NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

M.A.R.S

Military Asset Reporting System

New Mexico Institute of Mining and Technology
Department of Electrical Engineering
Senior Design Class of 2018

Acknowledgements

Engineering Board

Project Manager
Dr. Scott Teare

Technical Advisors
Dr. Aly El-Osery, Dr. Anders Jorgensen, Dr. Seda Senay, Dr. Kevin Wedeward

Department Lab Manager
Chris Pauli

Departments
Department of Electrical Engineering

Presentation Outline:

1. Motivation & Background: 10 min
2. Subsystem Development: 15 min + 10 min Q&A (each)
    a. Power Scavenging Team
    b. Tag Development Team
    c. Node Development Team
    d. User Interface / Server Development Team
3. Integration, Testing, and Conclusions: 10 minutes + Q&A
4. Functional Demonstration

Introduction

Courtney Bamonte, Nikita Belooussov, Thomas Dearing, Albert Reed

Motivation

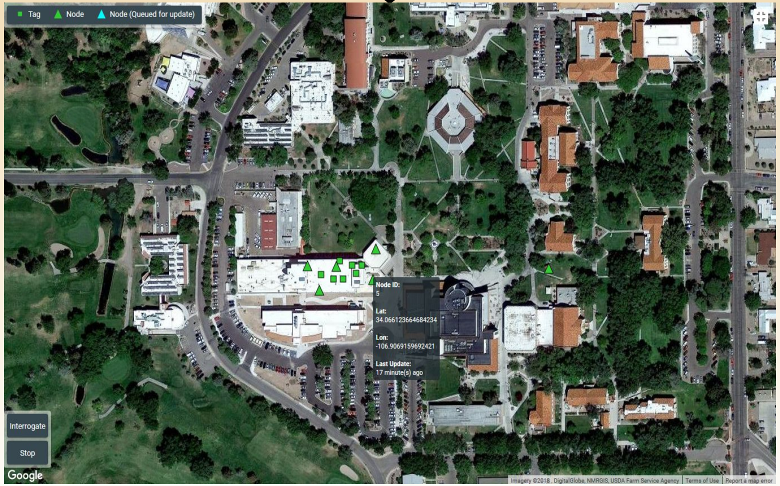
Current military asset inventory procedures are...

- Infrequent
- Manually performed & recorded
  - Slow
  - Wasteful

Automated solutions exist for COTS retailers:

- Static, or high maintenance installation
- Critically vulnerable to attack

<u>Neither are suited to Battlefield conditions</u>



Motivation

GOAL: An automated system to collect, receive, and interpret battlefield asset data

Required capabilities:

- High mobility, scalability, and resilience on battlefield
- Monitor at higher ranges than conventional RFID
- Deliver asset position & time-of-measurement
- Low maintenance and deployment cost

Desired capabilities:

- Deliver information on other “local conditions”
- Provide queryable user interface for specific assets

Design Challenges

- Data integrity
- Limited power availability
- Long-range communications
- Long operational lifetime
- Device size limitations
- Rapid response (Emergency)

Considerations omitted from this study:

- Military systems, frequencies, or encryption

What is M.A.R.S.

A feasibility prototype of a **Military Asset Reporting System**, which will collect, interpret, and deliver battlefield asset data to the end-user.

Or…

A Supervisory Control and Data Acquisition (SCADA) system composed of a self-powered distributed data collection and sensor network

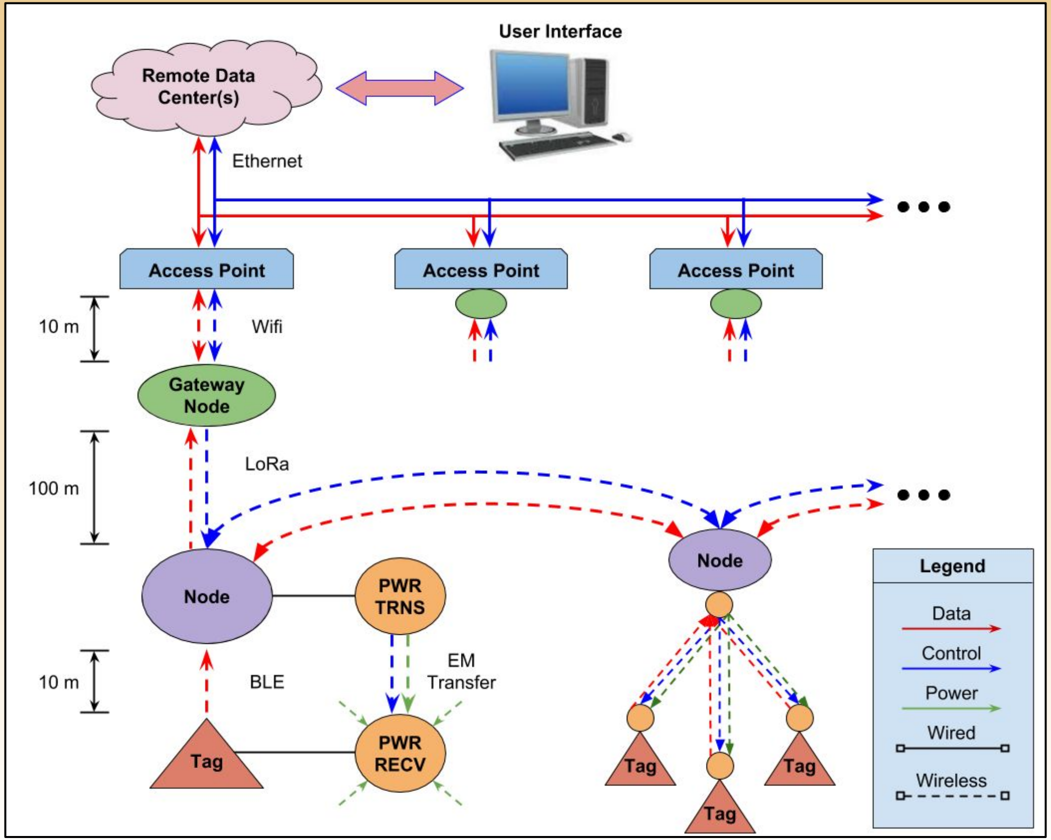
What is M.A.R.S.

A distributed sensor network approach is well suited to this application:

- Distributed monitor hardware promotes:
  - Resilience to environmental damage
  - High scalability
  - Gradual deployment & low maintenance
  - Lower energy requirements

- Automated database promotes:
  - High data integrity
  - Easy access from end-user

Design Overview: Subsystem Breakdown

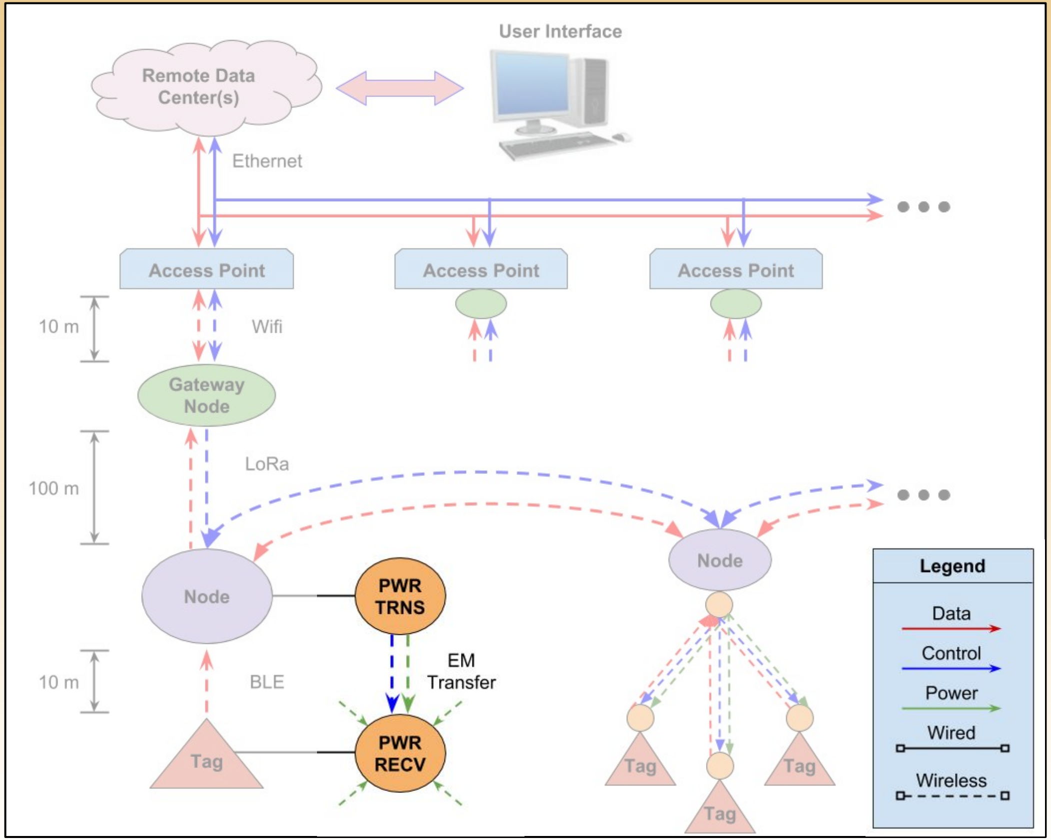


Design Overview: Design Teams

- Power Team
- Tag Team
- Node Team
- UI/Server Team

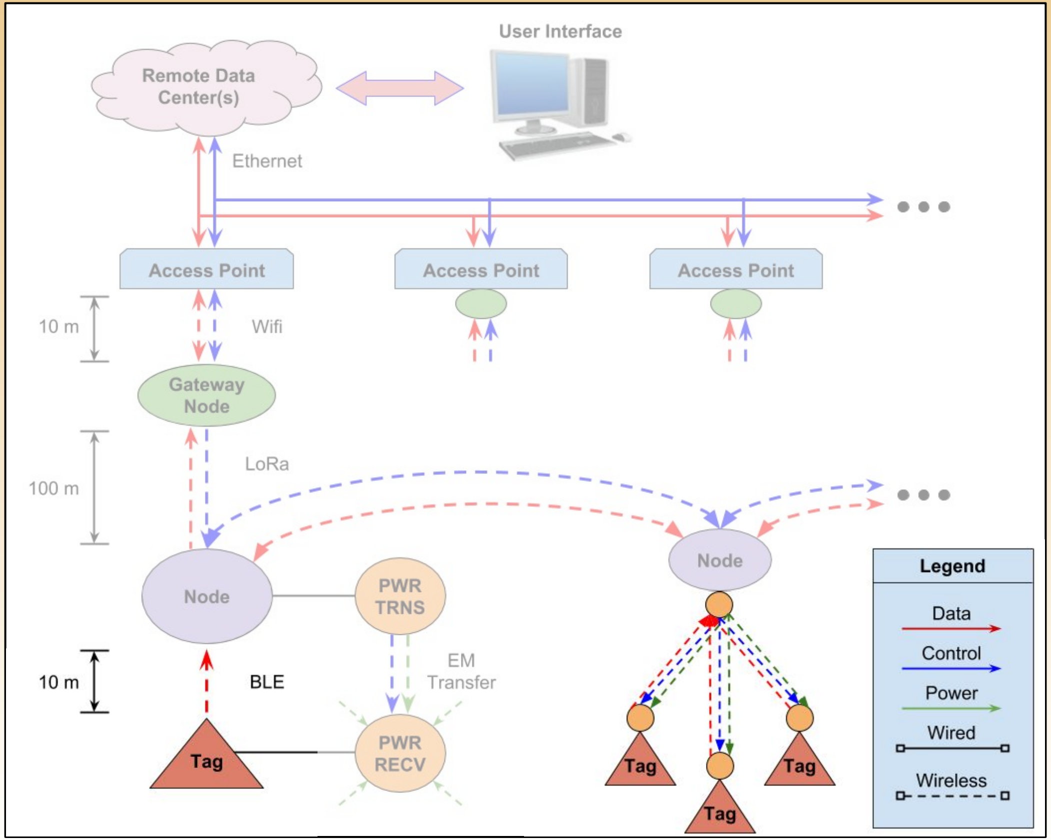
Power Team

1) Power asset Tags
2) Offer means of Node interrogation



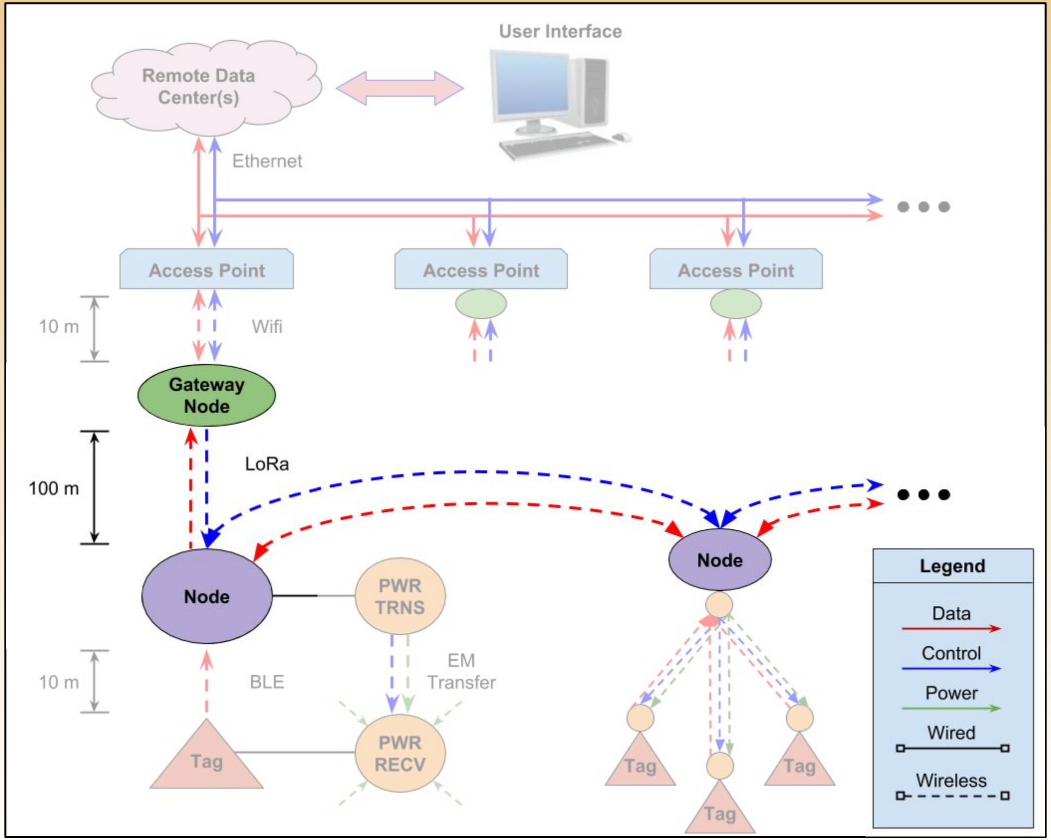
Tag Team

1) Gather sensor data from tagged assets
2) Prep data for Node transmission



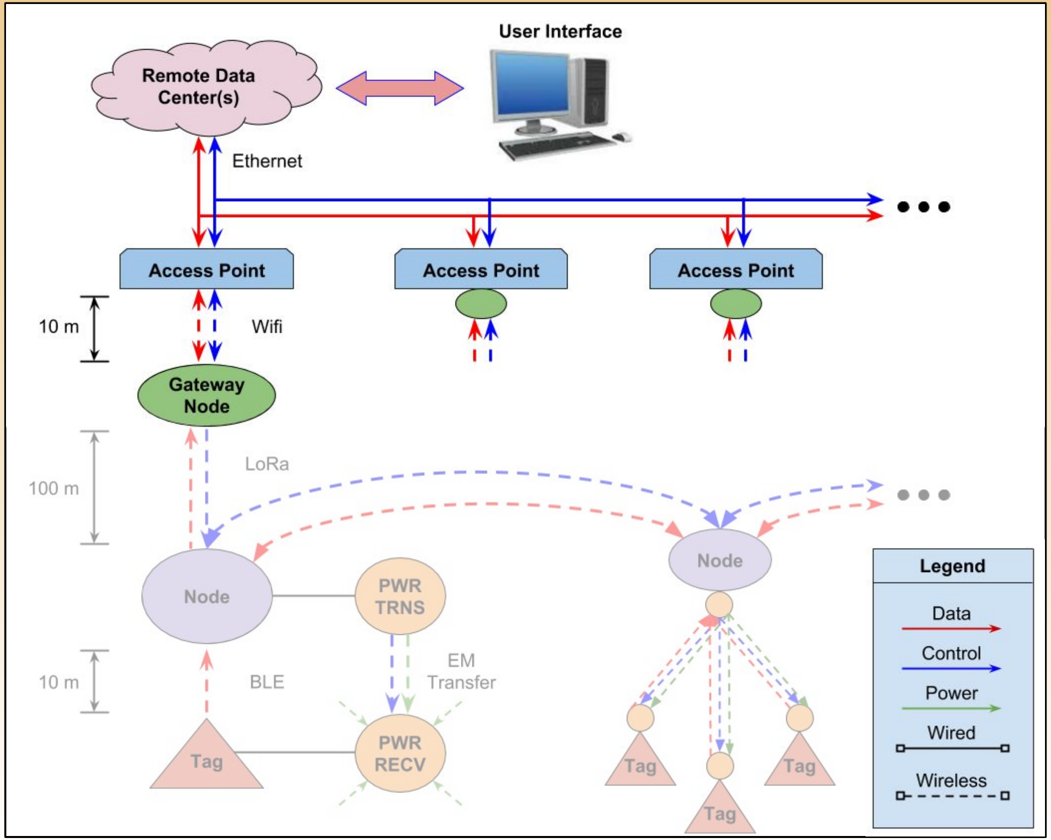
Node Team

1) Gather tag data
2) Add asset location and time
3) Packetize for network

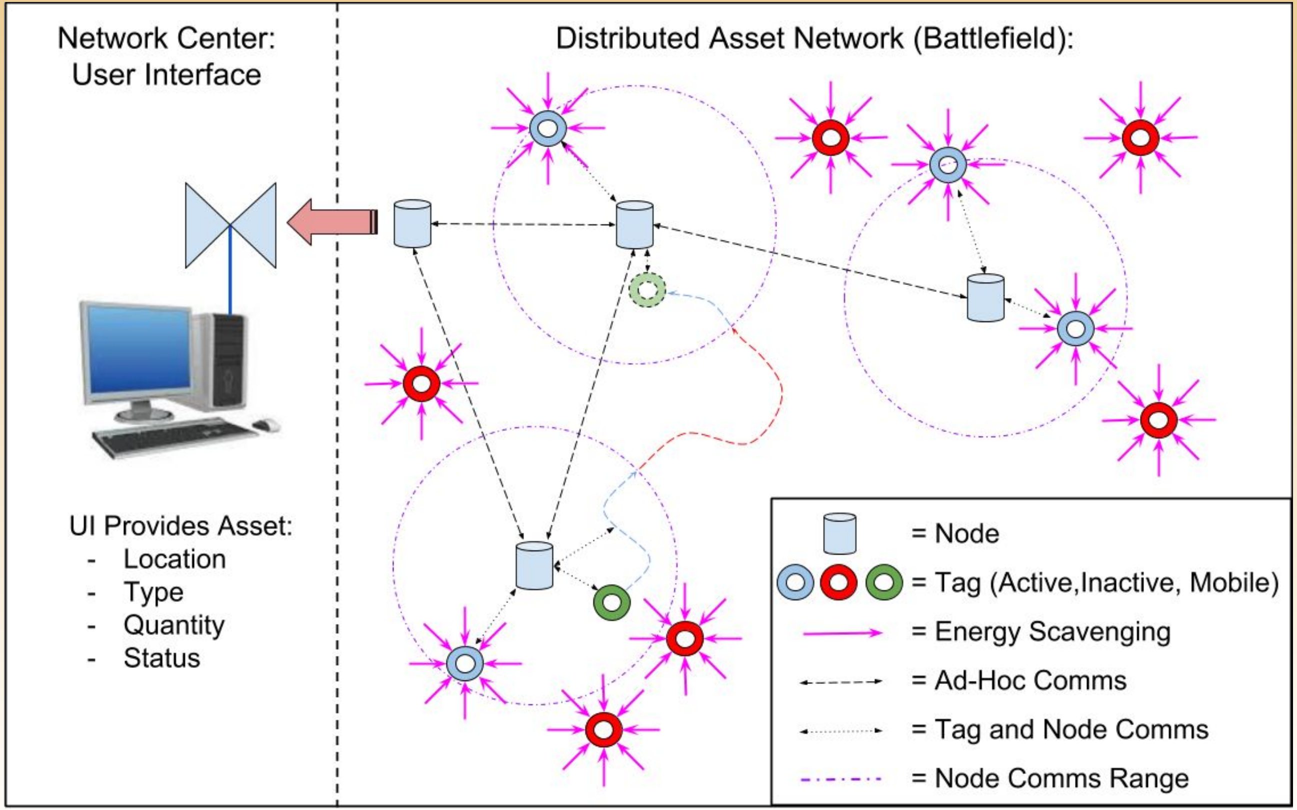


UI/Server Team

1) Provide means of communication across nodes
2) Update server with data from network
3) Display information and initiate interrogation from UI



MARS Concept of Operation: Active Tag RFID



Application Specifications

Specification	Value	Description
Communications Range	**To Tags: 10 m** **To Nodes: 100 m** **To Gateway: 100 m**	**Minimum** operating range
Maintenance Period	**Tags: > 1 year** **Nodes: > 1 shift**	**Minimum** time before Node/Tag recharge
Monitor Update Period	**Normal: 1 hr** **Emergency: 5 min**	**Minimum** inventory update period
Scalability	**100 Tags & Nodes**	**Minimum** number of connections per Node
Server Scalability	**100 Tags per Node** **100 Nodes**	**Minimum** number of connected devices server can handle
Positioning Error	**< 10 m**	**Minimum** location error for monitored assets

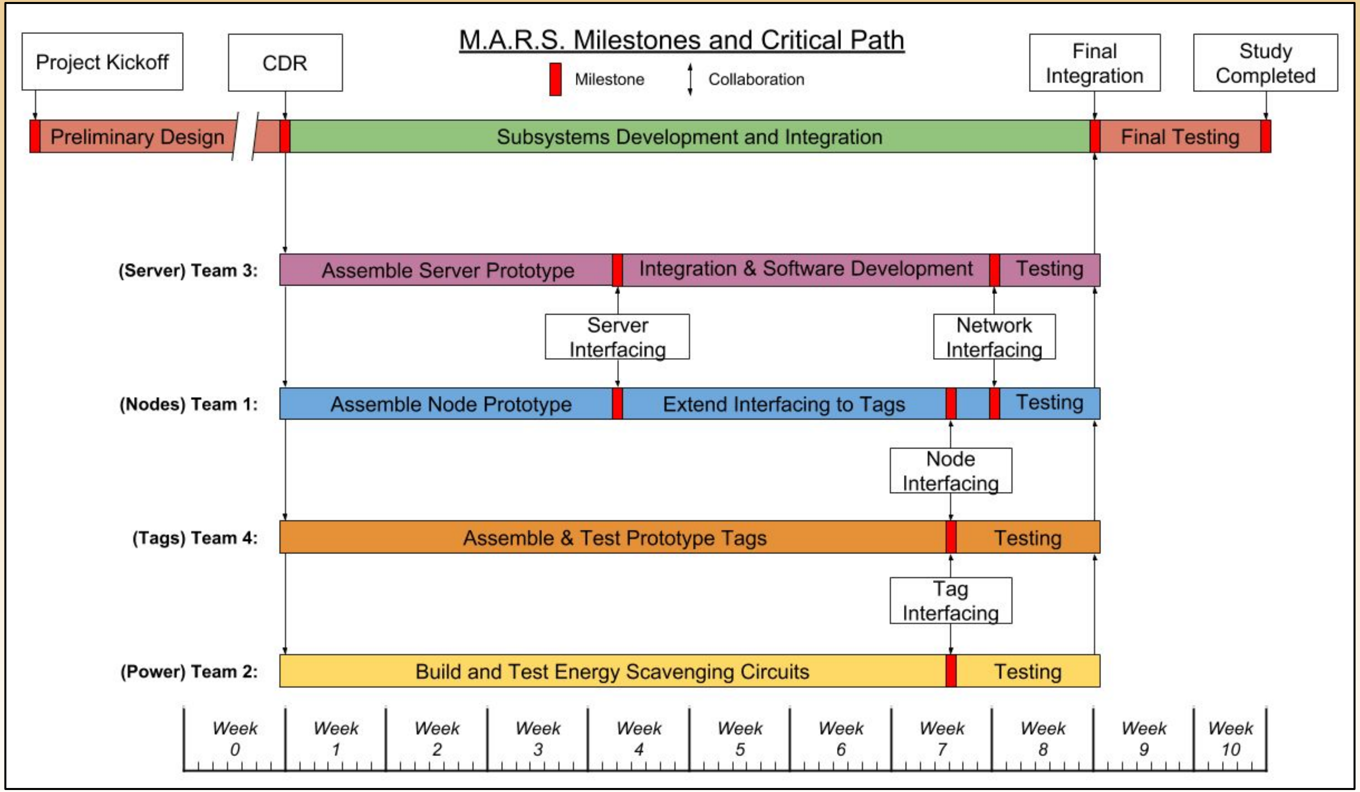
Timeline & Budget

Project Timeline:

1. Design Phase (14 Weeks)
2. Prototype Phase (11 Weeks)

Hardware Budget:

$4000



Power Team

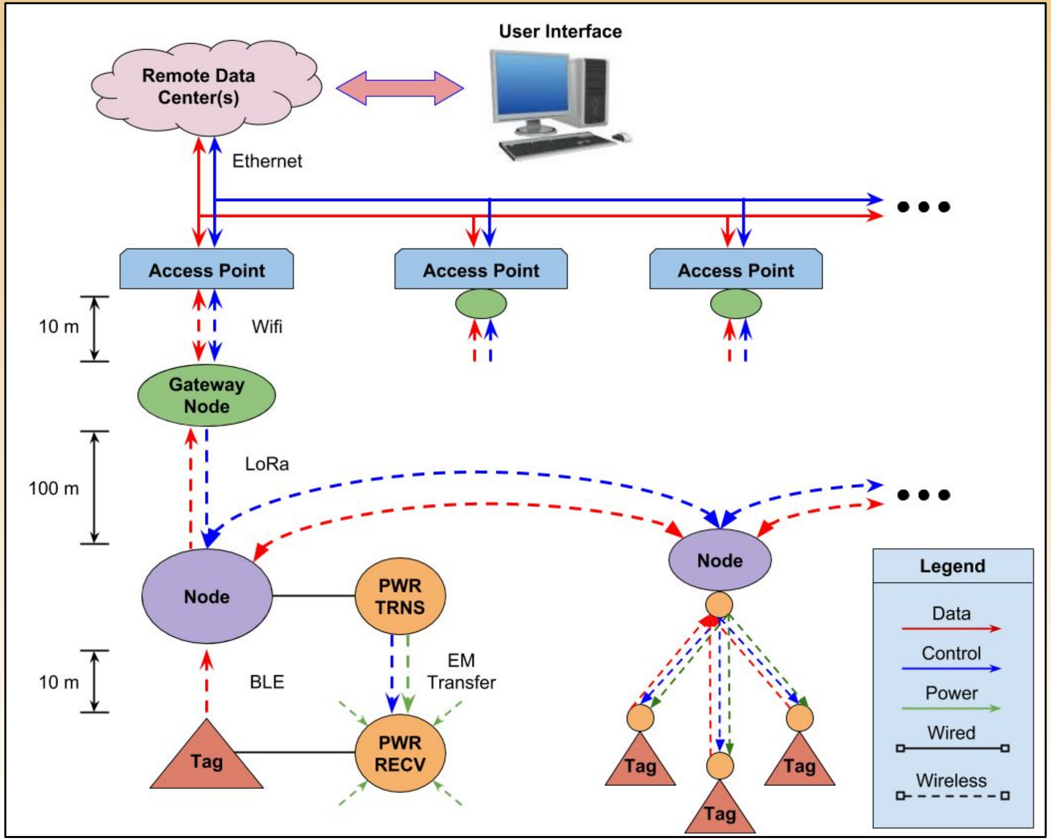
Jaclyn Chang, Ricardo Del Toro, Delos Edick, Vincent Grap, Albert Reed, Jacob Schmelzel

Subsystem Introduction: Power Scavenging

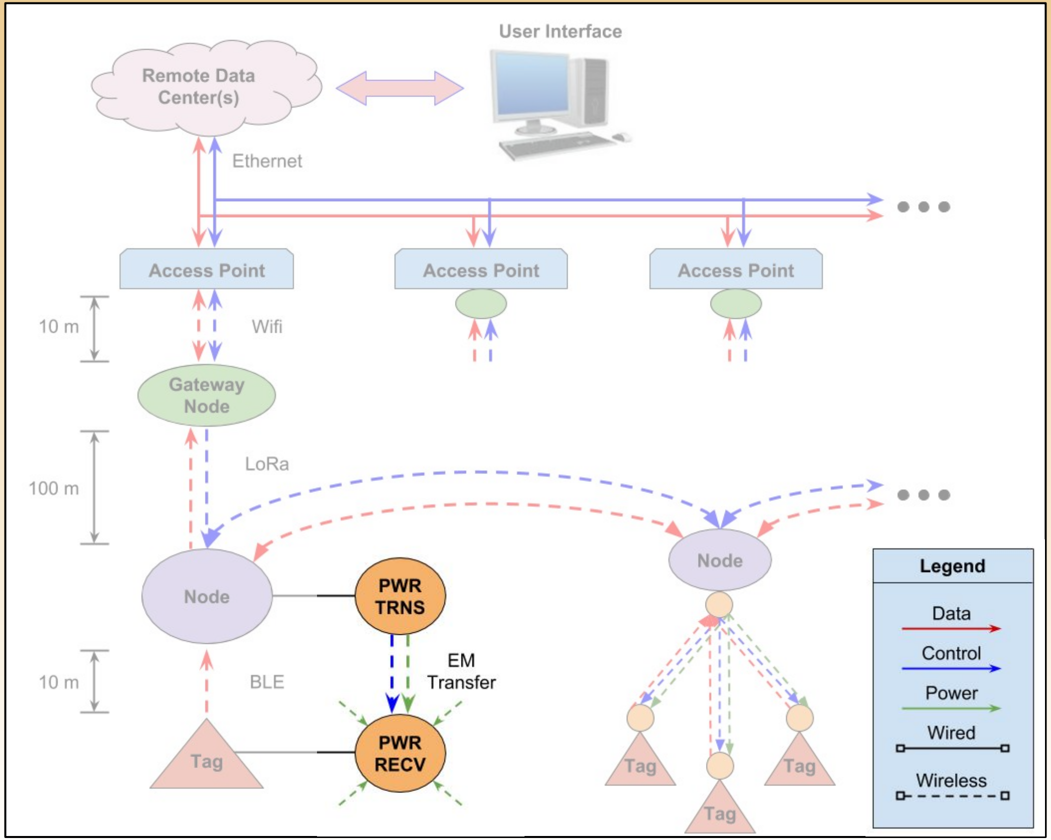
MARS is a Supervisory Control and Data Acquisition (SCADA) system composed of a self-powered distributed data collection and sensor network.

The **Power Subsystem** uses energy scavenging to provide power to the tags.

Full System Model



Power Subsystem



Subsystem Specifications

Specification	Value	Description
Power Transfer Range	**> 10 m**	**Minimum** requirement to supplement node to tag comms
Average Power	**> 4.8 uW**	**Minimum** average power to keep tags operational indefinitely

Power Sources Decision Matrix

Power Source	Environmental Versatility Rating	Power Production Vs. Size of Unit	Feasibility for Tag Integration	Total
EM Scavenging	7	8	9	91
Thermal Energy Harvesting Unit	2	4	3	32
Piezoelectric	4	8	9	80
Inductive Coupling	1	8	1	33
Magnetic Resonance	2	8	1	35
Solar	6	10	7	88
Weight (1-5)	5	3	4	

Power Storage Unit Decision Matrix

Storage Type	Size	Storage Capacity	Lifetime	Maintenance Rating	Total
None	10	0	0	0	10
Capacitor	9	1	10	2	88
Rechargeable Battery	6	10	5	8	109
Non-Rechargeable Battery	6	10	0	5	78
Weight (1-5)	3	5	5	2	

Engineering Standards & Ethical Considerations

FCC Regulations on ISM Communication Bands

Frequency	Maximum Transmitter Output Power	Antenna Gain	Effective Isotropic Radiated Power (EIRP)
902 - 928 MHz	30 dBm (1 W)	6 dBi	36 dBm (4 W)
2.400 - 2.4835 GHz	30 dBm (1 W)	6 dBi	36 dBm (4 W)
5.725 - 5.875 GHz	30 dBm (1 W)	6 dBi	36 dBm (4 W)

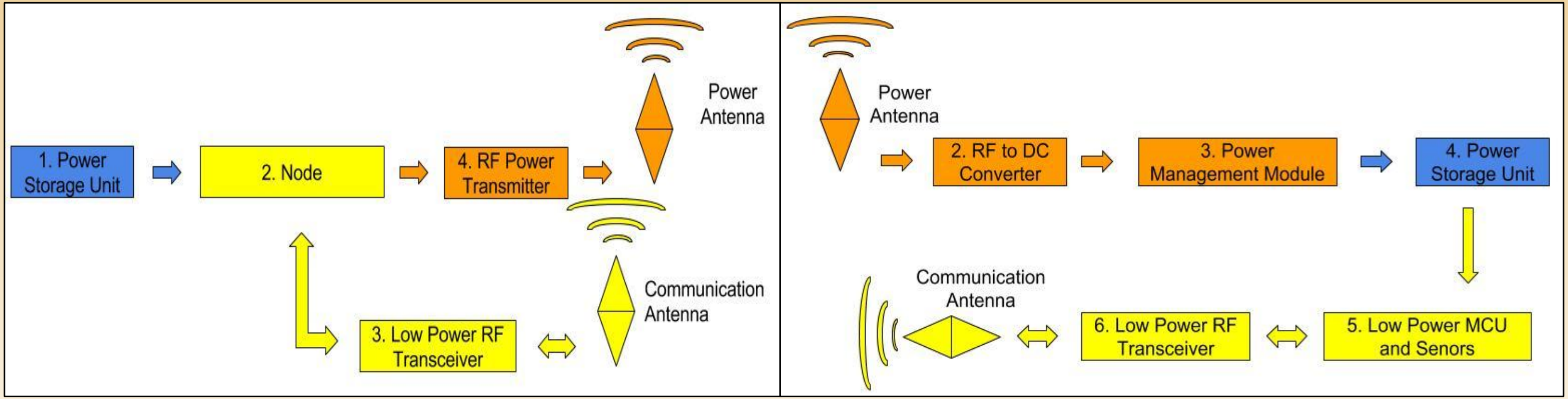
Engineering Standards & Ethical Considerations

Safety Concerns: FCC Limits for Maximum Permissible Exposure

Limits for Exposure	Power Density @ 900 Mhz ($S = mW/cm^2$)	Average Exposure Time
Occupational/Controlled	S = 3	6 Minutes
General Population/Uncontrolled	S = 0.6	30 Minutes

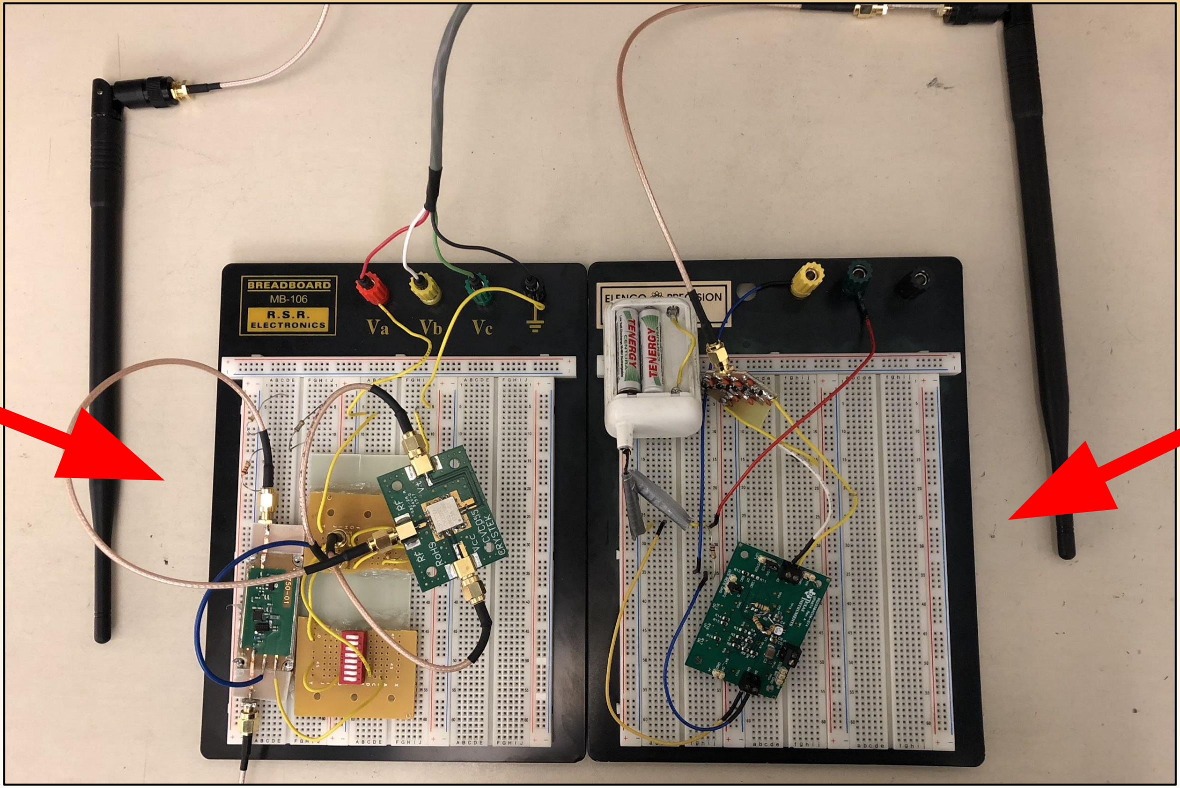
Our Parameters:
Transmitted Power - 1 Watt at 30dBm
Antenna Gain - 5dBi

Power Transmission



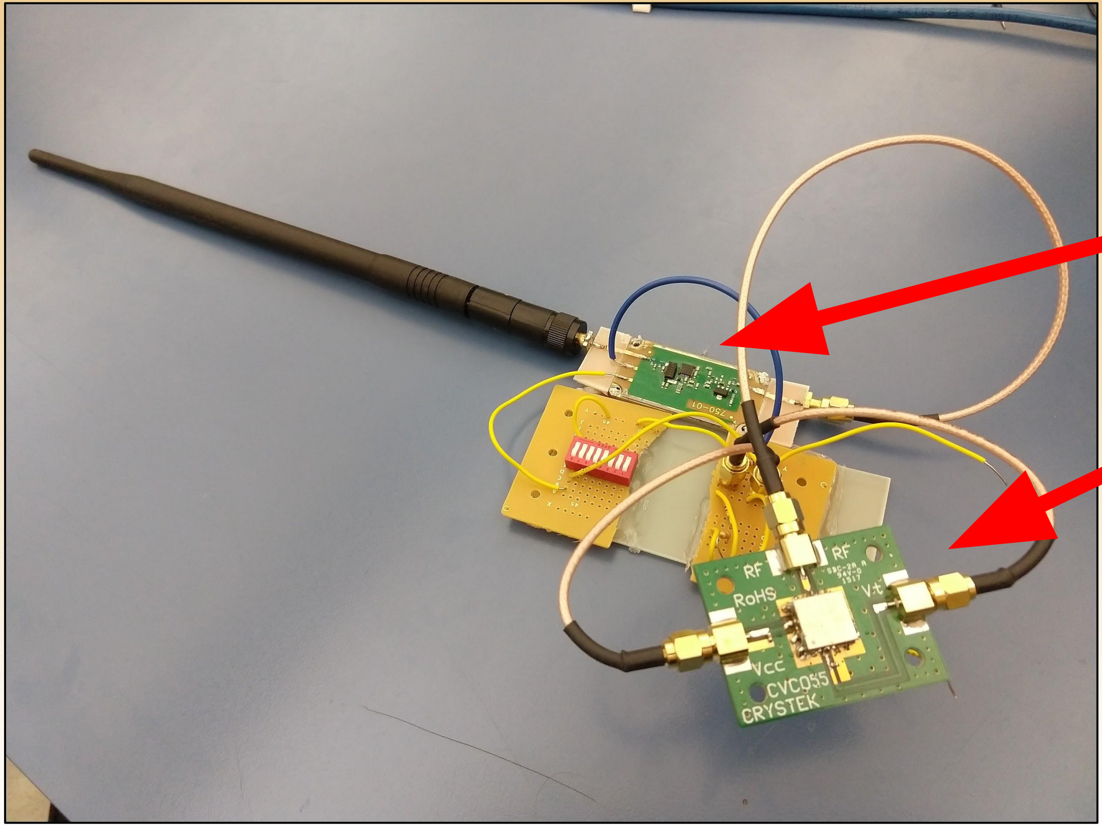
Power Transmission Circuitry

Transmitter



Receiver

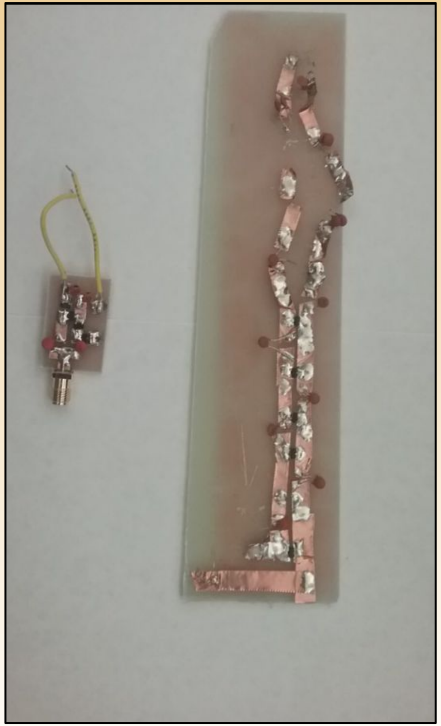
Power Transmission Circuitry

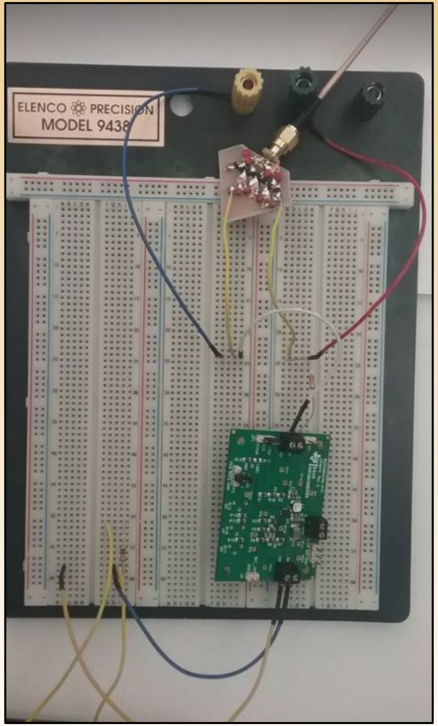


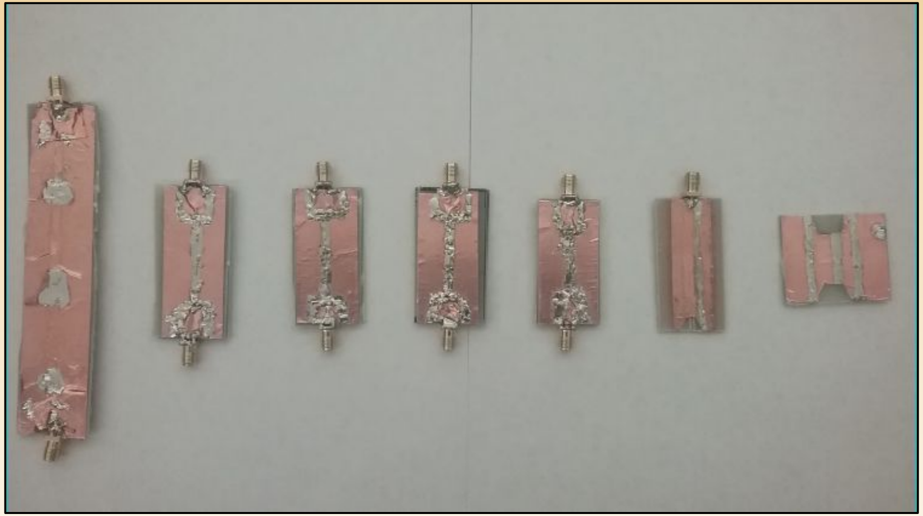
Amplifier

Voltage controlled oscillator

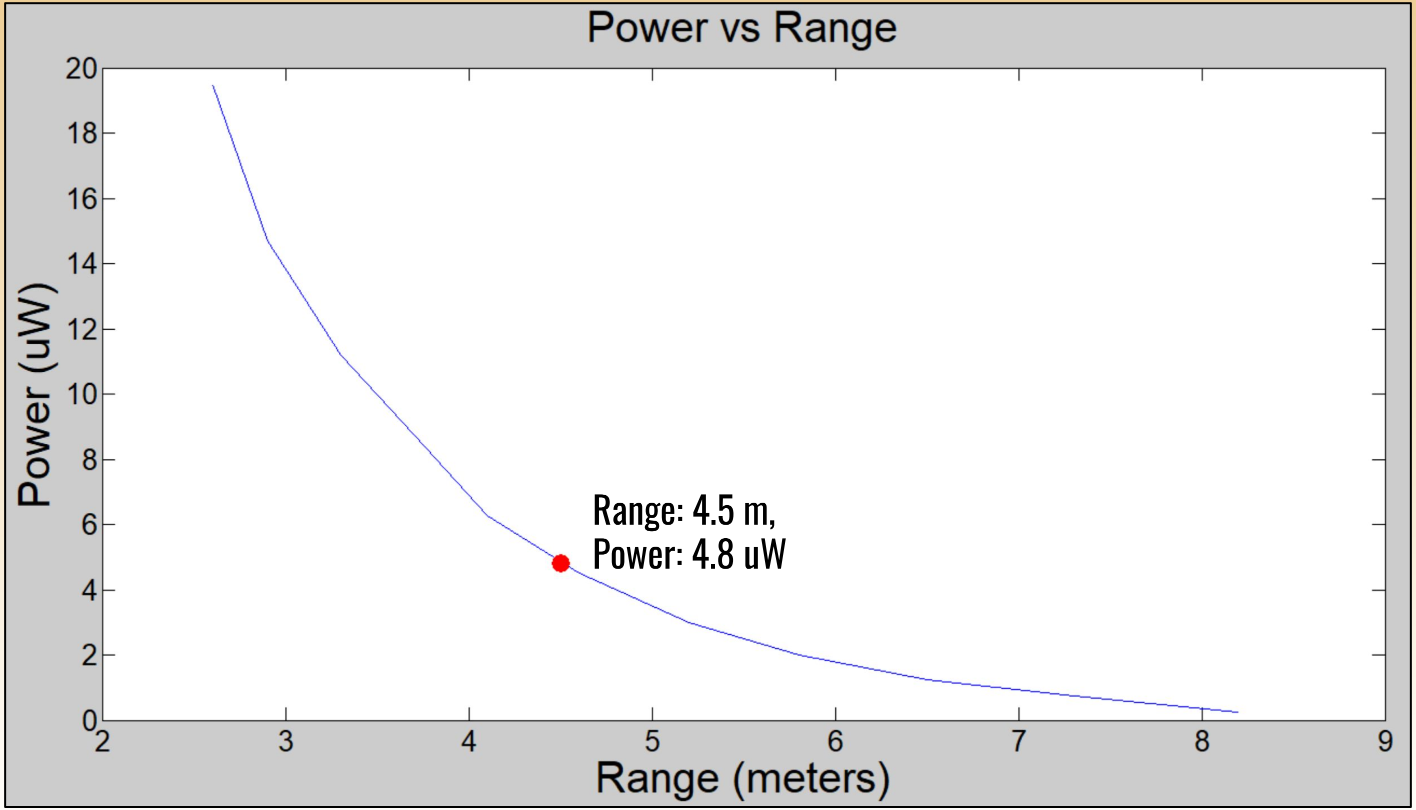
Power Receiver Circuitry



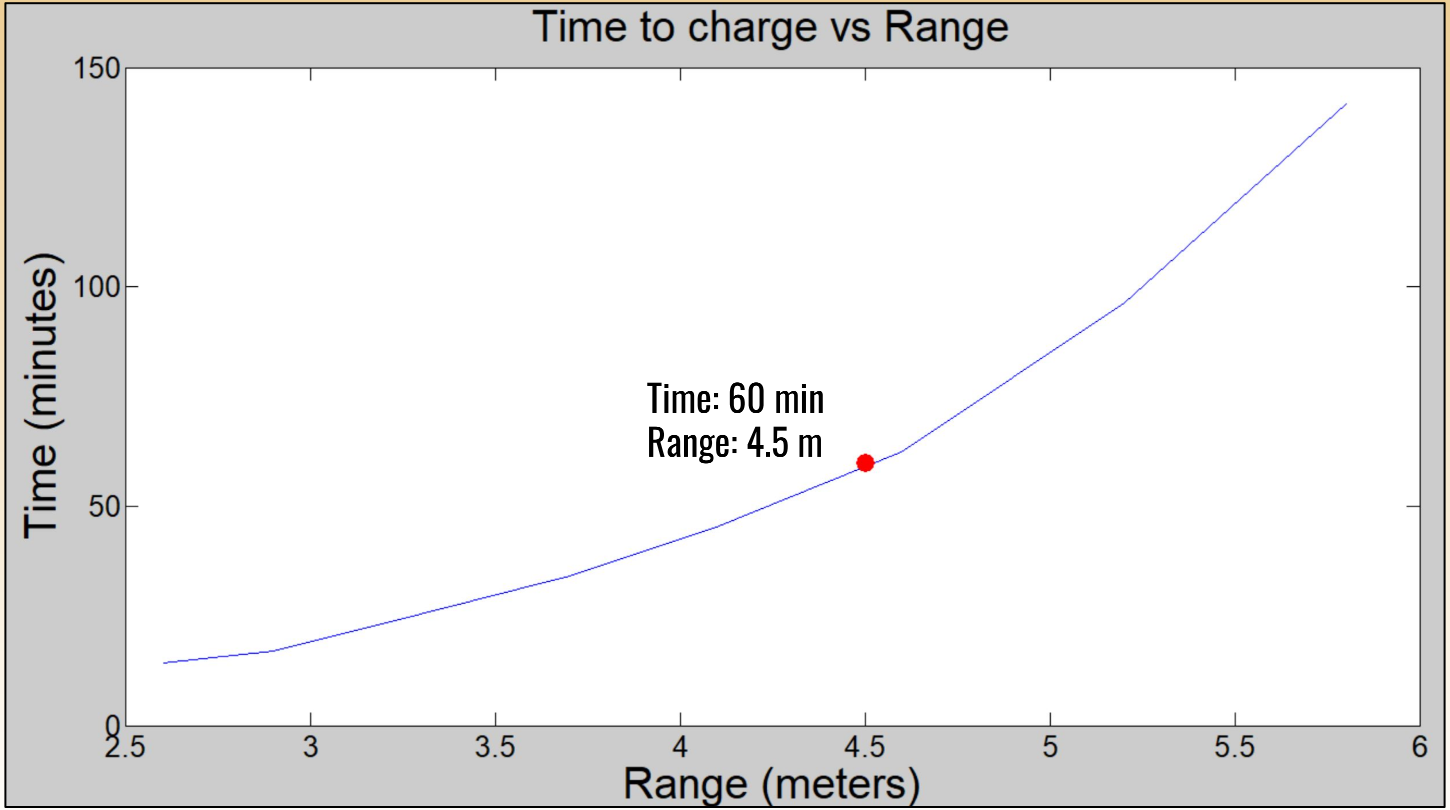




Results: Power vs. Range

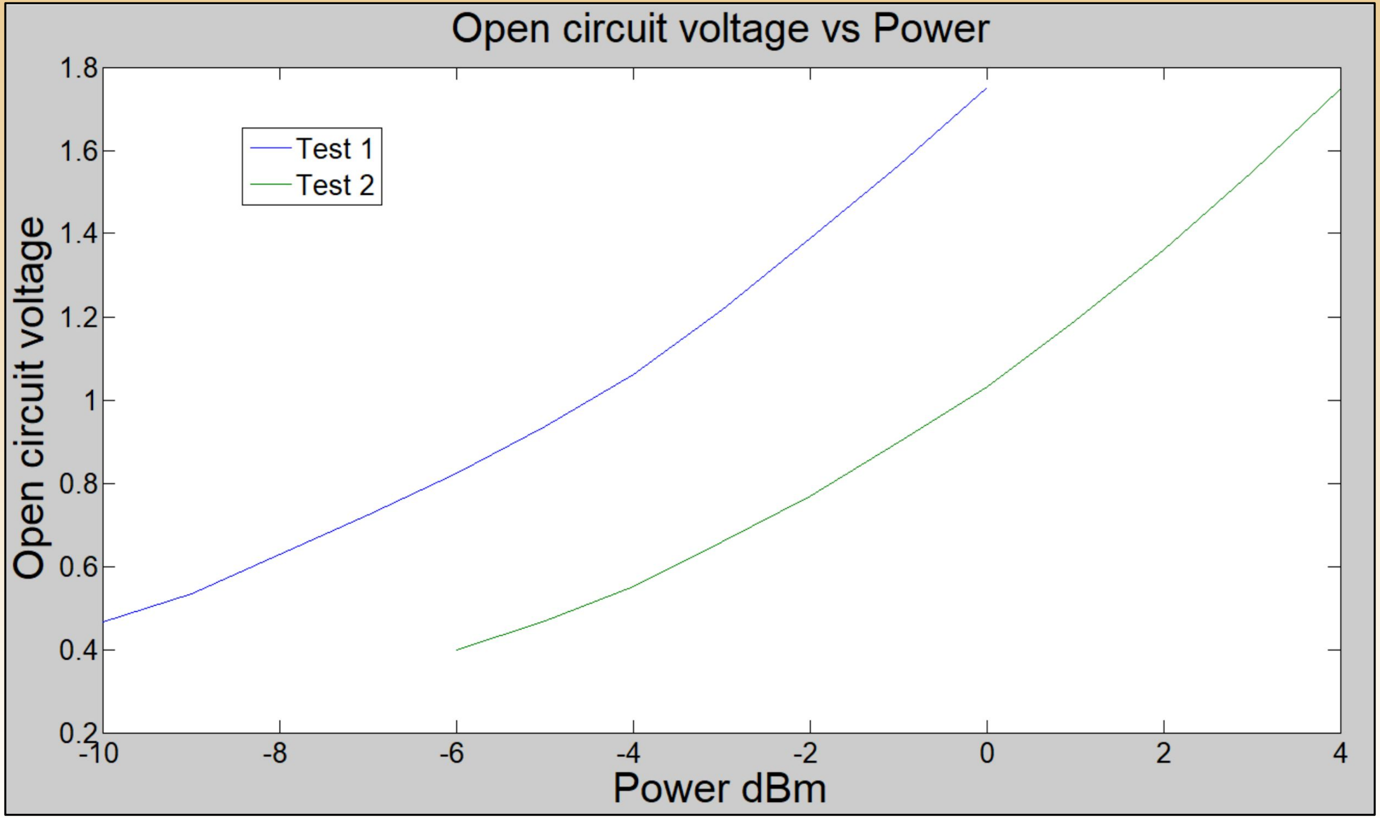


Results: Distance vs. Time to Replace 17 mJ

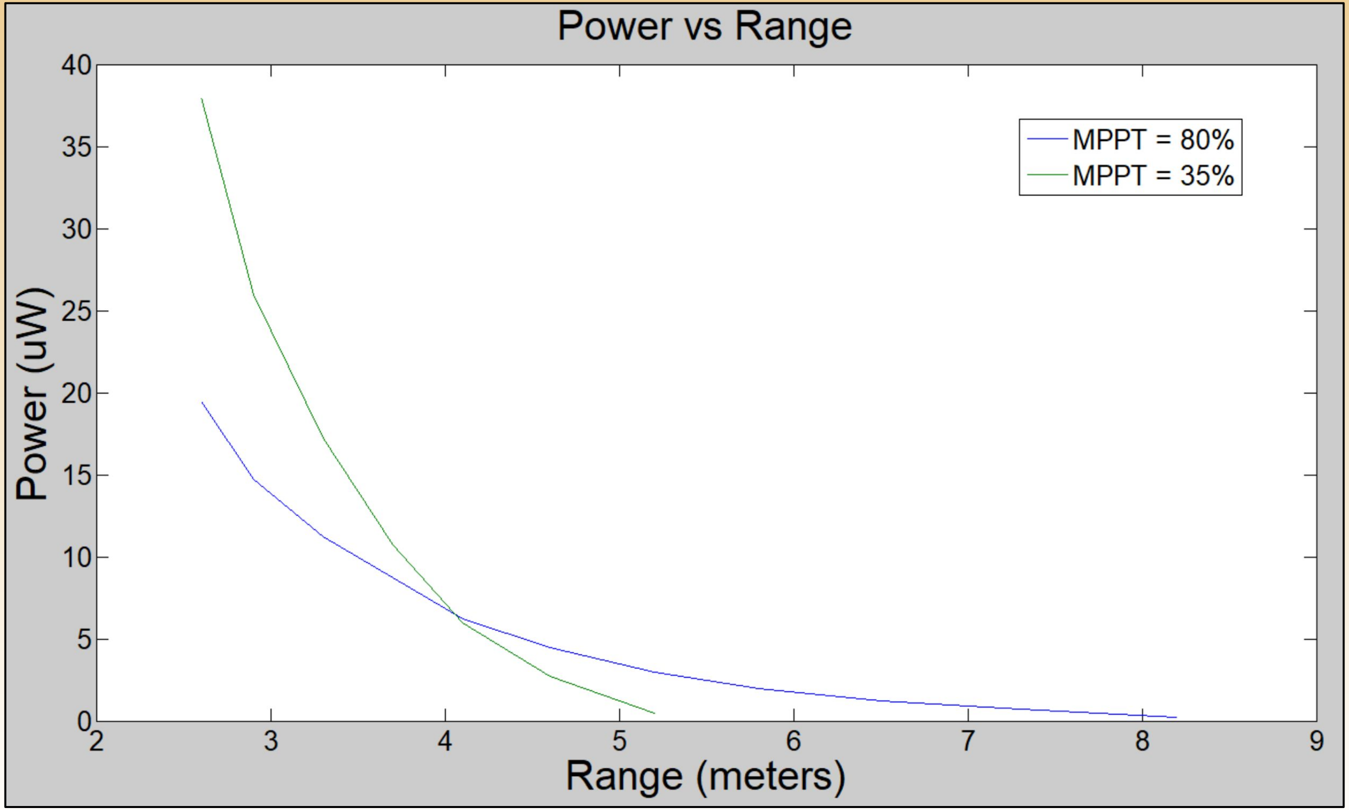


Results: Efficiency vs. Range

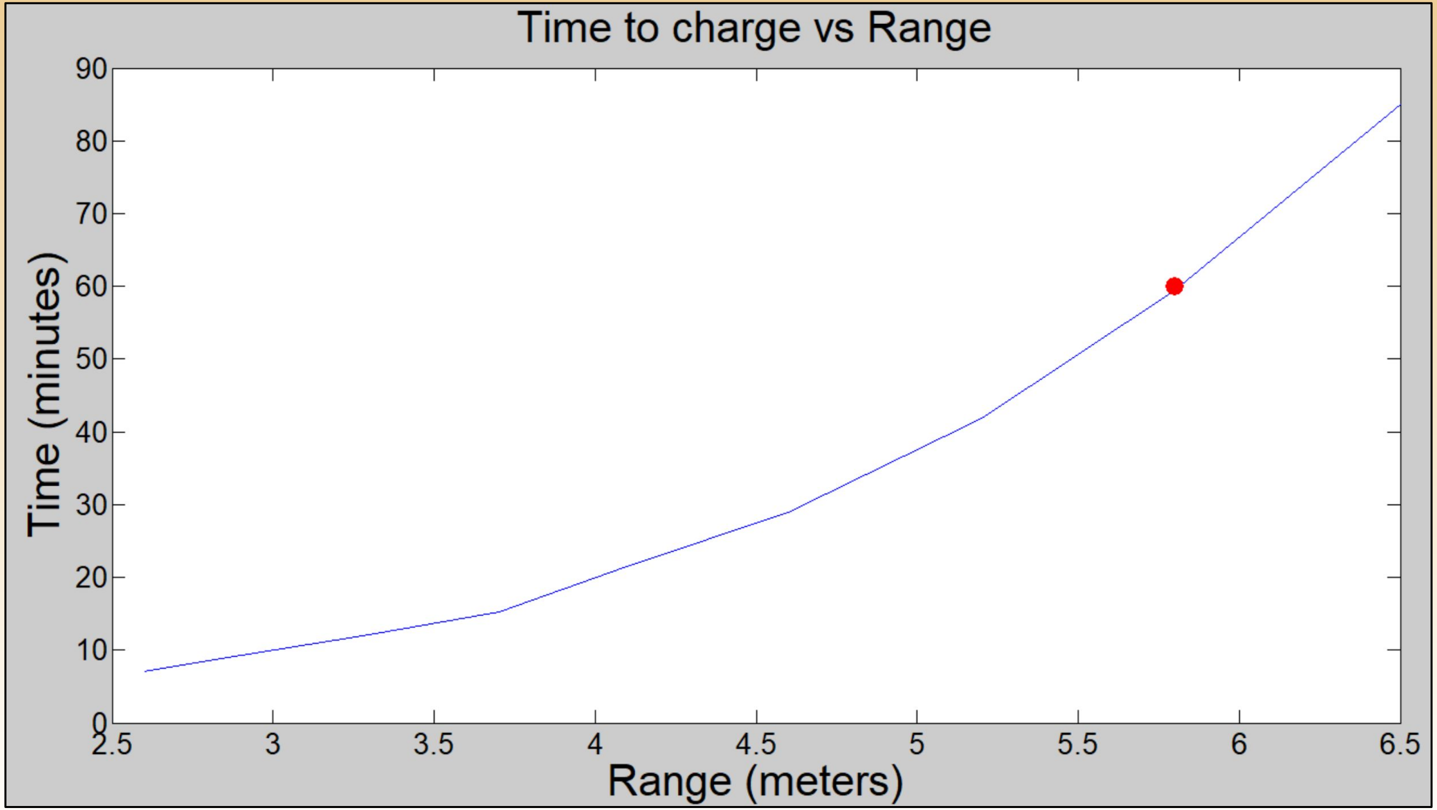
Results: Open Circuit Voltage vs. Power



Results: Improved Power vs. Range



Results: Charging Time vs. Range



Results: Efficiency

	Measured Section Losses	Total Power Delivered after each Stage (Overall Efficiency)
Reflection	10%	90%
Cable losses	10%	81%
Multiplier	95%	4%
Battery management	50%	2%

Results: Simulation vs. Measured

- Transmitted Power:
  - 30 dBm
  - < 0.6 mW/cm^2
- Power Transfer Efficiency:
  - Replenish TX Power Usage (17 mJ) < 60 min
  - Maximum Range: 4.5 meters

- Problems:
  - Multiplier circuit requires new diodes
  - Efficiency issues due to cheap construction
- Resolutions:
  - Rebuild multiplier circuit with new diodes
  - Integrate new multiplier circuit with MPPT
  - More accurate capacitor values

Skills and Technical Innovations

Skills Developed

- Iterative Design
- Multisim Simulations
- High Frequency Circuit Fabrication
- RF Test Equipment: Spectrum Analyzer, Vector Network Analyzer
- Etching a PCB

Innovations Implemented

- RF power transfer with 3 volt minimum threshold
- Inexpensive solution to RF power transfer

Questions?

Tag Team

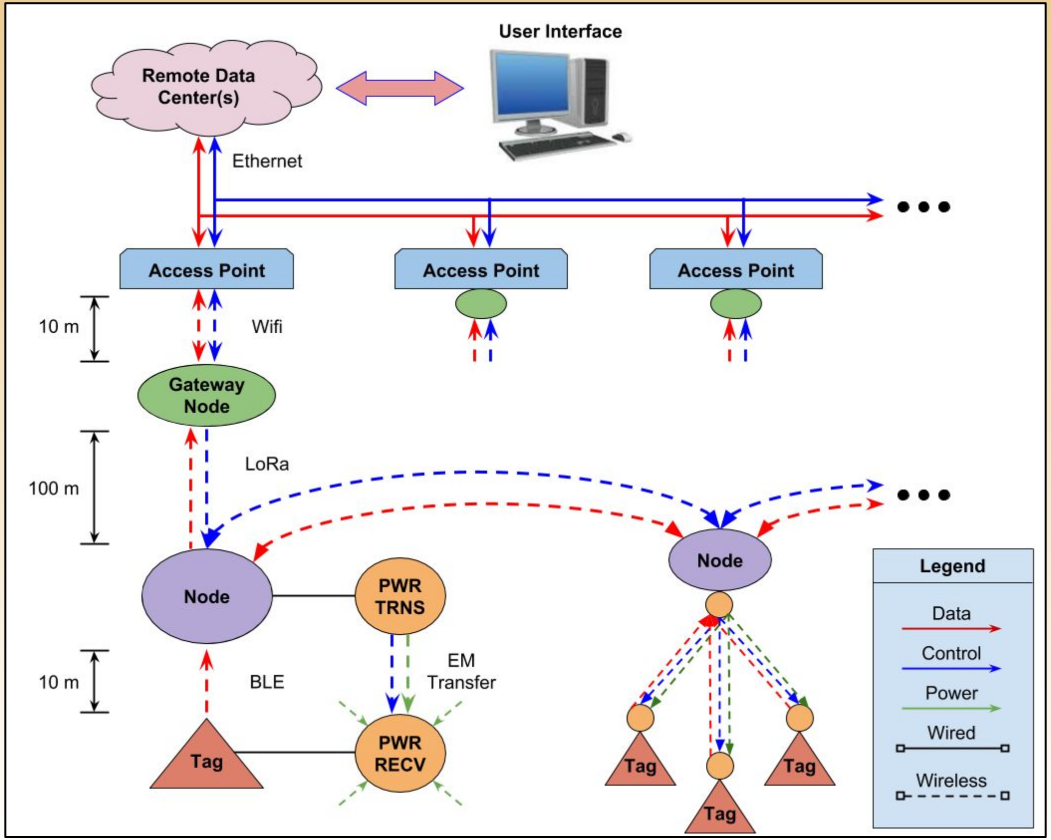
Nikita Beloоussov, Nathaniel Freeman, Austin Rudolph, Enrique Sandoval, Matthew Sandoval

Subsystem Introduction: Tags

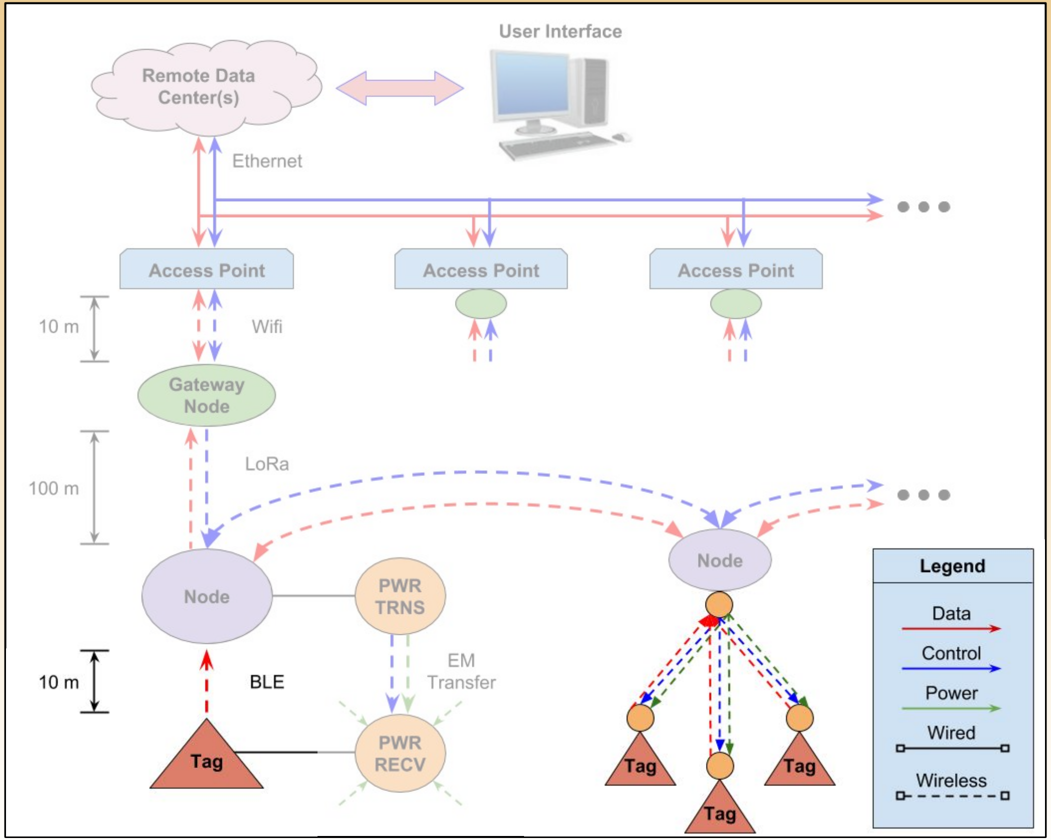
MARS is a Supervisory Control and Data Acquisition (SCADA) system composed of a self-powered distributed data collection and sensor network.

Tags are attached to valuable military assets, provide identification and sensor data at least 10 meters from nodes, and respond to asset interrogation signals.

Subsystem as Part of Overall System



Subsystem as Part of Overall System



Subsystem Specifications

Specification	Value	Description
Communication Range	**> 10 m**	**Minimum** tag-to-node operating range
Power	**< 5 μW**	**Maximum** average power usage
Scalability	**> 100 tags**	**Minimum** tags each node can gather data from
Emergency Interrogation Signal	**< 5 min**	**Maximum** interrogation response time

Decision Matrix: Communication Type

	Range	Practicality	Interference	Total
Radio Frequency	9	10	5	100
Light	5	7	8	77
Wired Connection	6	4	9	73
QR	3	7	8	67
Sound	3	2	3	32
Weight (1-5)	5	4	3	

Decision Matrix: Communication Protocol

	Power	Range	Max Connections	Availability	Total
Bluetooth Low Energy	10	7	8	10	126
Zigbee	9	8	9	8	121
Dash 7	8	9	10	3	107
ANT	9	7	9	4	107
Wifi	4	10	7	9	95
Thread	7	7	7	4	89
LoRaWan	7	10	6	3	88
Weight (1-5)	5	2	4	3	

Decision Matrix: Microcontroller

	Required Current	Required Voltage	Availability	Price	Total
PIC16F1708	10	10	5	10	150
ATTiny84	6	10	10	8	144
PIC16F877	2	5	5	7	76
Weight (1-5)	5	5	4	3	

Engineering Standards & Ethical Considerations

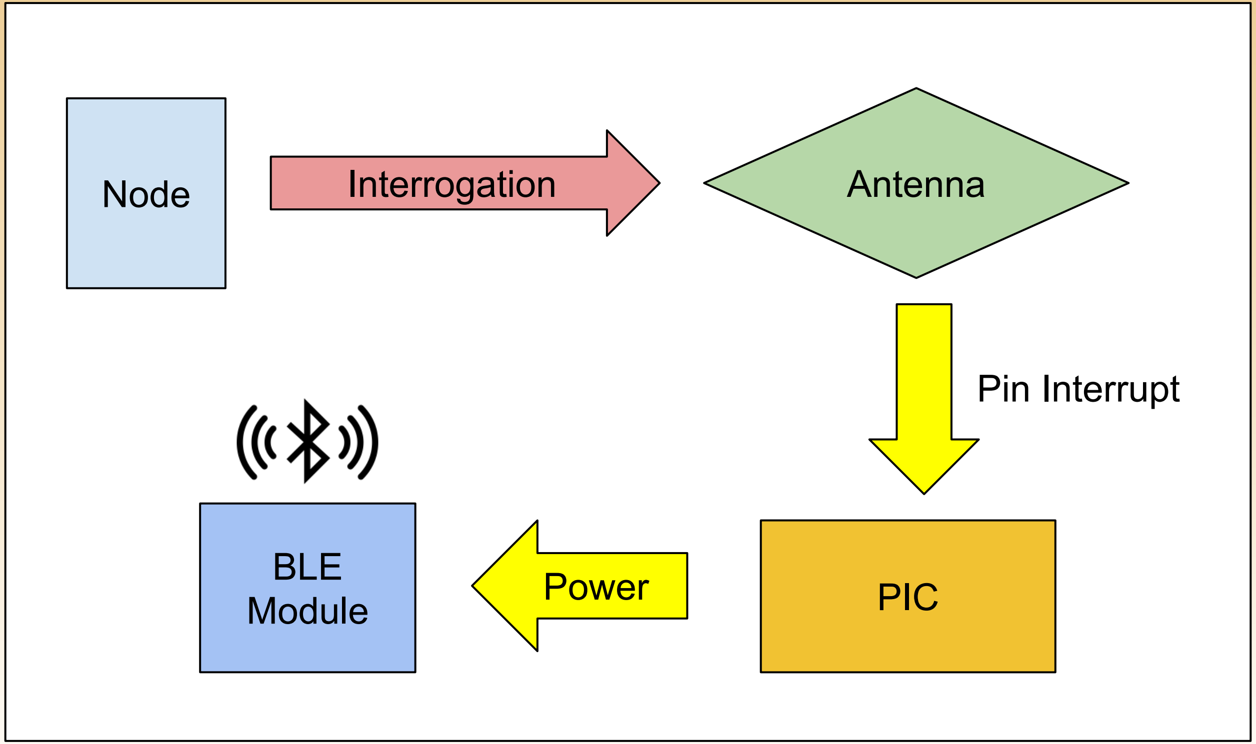
Communications Protocols:

- Bluetooth standards (IEEE 802.15.1)

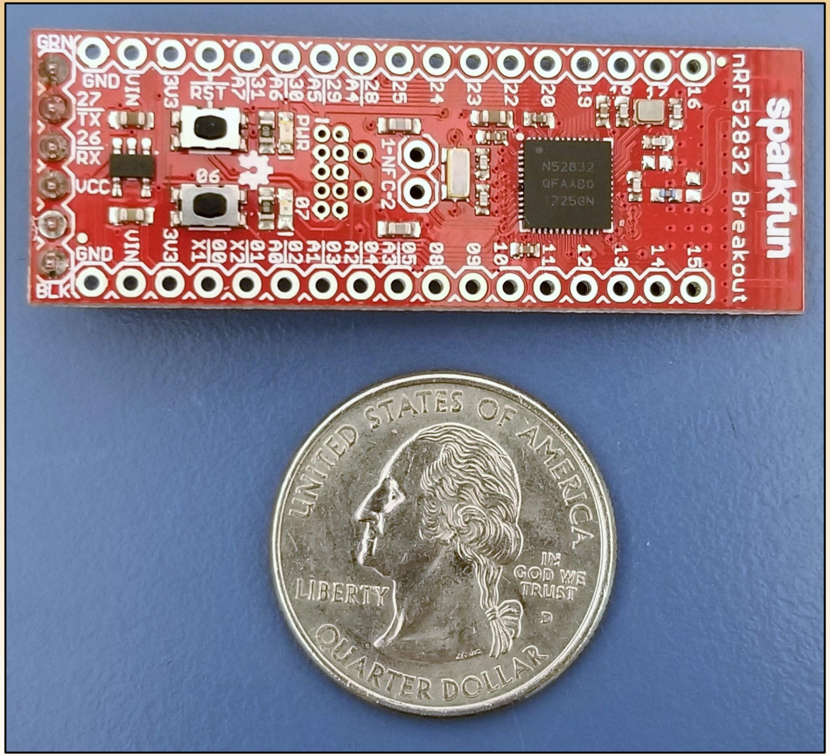
Emissions Safety Regulations:

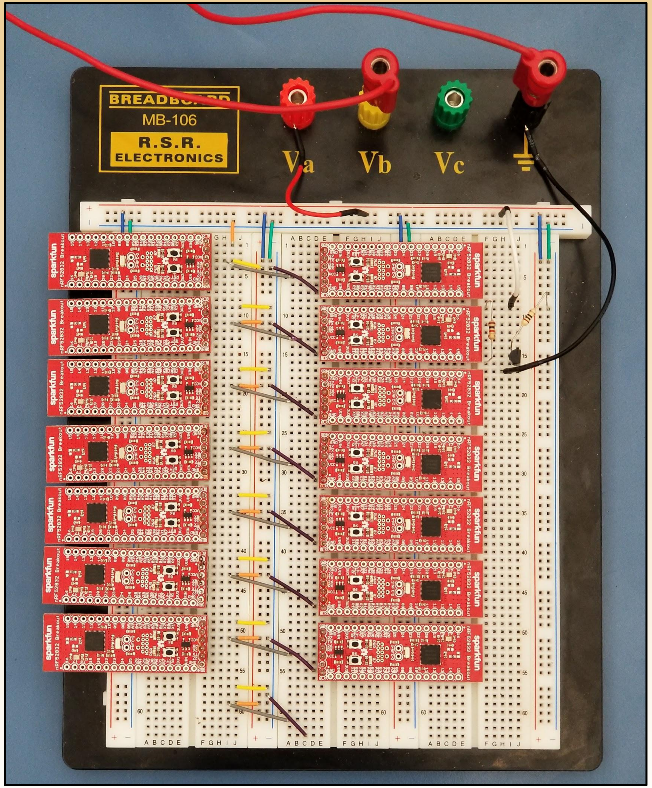
- WBAN compliant (IEEE 802.15.6)
- FCC frequencies and power

Tag Design Approach



Tags Testing Setup

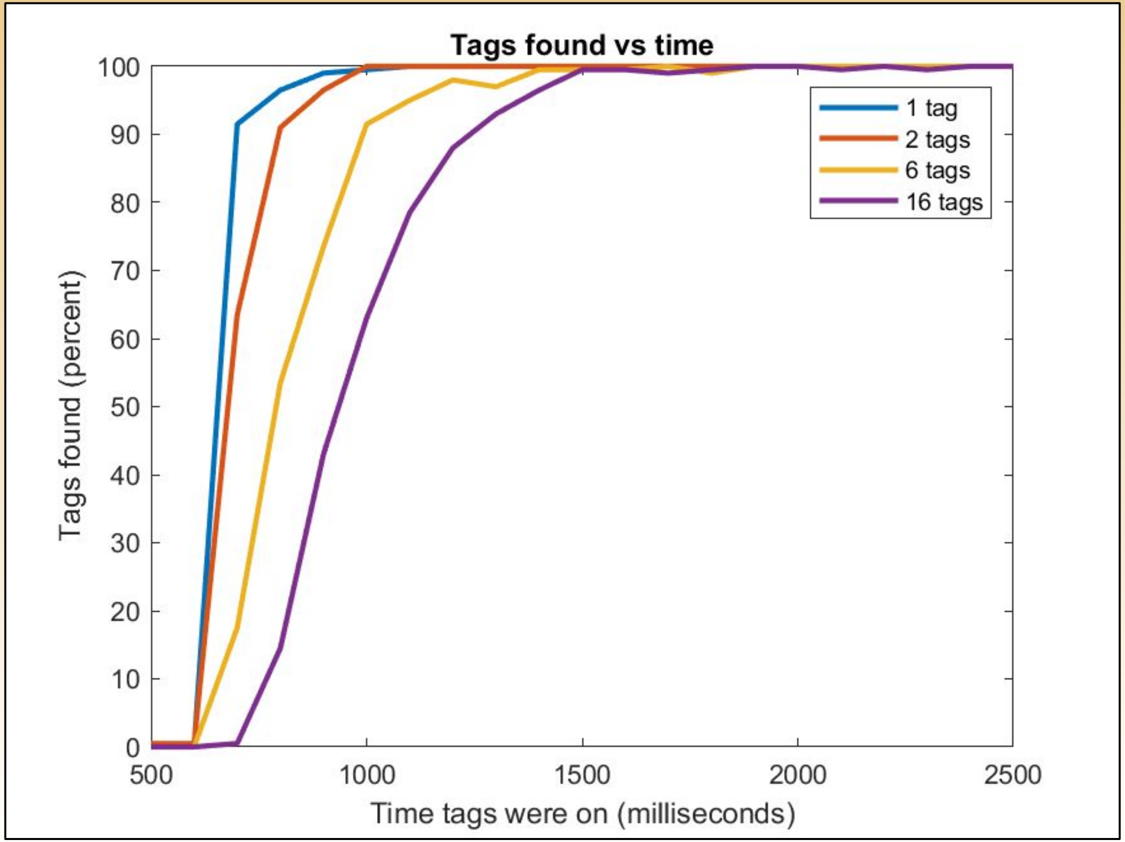




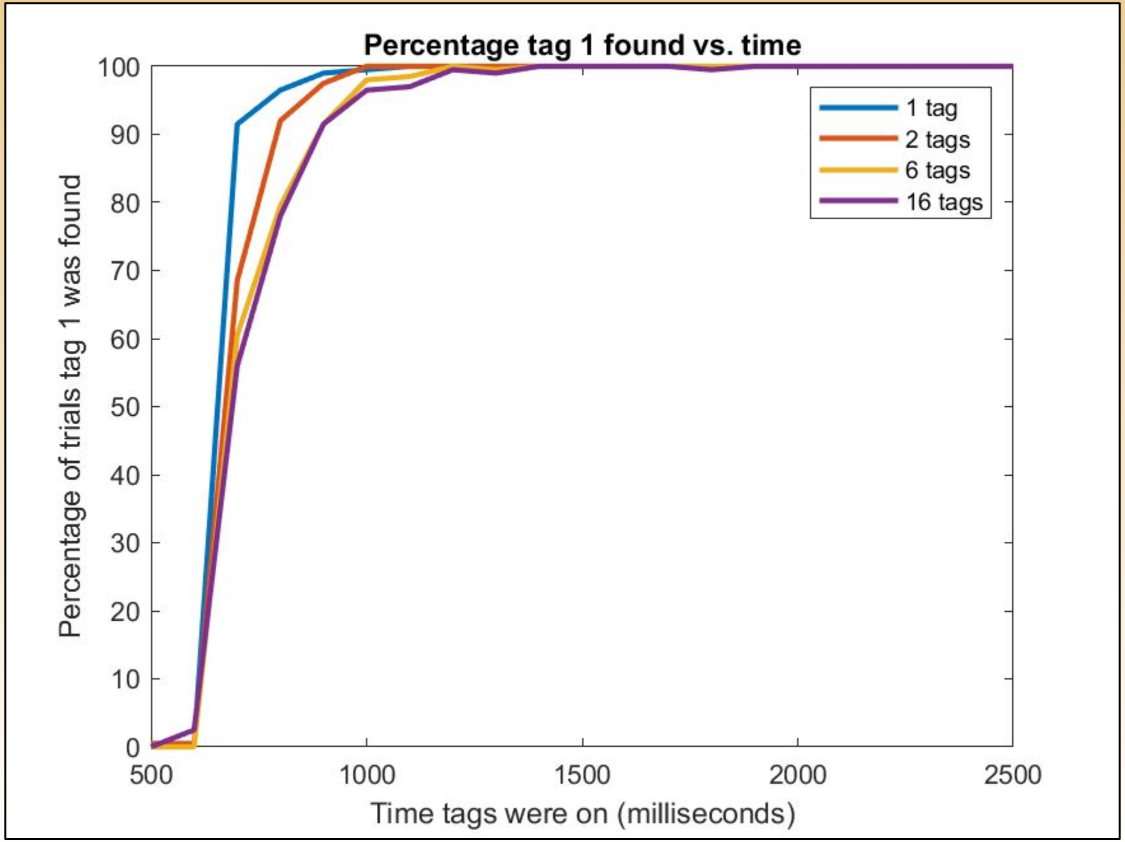
Power Budget

Power	Activity	Datasheet	Measured
nRF (Bluetooth)	Active	13 mW	16 mW
PIC	Sleep	1μW	65μW
	Active	0.5 mW	1.5 mW
Tag average power	Active 1 sec/hour	**4.8 μW**	68 μW
	Active 2 sec/hour	8.5 μW	73 μW
Battery life with 800mAh alone	Active	6 days	5 days
	Active 2 sec/hour	26 years	**3 years**

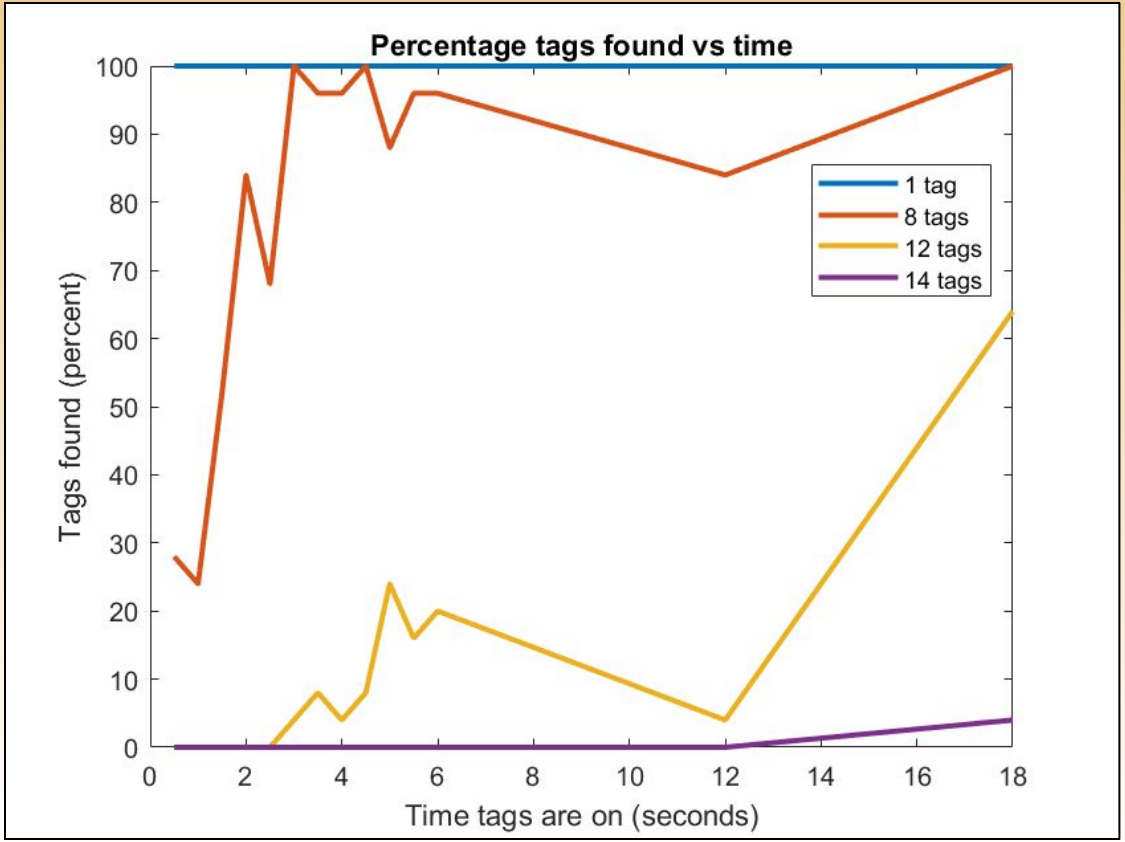
Communication Results: Time Tests (0 meters)



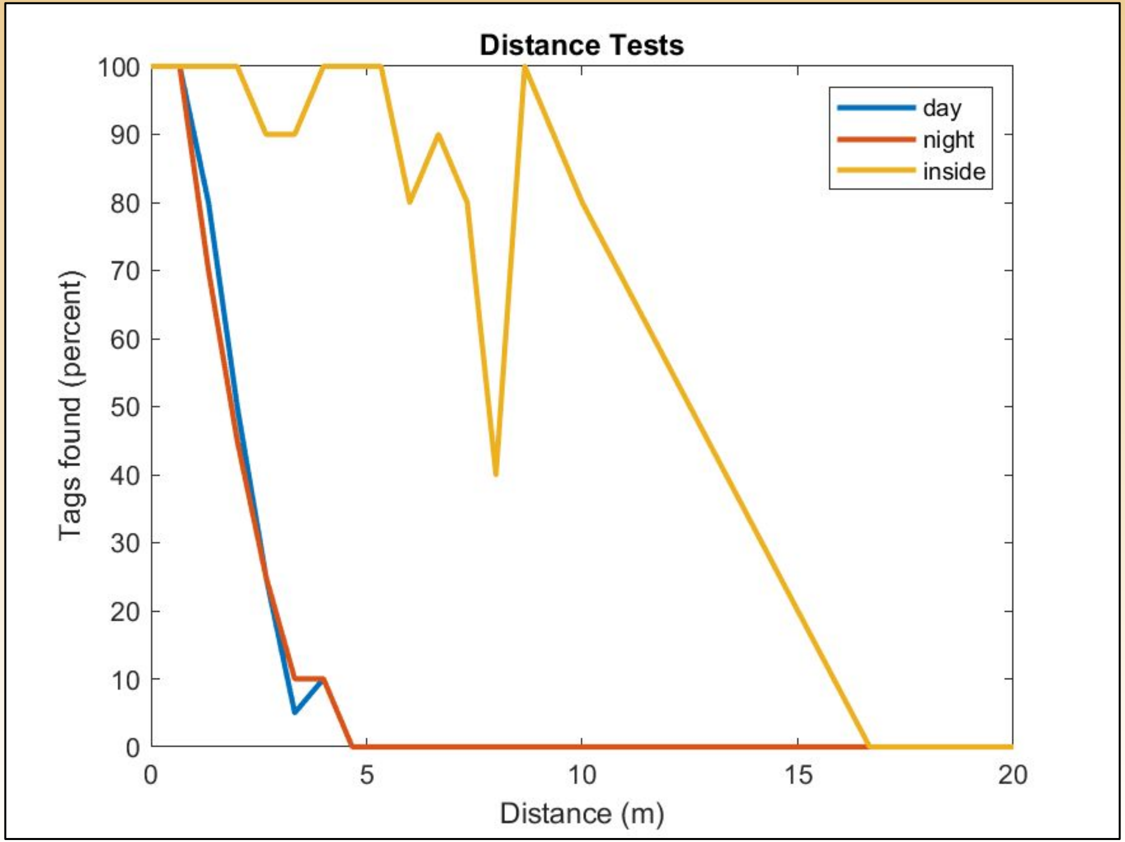
Communication Results: Time Tests (0 meters)



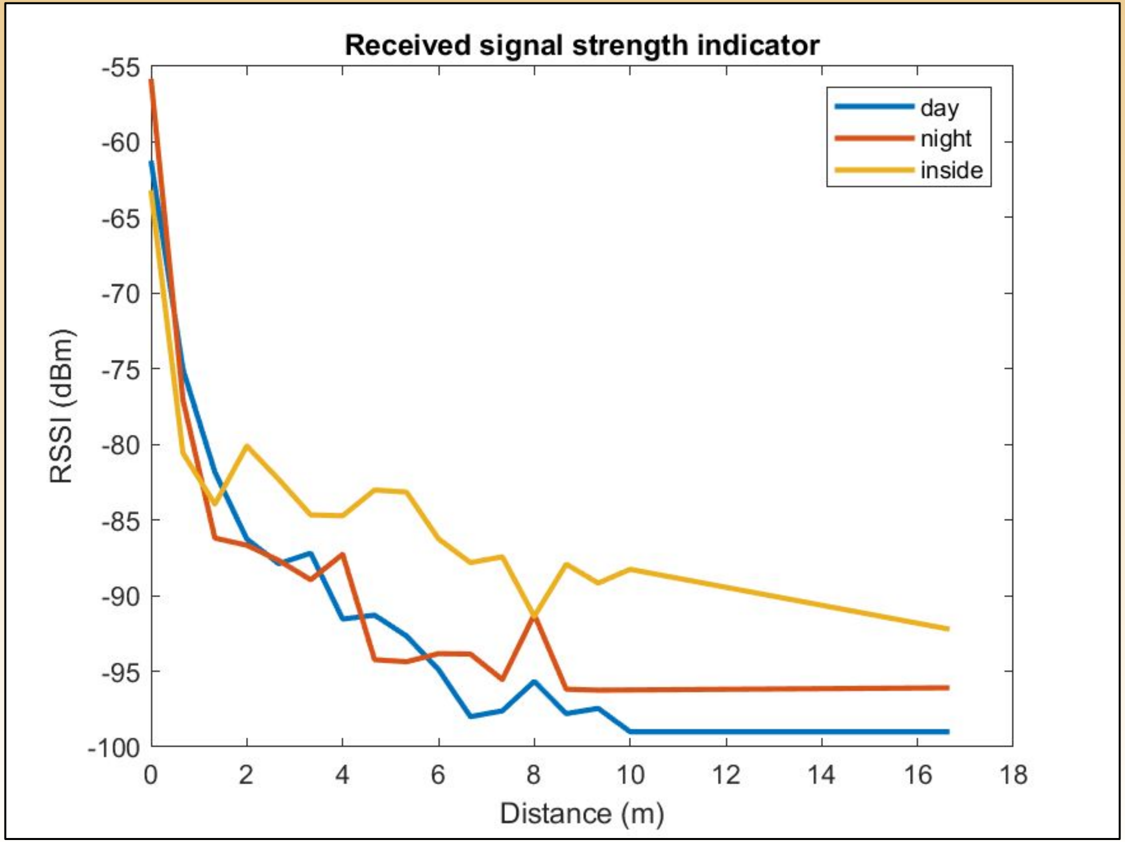
Communication Results: Time Tests (10 meters)



Communication Results: Distance Tests (6 tags)



Communication Results: Distance Tests (6 tags)



Communication Results: Summary

Can gather 100% of tag data at 15 meters indoors
The percentage quickly drops off outside
Longer scan times improve the percentage

Average RSSI:

- 0 meters: -50dBm to -60 dBm
- 10 meters: -90dBm to -100 dBm

Obstacle Test:

- Lowers Distance
- Metal Studs

Solutions:

- Better receiving antenna
- Stronger Signal

PIC Results

Sleep mode: low power and watchdog timer

External interrupt: wireless pin interrupt

- Most time in sleep
- Average sleep power: 65 μW
- Average awake power: 1.5 mW

Results: Summary

- Problems:
  - PIC uses more power than expected
  - Tags need longer transmitting time
  - Background noise outside is interferes more with the signal than expected

- Resolutions:
  - Optimize program for PIC
  - Stronger Signal
  - Better Receiving Antenna on nodes
  - Design SOC with desired communication

Overall Results In Comparison to Specs

Specification	Ideal	Measured
Communications Range	Tag to Nodes: 10 m	15 m (indoors) 13 m (outdoors)
Power Usage	< 5 μW	73 μW
Scalability	100 Tags per node	>150 tags
Emergency Interrogation Signal	< 5 min	3 min 25 seconds @ 3 meters

Skills Learned and Innovation

Skills Learned

- Design
- Programming with MPLab-X IDE
- Experience with BLE
- Power saving methods

Innovation

- Scanning device IDs rather than device-to-device connections
- Wireless pin interrupt

Questions?

Node Team

Thomas Dearing, Duggan Matson, Brendan Noone

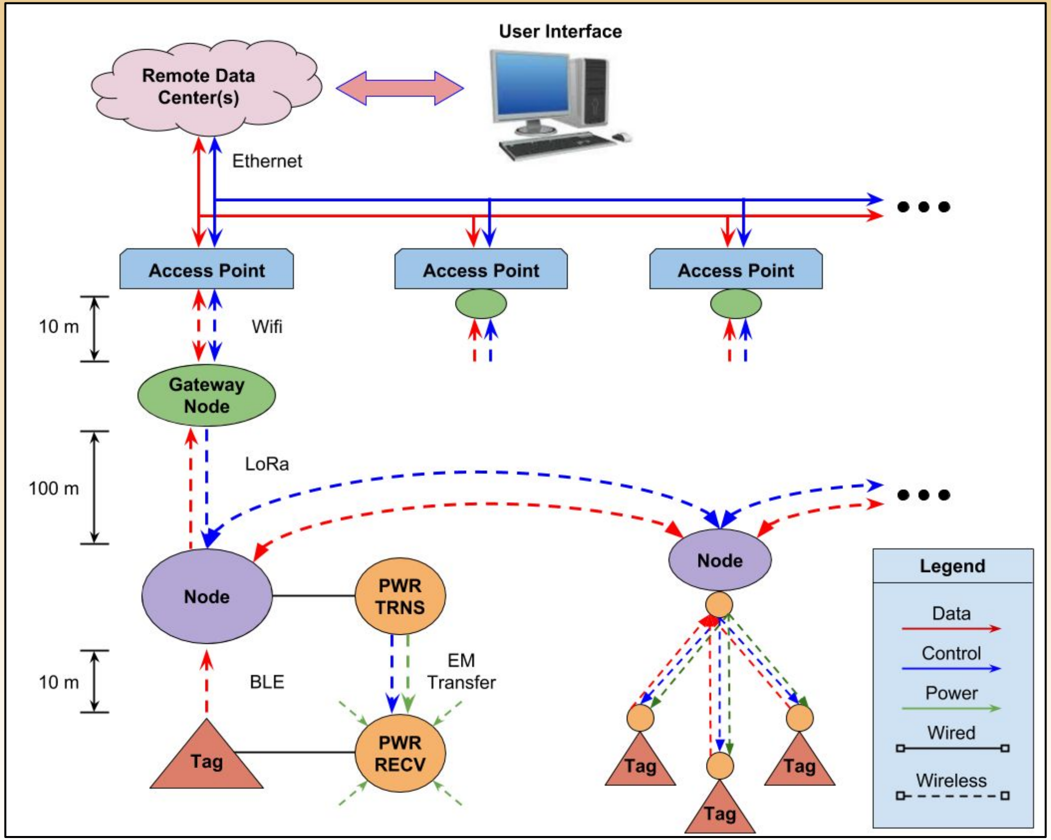
Subsystem Introduction: Nodes

MARS is a Supervisory Control and Data Acquisition (SCADA) system composed of a self-powered distributed data collection and sensor network.

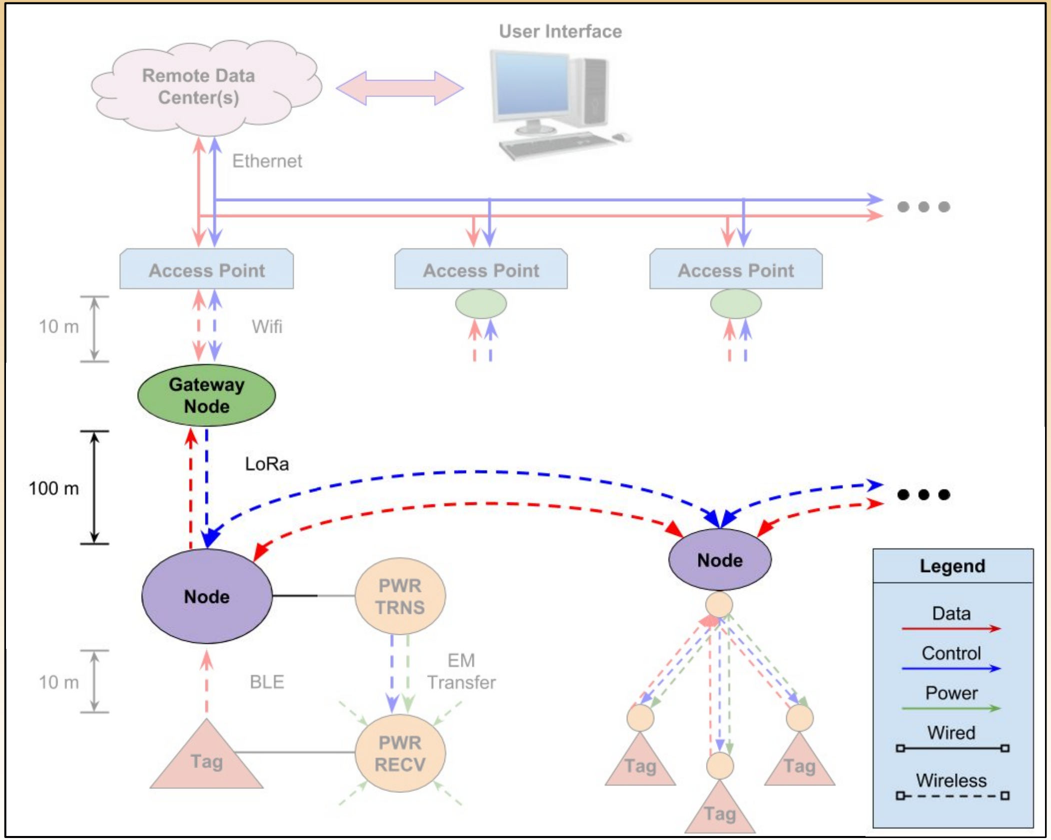
NODES are mobile, mesh-networked sensors which...

- Collect local tag inventories (type and location)
- Report local inventory to UI server
- Coordinate packets from other Nodes
- Provide power to asset Tags

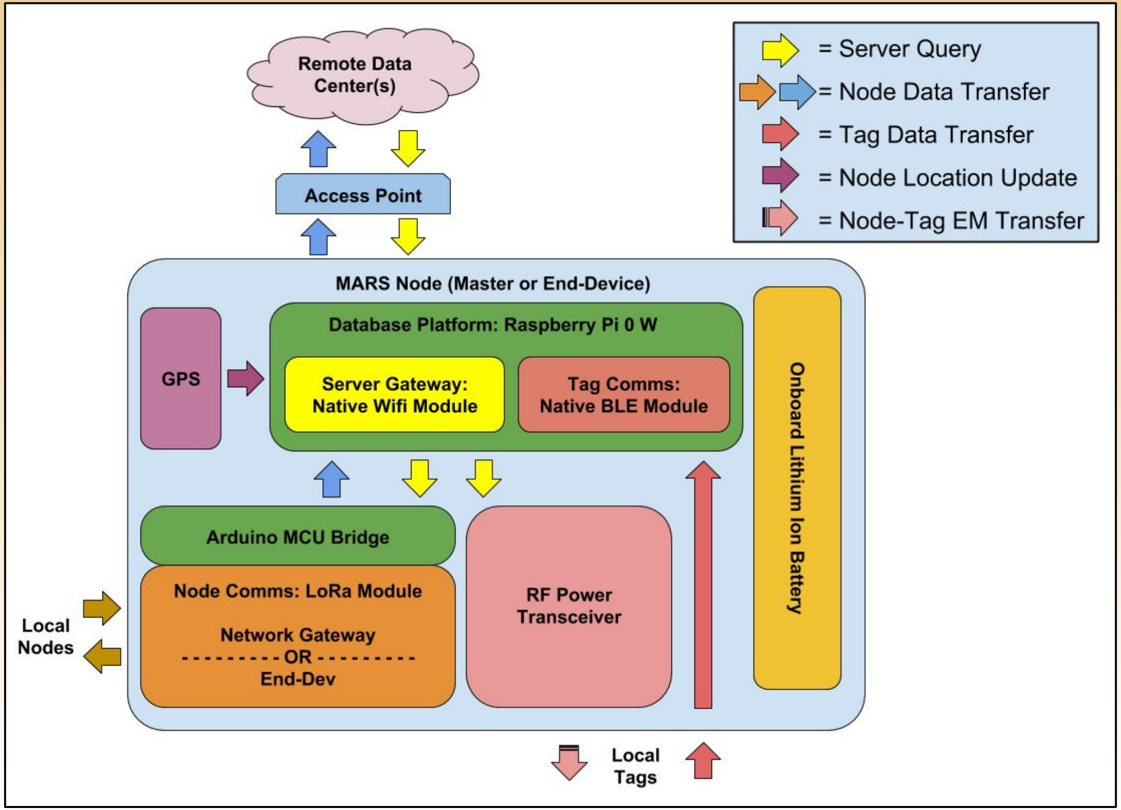
Full System Model



Node Subsystem



Subsystem Overview



Subsystem Specifications

Specification	Value	Description
Communications Range	**To Tags: 10 m** **To Nodes: 100 m** **To Gateway: 100 m**	**Minimum** operating range
Positioning Error	**< 10 m**	**Minimum** location error
Runtime	**18 Hours**	**Minimum** uptime *between charges* at 100% load
Tag Update Period	**5 min**	**Minimum** inventory update period
Scalability	**100 Tags & Nodes**	**Minimum** number of connections per Node
Mobility	**Volume: < 300 cm^3** **Weight: < 250 g**	**Maximum** dimensions/mass to easily carried/worn

Decision Matrix: Hardware Development Platform

Platform	INSTR/s	Memory	Power Usage (Idle)	Max Power Usage	Software Availability	Total
Raspberry Pi 3	10	10	1	1	10	130
Raspberry Pi Zero W	9	9	8	8	9	188
Beaglebone Black	9	9	4	5	8	149
ESP32	5	7	10	10	4	164
Arduino 101	6	5	10	10	3	156
Arduino Uno	3	3	7	9	3	116
Weight (1-5)	4	4	5	5	4	

Decision Matrix: Location & Timing Services

Location & Timing Service	Price	Update Rate	Accuracy	Weight	Total
RB-EAG-11	1	1	5	9	48
Quadrino GPS i2c Module	4	10	5	1	65
Ublox NEO-M8N GPS	10	1	8	2	67
MT3329 GPS Module	10	1	1	6	40
Adafruit 66 Channel v3	9	10	10	10	118
Weight (1-5)	2	3	5	2	

Decision Matrix: Power Subsystem

Part Name	Capacity	Volume	Interface	Price	Total
PowerCore 13000	10	9	10	8	101
PowerCore 10000	9	10	9	9	104
KMASHI 10000mAh Portable Power Bank	9	8	10	10	97
Weight (1-5)	3	5	1	2	

Collaborative Design Decisions

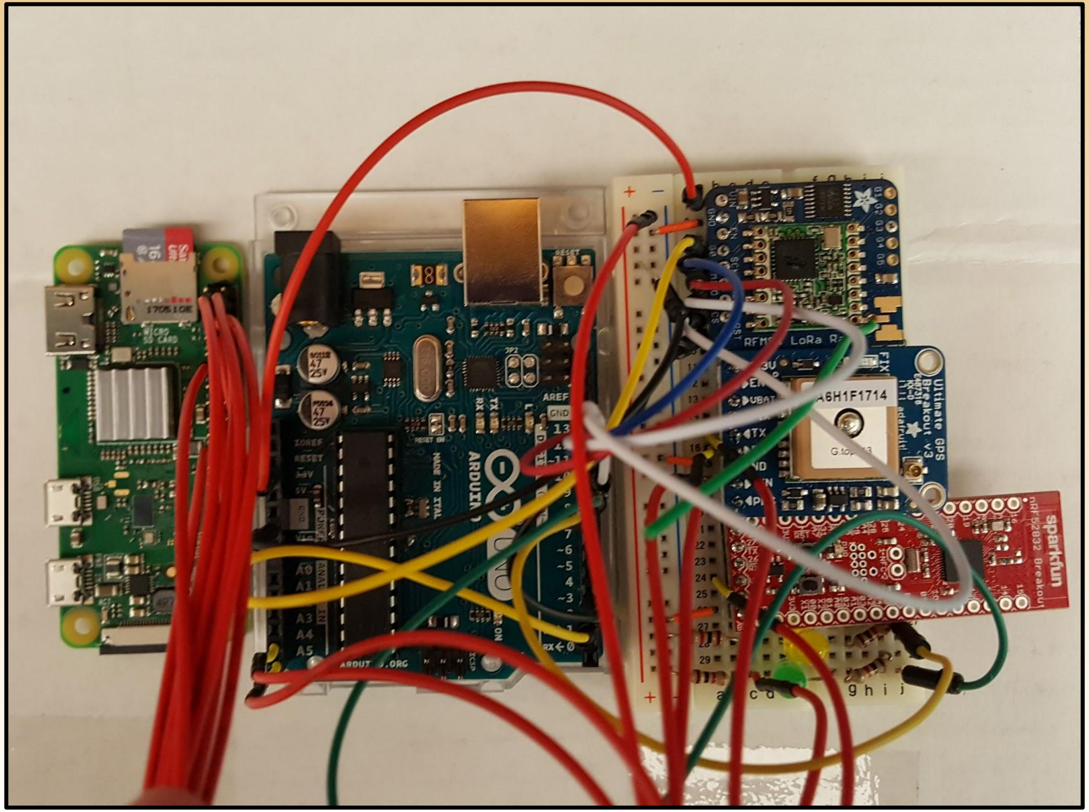
- Communications protocols:
  - Node-Tag: Bluetooth Low Energy
  - Node-Node-Gateway: LoRa

- Software development platform: Node.js

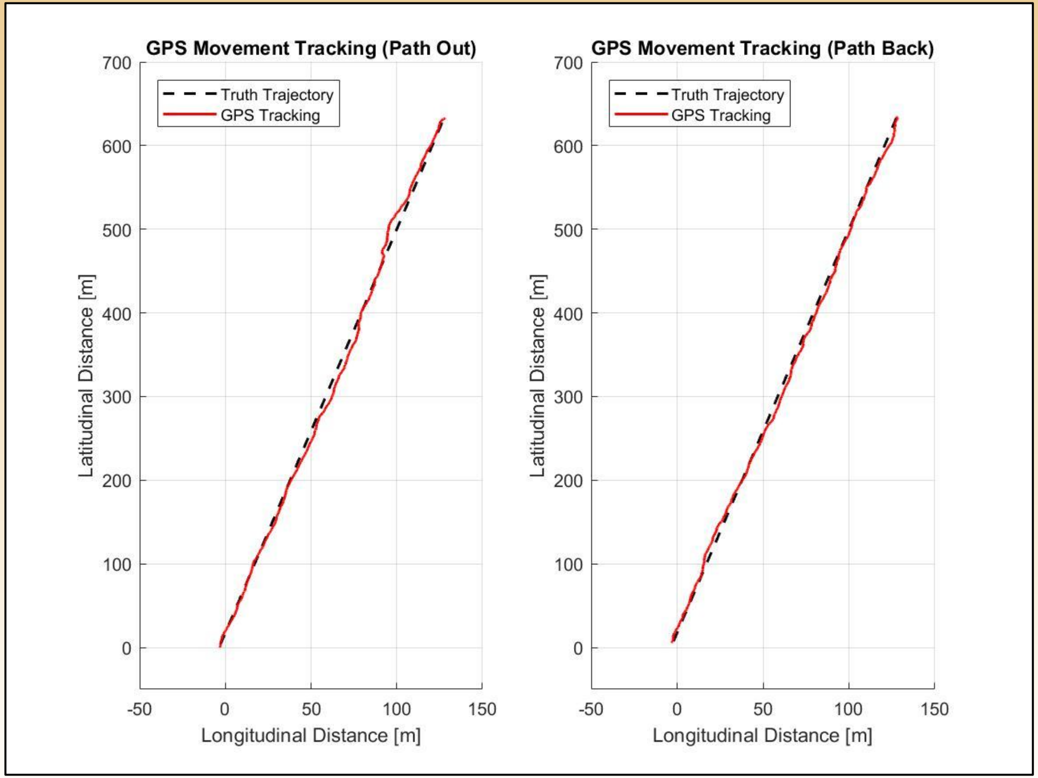
Engineering Standards & Ethical Considerations

- Communications Protocols:
  - Bluetooth (IEEE 802.15.1)
  - LoRa-WPAN (IEEE 802.15.4)
- Emission Safety Regulations:
  - Unlicensed RF emissions (FCC Title 47)
  - Usage and interference in ISM bands (IEEE 802.11)
  - Safety for on-body WBAN devices (IEEE 802.15.6)
- Information Standards:
  - Geographic location (ISO 6709)
  - Standardized date and time (ISO 8601)
- Standards for Deployment (Phase 2):
  - Military testing regulations (MIL-STD-810)

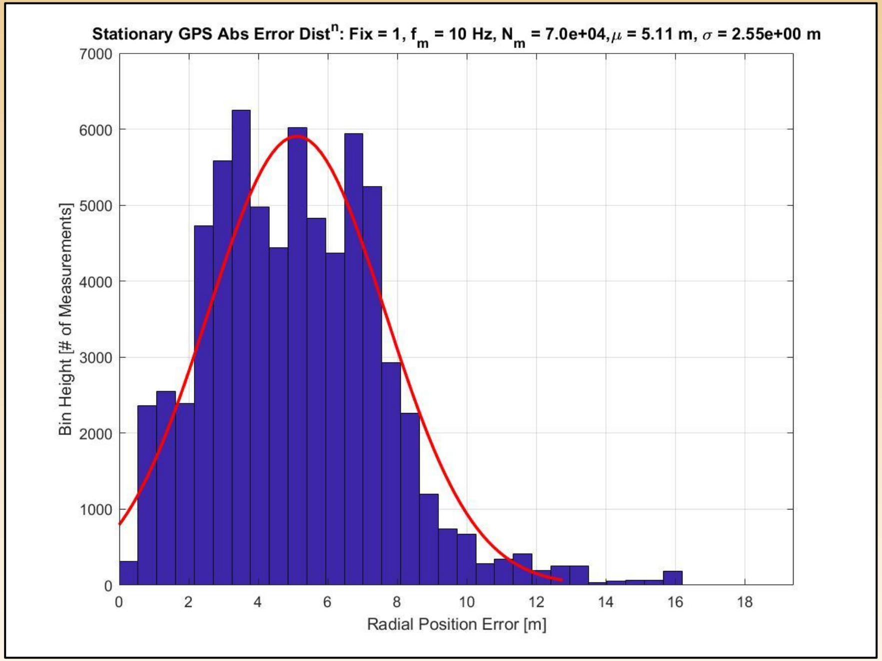
Results: Node Prototype

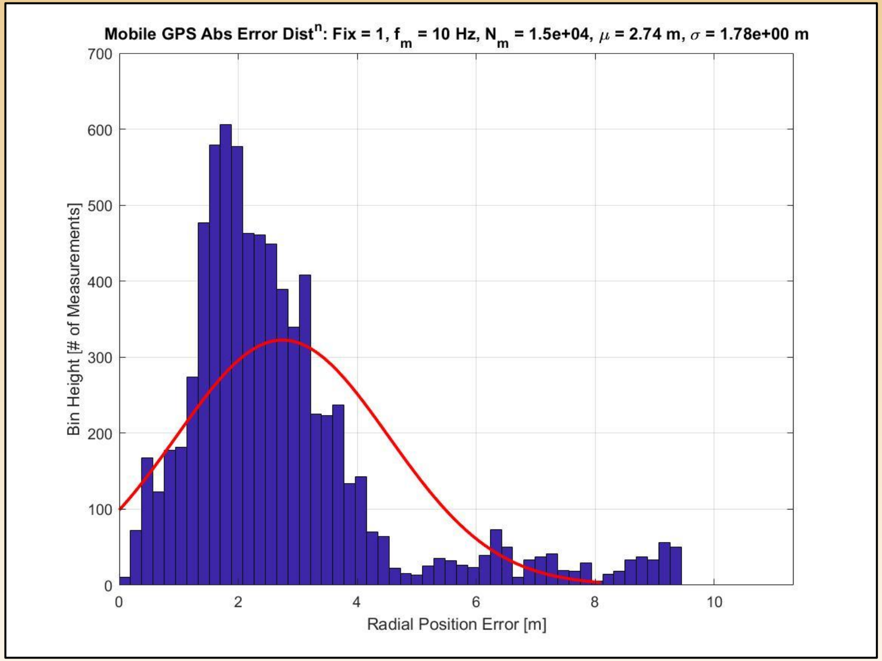


Results: GPS Characterization Tests



Results: GPS Tracking Error





Results: GPS Tracking Error

- Stationary Positioning Error (N_{sat} = 7):
  - Low FOV
  - Mean Error: 5.1 m < 10 m
  - 95% CI Range: 10.2 m (2%) > 10 m

- Mobile Positioning Error (N_{sat} = 10):
  - High FOV
  - Mean Error: 2.7 m < 10 m
  - 95% CI Range: 6.3 m < 10 m

- Using ISO 6709/8601 for reporting

- Problems:
  - Error tolerance varies with N_{sat}
  - Estimate is a minimum value

- Resolutions:
  - Aiding antenna used to increase N_{sat}
  - Require $N_{sat} \geq 10$ on fix
  - Enabled tag triangulation

Results: Runtime

- 18 H runtime on 10,000 mAH battery
  - 2.78 W Max
- Per-element maximal power usage:
  - Pi Zero (CPU Max): 1.25 W
  - Arduino Uno (Max): 0.40 W
  - GPS (Fixed): 0.07 W
  - BT & LoRa TRX: 0.73 W
  - RF Transmitter: 6.50 W

  Measured 1.1 W
- Current runtime at 7.6 h < 18 h
  - 45 h w/o transmitter

- Problems:
  - RF transmitter is inefficient
- Resolutions:
  - Improve efficiency of power transfer
  - Establish battery charging rotation
  - Single board / MCU solution

Results: Communications Ranges

- Node-Tag: BLE
  - Indoor LOS: > 15 m 0% Loss
  - Outdoor LOS: > 13 m 0% Loss

- Node-Node-Server: LoRa
  - Indoor LOS: < 50 m 0% Loss
  - Indoor OBS: < 50 m 0% Loss
  - Outdoor LOS: <120 m 0% Loss
    >230 m 35% Loss
  - Outdoor OBS: Obstruction dependent

- Problems:
  - Tags transmission distance outside
  - LoRa blocked by large buildings

- Resolutions:
  - Add external receiving antenna
  - Determine building size / construction and consider in deployment

Results: Asset Update Period, Scalability, & Mobility

- Asset ID / location update time
  - Routing length: 10 Nodes
  - 1-Node routing time: 411 ms
  - Max routing delay: 4.11 s << 1 hr

- Functional Req. of 100 Nodes / Gateway
  - 120 Nodes / Gateway at 10% Net loss

- Prototype Size & Weight
  - Size: 270 cm^3 < 300 cm^3
  - Weight: 247 g < 250 g

Results: Summary

Specification	Ideal Value	Measured
Communications Range	To Tags: 10 m To Nodes: 100 m To Gateway: 100 m	13 m 120 m 120 m
Positioning Error	10 m	6.5 m
Runtime	18 hrs	7.6 hrs
Tag Update Period	5 min	4 s
Scalability	Tags: 100 Nodes: 100	100 120
Mobility	Volume: 300 cm^3 Weight: 250 g	270 cm^3 247 g

Skills and Technical Innovations

- Skills Developed:
  - Iterative Design
  - Project management and leadership
  - Development of a functional Ad-Hoc mesh sensor network
  - Development of a GPS accuracy characterization protocol
  - Protocols: JSON, LoRa, and BLE

- Innovative Design Element:
  - LoRa Mesh Network (Coop with UI/Server Team)

Questions?

UI/Server Team

Courtney Bamonte, Dominic Borunda, Zach Harris, Christopher Rey

Subsystem Introduction: UI/Server

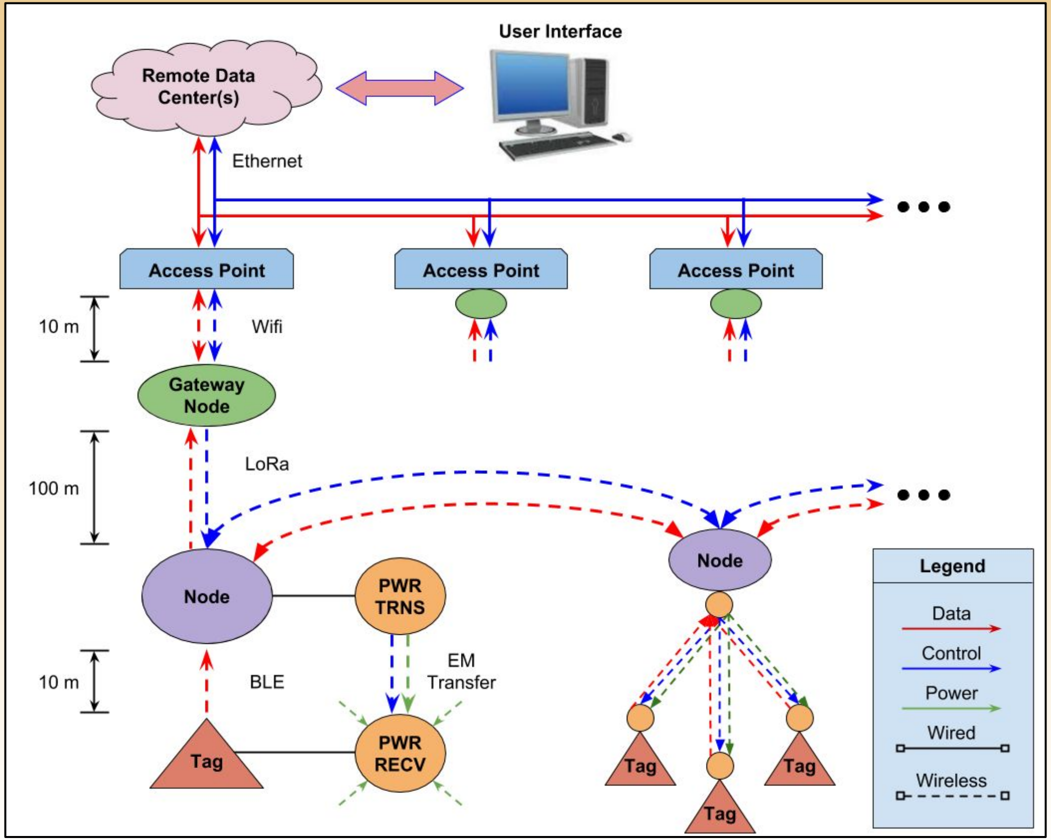
MARS is a Supervisory Control and Data Acquisition (SCADA) system composed of a self-powered distributed data collection and sensor network.

The **User Interface and Server** is an interactive interface which sends and receives information throughout MARS and allows the user to access specific and systemwide data.

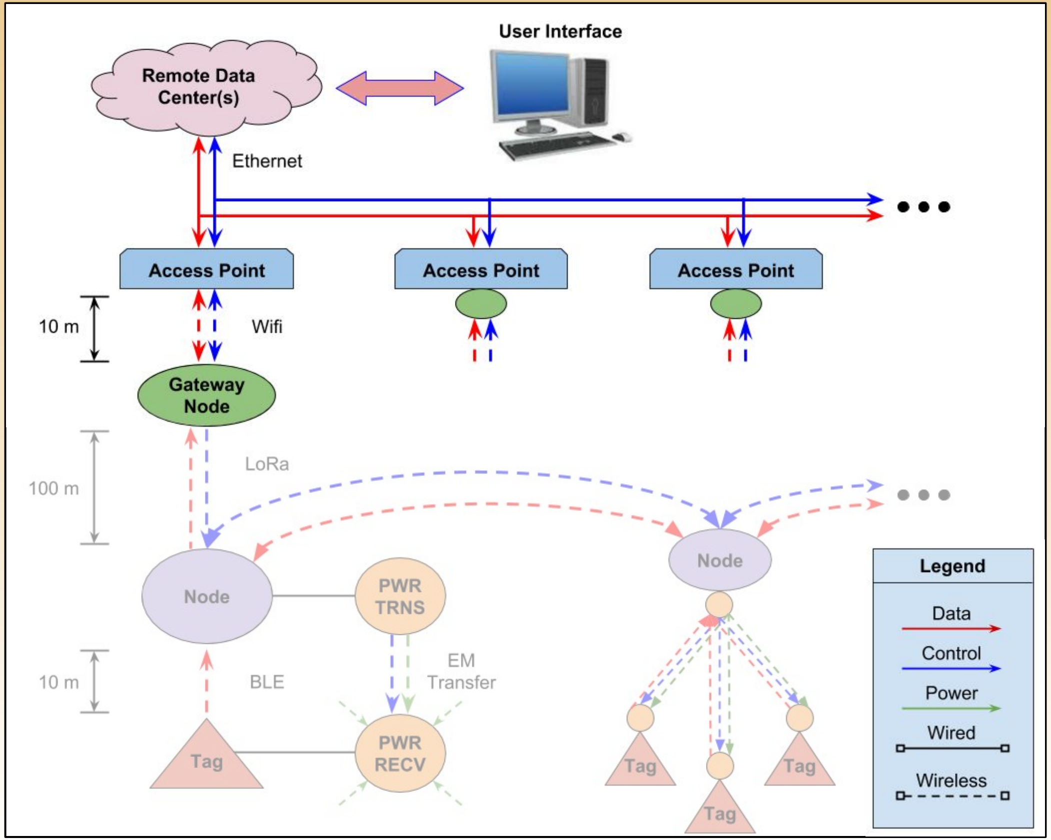
Design Goals

- Robust server to collect and store information
- Organize display for easy asset discovery
- Reliable communication to battlefield
- Resilient network structure
- Optimize data packetization

Full System Model



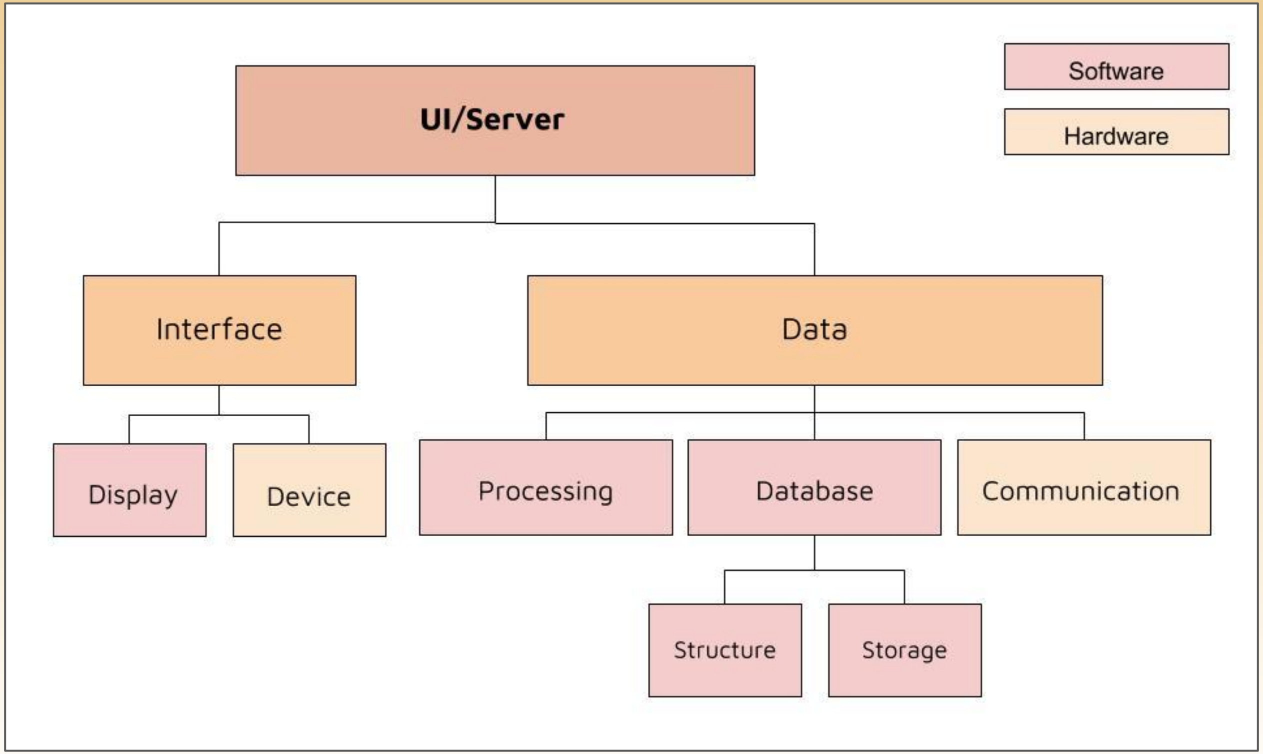
Server Subsystem



Subsystem Specifications

Specification	Value	Description
Communications Range	To Nodes: 100 m To Gateway: 100 m	**Minimum** operating range for protocol
Positioning Error	< 10 m	**Minimum** location service error for tag triangulation
Hardware Scalability	100 Nodes w/ 100 Tags	**Minimum** number of connected devices per Node
Server Scalability	100 Nodes w/ 100 Tags each	**Minimum** number of connected devices server can handle
Throughput	10 kbps	**Minimum** network load
UI Functions	Tag Triangulation Interrogation Signal	**Minimum** functional applications on UI

Design Breakdown



Decision Matrix: Server to Node Communication

	UI	Performance	Modularity	Reactivity	Feasibility	Total
HTTP	2	8	2	6	2	90
Golang	2	10	4	6	6	118
NodeJS	10	6	10	10	10	180
Qt	2	10	10	2	6	116
Vert.x	6	6	8	10	8	152
Weights (1-5)	4	5	3	5	3	

Decision Matrix: Gateway Node to Node Communication

	Range	Data Rate	Network Size	Power	Total
Zigbee	3	5	9	8	88
6LoWPAN	3	5	2	9	79
Z-Wave	4	3	8	7	80
LoRa	10	1	7	5	92
Ethernet	5	10	1	1	62
Weights (1-5)	5	3	2	5	

Decision Matrix: Data Management and Storage

	Structure	Accessibility	Feasibility	Total
Text File	2	3	10	77
SQL	6	10	7	91
MongoDB	9	10	10	115
Weights (1-5)	5	4	3	

Engineering Standards & Ethical Considerations

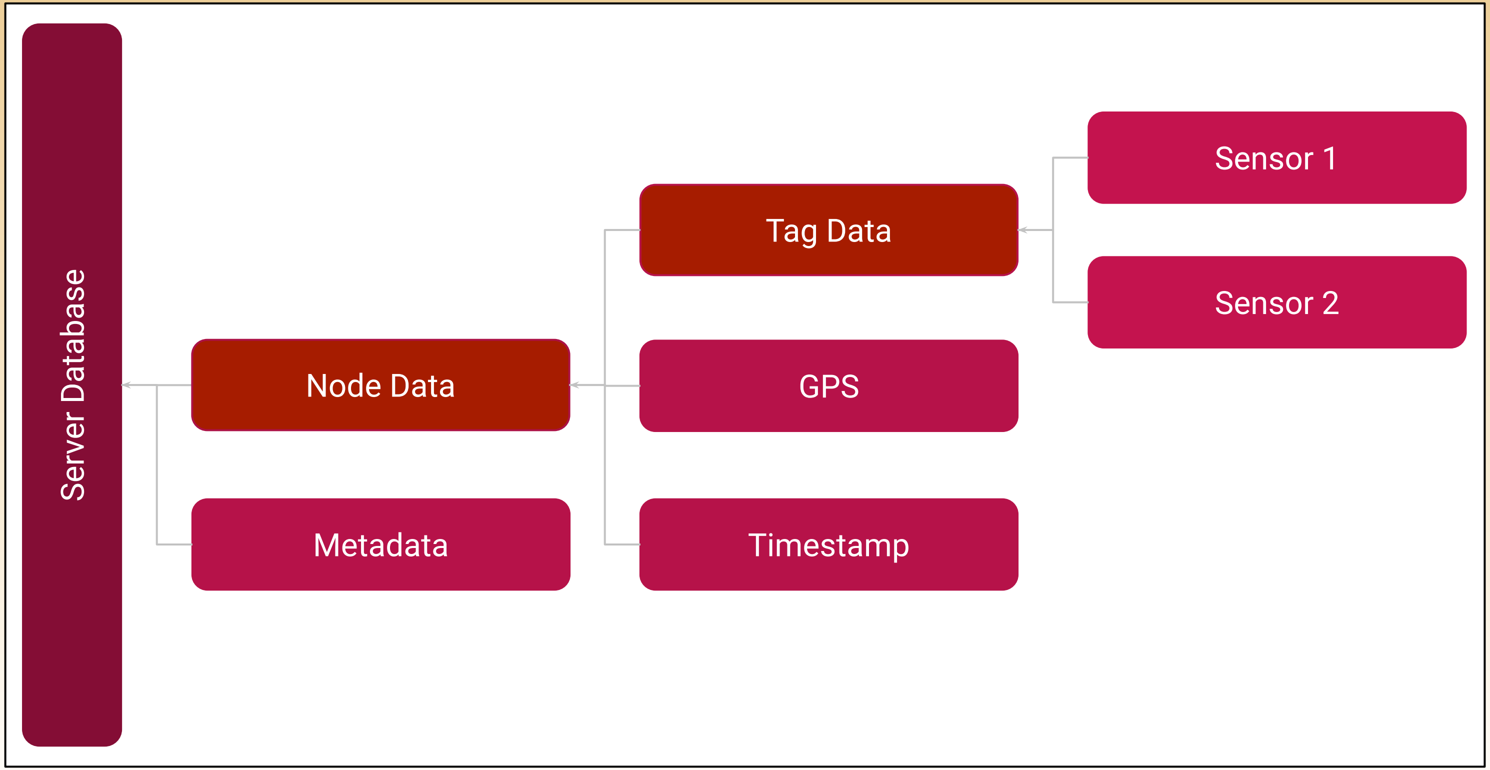
Emissions and Communications Protocols:

- Unlicensed RF emissions (FCC Title 47)
- LoRa-WPAN (IEEE 802.15.4)
- Usage and interference in ISM band (IEEE 802.11)

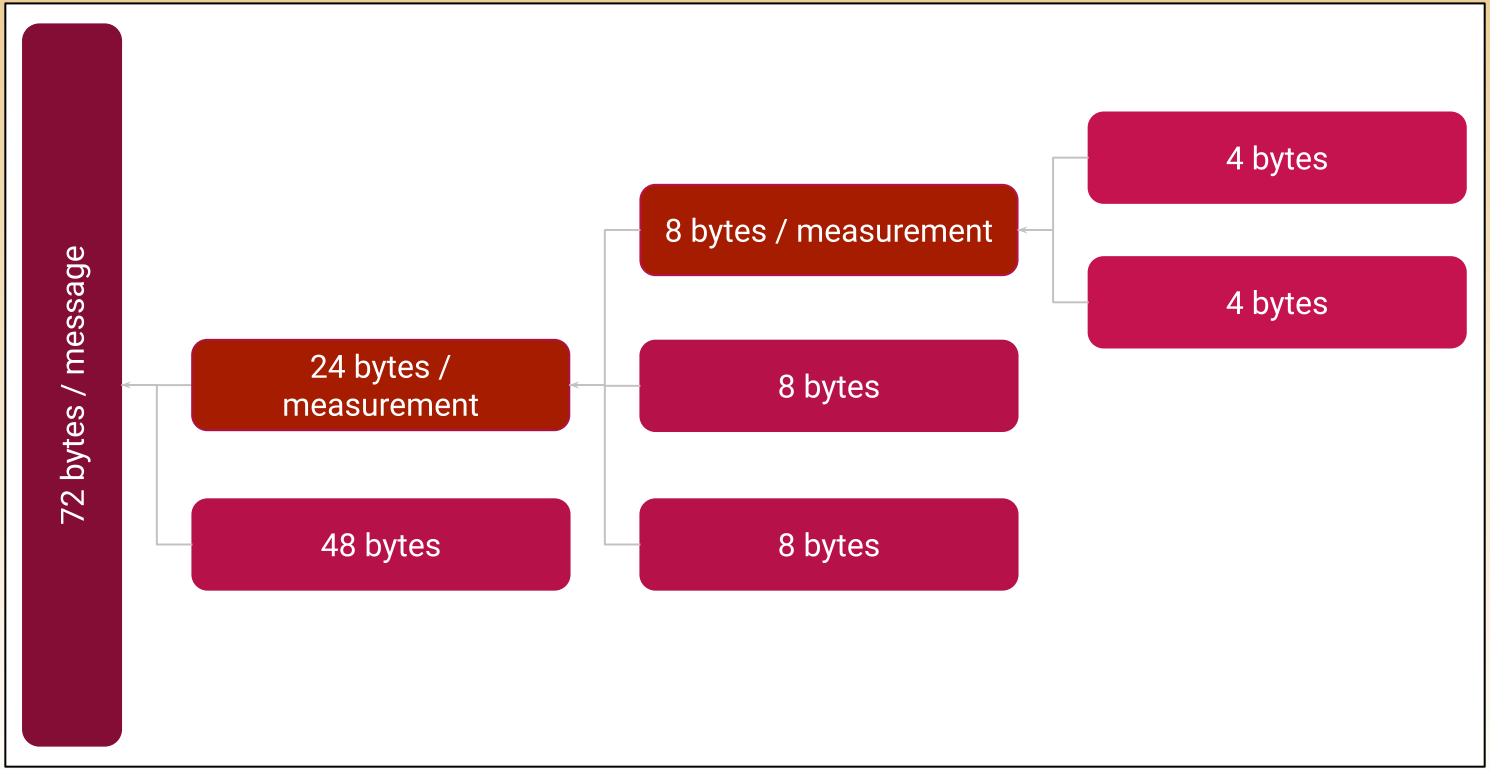
Information Standards:

- GPS Location (ISO 6709)
- Time and Date (ISO 8601)

Data Flow Diagram

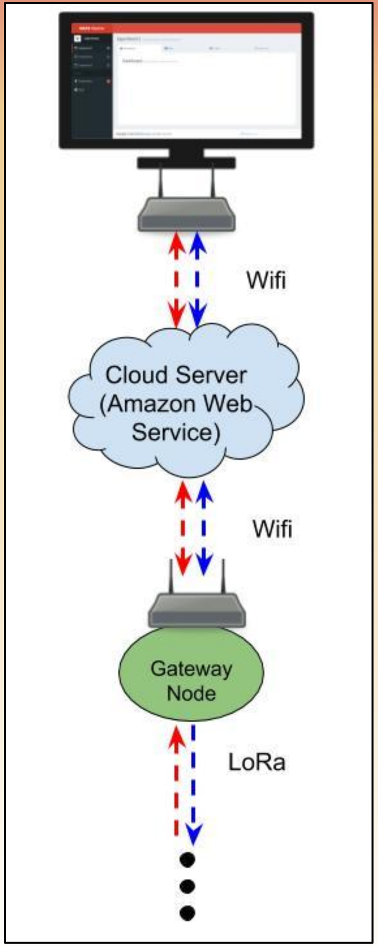


Data Flow Diagram



Communication Results: Server to Node

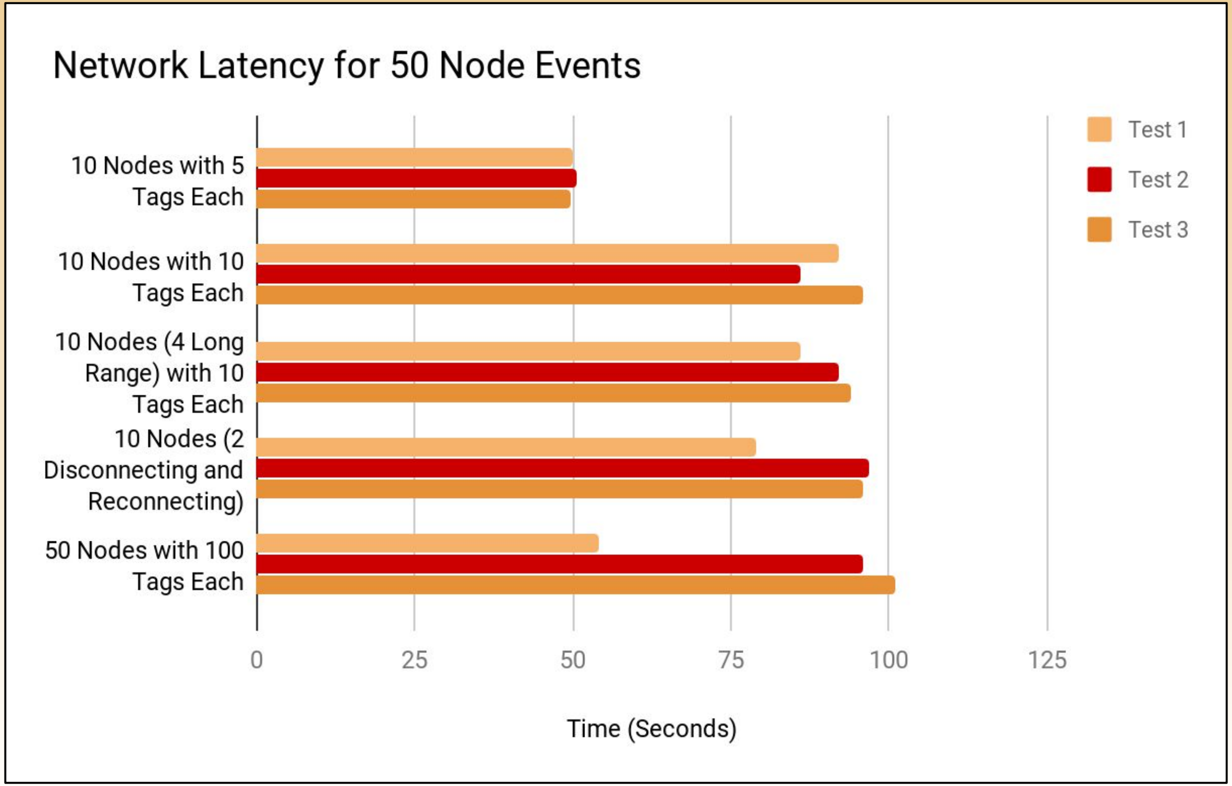
- Server running on specific computer
- Interrogation signals initiate on UI through server
- Data is collected and updates the database from the network
- Network is constantly ready to receive data



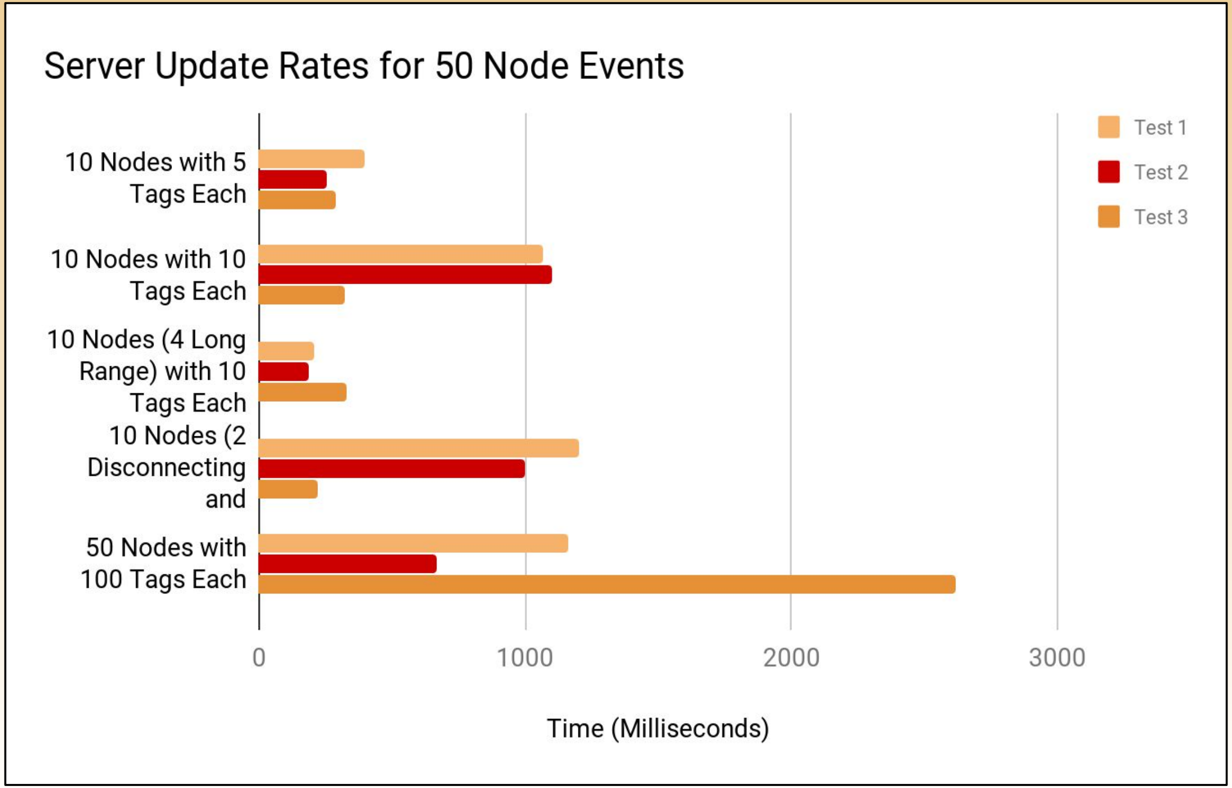
Communication Results: Node to Node

- LoRa mesh network
- Nodes propagate interrogation signals to correct node address
- Nodes alternate between receiving and transmitting for data relay
- Stop signal to end transmissions

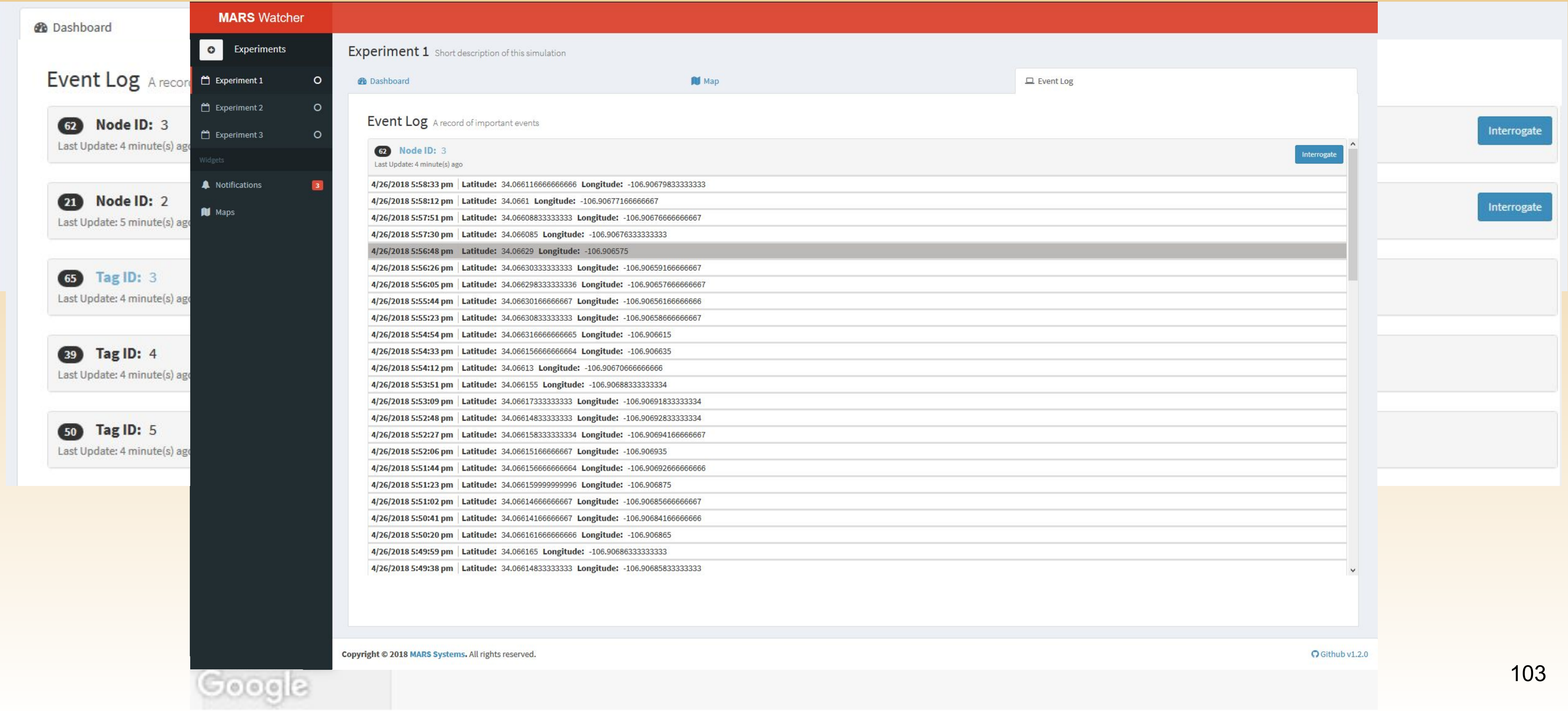
Data Management Results: Network Collection Time



Data Management Results: Server Update Rate



User Interface Results



Results

- UI/ Server
  - Server can reliably handle ~80 nodes and 100 tags per node
  - UI updates reactively to changes in the server database
- Communication
  - Gateway nodes are able to packetize and send data from other nodes and tags in the network
  - Server is able to parse and sort packets received by gateway nodes

- Problems:
  - UI latency increases significantly for large numbers of incoming data packets.
  - Extra signal propagation between nodes
- Resolutions:
  - More robust server for increased network size
  - Stop signal to end signal “bouncing”

Results Summary

Specification	Ideal Value	Measured
Communications Range	To Nodes: 100 m To Gateway: 100 m	120 m 120 m
Positioning Error	10 m	6.5 m
Hardware Scalability	Tags: 100 Nodes: 100	100 120
Server Scalability	Tags: 100 / Node Nodes: 100 / Gateway	100 Tags per Node < 81 Nodes
Throughput	10 kbps	> 10 kbps
UI Functions	Tag Triangulation Interrogation Signal	Functional Functional

Skills Learned and Innovation

- Skills Learned
  - Project Design
  - Interacting with Google Maps and Web design
  - Developed packetization scheme for gateway to server communication
  - Implementation of NodeJS and MongoDB
  - Developed functional Ad-Hoc mesh sensor network
  - Work with LoRa
  - Languages: Javascript, HTML, Python, and C

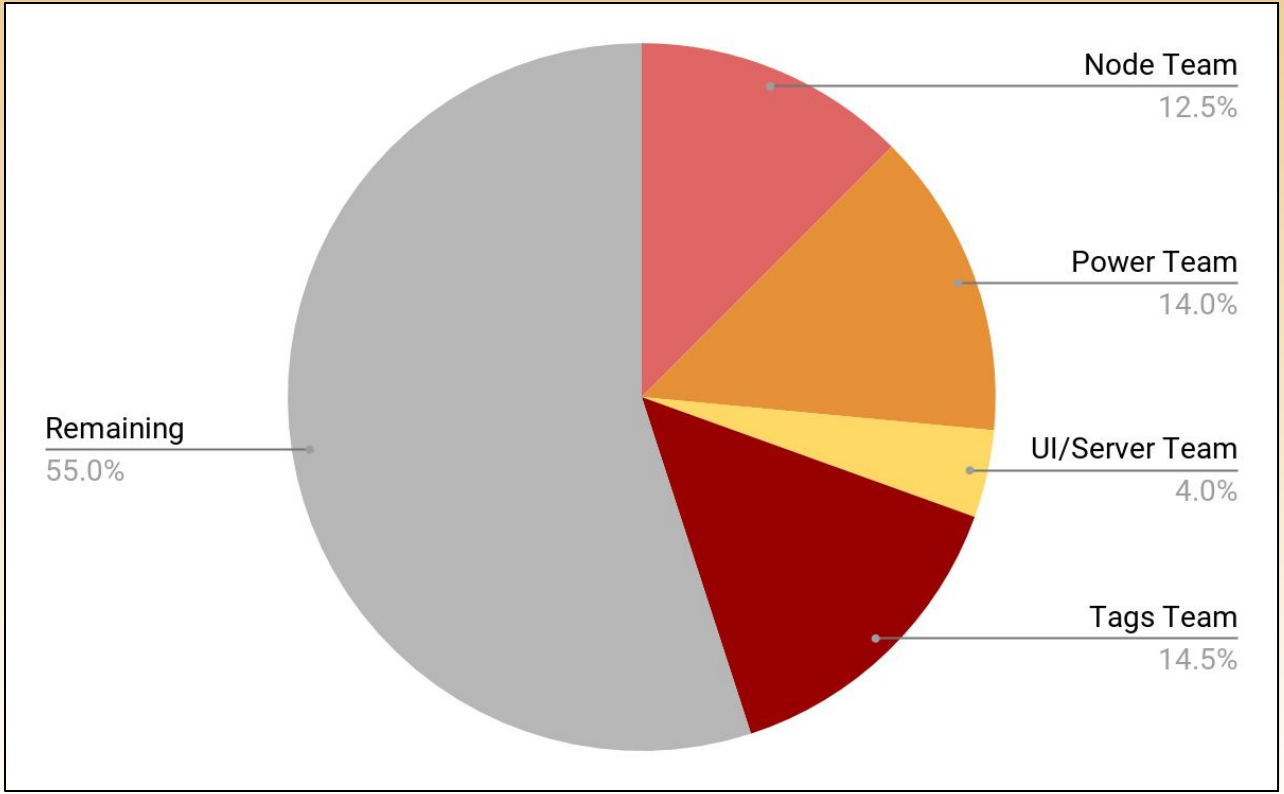
- Innovations:
  - LoRa Mesh network for Node to Node communication (Co-op with Node Team)
  - Interrogation scheme from UI

Questions?

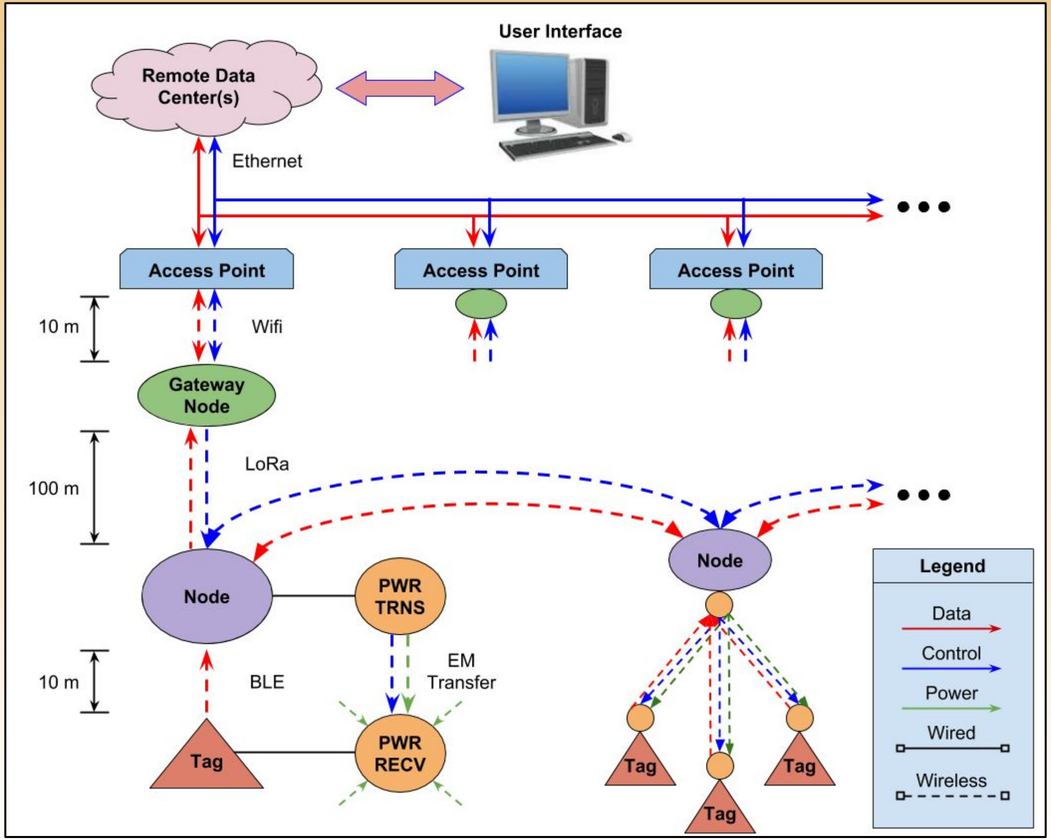
Results

Courtney Bamonte, Nikita Belooussov, Thomas Dearing, Albert Reed

Budget: Used $1800 / $4000



Operation/Implementation



MARS Performance Summary

Specification	Desired Value	Measured
Communications Range	To Tags: 10 m To Nodes: 100 m To Gateway: 100 m	13 m 120 m 120 m
Maintenance Period	Tags: > 1 year Nodes: > 18 hours	3 years 7.6 hours
Monitor Update Period	Normal: 1 hr Emergency: 5 min	Configurable 4 min @ 3 m
Node Scalability	100 Tags & Nodes	100 Tags, 120 Nodes
Server Scalability	Tags: 100 / Node Nodes: 100 / Gateway	100 Tags per Node < 81 Nodes
Positioning Error	< 10 m	6.5 m

Full System Test & Functional Demonstration

Network Demonstration

- 1 Gateway Node
- 3 Nodes
- 2 Interrogation Tags
- 4 Moving/routine update Tags

Power Scavenging Demonstration

- Power scavenging to charge battery

Project Achievements

Successful implementation of a Distributed Sensor Network

Scalable system prototype for 1000+ Tags and 80+ Nodes

Successful RF scavenging system to supplement Tag lifetime

Met design criteria for implementation in Battlefield environment

<u>Final conclusion</u>**:** MARS concept is an **Outstanding Success**

Other MARS Applications

- Commercial inventory applications (Warehouses)
- Mail tracking
- Smart inventory system
- Mobile sensor network

Questions?

Demonstration