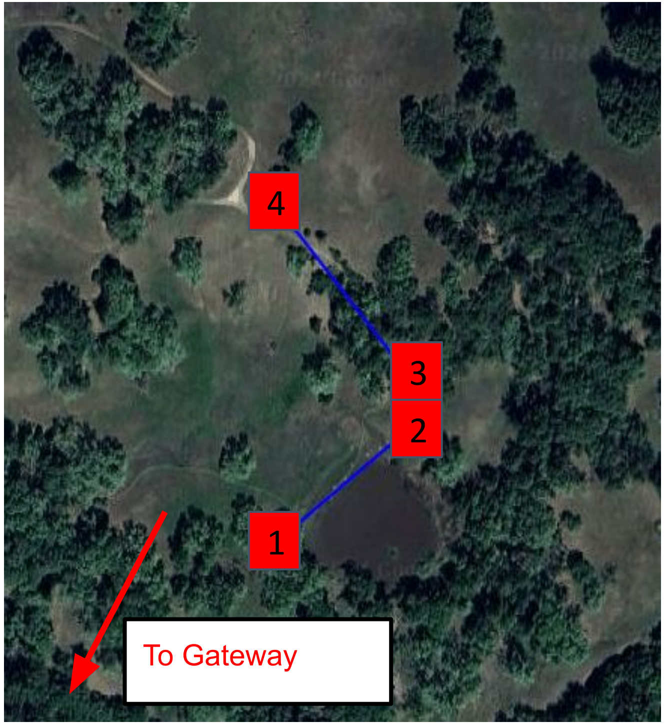
Setup:



Function Test 1 (ER2)

Results:

Node	1	2	3	4
Latitude(X)	38.3506	38.3512	38.3514	38.3523
Longitude(Y)	-122.587	-122.586	-122.586	-122.587
Elevation(Feet)	2066	2076	2091	2151
Distance from Gateway (Miles)	0.651	0.725	0.727	0.745
RSSI (dB)	-134	-113	-112	-117
SNR (dB)	-15.5	-8	-7	0.5



Function Test 1 (ER2)

Conclusion:

Every transmission of data from the Node to the Gateway was completed successfully with the antennas we used.

This test was completed again with the final hardware we will be using for the project.

Future Plans:

If the distance to where Nodes are installed needs to be increased in the future, the antenna on the Gateway can be elevated to a better position, though this would require permits to do and is not necessary for our project.

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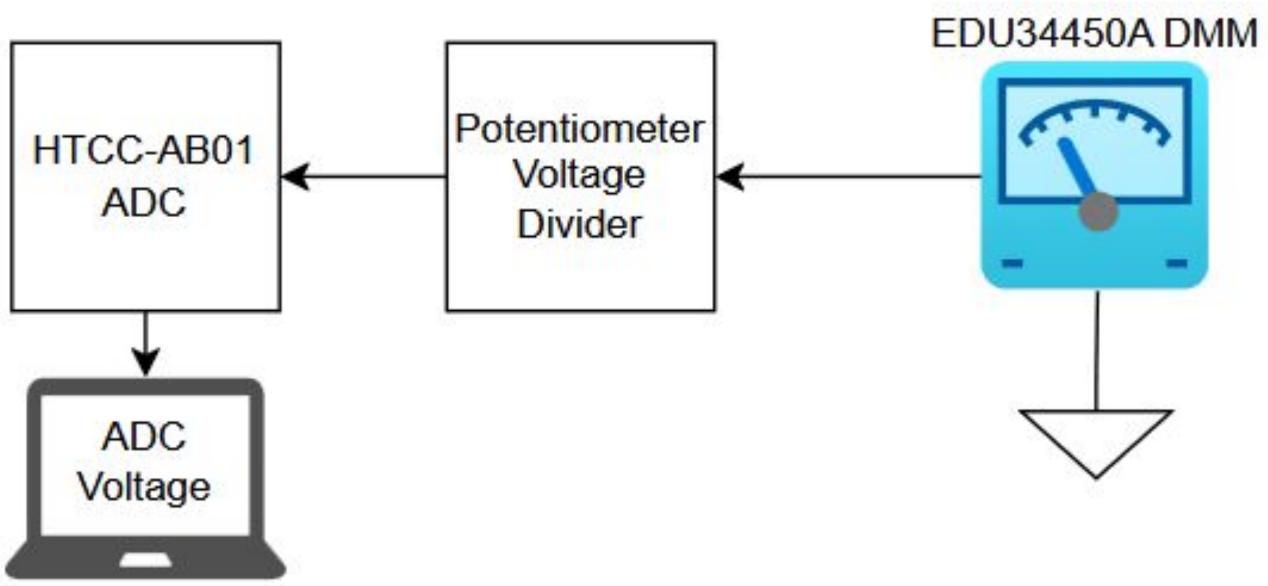
Function Test 8 (ER7)

Purpose:

- Verifying that the 12-bit ADC is reporting the correct voltage reading with a Digital Multimeter (DMM)

Setup:



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Function Test 8 (ER7)

Data:

	Claimed 2.4V ADC Reference				
	DMM_mV	ADC_Low_mV	ADC_High_mV	Low_Error_mV	High_Error_mV
1	52.62	52.15	52.73	-0.48	0.10
2	249.57	249.43	250.55	-0.14	0.98
3	508.21	510.29	511.41	2.08	3.20
4	750.95	754.75	755.80	3.80	4.85
5	1005.30	1010.98	1011.68	5.68	6.38
6	1500.30	1508.59	1510.14	8.29	9.84
7	2000.90	2012.34	2013.16	11.44	12.26
8	2381.10	2394.38	2395.66	13.28	14.56

Manufacturer specified reference voltage of 2.4V resulted in gain error (up to 15 mV).

Function Test 8 (ER7)

Data:

Calibrated 2.385V ADC Reference					
	DMM_mV	ADC_Low_mV	ADC_High_mV	Low_Error_mV	High_Error_mV
1	52.48	51.94	52.46	-0.55	-0.02
2	247.38	246.29	246.99	-1.09	-0.39
3	504.15	503.79	504.19	-0.36	0.04
4	749.92	749.24	749.50	-0.68	-0.42
5	1001.10	1000.84	1001.24	-0.26	0.14
6	1502.70	1502.49	1502.99	-0.21	0.29
7	2004.80	2004.61	2005.27	-0.19	0.47
8	2380.10	2379.88	2380.19	-0.22	0.09

Reducing the ADC reference voltage to 2.385V removed the gain error.

Function Test 8 (ER7)

Conclusion:

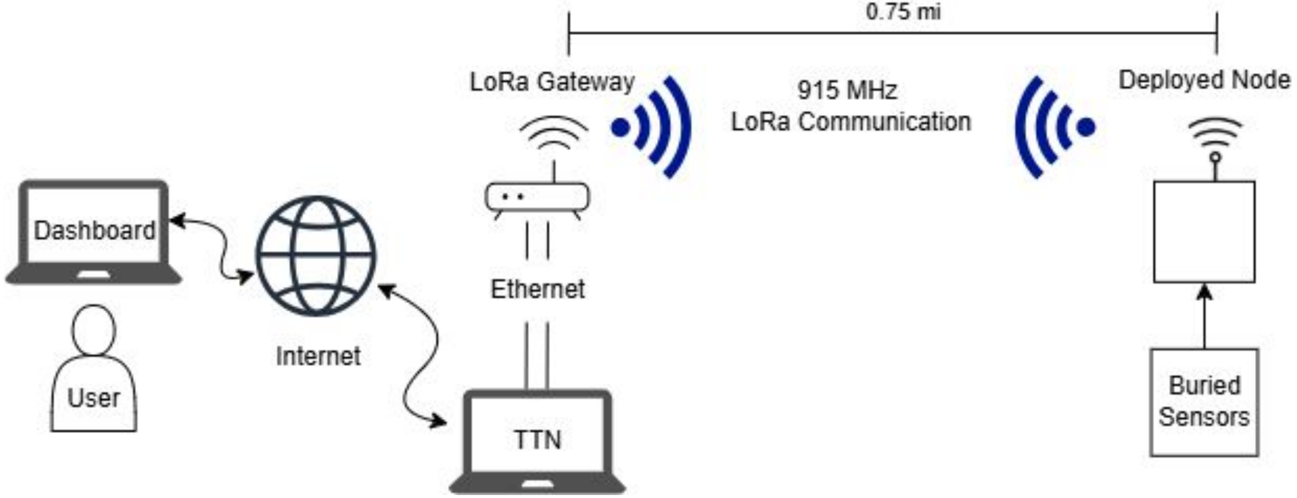
The gain error seen when using the manufacturers specification for ADC, while high, only caused a maximum error of 2 CB within our calibrated range. While adjusting the reference voltage removed the gain error entirely, it would have to be done on each Node. The LSB voltage is 582 uV, and max step error observed was 3 steps.

System Test 1 (ER 4,6)

Purpose:

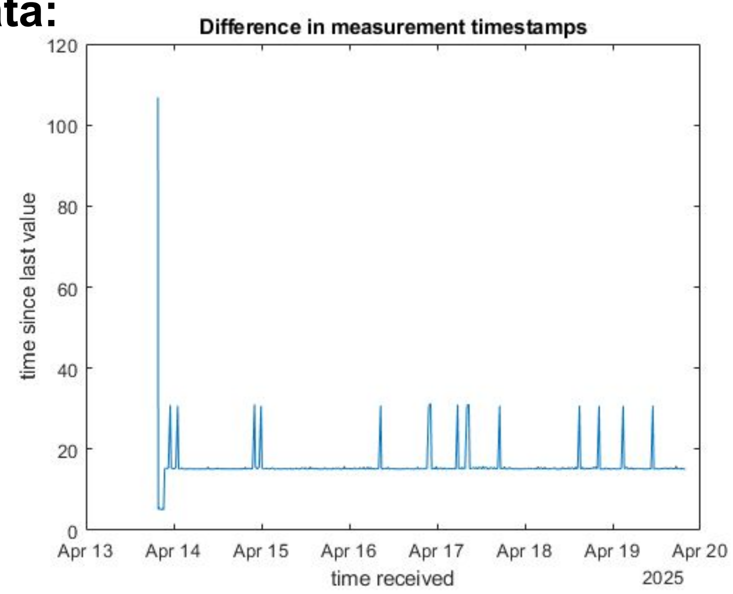
- Verifying that the Website is able to receive information from the Gateway and display it to the users
- Verifying that the Website is able to send downlink messages to the Nodes through the Gateway

Setup:

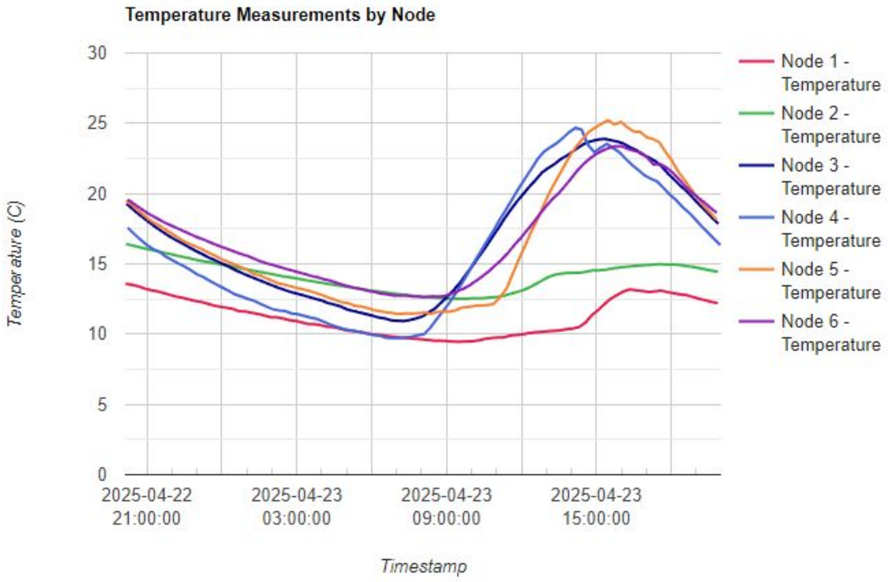


System Test 1 (ER 4,6)

Data:



Over the course of our testing, the Node with the worst connection dropped 16 packets out of 583 for a rate of 2.74%.



The graph on the webpage shows data received from the Nodes.

System Test 1 (ER 4,6)

Conclusion:

Users are able to see data uploaded from the Nodes visualized on a graph and schedule downlink messages to change the settings on the Nodes.

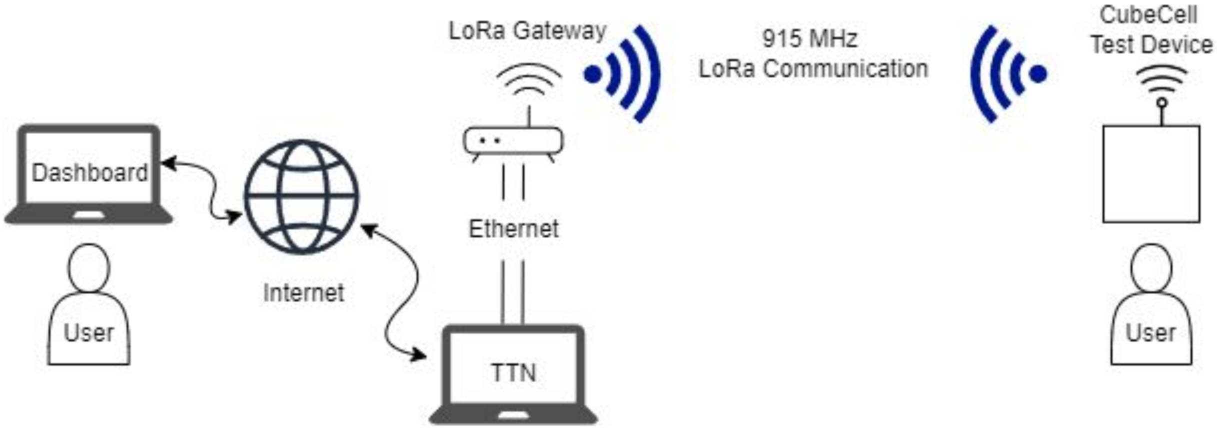
Data transmitted by the Nodes is received at a rate of 97.25% for the Node with the worst connection, well exceeding our goal of 90%.

System Test 2 (ER 4)

Purpose:

- Verifying that users can remotely change the duration of sleep on the Nodes by using the website.
- Verifying that sleep times are accurate

Setup:



System Test 2 (ER 4)

Data

```
Node 1: Avg = 907.39 seconds, Std Dev = 2.02 seconds
Node 2: Avg = 906.82 seconds, Std Dev = 1.45 seconds
Node 3: Avg = 906.80 seconds, Std Dev = 1.89 seconds
Node 4: Avg = 907.85 seconds, Std Dev = 2.98 seconds
Node 5: Avg = 912.73 seconds, Std Dev = 8.57 seconds
Node 6: Avg = 911.65 seconds, Std Dev = 7.80 seconds
```

By analyzing the difference between timestamps of measurements, the duration of sleep cycles was determined to be within specifications

nam1.cloud.thethings.network

Connected

{"end_device_ids":
{"device_id":"fob-n1","application_ids":
{"application_id":"fop-lora-network"},"dev_eui":"70B3
D57ED006FB1D","join_eui":"0000000000000000","d
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gs:tx_ack:01JSJW6D47GAH0QDJR4R8R7EGM","gs:up
link:01JSJW6CPCT7WTDZRSDM0VB85D","ns:transmis
sion:01JSJW6D3C4CW51XYSX0NGJQJC"],"received_a
t":"2025-04-24T03:06:53.961447042Z","downlink_s
ent":
{"session_key_id":"AZZQYNpqXqHShk7hF+FVHg==","f
_port":15,"f_cnt":417,"frm_payload":"AA27oA==","pri
ority":"NORMAL","correlation_ids":
["as:downlink:01JSJW1W6ZYDWVX7630WRKYD06","
gs:tx_ack:01JSJW6D47GAH0QDJR4R8R7EGM","gs:up
link:01JSJW6CPCT7WTDZRSDM0VB85D","ns:transmis
sion:01JSJW6D3C4CW51XYSX0NGJQJC"]}}

v3/fop-lora-network@ttn/devices/fob-n1/down/sent

QoS 0

MQTT messages through TTN's broker show that Nodes receive scheduled changes

System Test 2 (ER 4)

Conclusion:

Nodes receive the downlink of sleep duration successfully and report this back to TTN for logging.

The sleep cycles entered by the Nodes are accurate to within a few seconds of the desired time.

Future Plans:

The Gateway could be made to log its output to the website. This would allow users to see when downlink messages got scheduled remotely and verify that Nodes received them.

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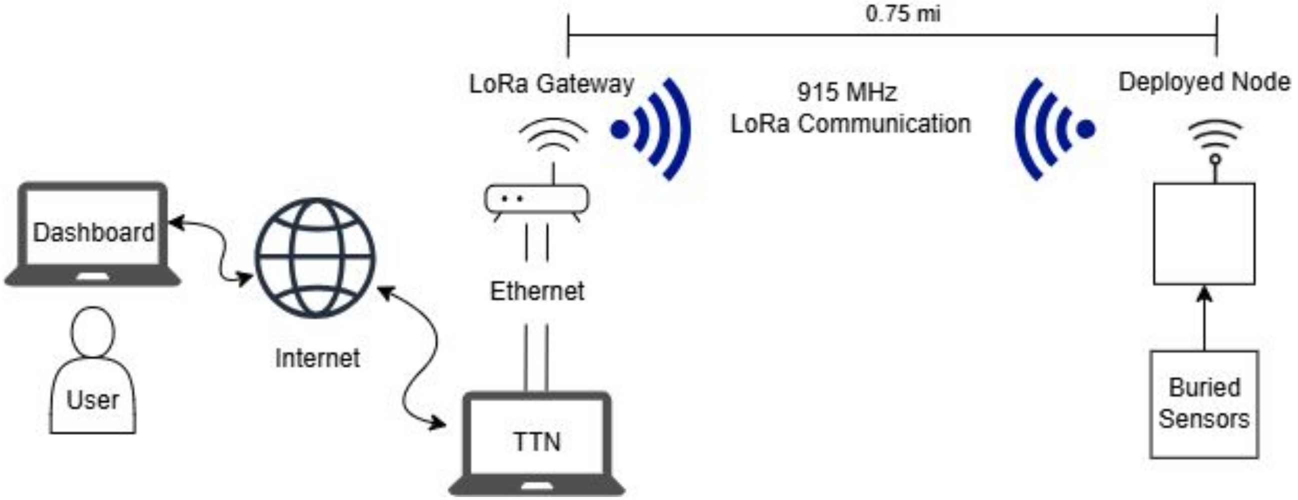
System Test 4 (ERs 2, 4, 6)

Purpose:

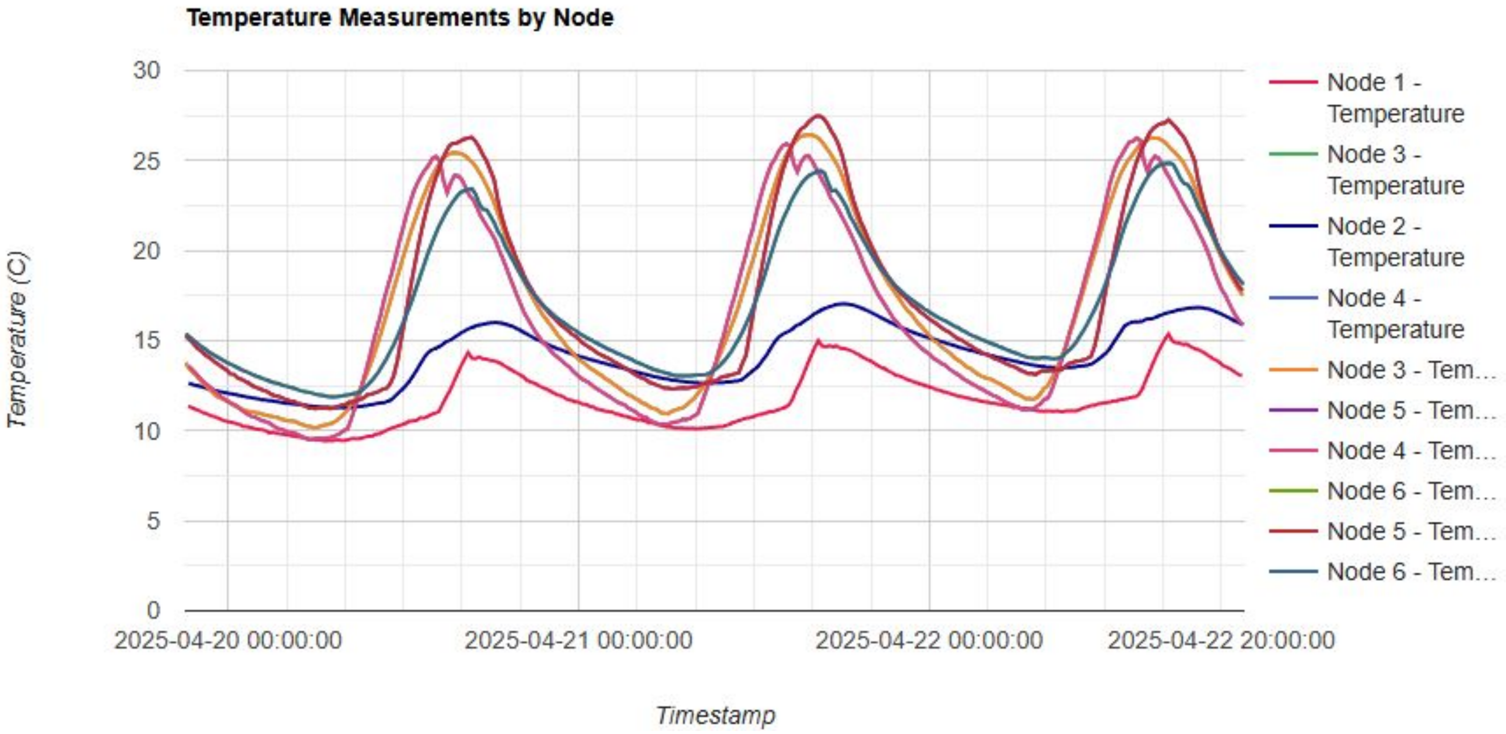
- Verifying that the Nodes can function autonomously for an extended period of time when installed on site
- Verifying that the downlinks function correctly when installed on site

Setup:



System Test 4 (ERs 2, 4, 6)

Measurements:



System Test 4 (ERs 2, 4, 6)

Conclusion:

The test is ongoing, as the Nodes are currently installed on the Fairfield Osborn Preserve and still reporting data. As of Saturday the 19th data has been successfully transmitted from the Node to the database. The sleep duration of the deployed Node can be changed remotely from the website. This was tested while Nodes were deployed in their final locations on the Preserve.

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Potential Upgrades

Future Plans:

- Data Storage
  - Node Storage on a SD Card
  - Gateway Storage while the Gateway is not connected to the internet
- Data Retransmission
  - A system for saving and retransmitting data if connection is lost
  - Requires a RTC on Node to timestamp data
- Microcontroller Change
  - More powerful microcontroller allows for more sensors
  - More ADCs or internal MUX allows for a simpler PCB
  - Requires reworking of power limitations
- PCB Rework
  - Fix issues with current PCB
  - Changes to circuit requires new PCB

Planned Data Loss Prevention

Data Loss Prevention:

- The Nodes were originally planned to have data storage on them using a microSD card, though because of time and hardware constraints this was not able to be implemented.

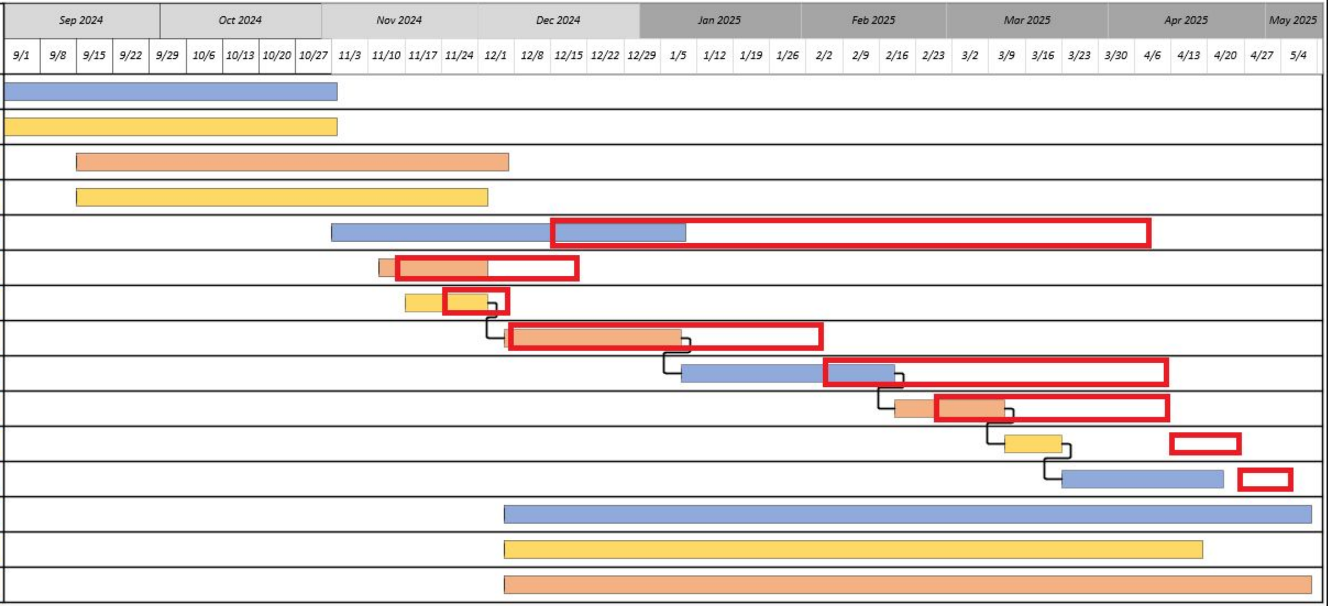
- Each data point uploaded to the Gateway will be responded to with an acknowledgement and if the receipt is not acknowledged then it would be flagged for retransmission when connection is reestablished.

- Each Node would have interfaced with a microSD card to store data locally as a way to ensure that it is not lost if a power failure occurs.

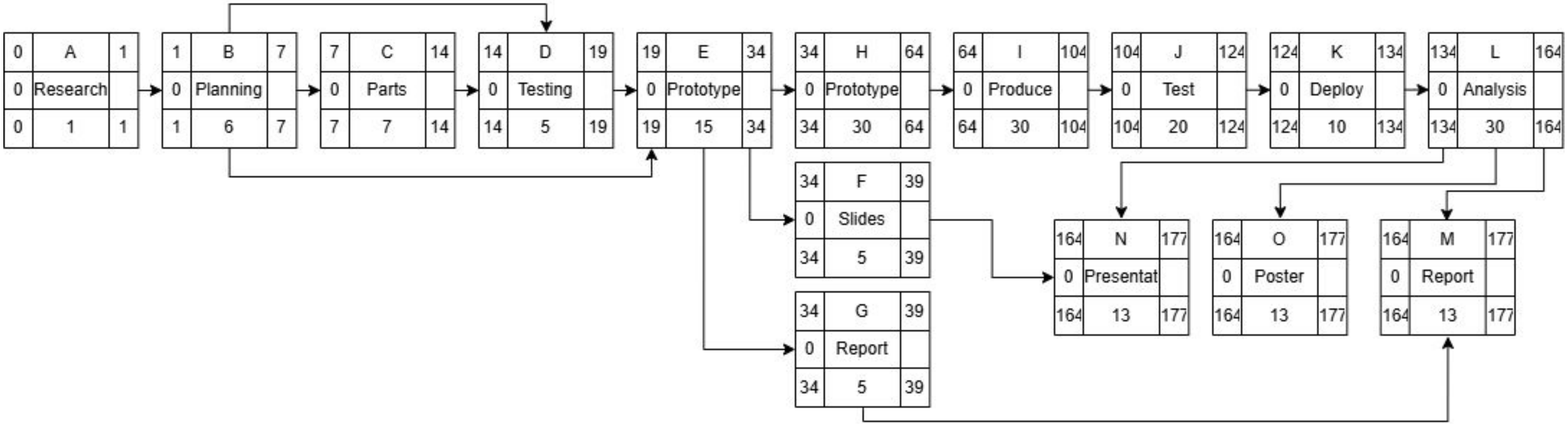
- Each measured data payload consists of only 9 bytes so with a 1GB card we would have capacity to store years worth of data even at high sampling rates

Schedule of Tasks

ID	Task Name	Start	Finish	Duration	Leader
1	Research Towards Solution	9/1/2024	11/3/2024	64d	Chris
2	Solution Planning	9/1/2024	11/3/2024	64d	Charlie
3	Draft of Report	9/15/2024	12/6/2024	83d	Josh
4	Draft Presentation Slides	9/15/2024	12/2/2024	79d	Charlie
5	Aquisition of Parts	11/3/2024	1/9/2025	68d	Chris
6	Initial Testing of Solution	11/12/2024	12/2/2024	21d	Josh
7	Initial Prototype of Solution	11/17/2024	12/2/2024	16d	Charlie
8	Refine Prototype	12/6/2024	1/8/2025	34d	Josh
9	Produce Product	1/9/2025	2/18/2025	41d	Chris
10	Test Product	2/19/2025	3/11/2025	21d	Josh
11	Deploy Product	3/12/2025	3/22/2025	11d	Charlie
12	After Deployment Analysis	3/23/2025	4/22/2025	31d	Chris
13	Final Project Report	12/6/2024	5/9/2025	155d	Chris
14	Final Project Presentation	12/6/2024	4/18/2025	134d	Charlie
15	Final Project Poster	12/6/2024	5/9/2025	155d	Josh



Critical Path



Total Budget

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Item	Part No.	Purpose	Manufacturer	Supplier	Price	Quantity	Ext. Price
Microcontroller	HTCC-AB01 V2	Controller	Heltech	Amazon	15	6	90
LoRa Concentrator	RAK2287	Gateway	RAKwireless	RAKwireless	155	1	155
Single Board Computer	SC0193(9)	Gateway	Raspberry Pi	RAKwireless	45	1	45
Various Parts	Various	Resistors, Connectors, Wires, etc.	Various	DigiKey	200	1	200
Web Hosting	N/A	Supporting Backend	Hostinger	Hostinger	100	1	100
Main Battery	LS17500	Main Power for Node	SAFT	Amazon	16.39	12	196.68
UV Resin	Fast	Battery Holder	Siraya Tech	Amazon	27.74	3	83.22
Soil Temperature Sensor	200TS	Temperature Compensation	Irrometer	Forestry Suppliers	40	6	240
PCB	Custom	Interfacing Node Components	PCBWay	PCBWay	6.35	10	63.5
IP67 Electrical Box	BG595935	Node Enclosure	Joinfworld	Amazon	15.1	6	90.6
Antenna	AOA-915-5ACM	Improve Signal Transmission	ALFA	Amazon	15	6	90
Soil Moisture Sensor	200SS	Measure Soil Moisture Content	Irrometer	Forestry Suppliers	44.5	12	534
						Final Total:	1887.72

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Demonstration

The deployed Nodes are sending data to our Website

By accessing the website graphs and Node locations can be seen

The three graphs show Battery Voltage, Water Tension (which indicates water content), and soil temperature

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Supporting Courses

- Electromagnetic Theory and Applications (EE 430)
- Introduction to Networking (EE 465)
- The Internet of Things (EE 470)
- Microprocessor & System Design (EE 310)
- Microelectronic Circuits (EE 334)
- Analog & Digital Communications (EE 442)

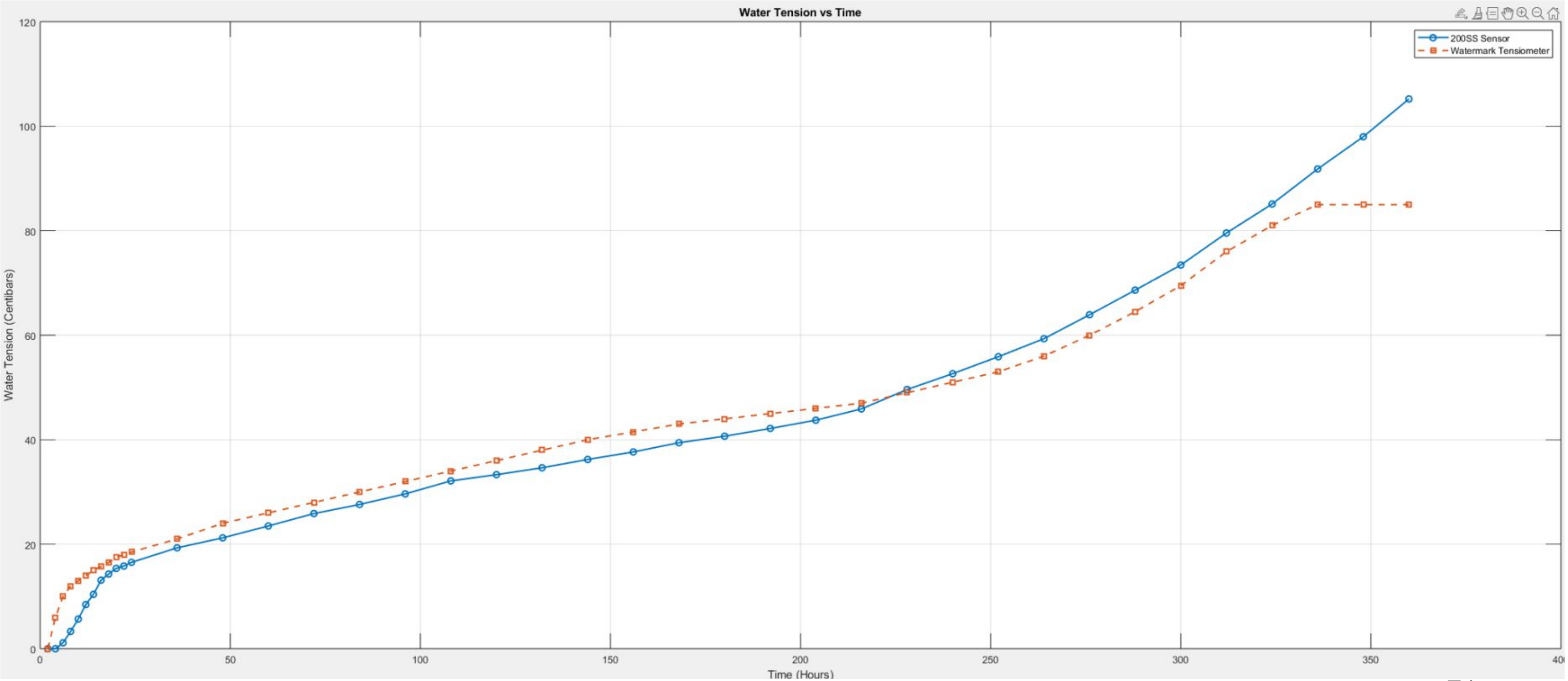
Questions

Questions/Comments

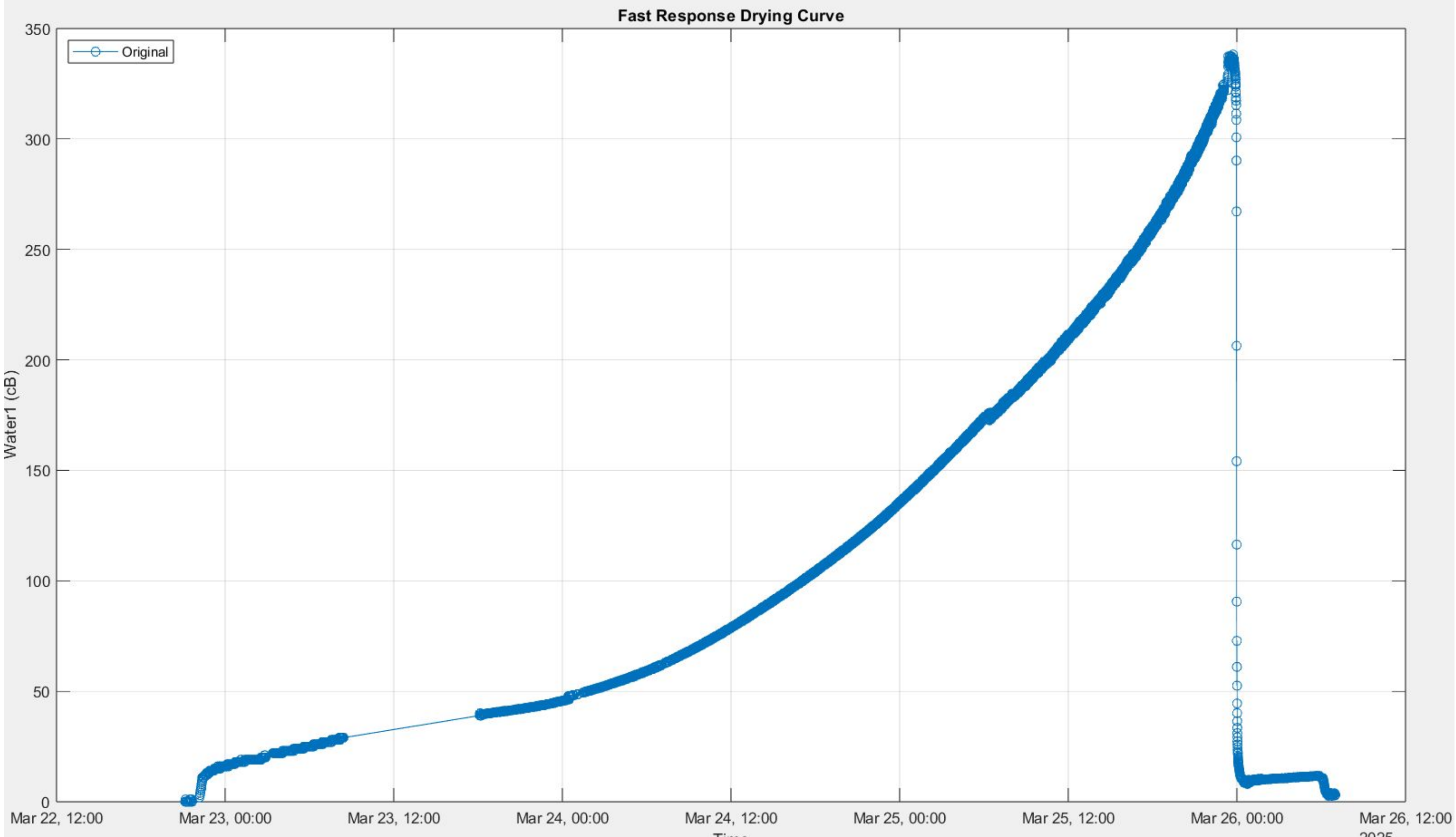
References

- Wu, Nansong, *Senior Design Presentation Template*. Sonoma State University, [Online Document], 2024. Available: https://canvas.sonoma.edu/courses/43075/files/4203618 [Accessed November 10, 2024]

Function Test 6



Function Test 6



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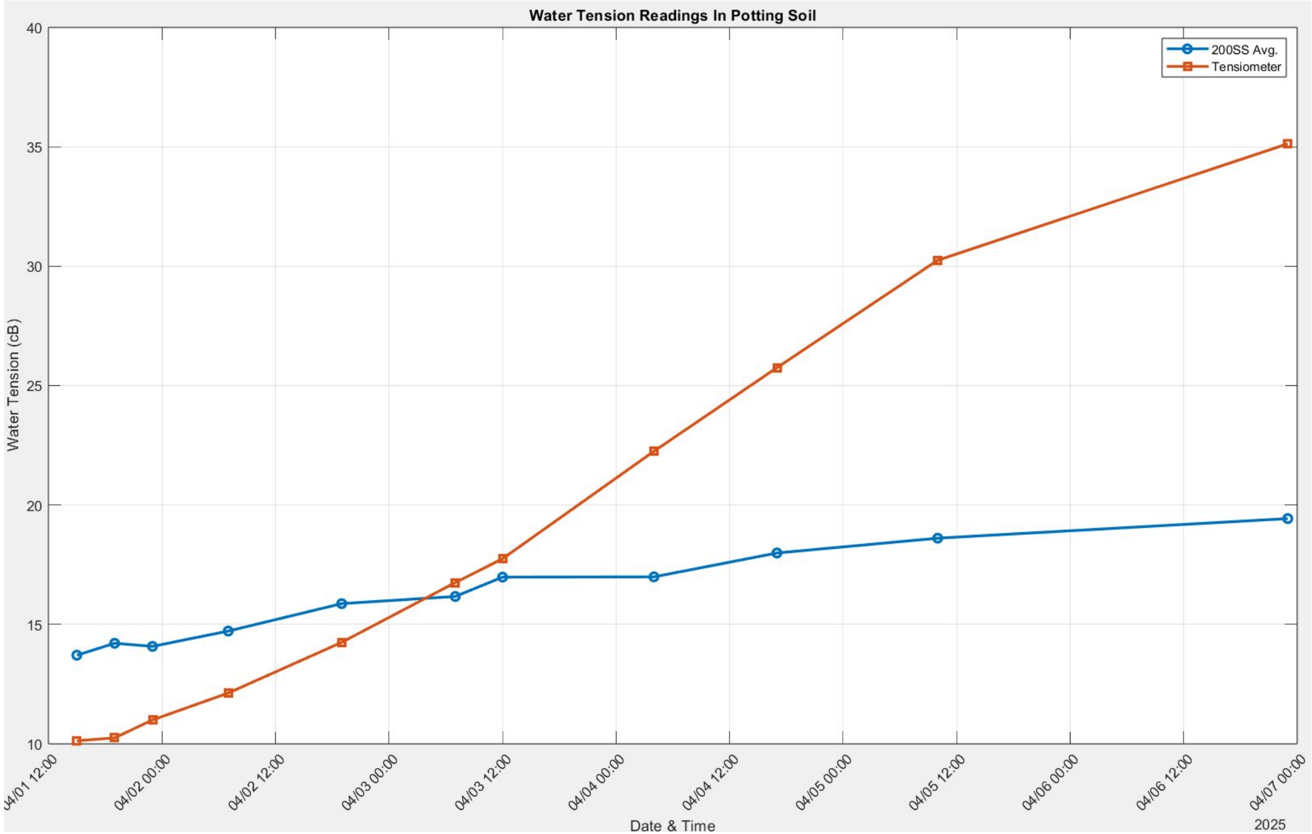
Function Test 6



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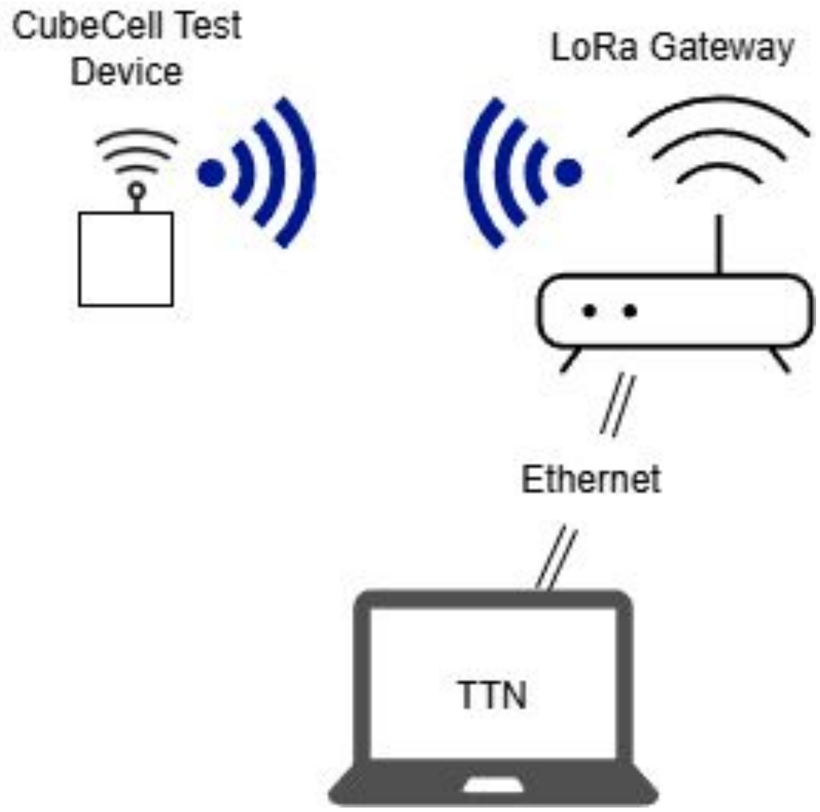
Function Test 8

	DMM_mV	ADC_Low_mV	ADC_High_mV	Low_Error_mV	High_Error_mV
1	52.62	52.15	52.73	-0.48	0.10
2	72.63	72.25	73.13	-0.38	0.50
3	110.85	110.86	111.56	0.01	0.71
4	155.25	155.04	155.39	-0.21	0.14
5	204.00	204.32	205.20	0.32	1.20
6	249.57	249.43	250.55	-0.14	0.98
7	303.72	303.98	304.39	0.26	0.67
8	350.17	351.74	352.91	1.57	2.74
9	408.19	410.10	410.80	1.91	2.61
10	450.12	451.76	452.17	1.64	2.05
11	508.21	510.29	511.41	2.08	3.20
12	553.38	555.46	556.11	2.08	2.73
13	602.76	605.45	606.15	2.69	3.39
14	658.71	661.45	662.41	2.74	3.70
15	714.33	717.83	718.65	3.50	4.32
16	750.95	754.75	755.80	3.80	4.85
17	818.30	822.77	823.13	4.47	4.83
18	851.73	856.05	857.11	4.32	5.38
19	900.42	904.80	905.55	4.38	5.13
20	955.13	960.41	961.52	5.28	6.39
21	1005.30	1010.98	1011.68	5.68	6.38
22	1099.80	1105.96	1106.31	6.16	6.51
23	1200.30	1206.98	1207.56	6.68	7.26
24	1303.10	1310.51	1311.39	7.41	8.29
25	1404.40	1412.81	1413.53	8.41	9.13
26	1500.30	1508.59	1510.14	8.29	9.84
27	1605.50	1614.63	1615.61	9.13	10.11
28	1701.40	1691.95	1712.46	-9.45	11.06
29	1804.20	1816.41	1817.40	12.21	13.20
30	1909.10	1919.98	1920.88	10.88	11.78
31	2000.90	2012.34	2013.16	11.44	12.26
32	2101.60	2113.59	2114.47	11.99	12.87
33	2200.10	2212.79	2213.61	12.69	13.51
34	2302.60	2315.92	2317.08	13.32	14.48
35	2381.10	2394.38	2395.66	13.28	14.56

	DMM_mV	ADC_Low_mV	ADC_High_mV	Low_Error_mV	High_Error_mV
1	52.48	51.94	52.46	-0.55	-0.02
2	72.23	71.91	72.26	-0.32	0.03
3	109.53	108.54	109.20	-0.99	-0.33
4	151.13	150.26	150.48	-0.87	-0.65
5	202.84	202.00	202.22	-0.84	-0.62
6	247.38	246.29	246.99	-1.09	-0.39
7	298.00	297.14	297.32	-0.86	-0.68
8	350.93	350.10	350.30	-0.83	-0.63
9	397.81	397.16	397.32	-0.65	-0.49
10	463.67	462.88	463.07	-0.79	-0.60
11	504.15	503.79	504.19	-0.36	0.04
12	554.06	553.56	553.69	-0.50	-0.37
13	598.48	597.58	597.88	-0.90	-0.60
14	653.58	652.98	653.24	-0.60	-0.34
15	703.48	703.11	703.53	-0.37	0.05
16	749.92	749.24	749.50	-0.68	-0.42
17	802.25	801.83	802.14	-0.42	-0.11
18	855.45	854.74	855.54	-0.71	0.09
19	903.91	903.56	903.95	-0.35	0.04
20	957.95	957.75	958.23	-0.20	0.28
21	1001.10	1000.84	1001.24	-0.26	0.14
22	1101.20	1100.86	1101.54	-0.34	0.34
23	1207.50	1207.02	1207.59	-0.48	0.09
24	1310.10	1309.97	1310.42	-0.13	0.32
25	1410.40	1410.41	1410.97	0.01	0.57
26	1502.70	1502.49	1502.99	-0.21	0.29
27	1603.80	1603.90	1604.16	0.10	0.36
28	1700.50	1700.28	1701.09	-0.22	0.59
29	1803.30	1803.21	1803.83	-0.09	0.53
30	1902.90	1902.86	1903.21	-0.04	0.31
31	2004.80	2004.61	2005.27	-0.19	0.47
32	2099.60	2099.74	2100.16	0.14	0.56
33	2200.70	2199.99	2200.54	-0.71	-0.16
34	2311.90	2311.16	2311.84	-0.74	-0.06
35	2380.10	2379.88	2380.19	-0.22	0.09

Demonstration



CubeCell Test Device sends preset sample data.

Gateway Collects sample data with additional SNR and RSSI values collected by gateway

Gateway dumps data onto TTN for viewing

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Schedule of Tasks - Winter Focus

ID	Task Name	Leader	Dec 2024			Jan 2025				
			12/15	12/22	12/29	1/5	1/12	1/19	1/26	
1	Power Consumption Test	Chris								
2	Solar Panel Test	All								
3	Soil Moisture Sensor Calibration	Chris								
4	Temperature Sensor Calibration	Charlie								
5	Two-Way Communication Test	Josh								

Power Consumption

By taking the current draw of components multiplied by the time active we can determine the amount of Ah used in a single measurement then the amount in one day:

$$I_{Day} = (I_{TX} + I_{RX} + I_{ADC} + I_{Sleep}) \times N_{Measurements} = 2.303 \text{ mAh/Day}$$

Using this calculation we determine the Ah needed for a year of operation:

$$I_{year} = I_{day} \times 365 = 0.841 \text{ Ah/year}$$

To be conservative with our estimates, we included an additional energy loss factor of 50%:

$$I_{year} = 0.841 \text{ (Ah/year)} \times (1 + 0.5) = 1.226 \text{ Ah/year}$$

Taking this into consideration, a battery with a 3.6 Ah capacity will last just under 3 years:

3.6 (Ah) / 1.226 (Ah/year) = 2.93 years or 1072 days

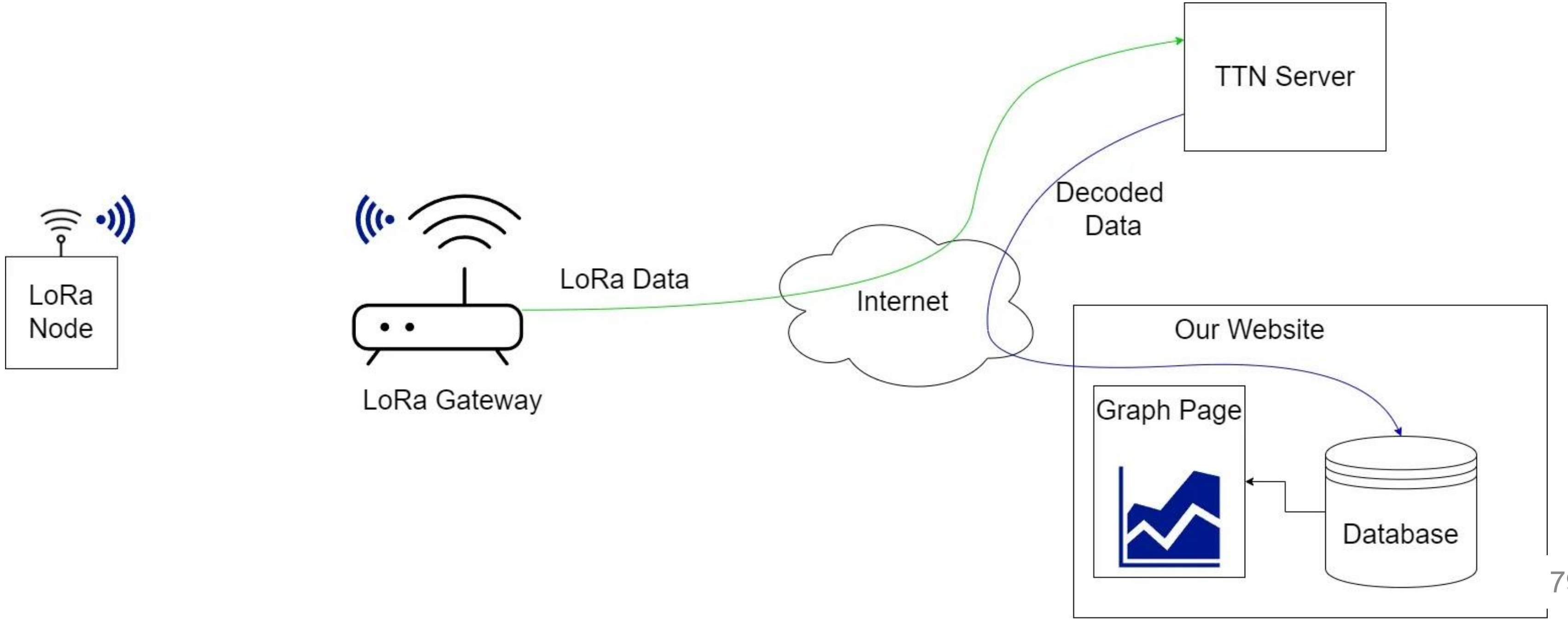
Risk Planning

	Wireless Transmission	Microcontroller	Power Supply	Device Enclosure
Risk	The signal is not strong enough for reliable data transmission.	Selected microcontroller struggles with data processing or storage limitations.	The battery capacity is insufficient for the amount of power consumed during autonomy period.	Equipment enclosure fails to protect electronics from the elements after deployment
Mitigation Plan	Conduct research and testing under similar conditions prior to any installation.	Select microcontroller with necessary peripherals and program/data storage.	The required battery capacity will be determined by calculation beforehand.	Test IP67 rated case using o-ring seals and standard IP67 connectors for external hardware.
Contingency Plan	Place an LTE capable Gateway in closer proximity to the sensor Nodes.	The microcontroller can be changed to a different model later with coding and hardware changes.	The battery capacity can be increased to a point, or the system could spend more time in low power mode	Add additional shielding/seals to main housing and wires in the case of animal damage.

Function Test 2 (ER6)

Purpose:

- Verifying that the system can autonomously upload data from Nodes to our dashboard website



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Function Test 2 (ER6)

Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,
Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,
Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,
Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,
Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,
Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,
Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,
Forward uplink data message DevAddr: 26 0C 05 58 Payload: { NodeId: 305419896, Temp45: 100.2, Temp6: 23,

Function Test 2 (ER6)

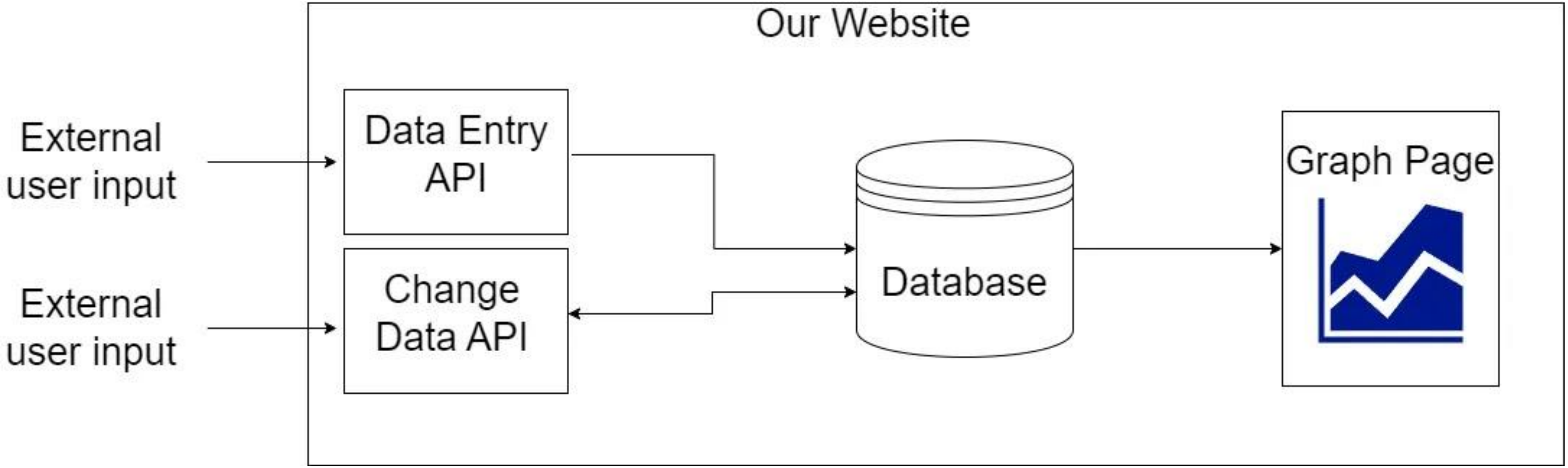
Conclusion:

We have been able to utilize existing and new APIs to transfer data all the way from the Nodes to the database through the TTN server and a Raspberry Pi as intermediaries.

Function Test 3 (ER6)

Purpose:

- Verifying that an end user of our control dashboard can control system parameters through our website



Comparison Chart Method

Different solutions are compared to each other and given relative scores on the scale from one to five with five being comparatively the best.

These scores are weighted by importance to the project overall and the combined total of the weighted scores is used to determine which technology is the best fit for our project

Example:
LoRaWAN has a relative cost score of 4, and the importance of cost is 0.4, so the weighted score is 1.6

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Function Test 3 (ER6)

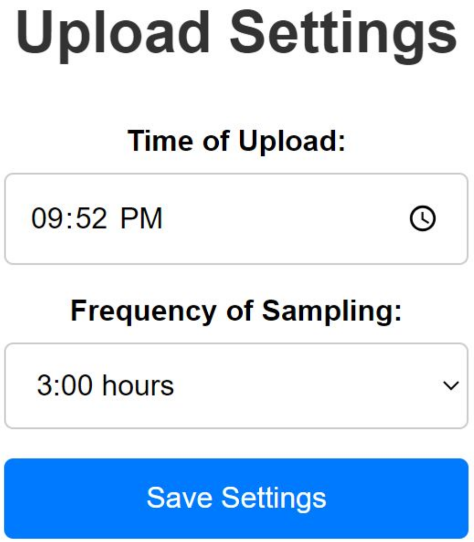
Conclusion:

We have been able to create the web server and APIs to interface data with our database.

Future Plans:

We need to configure the Gateway to read the configuration file and convert it to LoRaWAN packets to send to the connected Nodes. This can be done once we construct our Gateway

We will test the Raspberry Pi’s ability to use MQTT and create a LoRaWAN broadcast once we construct our Gateway




```
{
    "time_of_upload": "21:52",
    "sampling_frequency": "300"
}
```

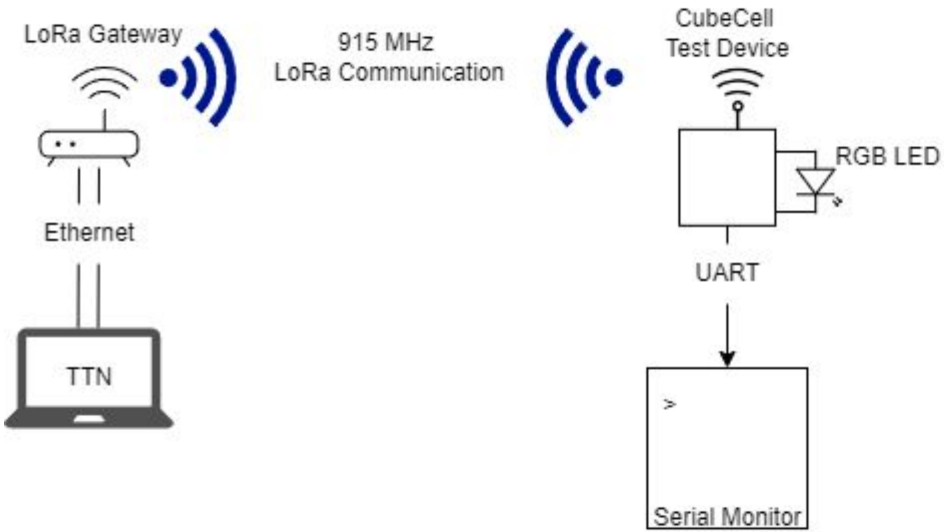
Function Test 4 (ER4)

Purpose:

- Verifying that the Gateway can send downlink messages to the Nodes

Setup:

-



Power Consumption

The energy used in a day can be found by summing the amount used by each component over a one day interval:

$$\mathbf{E}_{Day} = \mathbf{E}_{TX} + \mathbf{E}_{RX} + \mathbf{E}_{ADC} + \mathbf{E}_{Sleep}$$

$$\mathbf{E}_{Day} = 0.69\ \text{mWh} + 0.11\ \text{mWh} + 9.36\ \text{mWh} + 12.09\ \text{mWh} = 12.09\ \text{mWh}$$

We can divide by the battery voltage to get an average current draw per day

$$\mathbf{I}_{Day} = 12.09\ \text{mWh} \div 3.6\ \text{V} = 3.36\ \text{mA /Day}$$

We can obtain a value for the average power consumption of the nodes by taking the daily energy consumption and dividing by the amount of time in a day

$$12.09\ \text{mWh/Day} * 1\ \text{Day/ } 24\ \text{Hours} = 0.504\ \text{mW}$$

We can account for losses and unknown inaccuracies in the system by scaling our final numbers by a factor of 1.5 to be conservative with our estimates.

Function Test 4 (ER4)

Conclusion:

By using the MQTT broker provided by TTN, the Gateway is able to have a message pushed to a node after the node uploads data.

Future Plans:

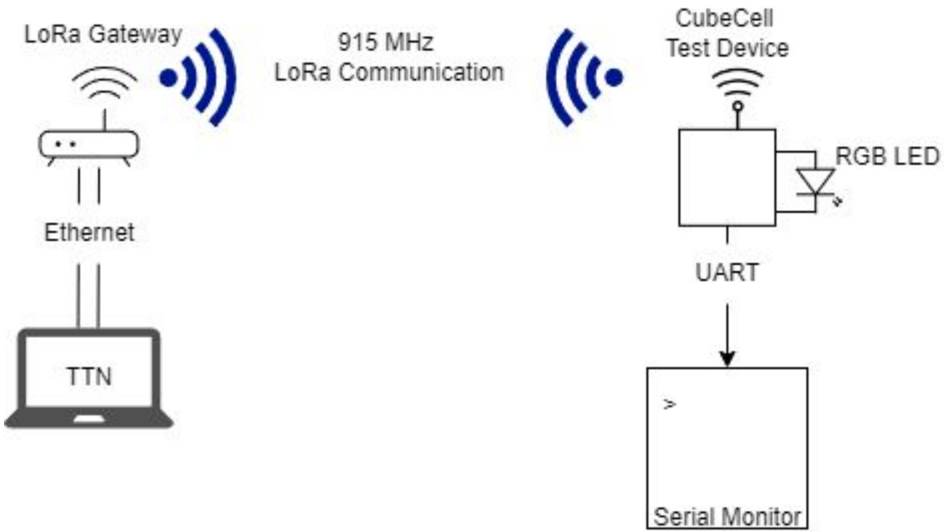
This could be expanded in the future to support different devices receiving different data by using different channels in the MQTT topic.

Function Test 7 (ER 21)

Purpose:

- Verifying that a Node will continue operating normally despite interruptions in the communication to the TTN website. Verifying that the state of the device can be determined by visual inspection of the multicolored LED on the device.

Setup:



Function Test 7 (ER 21)

Conclusion:

The Node continued operation as expected. If the data was unable to be received as a result of the Gateway being off or offline, the Node would not attempt to rebroadcast it before returning to sleep mode. No interruption of the connection was able to get the Node to stop working as intended.

The LED indicated the status of the device accurately compared to what the serial monitor output. This shows that the LED is a usable indication of what the Node is doing for use in the field where using a serial monitor is not possible.

Future Plans:

The test should be completed again if there are significant changes to the code that the Nodes run to ensure that they would still function properly.

Power Consumption

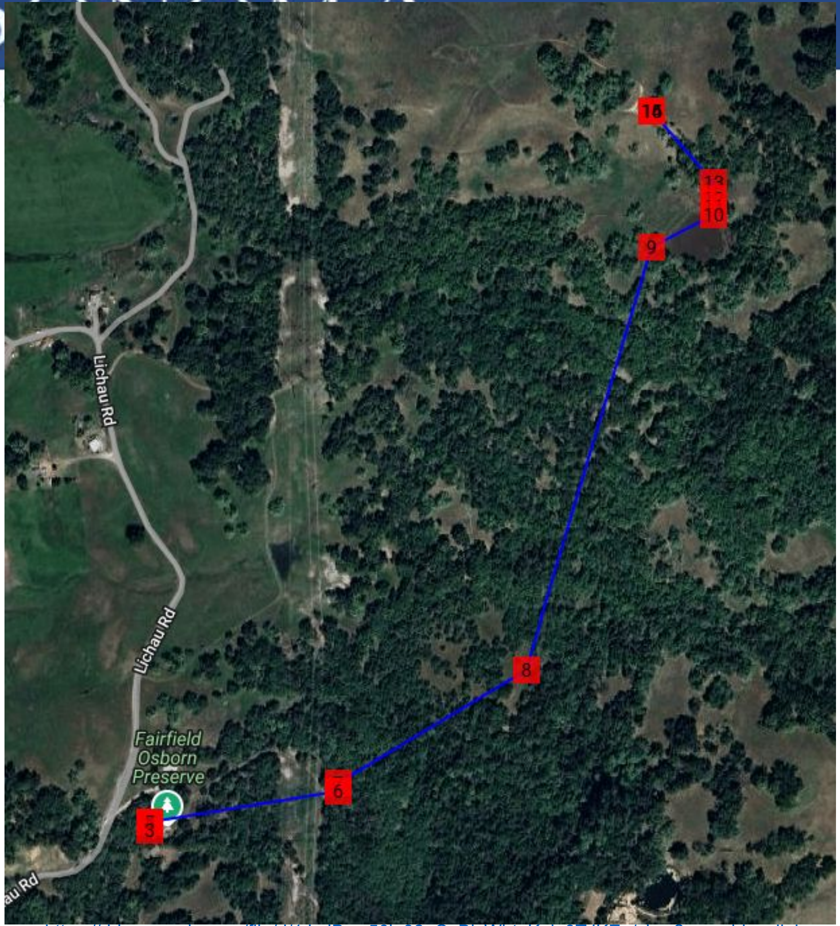
Based on average power consumption information provided by component datasheets, a sampling frequency of once per hour, and an upload frequency of once per day; we estimate that the daily energy consumption will be very low, on the scale of a hundred mAh per day. If these numbers are proven accurate with our measurements of actual power consumption, the power consumption will be low enough to provide our desired autonomy with less than a 50% depth of discharge using batteries typical of solar yard lights.

Once we construct our Nodes and interface the sensors and LoRaWAN modules to them we can measure the actual energy consumption with an energy meter to determine the required battery size and solar cell specifications.

Proposed Solution

- Nodes are interfaced with Sensors and installed on site at the Preserve.
- These Nodes are connected to the Gateway, installed inside the building at the Education Center, via LoRaWAN at the 915 MHz band.
- The Gateway utilizes ChirpStack to publish the LoRaWAN data to The Things Network (TTN) LoRaWAN server then uploads that data to our server's database.
- Users of our service can view data and control configuration of the installed Nodes and Gateway remotely by interacting with the webpage.

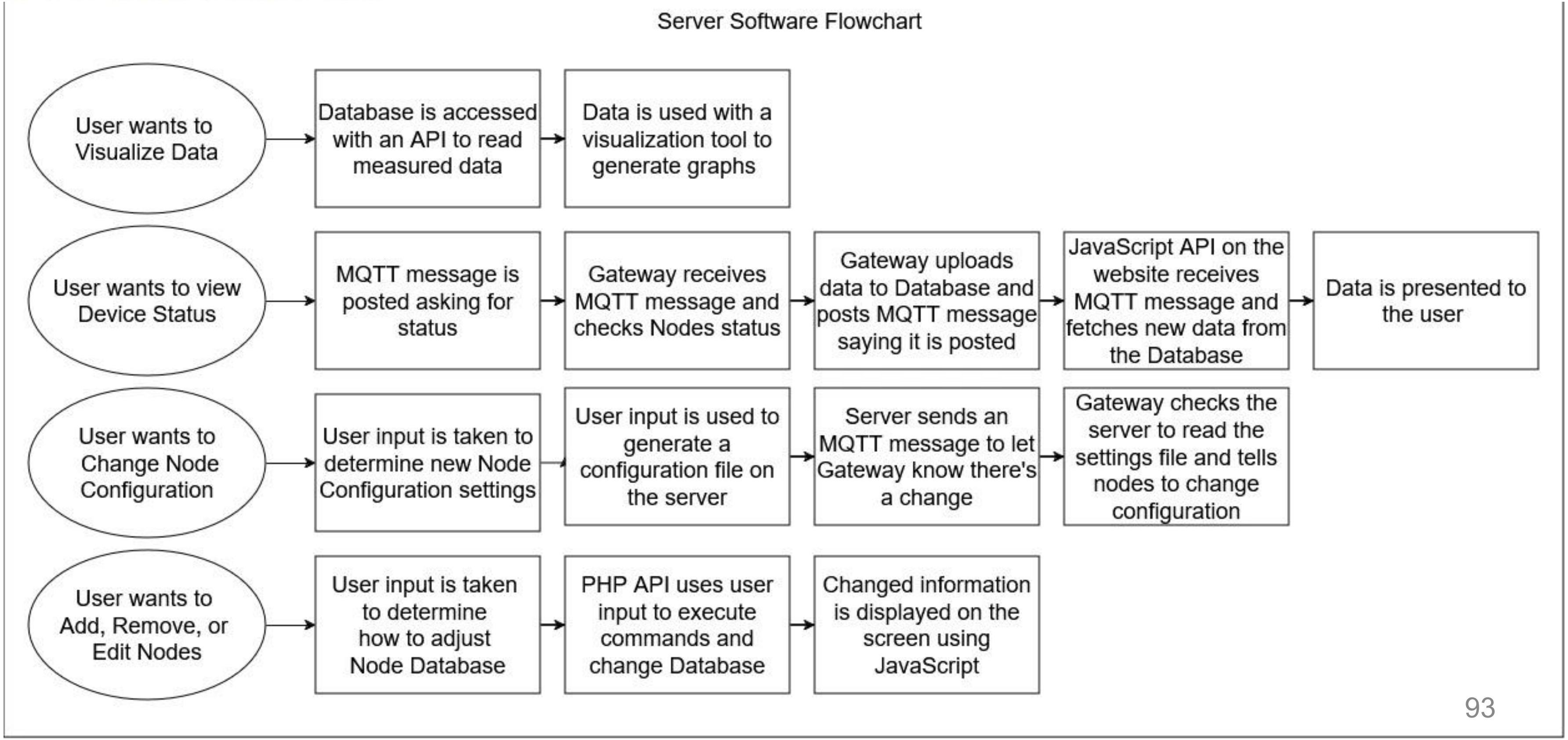
Function Test 1 (ER1)



https://drive.google.com/file/d/1JpJBpw56ja82nQvBlsWhteK_jo3TJKEe/view?usp=drive_link

1. RSSI: -21 , SNR: 9.8
2. RSSI: -48 , SNR: 9
3. RSSI: -60 , SNR: 10.2
4. RSSI: -12 , SNR: 9.5
5. RSSI: -17 , SNR: 10.8
6. RSSI: -115, SNR: -1.2
7. RSSI: -101, SNR: 8.5
8. RSSI: -116, SNR: -4.5
9. RSSI: -134, SNR: -15.5
10. RSSI: -124, SNR: -7.2
11. RSSI: -120, SNR: -6.5
12. RSSI: -113, SNR: -8
13. RSSI: -112, SNR: -7
14. RSSI: -113, SNR: -7.5
15. RSSI: -110, SNR: 2
16. RSSI: -117, SNR: 0.5

Server Software Design



Error Resolution

Node Status

Node ID	Location (Latitude, Longitude)	Type	Status	Battery Status
1	38.344700, -122.594300	Control	Status: OK	72%
2	38.344800, -122.594200	Control	Status: OK	45%
3	38.351000, -122.586000	Test	Status: OK	20%
4	38.352300, -122.587000	Control	Status: OK	63%
7	38.351400, -122.586000	Test	Status: OK	95%

Back

Users can view the current status and battery levels via a page on the dashboard.

The Gateway will ask for a status report from every Node, and if one fails to respond it will indicate that the connection failed.

By monitoring the reported battery level over time, users can determine if a Node is likely to fail soon.

Theory: Power Consumption

The energy used in a day can be found by summing the amount used by each component over a one day interval:

$$E_{Day} = E_{Micro} + E_{LoRa} + E_{Sensors} + E_{SD}$$

$$E_{Day} = 2.845\text{mWh} + 5.0358\text{mWh} + 1.980\text{mWh} + 0.0528\text{mWh} = 6.609\text{mWh}$$

We can divide by the battery voltage to get an average current draw per day

$$I_{Day} = \frac{E_{Day}}{V_{Bat}} \qquad I_{Day} = \frac{6.609\text{mWh}}{3.6\text{V}} = 1.836\text{mAh/Day}$$

We can obtain a value for the average power consumption of the nodes by taking the daily energy consumption and dividing by the amount of time in a day

$$6.609\frac{\text{mWh}}{\text{Day}} * \frac{1\ \text{Day}}{24\ \text{Hours}} = 0.2754\text{mW}$$

We can account for losses and unknown inaccuracies in the system by scaling our final numbers by a factor of 1.5 to be conservative with our estimates.