Rural Connectivity Testing

Low-cost LoRa sensing beyond Wi-Fi and cellular coverage

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Registered project: Evaluating Community AI-Assisted Anchor-Based Connectivity Models for Health Care Access for Low-Connectivity Rural Populations in Michigan

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Solar-powered Lightweight Acquisition for Bioelectrical Signal (SOLARIS)

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Project Support
MSU REI Center

The Why

- Michigan agriculture contributes approximately **$125 billion** to the state economy
- Supports roughly **25% of Michigan's workforce**
- Modern farming requires substantial **energy, water, and labor**
- Harvest periods can create especially high demands on farm workers
- Low-cost sensors could monitor both **plant conditions** and **worker/community well-being**
- Designed for rural farmland areas with **limited or unreliable cellular connectivity**

Challenges of Rural Healthcare

- Longer travel distances to healthcare services
- Limited access to specialty care
- Many older adults live alone, particularly in rural counties
- Growing need for home and community-based services

Question: How can healthcare providers continue monitoring patients when they are no longer in the clinic?

Sources: Rural Health Information Hub, "Healthcare Access in Rural Communities" and "Barriers to Transportation Programs in Rural Areas"; U.S. Census Bureau, "Older Population in Rural America"; Administration for Community Living, "Strengthening the Direct Care Workforce."

A Current Solution

Remote Patient Monitoring:

- Offers continuous monitoring outside the clinic
- Tracks health data such as heart rate, blood oxygen, falls, and other biometric data

RPM extends healthcare beyond the clinic – if there is a reliable connection

The Problem – Monitoring Beyond Wi-Fi/Cellular

Current remote monitoring systems often assume:

- Reliable home Wi-Fi or continuous cellular connectivity
- Sensors operating close to existing communication infrastructure
- Continuous device-to-cloud communication

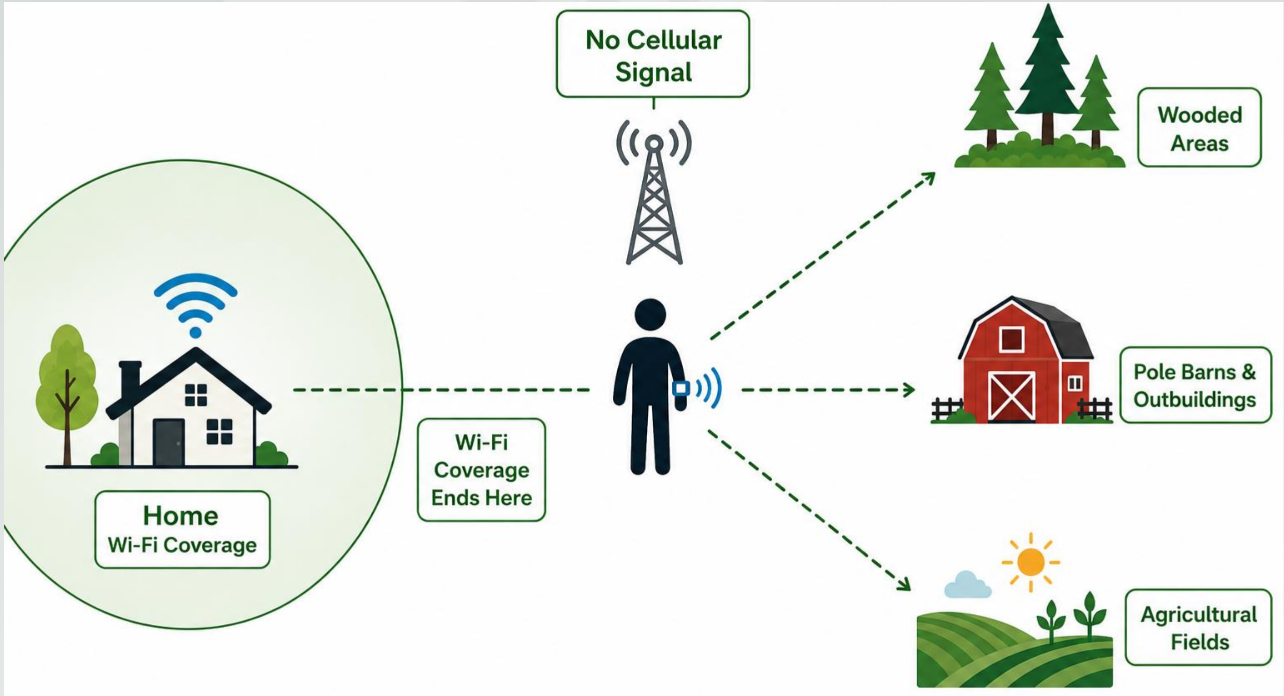
Source: U.S. Department of Health and Human Services [HHS], 2026; Rural Health Information Hub [RHIhub], 2025

Beyond Wi-Fi/Cellular Monitoring

Where current systems can fail:

- Agricultural fields
- Wooded environments
- Pole Barns and outbuildings
- Other low connectivity rural environments

- Wi-Fi coverage often does not extend to these locations, and cellular connectivity may be weak, intermittent, or unavailable.



How can reliable remote monitoring be maintained when users move beyond Wi-Fi and cellular range?

Goal: Develop and evaluate a low-cost, long-range communication architecture capable of extending remote patient monitoring beyond traditional Wi-Fi coverage and in areas with no cellular connection

Research Objectives:

- Design a LoRa-based remote monitoring prototype
- Characterize communication performance in rural conditions
- Demonstrate the architecture using a sample deployment

Research question: Can LoRa provide a reliable communication link between remote sensors and a gateway in low-connectivity environments?

What is LoRa?

LoRa is a low-power, long-range wireless communication method designed to send small amounts of data over long distances.

Long range

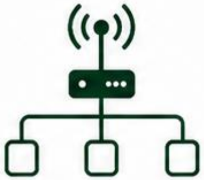
Can reach farther than home Wi-Fi

Low power

Suitable for battery-operated sensors

Small payloads

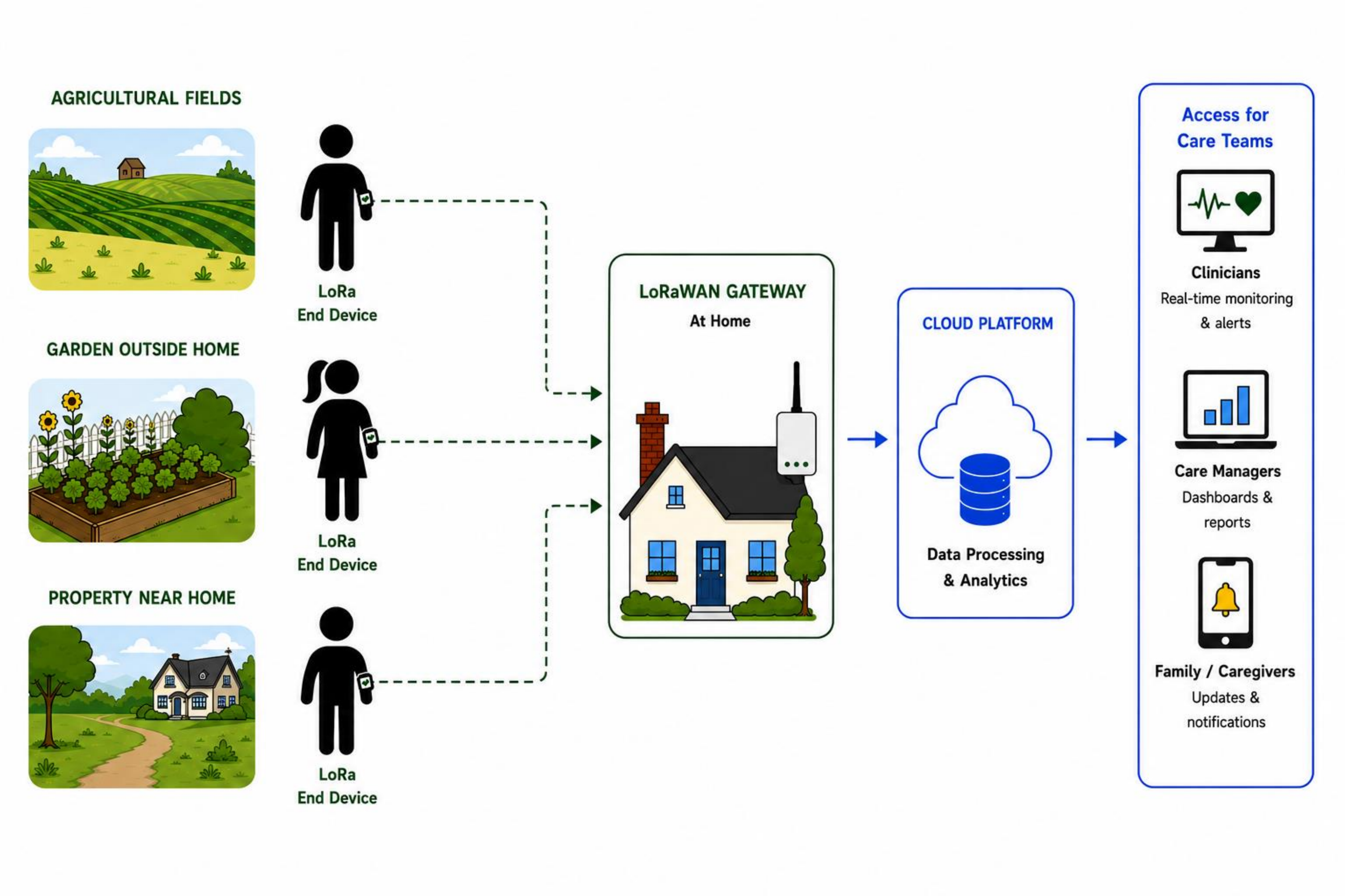
Designed for periodic readings and alerts, not video or continuous streaming



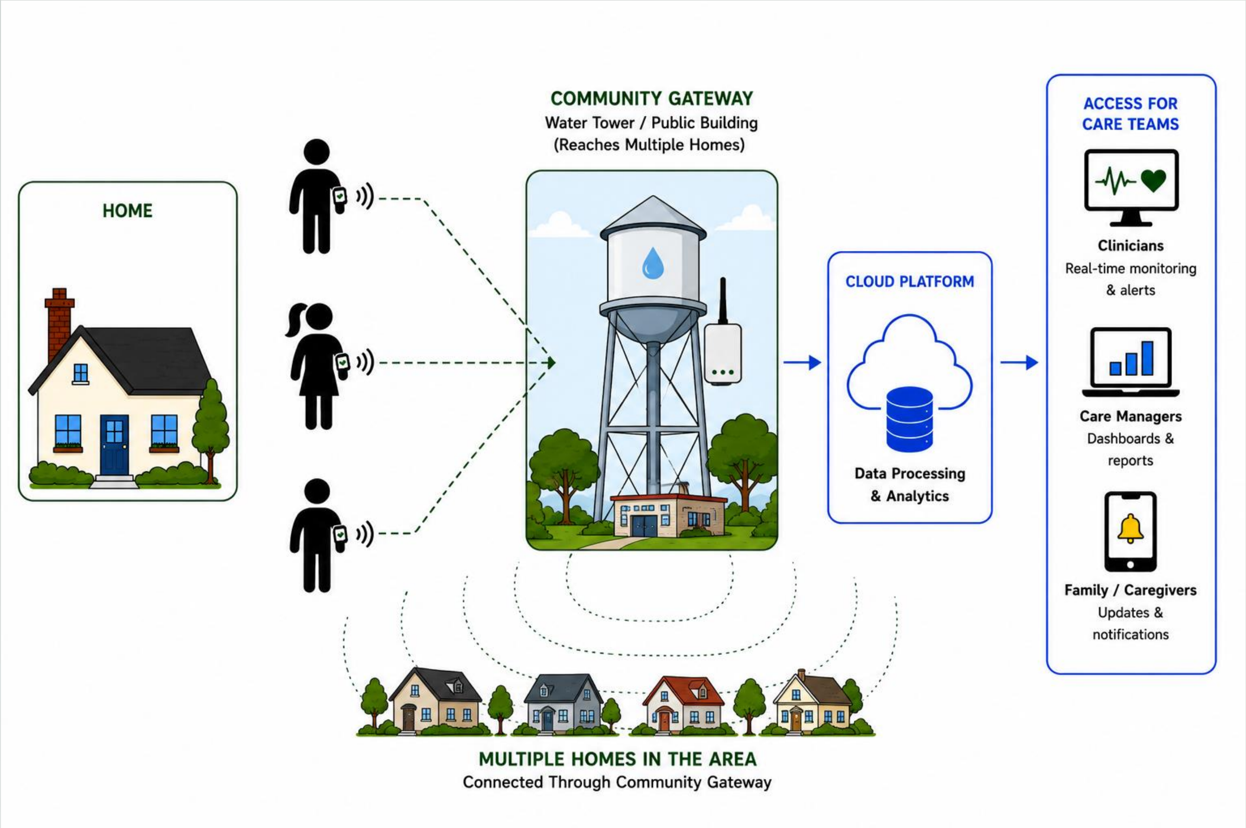
Bridge role

Not a replacement for cellular or broadband, it provides a first-mile link from a remote sensor to a gateway

Proposed Deployment Model



Gateway requires one backhaul connection
Wi-Fi, cellular hotspot, Ethernet, or satellite

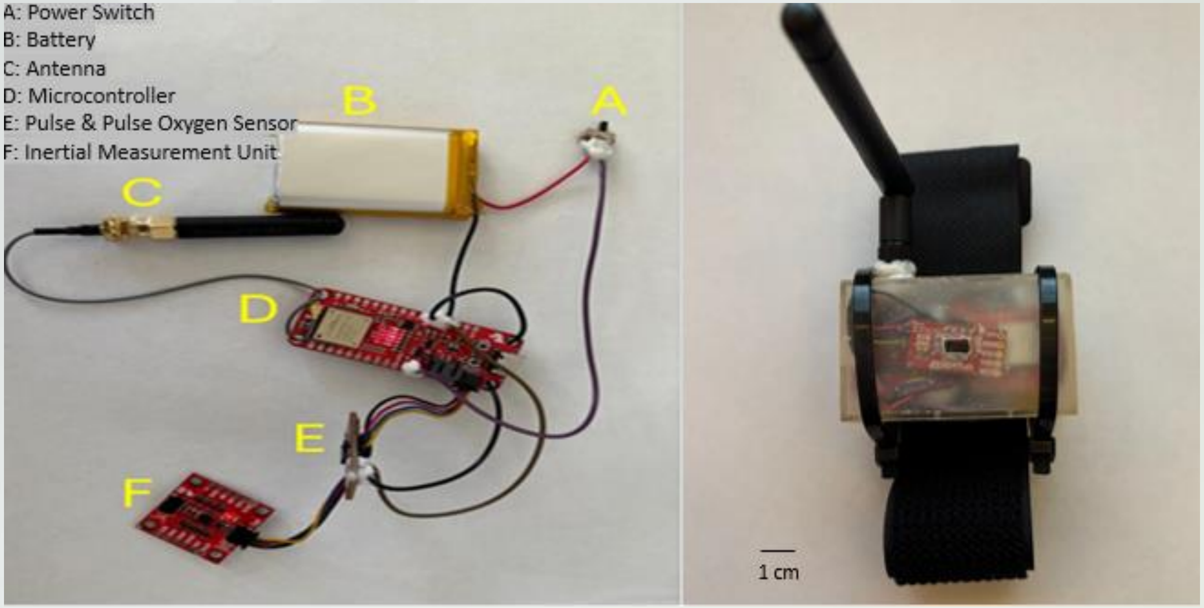


Community gateway requires one shared backhaul connection
Public-building internet, Ethernet, cellular hotspot, or satellite

- Both models concentrate internet backhaul at one fixed gateway location.
- LoRa extends that connection outward so individual wearables and sensors do not each need Wi-Fi or cellular service.

Prototype Device

- Device was built from commercially available components
- Prototype price: ~$156
- Gateway price: $199
- Cloud Platform: $0 for small scale testing



Core prototype hardware: approximately $355

Prototype Functions

- **Heart rate:** measures pulse rate in beats per minute (BPM)
- **Pulse oximetry:** reads blood oxygen saturation (SpO_2 %)
- **IMU-based fall alerts:** uses motion and orientation data to flag potential fall events
- **LoRa transmission:** sends periodic readings and event packets to the gateway

Why These Health Data Points?

Data point	Why it was chosen	What it demonstrates
Heart rate	Familiar, low-bandwidth health indicator.	Repeated sensor data packets.
SpO_2	Relevant to respiratory/health monitoring.	Small physiological payload.
Fall event	Time-sensitive safety alert.	Compact event transmission.

These were prototype payloads used to test the communication architecture—not clinically validated measurements or a deployed medical-monitoring product.

Field Validation Tests: From Baseline to Rural Limits

1. Baseline Function

Indoor + short-range benchmarks

Question: **“Can packets be sent and logged?”**

2. Severe Obstruction

Upper Peninsula woods

Question: **“Can it work when distance is short, but terrain is bad?”**

3. Mixed Terrain

Open field to tree line to woods

Question: **“What changes when conditions are mixed?”**

4. Property-Scale Coverage

Route to 833 m

Question: **“Can a full farm-scale route stay connected?”**

5. Extended Range

Beyond 1 km to 1.44 km

Question: **“Where does reception become intermittent?”**

6. Design Comparison

Omni vs directional antenna

Question: **“Which is better for a moving node?”**

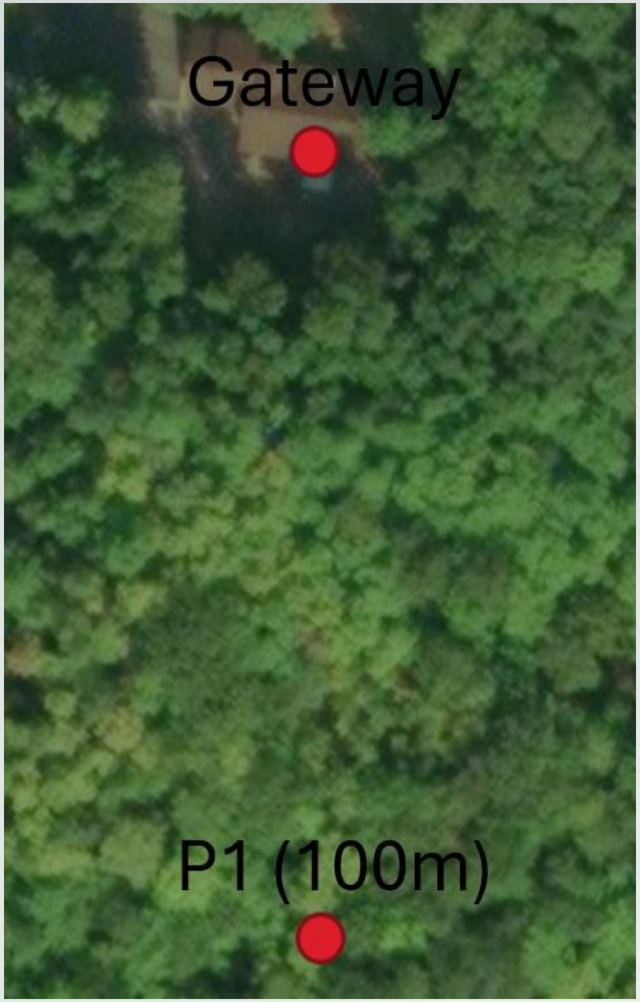
7. Application Extension

Fall-event packets + greenhouse nodes

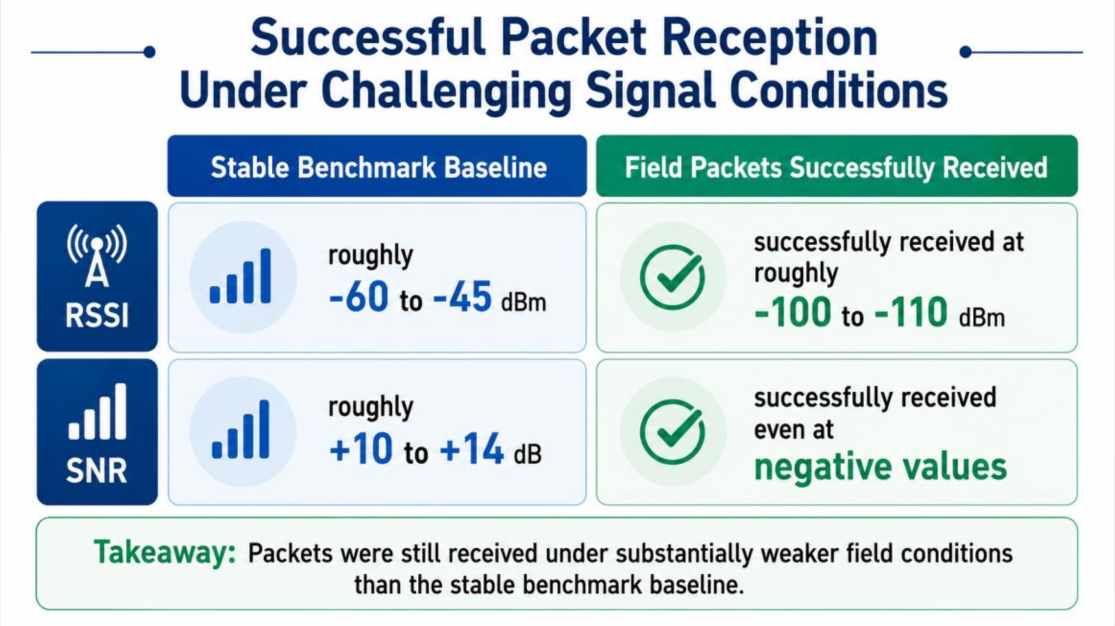
Question: **“Can the same link support other sensors?”**

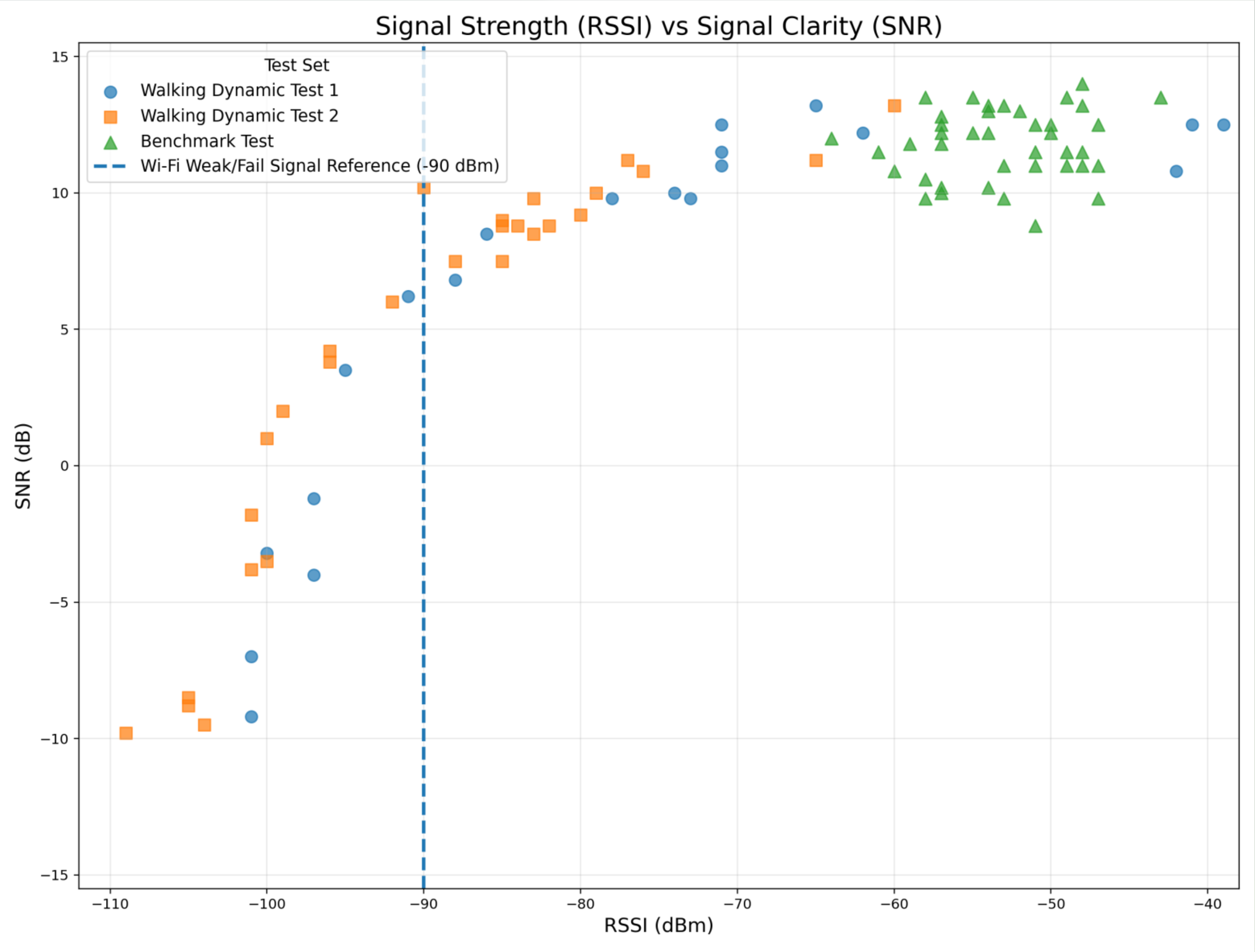
Tracked in each test: packet reception, signal strength, signal clarity, distance, terrain, antenna setup

A Short Route Can Still Be a Hard Radio Link



- Dense tree cover
- Uphill terrain
- Snow




Signal Strength (RSSI) vs Signal Clarity (SNR)
Test Set
Walking Dynamic Test 1
Walking Dynamic Test 2
Benchmark Test
Wi-Fi Weak/Fail Signal Reference (-90 dBm)
SNR (dB)
RSSI (dBm)
15
10
5
0
−5
−10
−15
−110
−100
−90
−80
−70
−60
−50
−40

Same Route, Different Link Behavior

Open Field: 0–462 m

Dense Woods: 462–690 m

Farthest point: 833 m

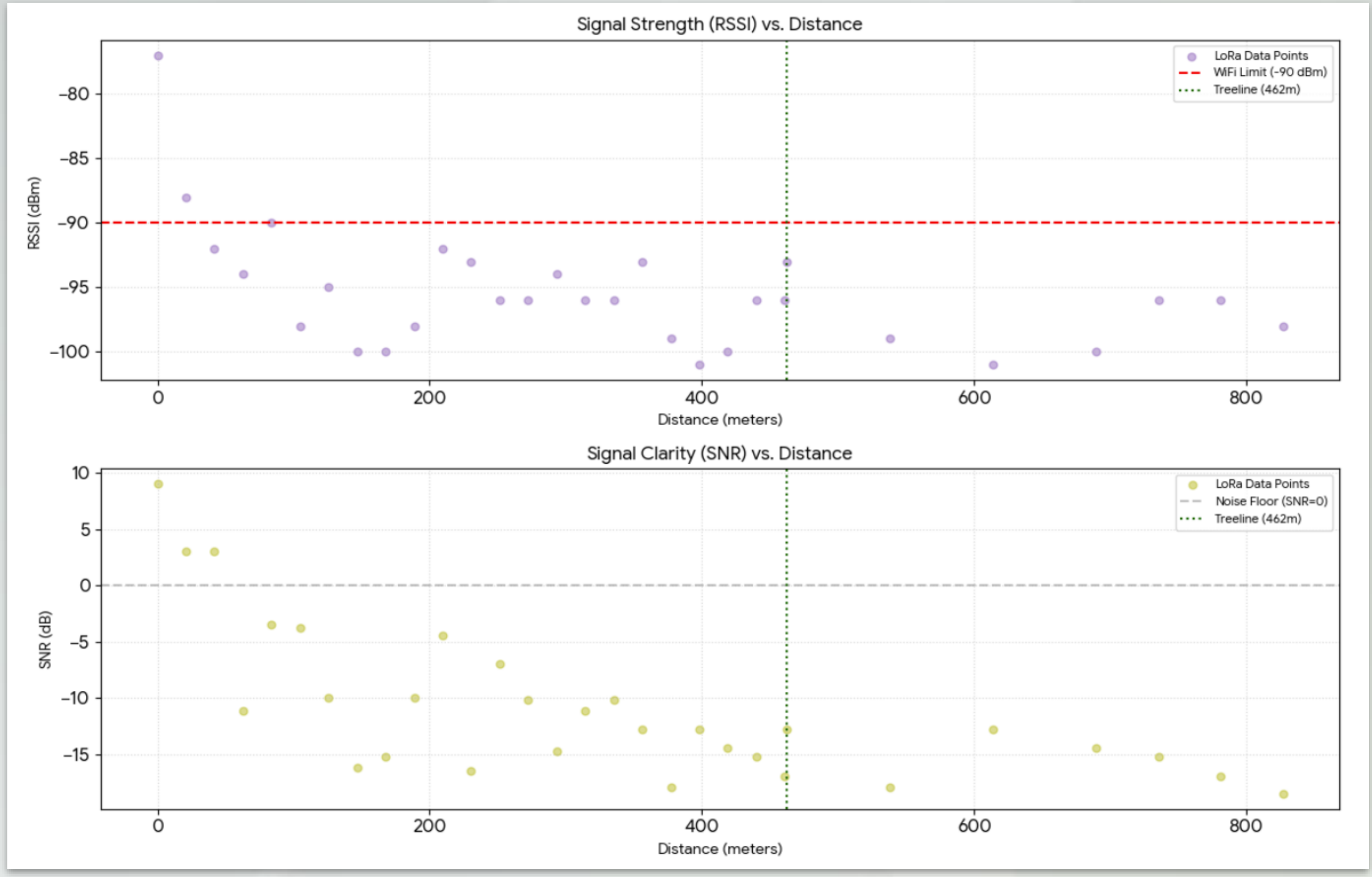
April 2nd Test:

- Reception became more marginal at extended range
- Link quality degraded and some packets were lost

April 30th Test:

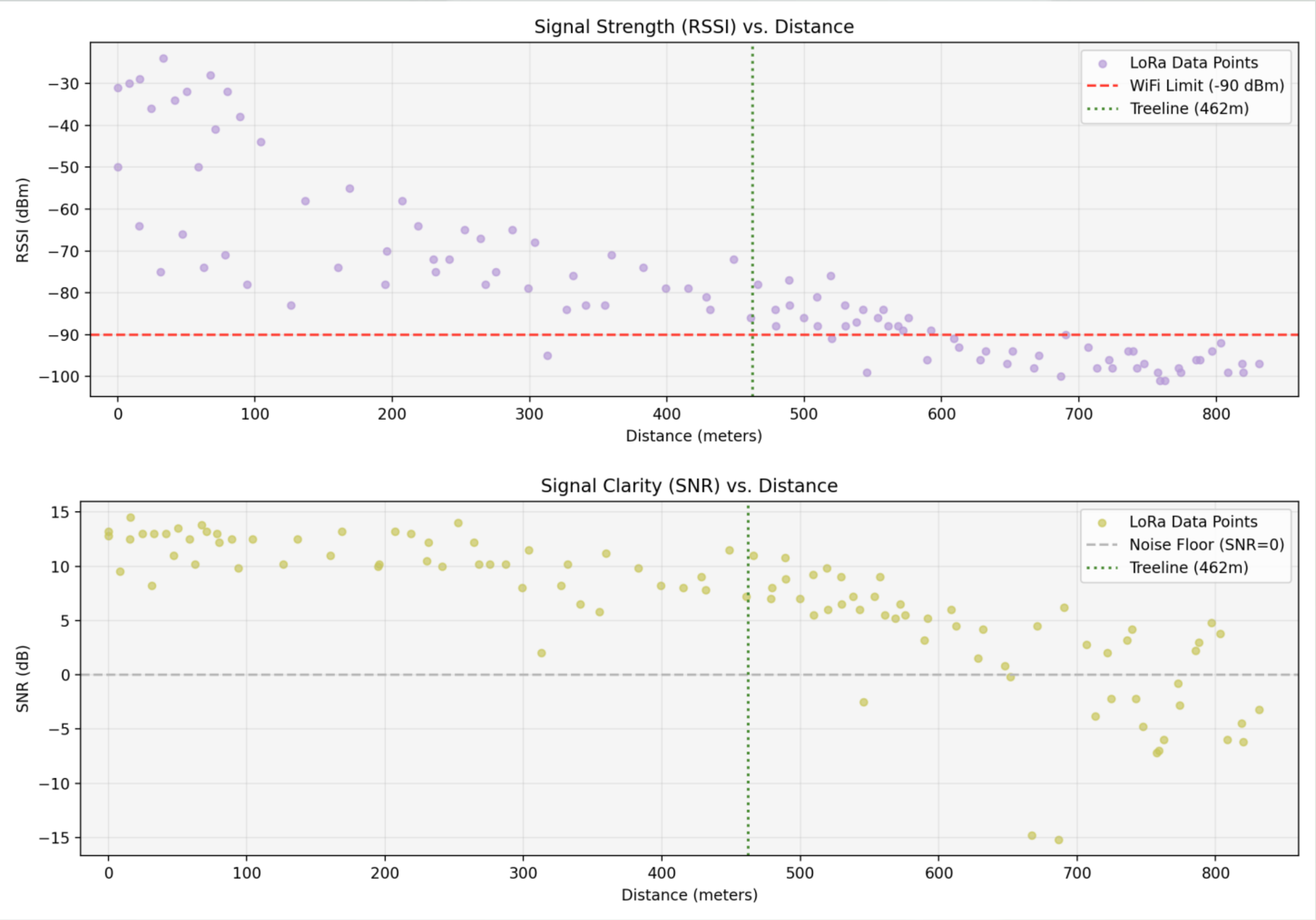
- Packets received through wooded section and out to 833 m
- Link degraded less quickly and many more packets reached gateway

April 2nd Test



- Packets received despite signal strength near -100 to -110 dBm and negative signal clarity but overall signal was weak

April 30th Test

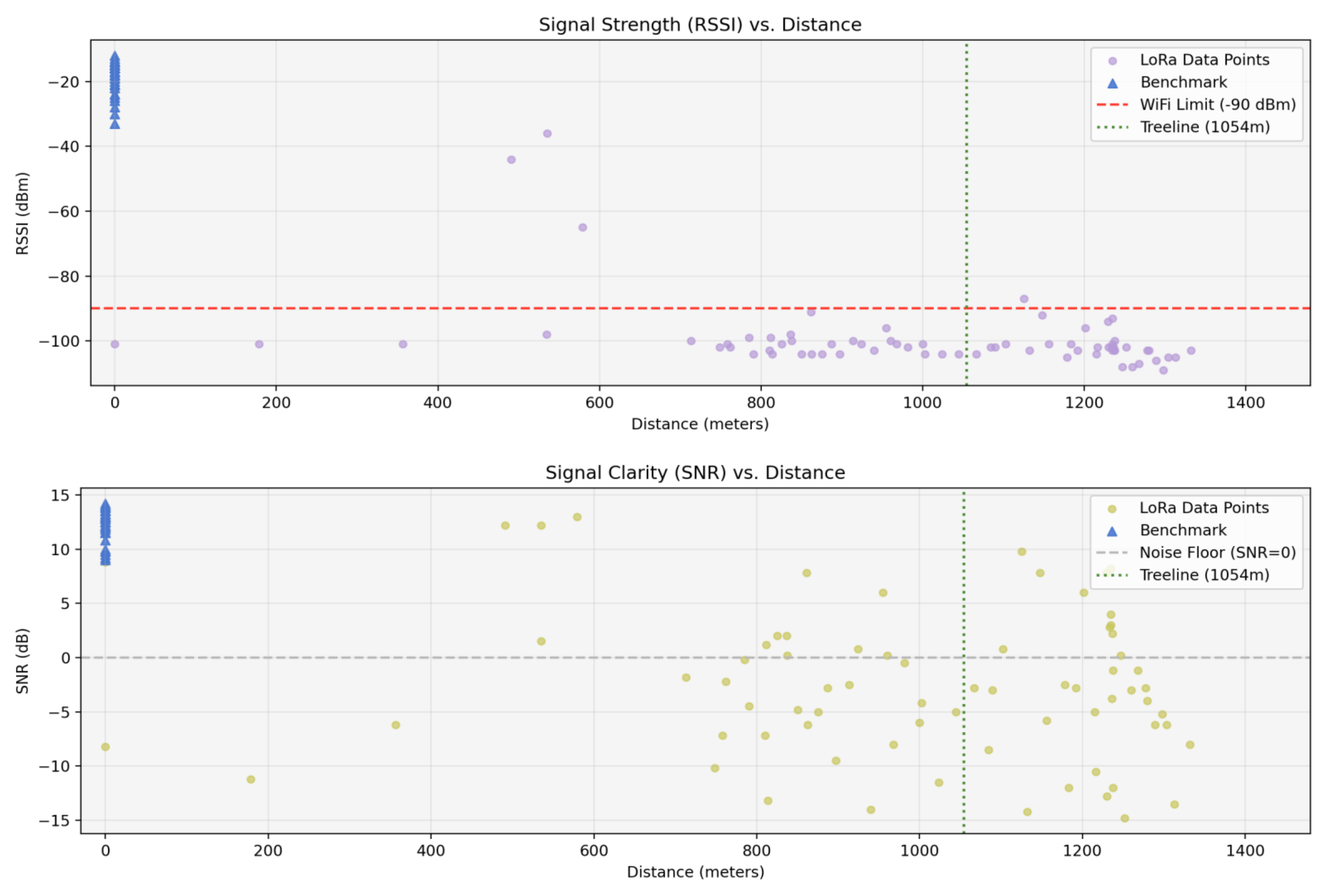


- More packets were received, with gradual signal degradation as distance increased.

Extended-Range Test: Communication Reached Beyond 1 km in Rural Terrain

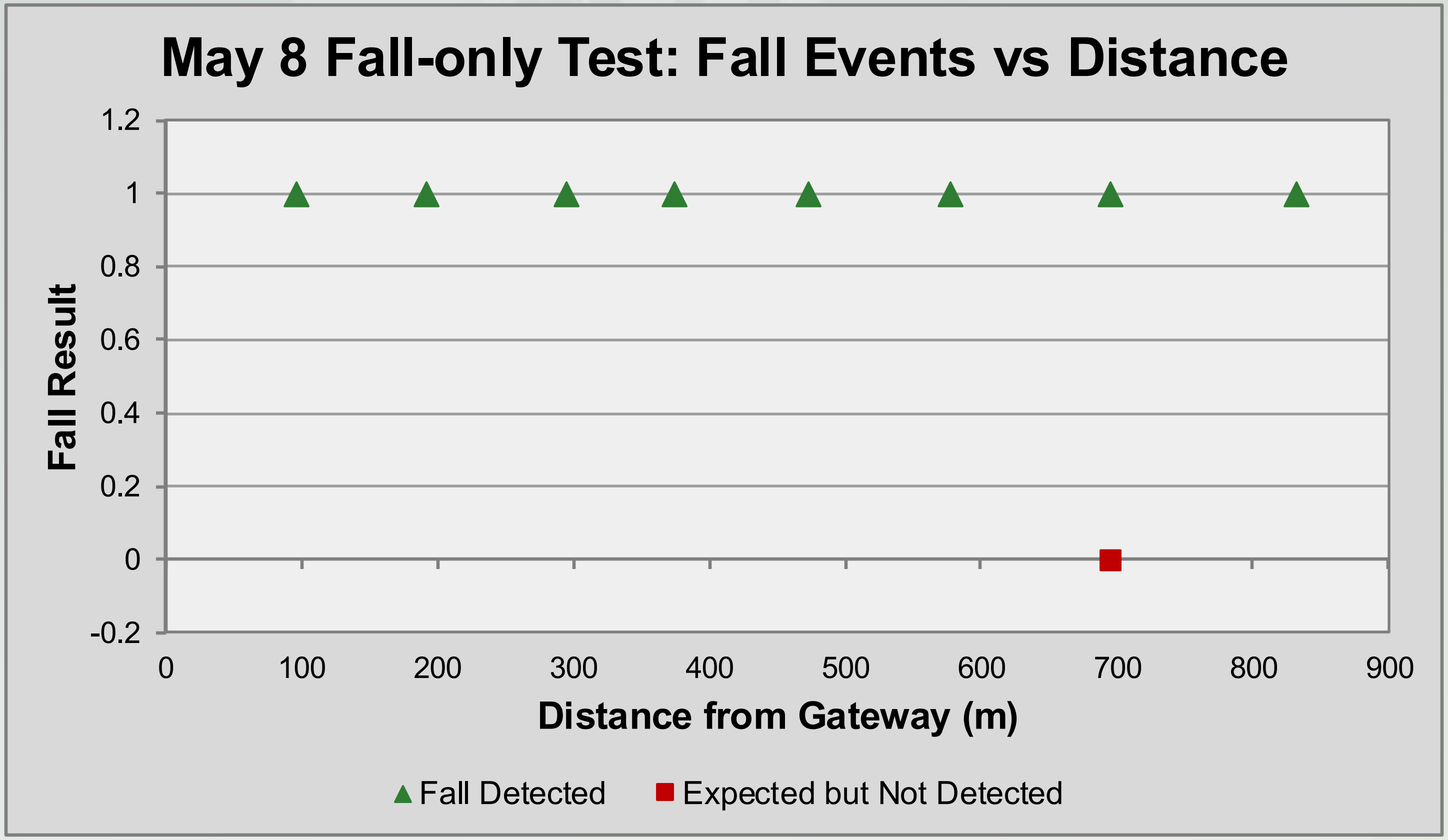
- 723–804m Early long-range coverage
- 879–1054m >1 km communication demonstrated
- 1156–1238m Extended-range reception observed
- 1271–1440m Outer tested region

Extended Range Test Data



- Furthest packet received at: 1.325 km (.82 mi), signal failed past this point
- Signal quality degraded significantly to as low as -15 dB clarity and -108 dBm strength but remained active with packet losses

Fall-Event Packets Reached Every Tested Distance Through 833 m



What the Field Tests Showed

Communication link

- Packets received through obstructed terrain and across farm-scale routes
- Gateway placement, vegetation, terrain, antenna configuration, and wearable orientation affected signal robustness

Wearable sensing

- HR/SpO_2 gaps were linked to sensor contact and motion
- Fall-event behavior was affected by enclosure damping, IMU coupling, orientation, and thresholds
- These were not automatically radio-link failures

Takeaway: The field tests established that LoRa can support small data packet transmissions across the tested routes, while also helping to identify the conditions and hardware factors that affect reliability.

Applying the Same Architecture to Greenhouse Monitoring

Deployment:

- 11 soil sensor nodes
- MSU Plant Resilience Center greenhouse
- 60-minute reporting intervals

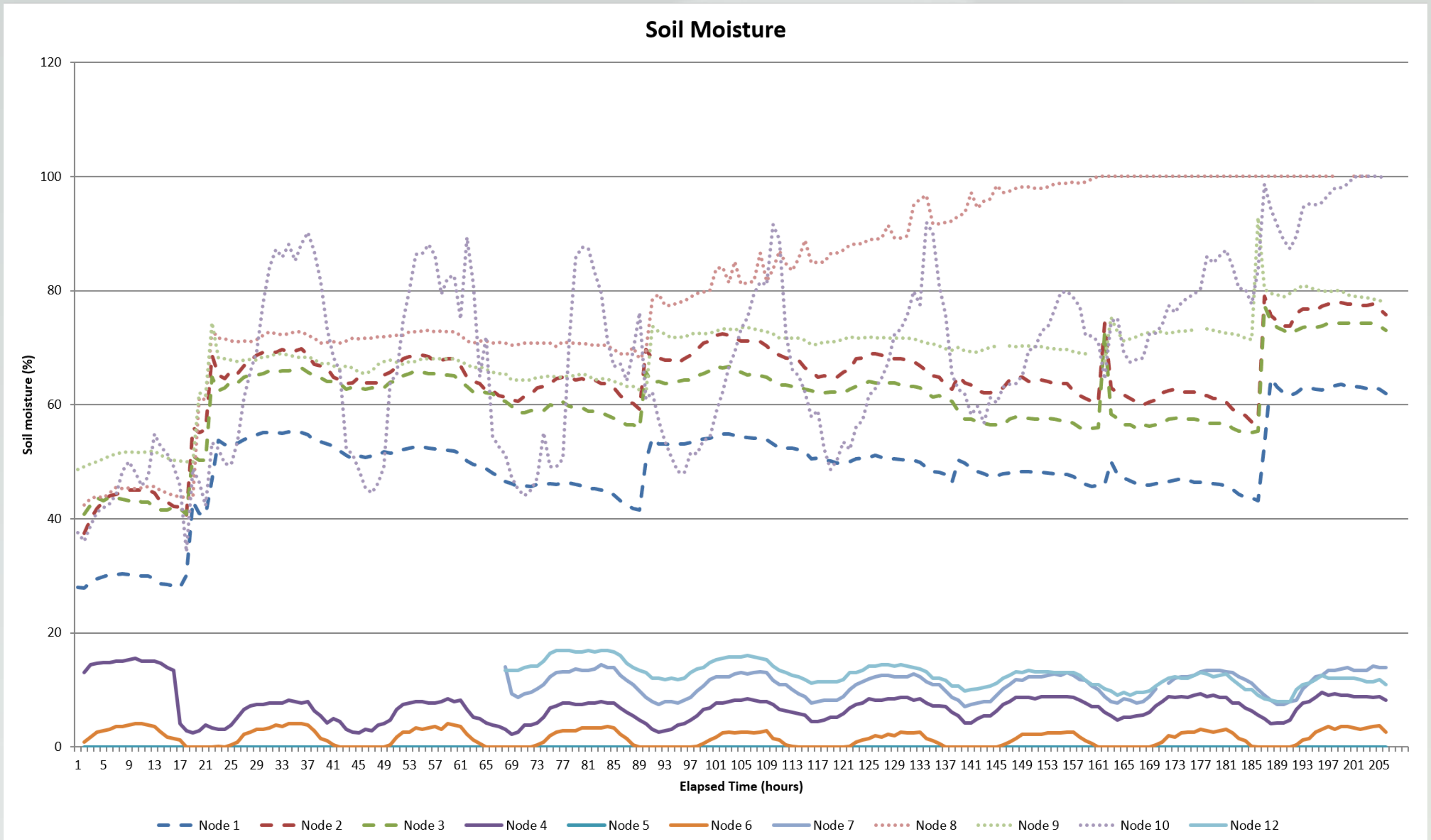
Data collected

- Soil moisture
- Air temperature
- Humidity
- Battery voltage
- Packet count, signal strength, and Signal clarity

Why it matters:

- Same gateway-to-cloud architecture
- Demonstrates the link is not limited to wearables
- Supports low-rate agricultural/environmental sensing

Why soil monitoring matters: It helps growers identify water stress, compare growing conditions, and make irrigation decisions using conditions measured at the plant level.



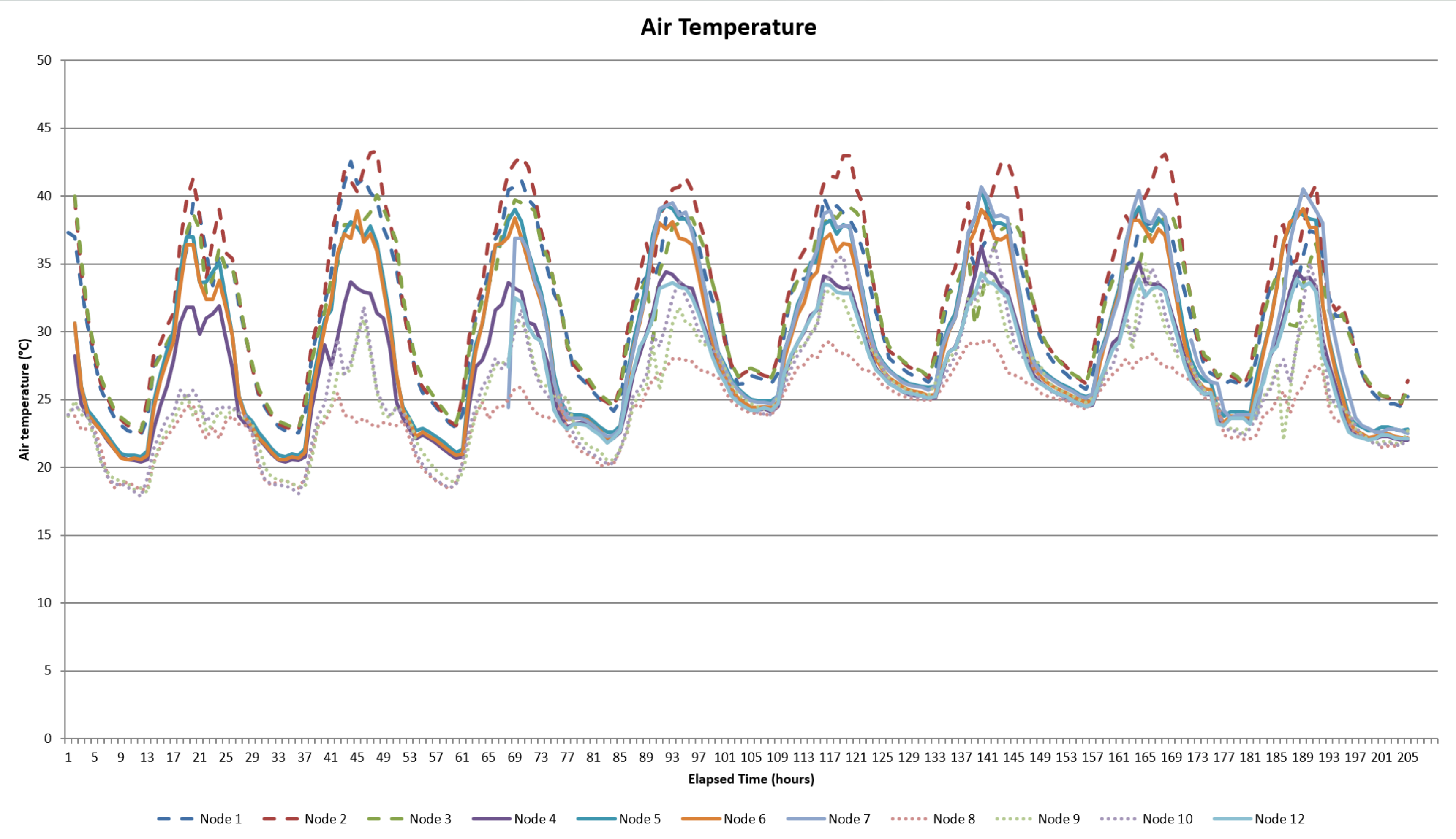
Node groups

- - - - - **Heat-stress environment:** Nodes 1, 2, 3

—— **Calibration / paired comparison:** Nodes 4, 5, 6, 7, 12

•••••••••• **Cool environment:** Nodes 8, 9, 10

Nodes 7 and 12 came online later than the initial deployment.



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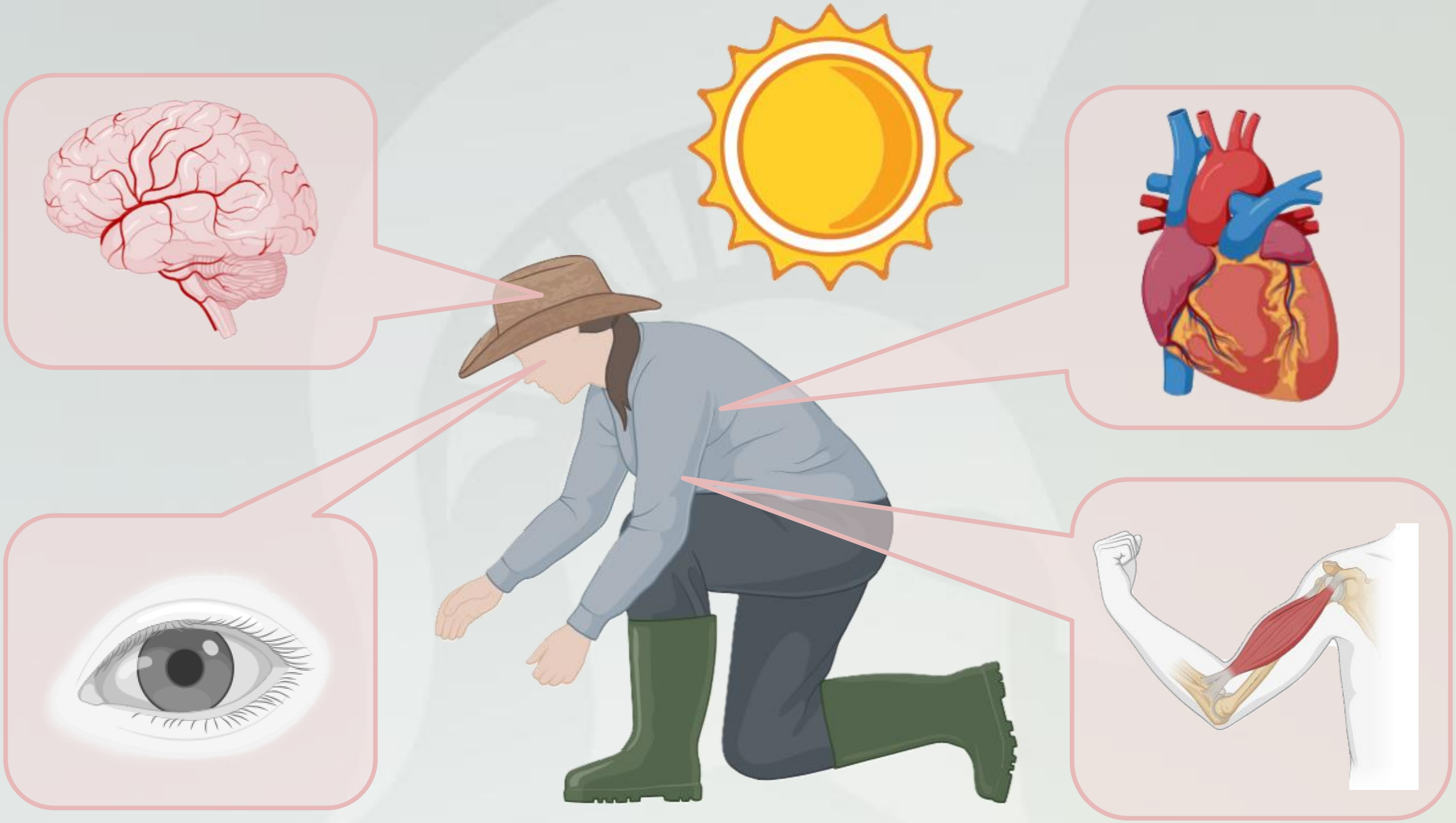
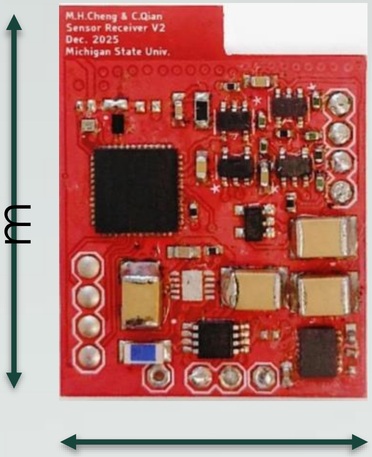


Commercial Solutions

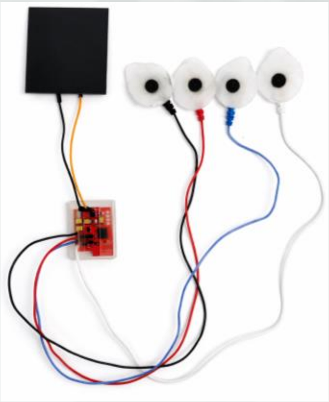
ECG	EMG	EEG	EOG	
				
Philips	Natus	Natus	BIOPAC	PLUX

SOLARIS: 1st Generation Prototype

28.8mm



26.5mm



1. Wireless real-time data transmission.
2. Two configurable acquisition channels supporting ECG, EMG, EEG, and EOG.
3. Light-powered design for extended operation.

(Under review) Cheng, M.-H. & Qian, C. (2026). A Light-Powered Integrated Sensor System for Wireless Bioelectrical Signal Acquisition. *IEEE Sensors Journal*.

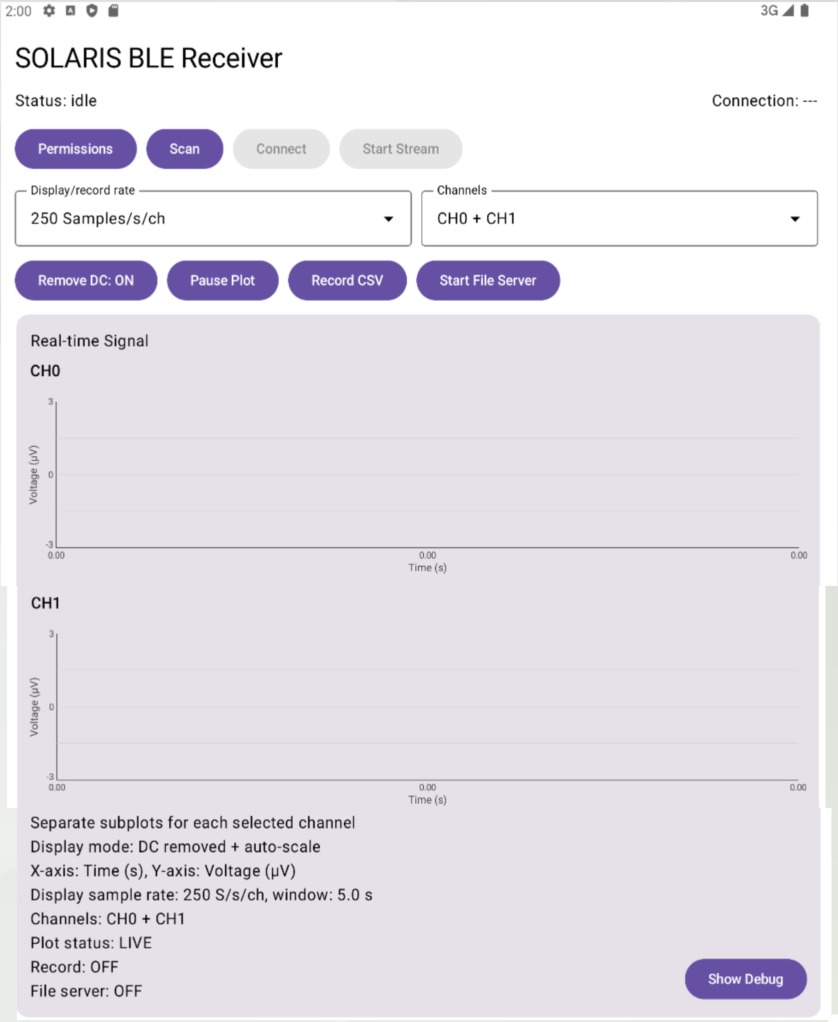
Cell Phone App

1. Data are saved locally on the mobile device.

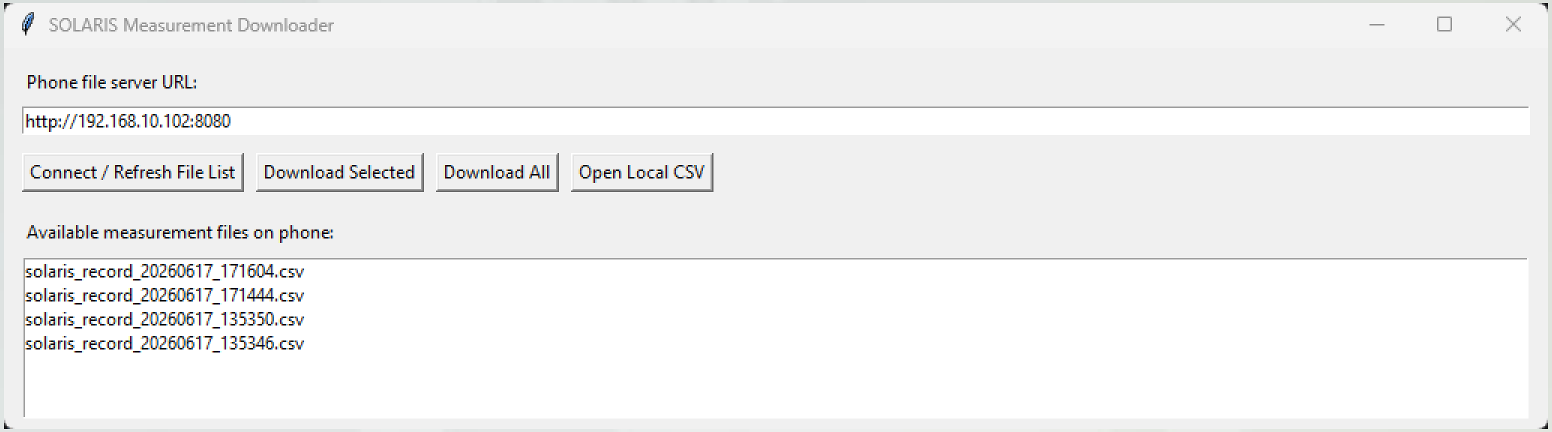
2. Computer software is designed for reading and further processing

Period	Data size (2 channels)
1 s	~8 kB
1 hr	~28.1 MB
1 day	~675 MB

Platform: Android



Computer-Based Graphical User Interface



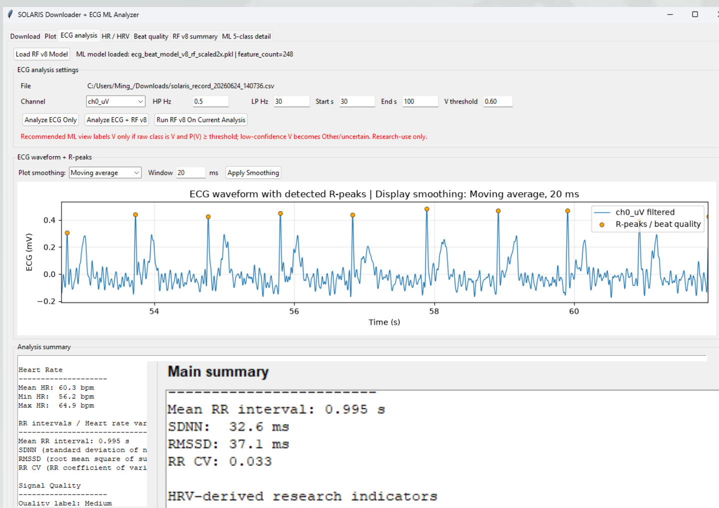
AI-Based Abnormality Detection

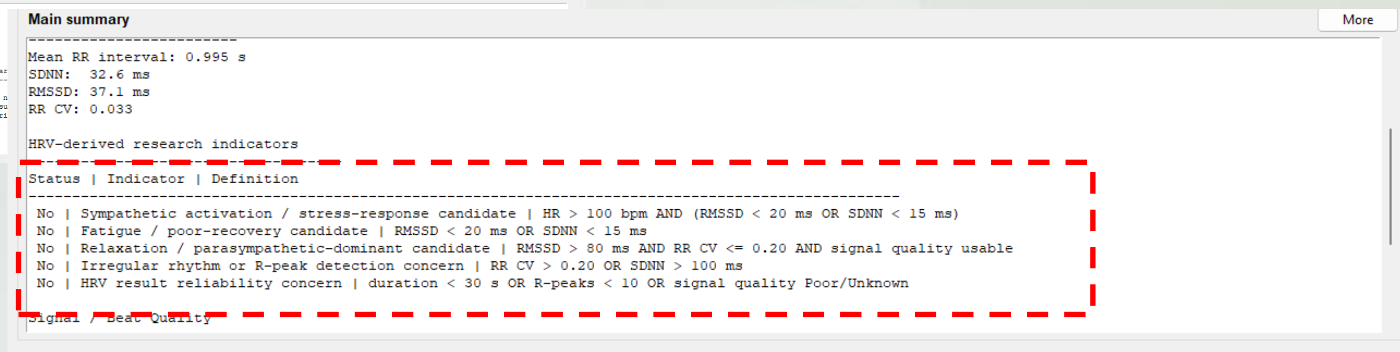
Filtering options

A. Heart Rate (HR)

B. Heart Rate Variability

AI-Based Abnormality Detection-cont.



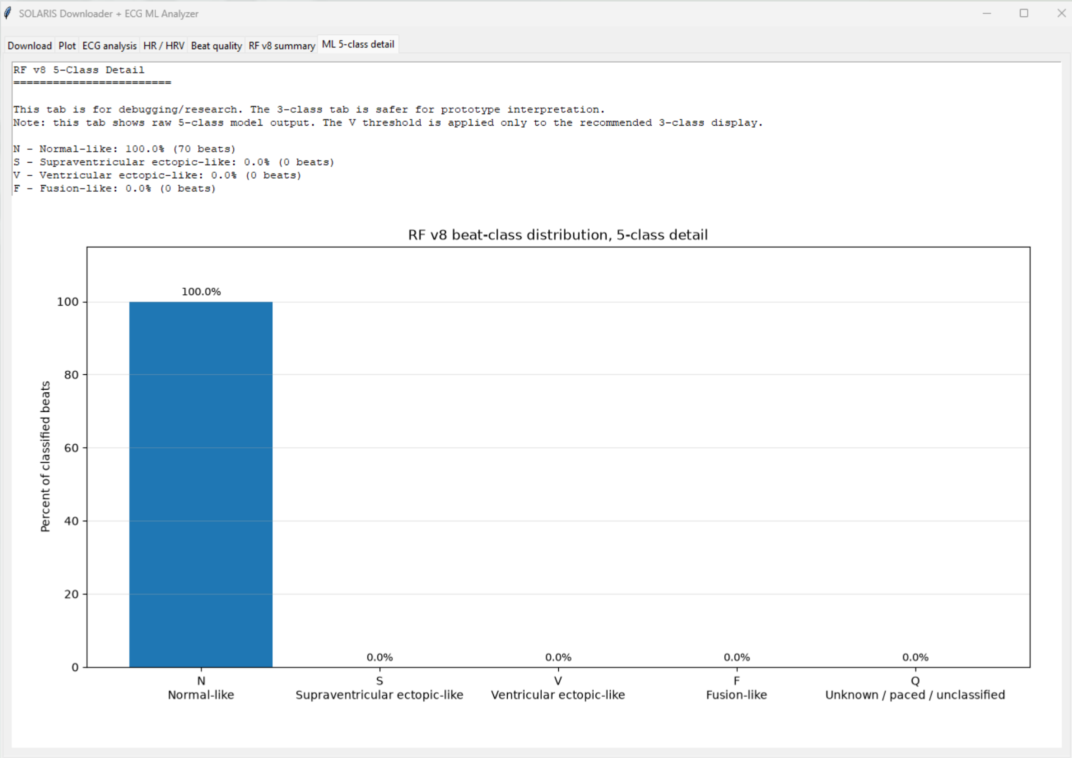


C. HR+HRV Interpretation

AI-Based Abnormality Detection-cont.

1. Trained and tested using MIT-BIH Arrhythmia Database.

2. Random forest beat classifier with 5 categories.

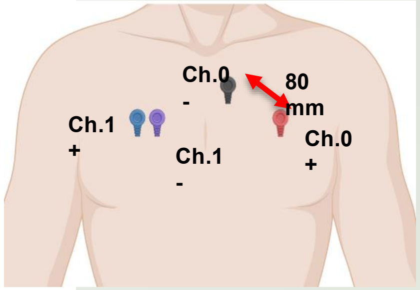


User Interface & Preliminary Data-ECG

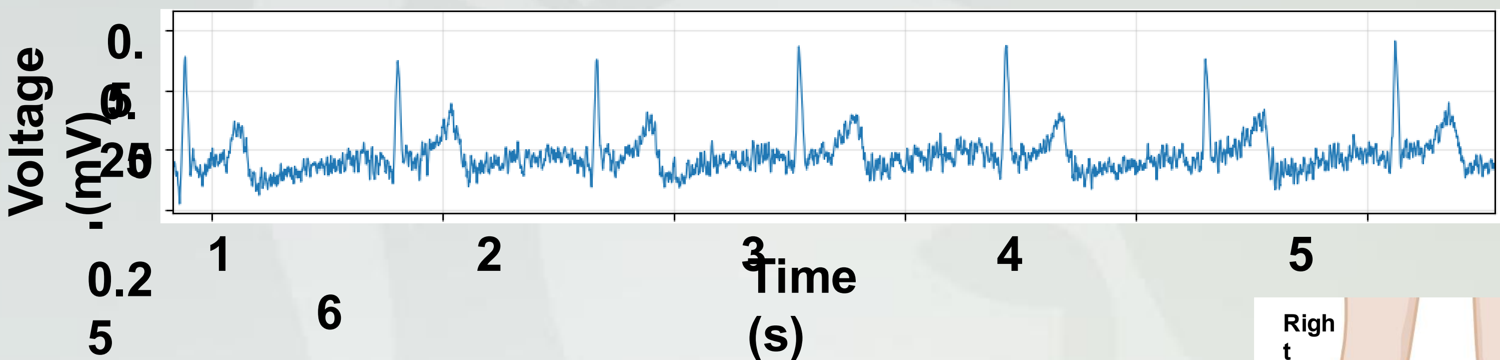
Raw

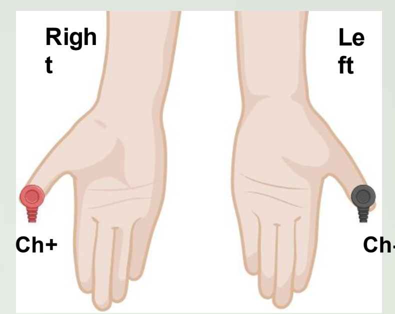
Filtered

Difference

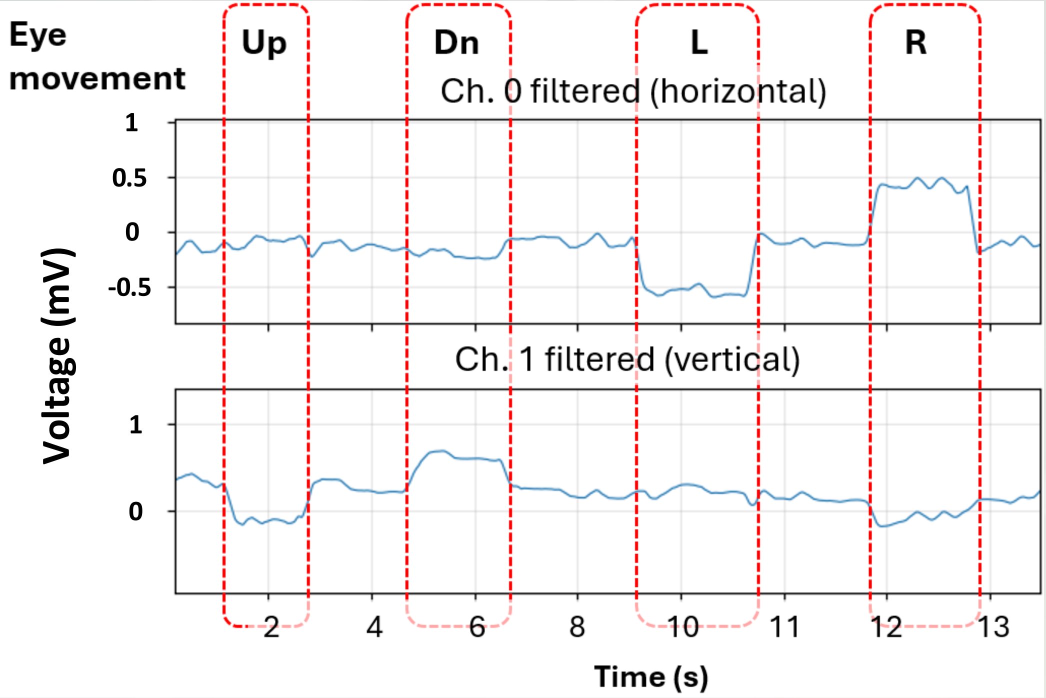


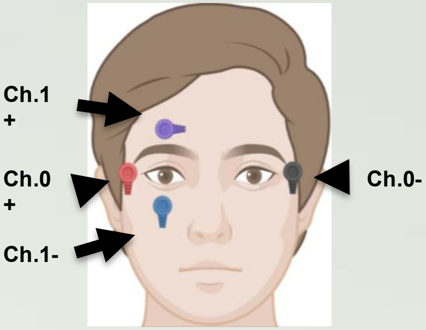
Preliminary Data-ECG



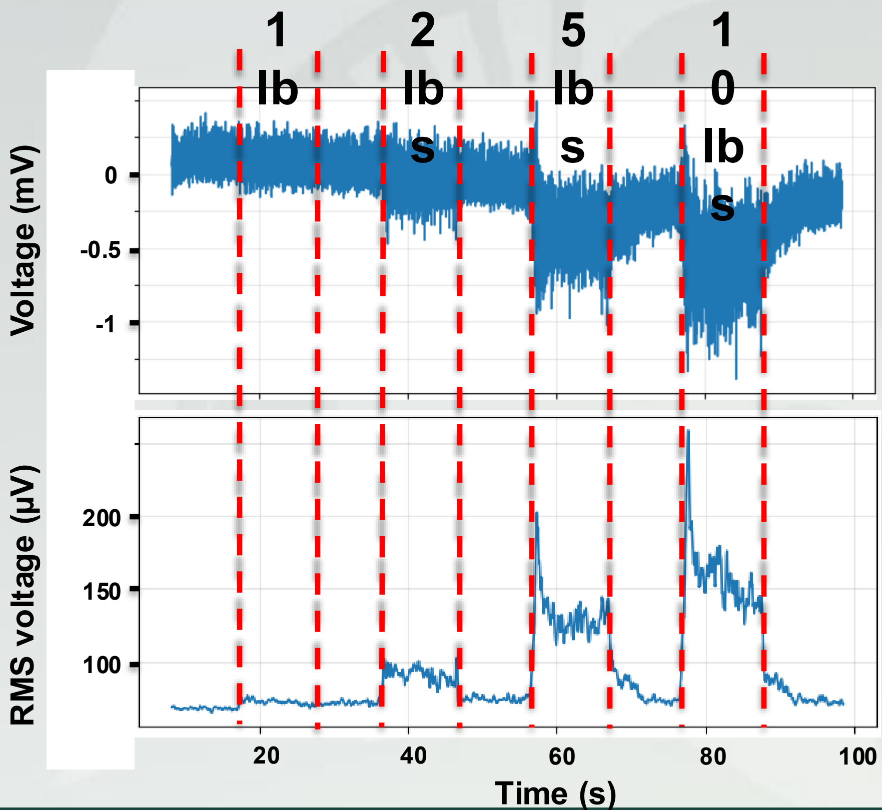


Preliminary Data-EOG

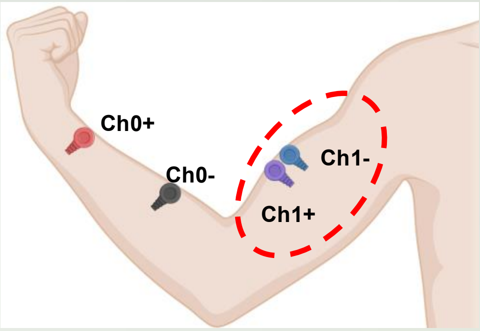




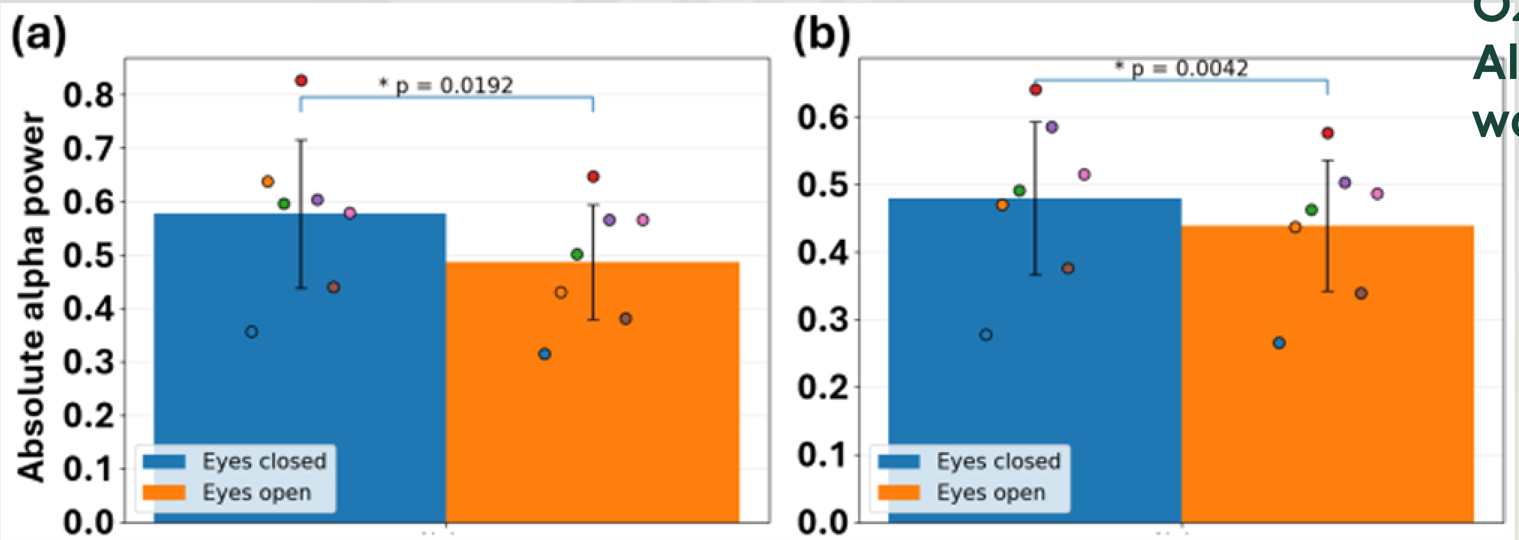
Preliminary Data-EMG



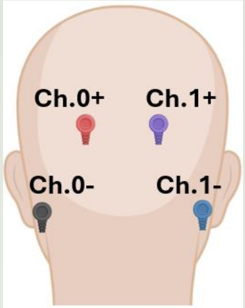
Sites: biceps



Preliminary Data-EEG



Sites: O1 & O2
Alpha wave



Acknowledgments

MSU REI Center — project support

Dr. Chunqi Qian — faculty mentorship / technical advising

Dr. Fei Sun — faculty mentorship/Societal Impact

Ziwu Zheng— field testing / data collection assistance

Questions?

Conclusion and Ongoing Work

- **LoRa communication was demonstrated across the tested rural routes**

  Packets were received through obstructed terrain, across farm-scale distances, and beyond 1 km in mixed conditions.

- **The architecture supported more than one sensing use case**

  The same gateway-to-cloud workflow supported wearable communication testing and multi-node greenhouse monitoring.

- **Current continuation: low-cost greenhouse sensing**

  Ongoing support with the MSU Plant Resilience Center will focus on maintaining and assisting the low-cost soil and environmental sensor deployment.

- **Main takeaway**

  A single connected gateway can extend low-rate sensing into locations where each sensor cannot depend on its own Wi-Fi or cellular connection.

Next Generation

Key improvements:

1. 8 read channels.
2. Longer battery life.
3. Wider input-signal dynamic range

Sources:

Rural Health Information Hub. (n.d.). *Healthcare access in rural communities*. Healthcare Access in Rural Communities Overview - Rural Health Information Hub

Rural Health Information Hub. (n.d.). *Barriers to transportation programs in rural areas.* Barriers to Transportation Programs in Rural Areas – RHIhub Toolkit

U.S. Census Bureau. (2019). *Older population in rural America.* Older Population in Rural America

Administration for Community Living. (n.d.). *Strengthening the direct care workforce.* Strengthening the Direct Care Workforce | ACL Administration for Community Living

U.S. Department of Health and Human Services. (2026, June 16). *Access to internet and other telehealth resources*. Telehealth.HHS.gov. Access to internet and other telehealth resources | Telehealth.HHS.gov

Rural Health Information Hub. (2025, March 12). *Connectivity considerations for telehealth programs*. Connectivity Considerations for Telehealth Programs - RHIhub Toolkit

How AI Fits Into the Larger Project

(Connectivity Models for Rural Health Monitoring)

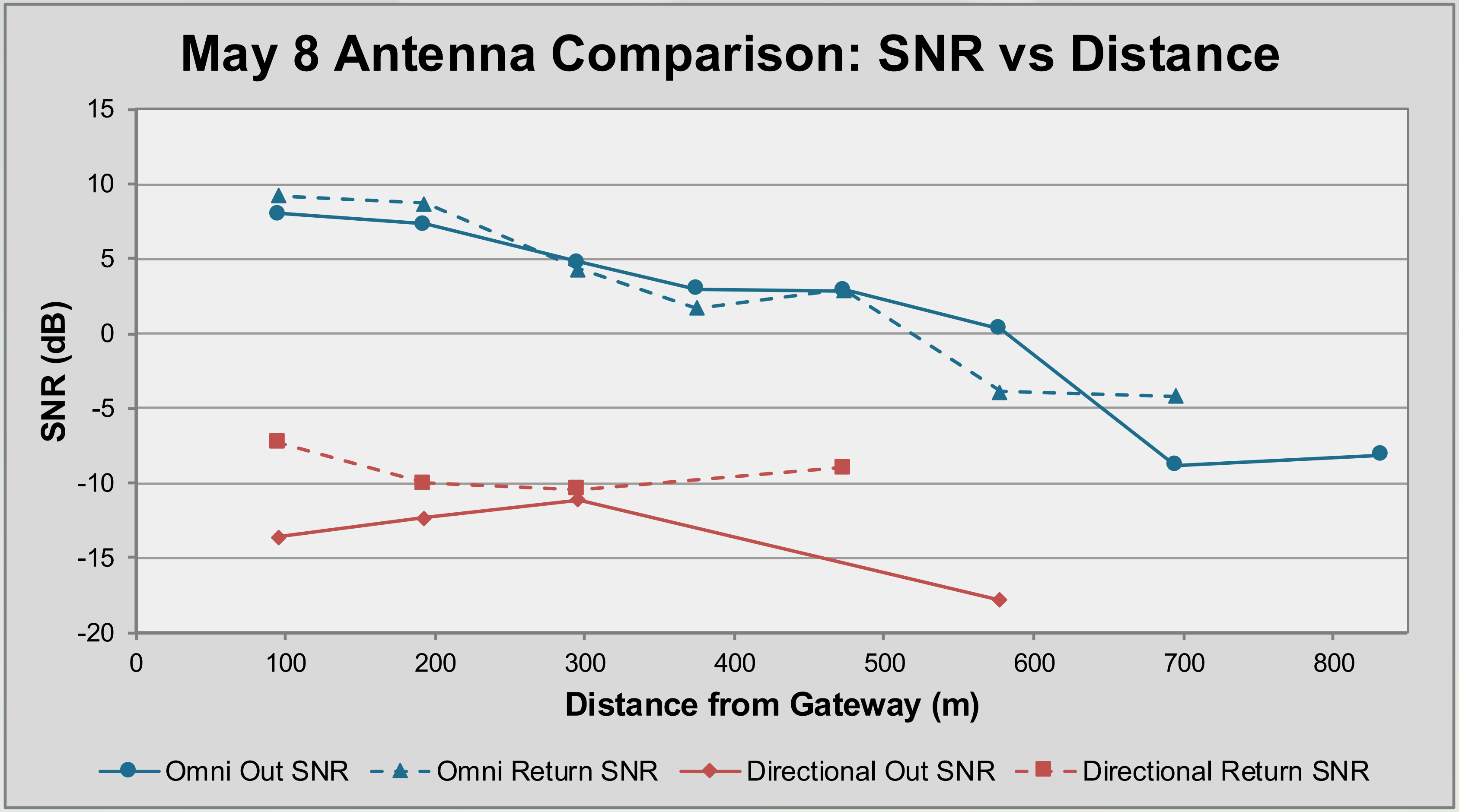
What future AI-assisted planning could do

- Use field data to estimate likely coverage from potential gateway locations
- Identify terrain or vegetation conditions linked to weak links
- Help select community-anchor placement before deployment

What this project did not do

- Did not train or validate an AI model
- Did not predict coverage
- Did not validate a healthcare deployment

Appendix: Antenna Configuration Comparison



Prototype Power Budget

Estimated Component Current	
Board	20 mA
MAX30101 base	1 mA
MAX30101 LED average	15 mA
MAX32664	3 mA
ICM-20948	2 mA
LoRa average	2 mA
Total	**43 mA**

1. Average current

43 mA (rounded to 50 mA for design estimate)

2. LoRa average current

118 mA × (0.33 s / 20 s) ≈ 1.95 mA ≈ 2 mA

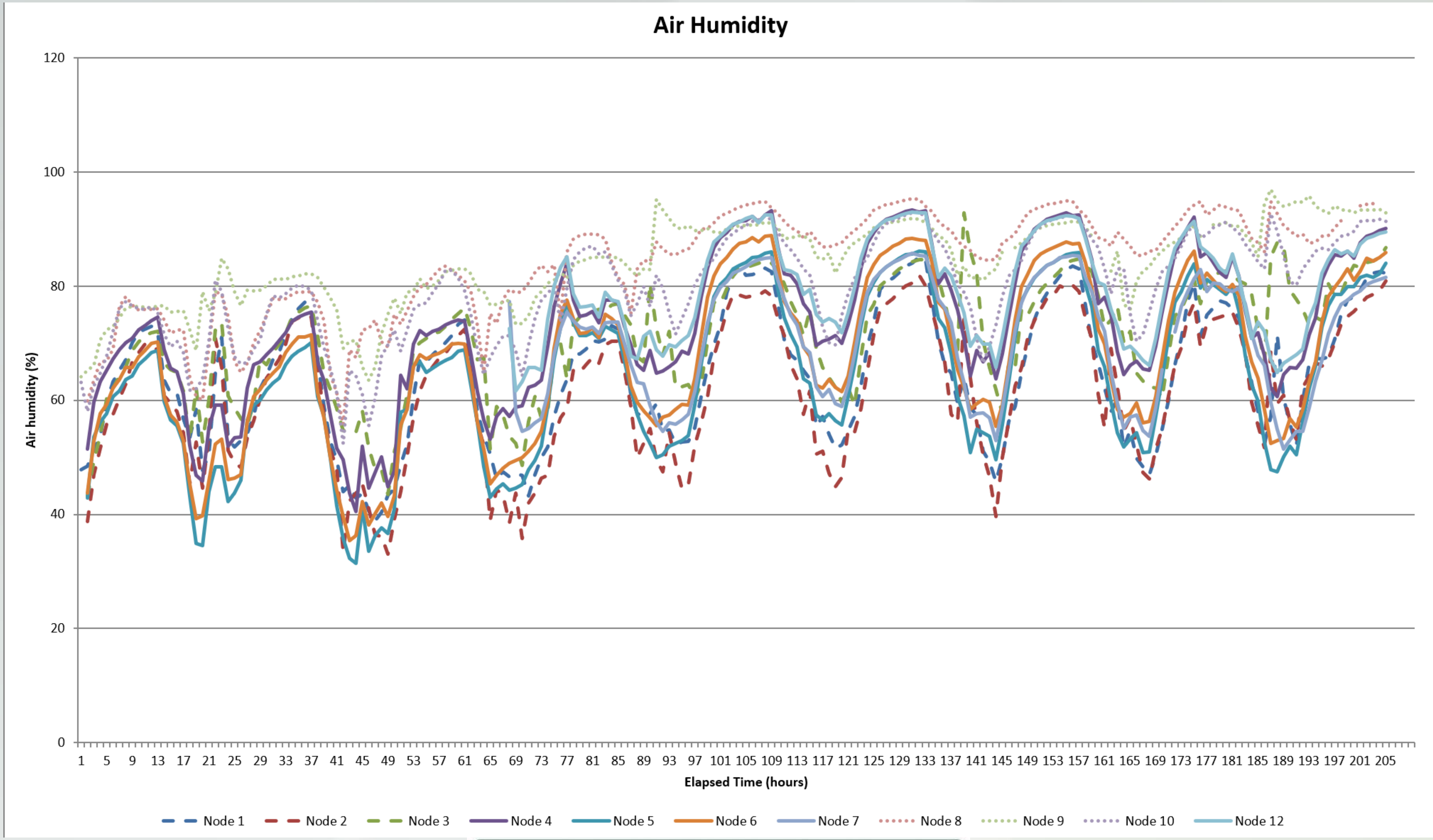
3. Peak current

LoRa peak 118 mA + other active load 20–60 mA
= about 140–180 mA

4. Power & battery life

Power: 3.7 V × 0.050 A = 0.185 W
Battery life (2000 mAh): 2000 mAh / 50 mA ≈ 40 hours

Estimated battery life before accounting for regulator losses, battery aging, or higher activity.



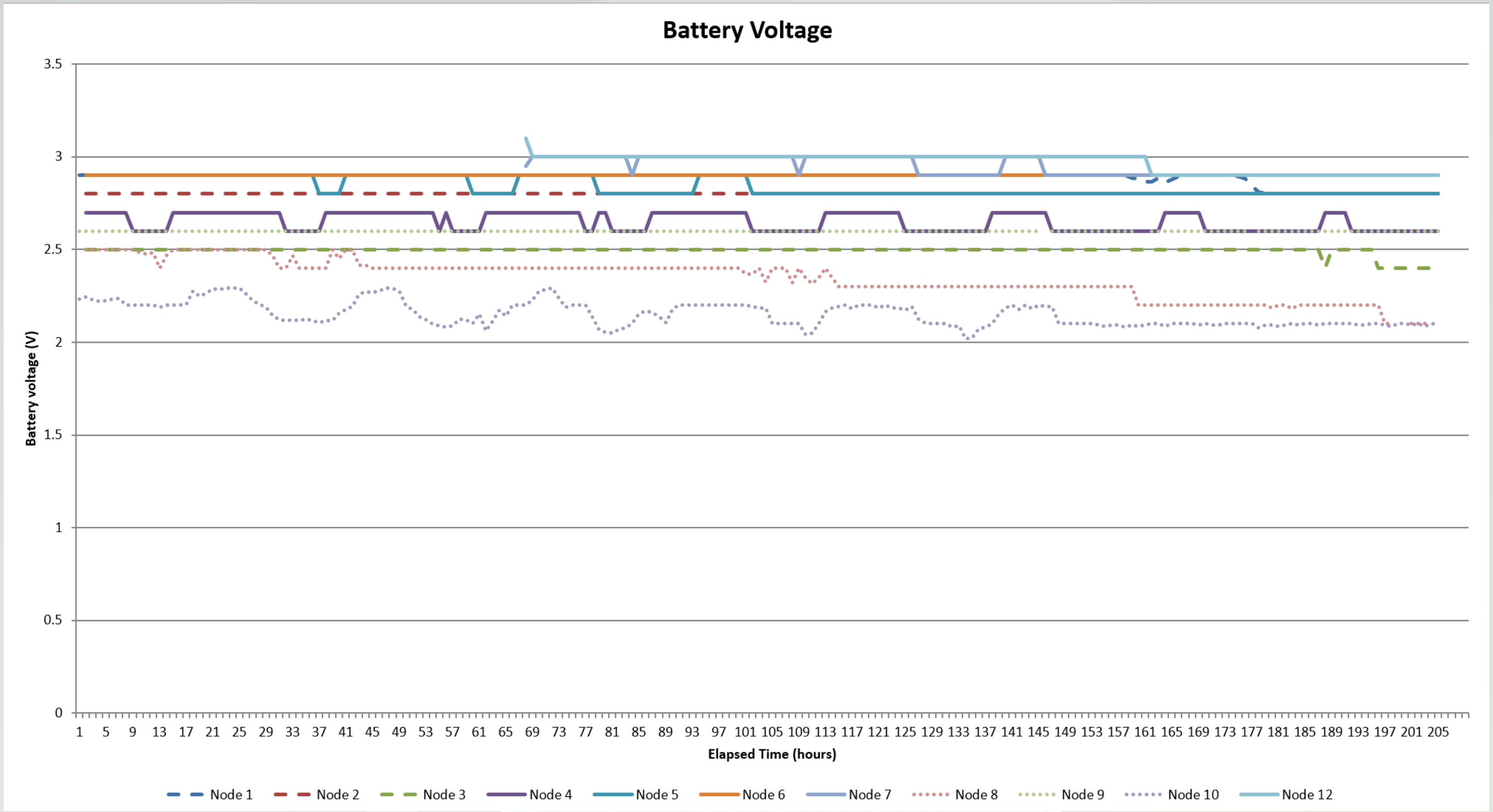
Node groups

Heat-stress environment: Nodes 1, 2, 3

Calibration / paired comparison: Nodes 4, 5, 6, 7, 12

Cool environment: Nodes 8, 9, 10

Nodes 7 and 12 came online later than the initial deployment.



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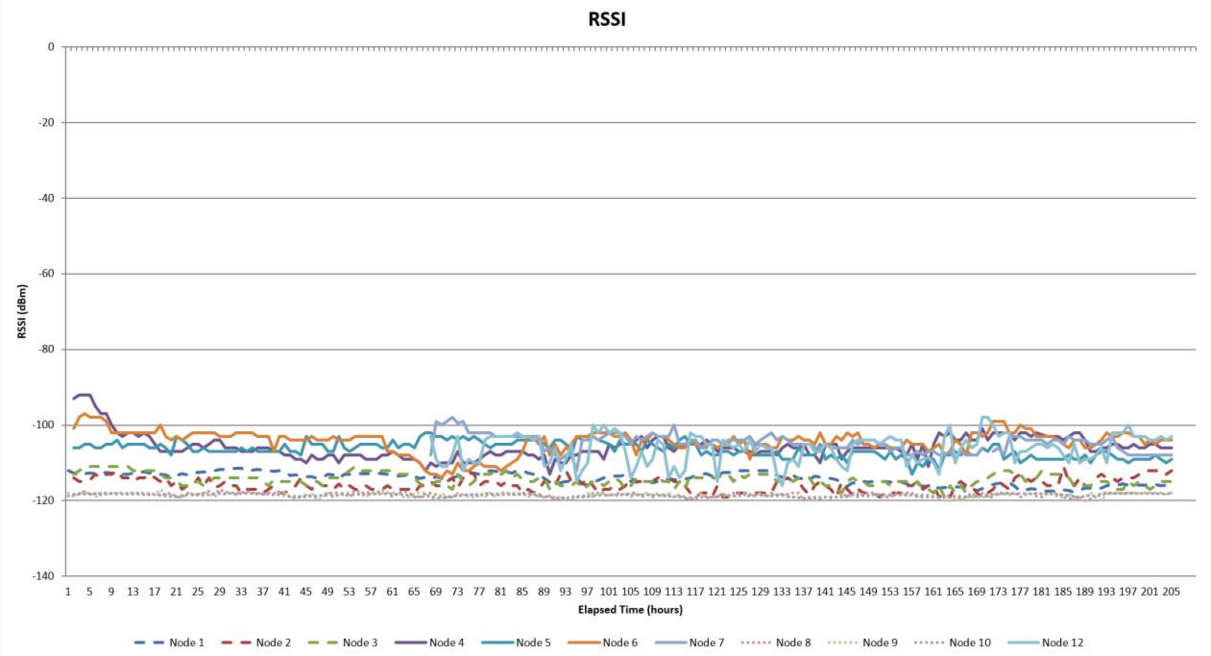
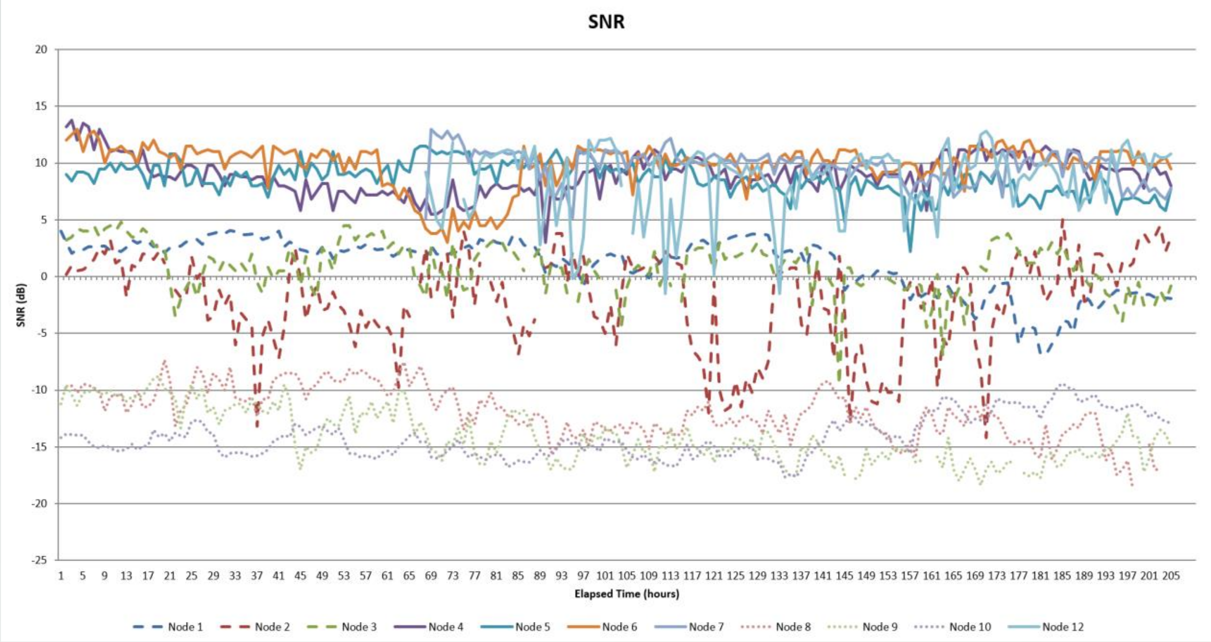

RSSI
RSSI (dBm)
0
-20
-40
-60
-80
-100
-120
-140
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133 137 141 145 149 153 157 161 165 169 173 177 181 185 189 193 197 201 205
Elapsed Time (hours)
Node 1
Node 2
Node 3
Node 4
Node 5
Node 6
Node 7
Node 8
Node 9
Node 10
Node 12


SNR
SNR (dB)
20
15
10
5
0
-5
-10
-15
-20
-25
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133 137 141 145 149 153 157 161 165 169 173 177 181 185 189 193 197 201 205
Elapsed Time (hours)
Node 1
Node 2
Node 3
Node 4
Node 5
Node 6
Node 7
Node 8
Node 9
Node 10
Node 12