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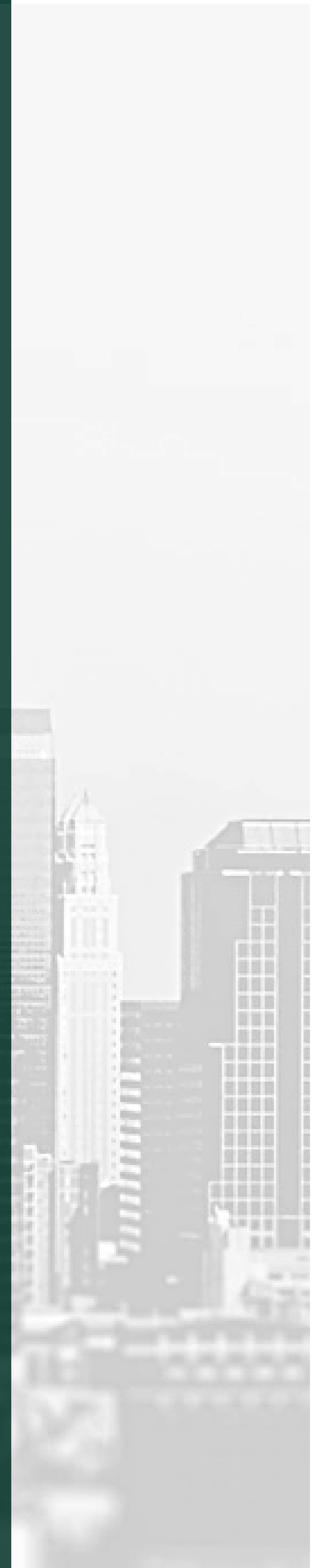
## 2026 Co-Learning Plan

## Evaluating Community AI-Assisted Anchor-Based Connectivity Models for Heath Care Access for Low-Connectivity Rural Populations in Michigan




**WRITTEN BY:**

Caleb Benninger, Dr. Chunqi Qian, and Dr. Fei Sun

# Evaluating Community AI-Assisted Anchor-Based Connectivity Models for Heath Care Access for Low-Connectivity Rural Populations in Michigan

*Michigan State University*

*Center for Community and Economic Development*

*Regional Economic Innovation*

Caleb Benninger, Dr. Chunqi Qian, and Dr. Fei Sun

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## 1. Introduction and Motivation

Rural communities in Michigan continue to face challenges related to limited broadband access, unreliable cellular coverage, geographic isolation, and constrained healthcare and agricultural support systems. These limitations affect older adults aging in place, rural residents living alone, agricultural workers, and others who may need basic health, safety, or environmental monitoring in areas where conventional communication infrastructure is limited. Many remote monitoring systems assume reliable Wi-Fi, strong cellular service, or broadband access. In rural environments, however, those assumptions may not hold, particularly outside the home, near agricultural fields, wooded areas, outbuildings, or other low-connectivity regions.

Low-Power, Wide-Area technologies, such as LoRa, offer a potential communication pathway for these conditions. LoRa is designed for low-power, long-range transmission of small data packets, making it well suited for compact sensor data such as fall alerts, heart rate, blood oxygen readings, soil conditions, environmental measurements, and various status updates. Unlike Wi-Fi, which is typically limited to short-range coverage around a home or building, LoRa can extend communication over longer distances while using relatively low power. This makes it a useful candidate technology for rural monitoring scenarios where continuous high-bandwidth communication is not required, but intermittent low-rate data transmission may still provide value.

LoRaWAN-based wearable health-monitoring systems have already been demonstrated in prior work. Abdulmalek, Nasir, and Jabbar (2024) developed a hybrid Internet of Wearable Things healthcare monitoring system using Wi-Fi and LoRaWAN to transmit health parameters including blood pressure, heart rate, and body temperature, reporting indoor and outdoor LoRaWAN transmission up to 1.5 km. Similar IoT-based sensor systems have also been evaluated in agricultural monitoring environments relevant to Michigan row crops. Wade, Check, Chilvers, and Dong (2025) developed an IoT-based monitoring system to track leaf wetness dynamics in corn and soybean fields. Their results showed that off-site weather stations underreported wetness events by 10% for low-canopy corn, 17% for upper-canopy corn, and 13% for soybean, while in-field IoT sensors provided more localized wetness and weather measurements.

The present project focuses on how a similar low-cost LoRa-based prototype behaves under rural Michigan field conditions, including vegetation, terrain, gateway placement, and antenna configuration.

The project vision proposes a broader anchor-based rural monitoring model in which wearable or remote sensing devices could transmit data to a local gateway positioned at a home, farm structure, clinic, library, or other community anchor site. In this model, the gateway would collect low-rate sensor data and forward information through whatever backhaul connection is available, such as cellular, satellite, wired internet, or local storage. For example, a home or farm could host a gateway that extends monitoring coverage beyond residential Wi-Fi range into yards, fields, wooded areas, or nearby outbuildings.

LoRa does not eliminate the need for backhaul when cloud access is desired. Instead, it moves the connectivity requirement from the mobile device to a fixed or semi-fixed gateway location, where a weak cellular or wired connection may still be adequate for forwarding small sensor packets to a cloud storage solution for remote access. This is important because broader deployment concepts, including community-anchor monitoring, health-event alerts, agricultural sensing, all depend first on the reliability of the device-to-gateway communication link.

This report evaluates LoRa as a rural IoT communication layer rather than as a complete healthcare, agriculture, or productivity solution by itself. Field testing focuses on packet reception, Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), gateway placement, environmental obstruction, distance, and antenna configuration.

Fall-event and pulse-oximeter behavior are included as application-layer examples, but they are interpreted separately from radio-link performance. This is important because rural monitoring systems depend not only on whether sensors can collect data, but also on whether useful information can be transmitted reliably under real-world deployment constraints.

This project focused on the sensing and communication infrastructure required to collect and transmit rural monitoring data. AI-based analysis was outside the scope of the present implementation but could be incorporated in future work after reliable data collection and communication are established.

## 2. Wearable Node

The wearable node served as the mobile sensing and transmission device in the prototype system. It was built around the SparkFun LoRa Thing Plus - expLoRaBLE, which combines an Ambiq Apollo3 microcontroller with a Semtech SX1262 LoRa radio. The board was selected because it provides a compact low-power embedded platform with integrated long-range wireless capability suitable for low-data-rate sensing applications. The expLoRaBLE platform supports LoRa-based communication and includes a shared antenna connection for the Apollo3 BLE and SX1262 RF paths through a U.FL antenna connector.

Two external sensors were connected to the node using the SparkFun Qwiic/I2C interface. Biometric measurements were collected using the SparkFun Pulse Oximeter and Heart Rate Monitor, which uses the MAX30101 optical sensor and MAX32664 biometric sensor hub. This module estimates heart rate and blood oxygen saturation using photoplethysmography (PPG), where red and infrared light are used to measure changes in light absorption through the finger.

Motion data for fall-event testing were collected using the SparkFun 9DoF IMU Breakout based on the ICM-20948. This sensor provides 9-axis motion tracking using a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer, making it suitable for wearable and Internet of Things (IoT) motion-sensing applications. In this project, the IMU was used to support fall-event flagging rather than full activity classification. Figure 1 shows the system.

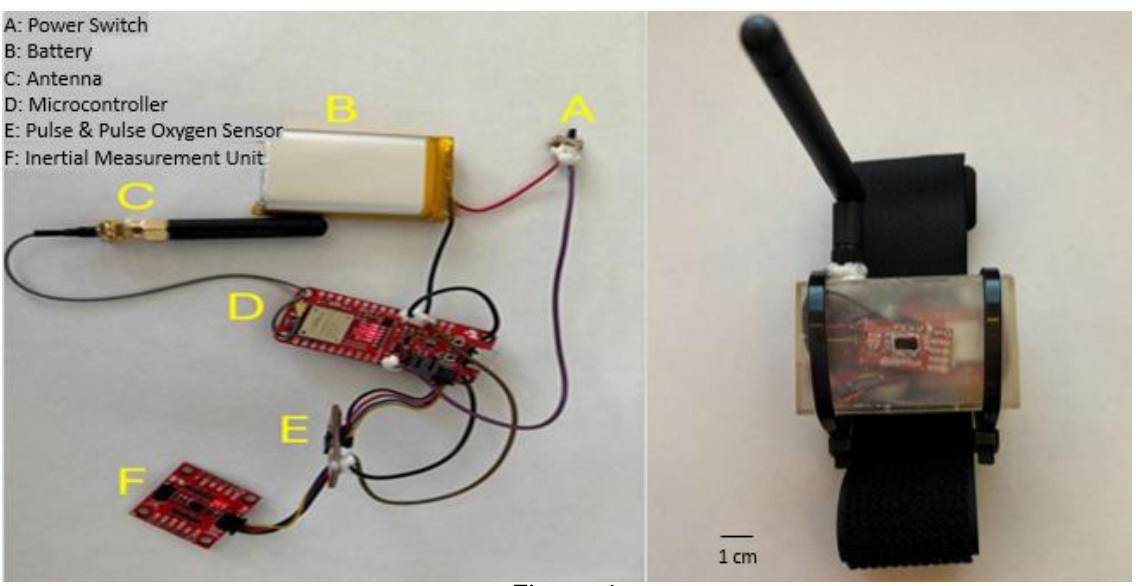


Figure 1

During field testing, the node transmitted low-rate packets containing application-layer data fields such as heart rate, SpO2, and fall-event status. After reception at the gateway, each packet was logged with radio data including RSSI and SNR. This allowed the system to be evaluated at both the communication layer and the application layer. A received packet indicated that the LoRa link was active at that moment, while valid heart rate, SpO2, or fall-event values depended on separate sensor and event-detection behavior.

### 2.1 Estimated Power Use

An approximate power estimate was made to check whether the wearable node could run from a small rechargeable battery. The estimated average current was about 50 mA, including the board, pulse-oximeter sensor, IMU, and averaged LoRa transmit current.

Although LoRa transmission can briefly draw around 118 mA for approximately 0.3 seconds, packets were sent only about once every 20 seconds, so the average LoRa contribution was small:

$$118mA \times \frac{0.3s}{20s} \approx 2mA$$

Using a 2000 mAh battery, the estimated runtime is:

$$\frac{2000mAh}{50mA} \approx 40 \text{ hours}$$

This is only a preliminary estimate. Actual runtime would depend on firmware sleep behavior, sensor duty cycling, transmit power, battery efficiency, and voltage regulation losses.

### 2.2 LoRa Gateway

The gateway used in this project was the Heltec HT-M2802 indoor LoRa gateway. It served as the fixed receiving point for packets transmitted by the wearable node. In the system architecture, the node collected sensor data and event flags, transmitted them over LoRa, and the gateway forwarded received packets to the LoRaWAN network server for logging and analysis.

The HT-M2802 was selected because of its affordability and because it offers a ready-to-use LoRaWAN gateway platform with Ethernet and Wi-Fi backhaul options. This distinction was important for the project: LoRa handled the low-power node-to-gateway radio link, but the gateway still required an internet connection to forward packets to the cloud/network server. The gateway represented the fixed infrastructure point in the proposed rural monitoring model.

### 2.3 Selected Monitoring Data Fields

Heart rate, SpO2, and fall alerts were selected because they represent compact, low-bandwidth data types that are well matched to LoRa communication. Unlike video, audio, or continuous waveform monitoring, these values can be transmitted as small packet fields at periodic intervals or when an event occurs. This makes them appropriate for evaluating whether LoRa can support basic wearable monitoring in rural areas where high-bandwidth connectivity may not be available.

Heart rate was included as a basic biometric indicator. In a remote monitoring context, heart rate can provide general information about physiological state, activity, stress, exertion, or abnormal changes from a person's typical baseline.

SpO2 was included because blood oxygen saturation is another compact biometric value that can be useful in basic health monitoring contexts. In this prototype, SpO2 was used to demonstrate that the system could transmit pulse-oximeter-derived data over LoRa. The project did not attempt to validate clinical pulse oximeter accuracy.

Fall-event status was included because fall detection is strongly suited to low-power wide-area communication. A possible fall can be represented as a simple event flag rather than a continuous data stream. This is important for rural monitoring because the system may not need to transmit large amounts of data continuously; instead, it may only need to send a small alert packet when a safety-relevant event occurs. In this project, the fall-event field was used to evaluate whether an event-based safety flag could be included in the LoRa packet payload.

Together, these three fields allowed the prototype to evaluate both periodic biometric transmission and event-based safety monitoring. Heart rate and SpO2 represented low-rate physiological data, while fall-event status represented a low-rate safety alert. This combination provided a practical application-layer test case for LoRa-based rural monitoring without requiring high-bandwidth communication.

### 2.4 LoRa Communication Link

The primary communication pathway evaluated in this project was the LoRa link between the wearable node and the gateway. The node transmitted low-rate packets over the 915 MHz Industrial Scientific and Medical (ISM) band using SF10 operation. In LoRa communication, the spreading factor (SF) controls how long each symbol is transmitted over the air. Higher spreading factors increase receiver sensitivity and improve robustness at longer distances but reduce data rate and increase airtime. SF10 was therefore selected to prioritize range and reliability over speed.

With SF10 and 125 kHz bandwidth, the effective data rate is approximately 1 kbps, which is sufficient for compact packets containing data such as heart rate, SpO2, fall-event status, and other forms of data. In this context, bandwidth refers to the width of the frequency channel used by the LoRa signal. A wider bandwidth can support higher data rates but generally reduces receiver sensitivity, while a narrower bandwidth improves sensitivity and range at the cost of lower throughput. The 125 kHz setting is a common LoRaWAN bandwidth and provides a practical balance between range, robustness, and low-rate sensor data transmission.

## 3. Field Testing Methods

Field testing was conducted to characterize the communication performance of the LoRa wearable node under progressively more realistic rural conditions. The tests were designed to evaluate both baseline system functionality and communication behavior across distance, terrain, vegetation, gateway placement, and antenna configuration. The primary communication metric was whether packets transmitted by the wearable node were successfully received by the gateway and logged through the selected cloud software, The Things Network. Additional radio-link metrics, including RSSI and SNR, were recorded for each received packet.

Distances were evaluated using straight-line gateway-to-node separation rather than walking-path distance. Measurement points were marked along the test route and associated with approximate distances from the gateway.

### 3.1 General Testing Procedure

For each test, the gateway was placed at a fixed location, and the wearable node was carried along a planned route, collecting data the entire time. The gateway was positioned approximately 4 feet from the ground. At selected points, the tester paused to observe packet reception and recorded test notes. Where applicable, fall-event tests were performed by applying motion to the node to trigger a fall-event. Pulse oximeter readings were collected when finger placement and sensor contact allowed valid readings. Packet logs were later exported from The Things Network and compared with field notes to associate packet reception data, distance, and application-layer behavior with each measurement point.

Communication success was defined as receipt of packets at the gateway with associated RSSI and SNR values. Intermittent communication was defined as packet reception with missed packets, skipped frame counts, or inconsistent reception across nearby points or travel directions. No communication was defined as the absence of received packets at a measurement point or region despite continued testing.

### 3.2 Benchmark System Function Test

A general Benchmark test was conducted to verify that the integrated system could transmit expected data fields under favorable conditions at short range before interpreting longer-range field tests. This test was not intended to establish maximum range. Instead, it demonstrated baseline system function by confirming that heart rate, SpO2, fall-event status, packet count, RSSI, and SNR could be received and logged.

Packet number was used as the x-axis to show repeated packet transmission over time. These tests confirmed baseline prototype operation across multiple test days.

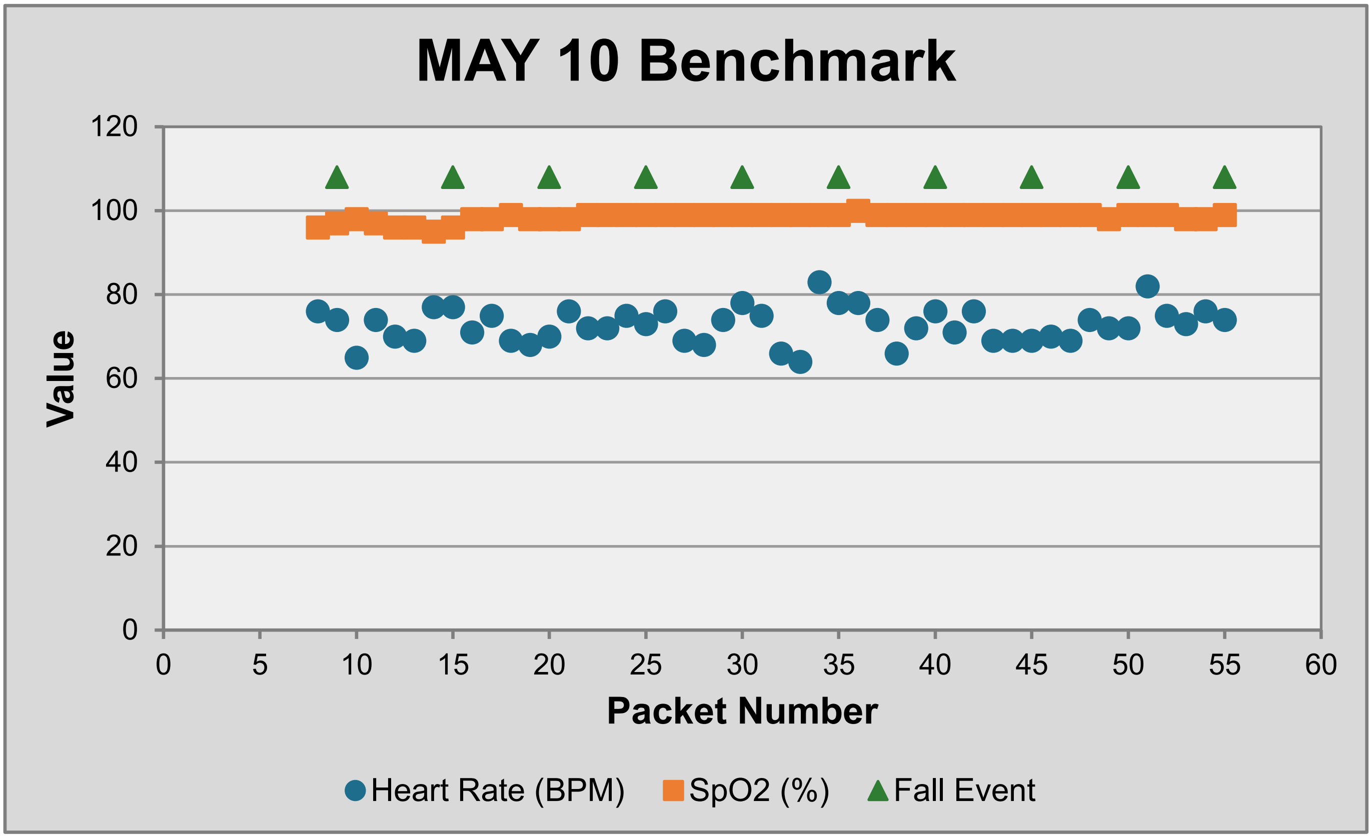


Figure 2. Benchmark packet data.

**3.3 Data Processing and Interpretation**

Packet logs were exported and organized by test, timestamp, frame count, RSSI, SNR, heart rate, SpO2, and fall-event status. Field notes were then matched to packet timestamps and measurement points.

The results were analyzed in layers. First, packet reception and radio metrics were used to evaluate LoRa communication performance. Second, fall-event results were evaluated as application-layer behavior dependent on IMU motion, threshold logic, timing, and packet delivery. Third, heart rate and SpO2 values were interpreted as biometric sensor outputs dependent on finger placement, motion, temperature, and sensor contact.

### 3.4 Upper Peninsula Obstructed Terrain Test

An early field test was conducted in the Upper Peninsula under heavily obstructed rural conditions. The gateway was positioned on the second floor of a residential home and used a 915 MHz half-wavelength antenna. The wearable node used a quarter-wavelength antenna and was carried to a test point approximately 100 m from the gateway and back. Although the distance was relatively short, the route included dense tree cover, snow-covered ground, a residential structure, elevation change, and non-line-of-sight propagation. The test was conducted at approximately 32°F.

Figure 3 shows the approximate gateway and test-point locations. The purpose of this test was not to evaluate maximum range under ideal conditions, but to determine whether LoRa communication could remain usable under short-range, highly obstructed rural terrain. Two walking dynamic trials followed the same uphill route from the gateway toward Point 1, allowing the results to be compared across repeated movement through the same obstructed path.

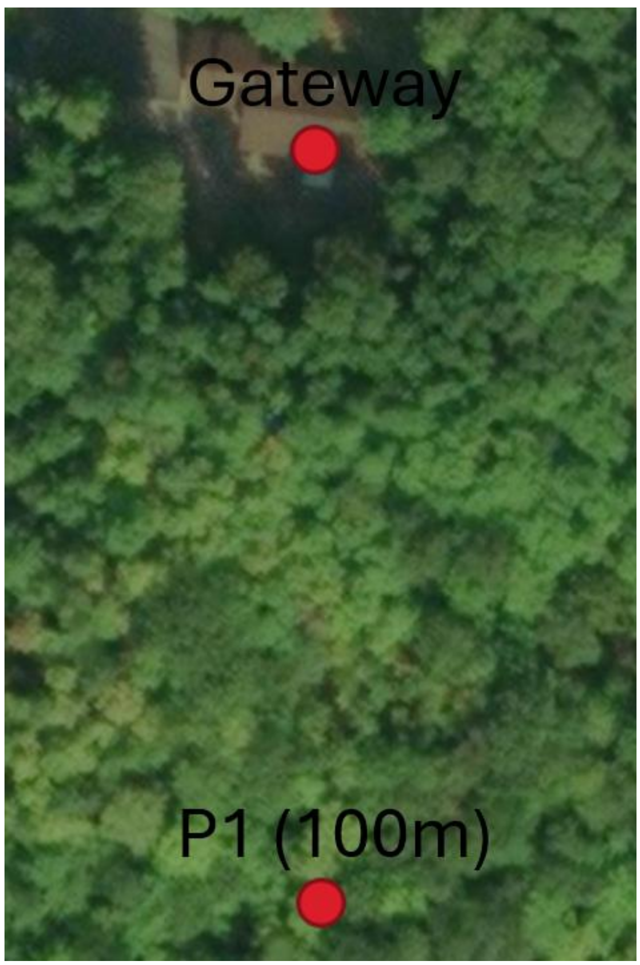


Figure 3. Test pathway for Upper Peninsula Test

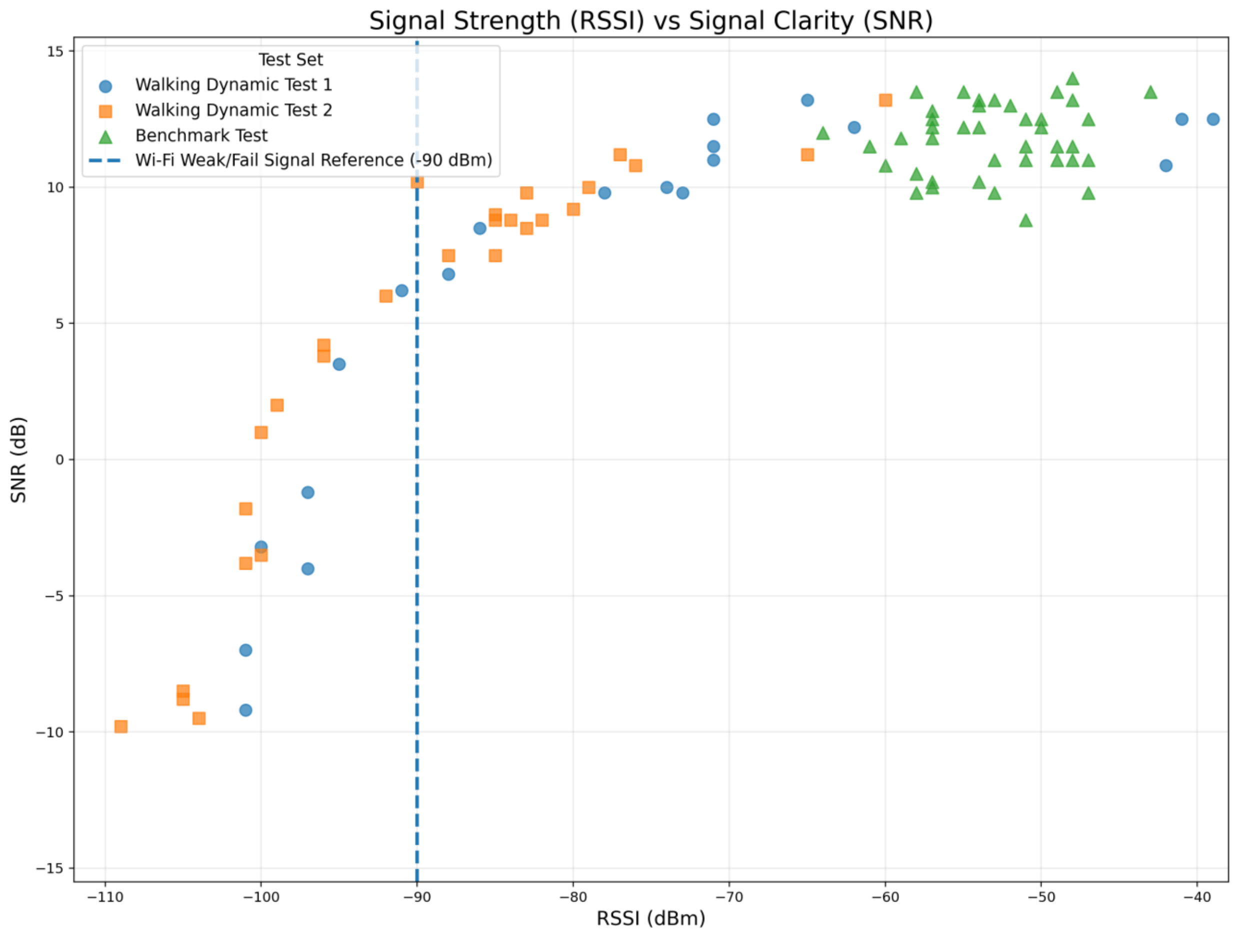


Figure 4: Upper Peninsula Test Analysis. RSSI vs SNR showing the relationship between signal strength and quality under dense obstruction.

The Upper Peninsula test showed that LoRa communication remained possible under dense obstruction, but signal quality declined substantially as the node moved away from the gateway and into the wooded uphill route. The benchmark test produced a compact cluster of stronger link measurements, with RSSI generally between -45 and -65 dBm and SNR between 9 to 14 dB. This indicates stable communication under favorable conditions.

In contrast, the two walking dynamic tests showed a much wider spread in RSSI and SNR. As the node moved through the obstructed path toward the 100m test point, RSSI decreased toward -110 dBm, while SNR dropped from positive values to the negative range, in some cases approaching -10 dB. This shows that the received signal became much less robust under tree cover, terrain obstruction, and changing node orientation.

The dashed line at -90 dBm is included as an approximate weak-signal reference for typical Wi-Fi connectivity. Although Wi-Fi failure thresholds vary by hardware, antenna placement, background noise, and required data rate, Wi-Fi links are generally unreliable near this RSSI level. Several LoRa packets were still received below -90 dBm. This suggests that the LoRa link remained usable in conditions where a typical Wi-Fi connection would likely become unstable or unavailable.

The repeated trend across Walking Dynamic Test 1 and Walking Dynamic Test 2 supports the conclusion that the observed degradation was primarily caused by the physical environment rather than a single test anomaly. Both walking tests followed the same route and showed similar RSSI/SNR behavior. Overall, the result demonstrates that LoRa can maintain packet reception in heavily obstructed short-range rural conditions, but SNR becomes a key indicator of link stress as vegetation, terrain, and building obstruction increase.

### 3.5 Lower Michigan Mixed Terrain and Treelined Tests

Mixed-terrain testing was conducted along routes that included open field, tree line boundaries, and wooded regions. These tests were intended to evaluate how communication behavior changed as the node moved from relatively open conditions into vegetation and obstructed terrain. Measurement points were associated with approximate distance from the gateway and environmental context, such as open field, tree line, or wooded area.

These tests were especially important for comparing RSSI and SNR behavior. RSSI was used to represent received signal strength, while SNR was used to represent signal clarity relative to background noise.

#### 3.5.1 April 2nd Test

One of these tests was conducted on April 2nd. Its test path and results are shown in Figures 5 and 6, respectively.


Figure 5: April 2nd, 2026 mixed Terrain Test Path and Measurement Points. Test path showing progression from open field to dense vegetation, with the tree line at ~462 m. Measurement points indicate distances from the gateway.

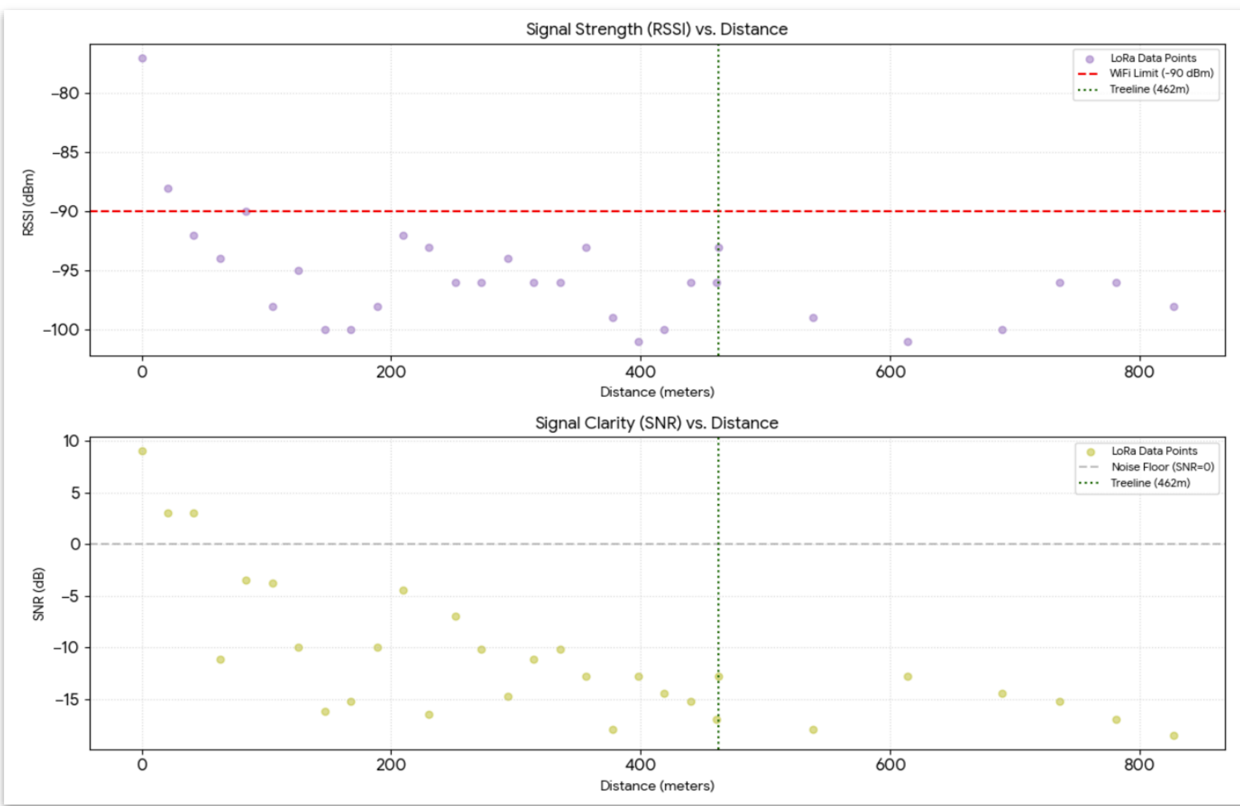


Figure 6: RSSI and SNR vs Distance

The April 2nd mixed-terrain test showed that LoRa communication became significantly less robust as the node moved from open field conditions into the tree-line region as fewer packets were received. RSSI remained relatively clustered in the weak-signal range, generally near -90 to -100 dBm. SNR showed a similar trend with negative SNR throughout most of the tests. This indicates that LoRa was operating near its limits due to the environmental conditions. The test was conducted at approximately 50°F with 100% humidity, so wet vegetation, ground moisture, and dense foliage may have contributed to reduced signal penetration and increased multipath or attenuation. However, because humidity was not isolated from vegetation, terrain, gateway placement, and antenna orientation, the result should be interpreted as evidence of reduced link margin under wet mixed-terrain conditions rather than proof that humidity/moisture alone caused the degradation.

### 3.5.2 April 30th Test 1

One of the April 30th mixed-terrain field tests evaluated LoRa communication and sensor behavior across the exact same route. The gateway was again positioned near an agricultural structure, while the wearable node was carried through nine marked test points labeled P1 through P9. The route began in open field conditions, passed through a wooded region, and then continued into a longer-range open field section beyond the wooded area. Data was collected on both the outbound and return paths.

Figure 7 shows the test layout and approximate straight-line distances from the gateway. Points P1 through P4 represented the open-field portion of the test, ranging from 96 m to 375 m. Points P5 through P7 were located near the wooded obstruction zone, ranging from 473 m to 578 m. Points P8 and P9 extended beyond the wooded section at 695 m and 833 m. This layout allowed the test to evaluate not only increasing distance, but also the effect of vegetation and terrain transitions on signal quality.

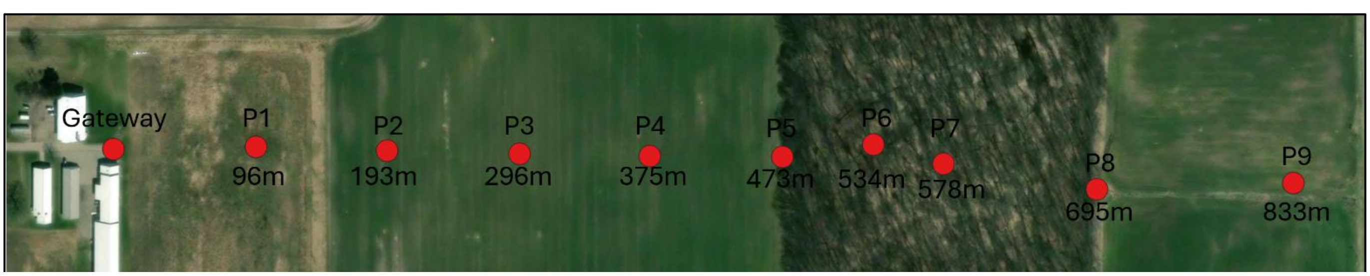


Figure 7. April 30, 2026 test path

The main communication result was that the LoRa link remained active at all marked points. Packet reception was observed across the full route from P1 to P9, including the farthest point at approximately 833 m. Therefore, the test did not show a complete communication loss at any marked point. However, the RSSI and SNR values showed that the communication link became less robust as the node moved farther from the gateway and passed through the tree line region. In the open-field portion of the route, signal quality remained comparatively stronger. Near the tree line and at longer distances, RSSI decreased and SNR became more variable, indicating reduced link margin even though packets were still received.

The application-layer results were less consistent than the communication results. Heart rate and SpO2 readings were unavailable at several shorter-distance points, including P1 through P4, even though these points were relatively close to the gateway. Valid biometric readings later appeared at more distant points, including P5, P6, P8, and P9. This indicates that missing biometric data were not primarily caused by LoRa range limitations. Instead, the inconsistent biometric readings were likely caused by pulse oximeter contact, finger placement, motion during walking, cold conditions, or sensor behavior.

Fall-event testing was also inconsistent. Several fall tests failed even though LoRa packets continued to be received. This suggests that fall-test failure should not be interpreted as communication failure. A likely factor was the physical packaging of the prototype. The node was enclosed in a protective container during testing, and the container may have absorbed or damped part of the impact during fall trials. As a result, the IMU may not have experienced the acceleration profile needed to trigger the threshold-based fall-event logic. Node orientation, impact direction, cooldown timing, and the mechanical coupling between the enclosure and IMU may also have affected fall-event detection.

Overall, the April 30 test supports the feasibility of LoRa communication across a mixed rural route up to approximately 833 m, but it also shows that communication reliability and sensing reliability must be evaluated separately. The LoRa link remained active throughout the route, including at the farthest test points. However, RSSI and SNR trends showed reduced link margin near the tree line and longer-range sections. At the same time, inconsistent heart rate, SpO2, and fall-event behavior showed that the sensing hardware and mechanical prototype design require additional refinement before application-layer reliability can be claimed.

A summary of the test interpretation is shown in Table 1.

| Point | Distance | Environment | Radio-link result | Application-layer result | Interpretation |
|---|---|---|---|---|---|
| P1–P4 | 96–375 m | Open Field | Packets received | HR/SpO2 mostly unavailable; no fall tests | Missing biometric data likely caused by sensor/contact behavior, not communication loss |
| P5–P7 | 473–578 m | Open field to inside wooded area | Packets received | HR/SpO2 sometimes available; fall tests inconsistent | Vegetation reduced signal quality, while sensor/fall behavior remained application-layer limited |
| P8–P9 | 695–833 m | Wooded area to open field | Packets received | HR/SpO2 available at times; fall tests mostly failed with one pass at P9 return | LoRa remained usable at longer range, but fall detection was limited by packaging, IMU coupling, or threshold behavior |

Table 1. April 30, 2026, Test 1 results

Test data can be seen in Figure 8.

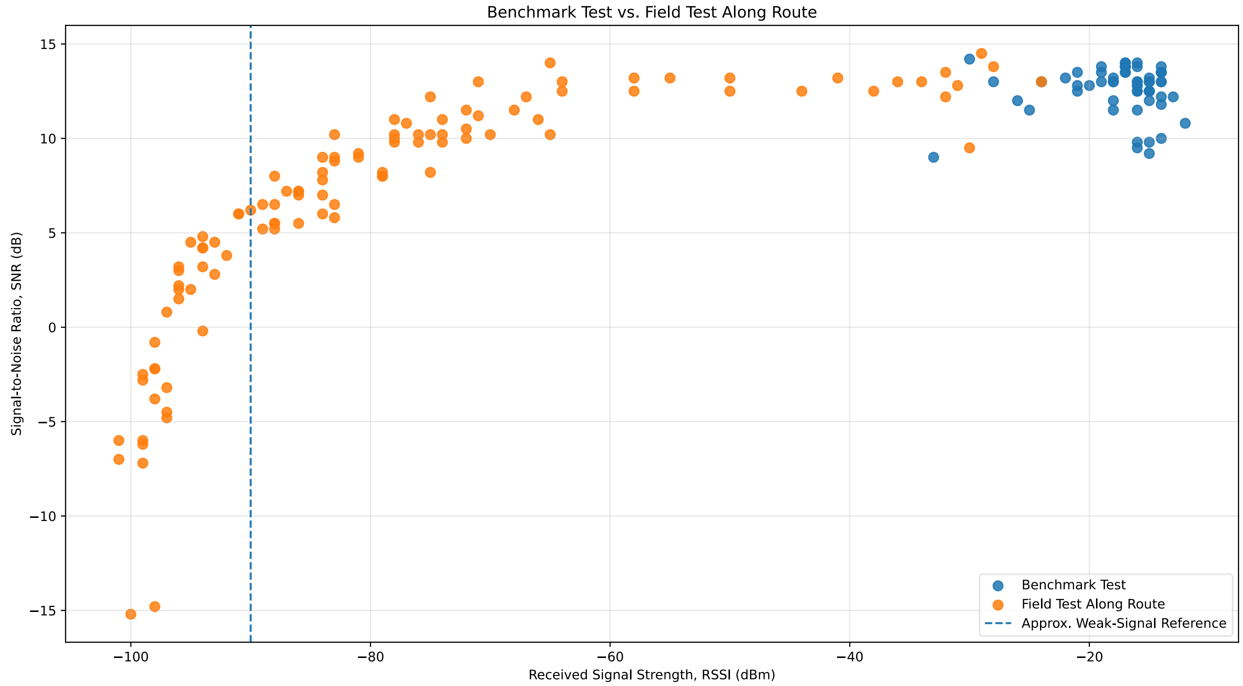


Figure 8. RSSI VS SNR

### 3.5.3 April 30th Test 2: Extended Range Test

A second mixed terrain extended range test was conducted on April 30th, 2026 using a longer rural path with measurement points extending beyond 1 km from the gateway. Points were labeled by distance from the gateway, with the furthest test point at approximately 1.44 km. The test included both outbound and return-path observations, allowing packet reception and application-layer behavior to be compared in both directions. This test path can be seen in Figure 9.

During this test, field notes recorded whether packets were received, whether fall-event tests passed or failed, and whether heart rate or SpO2 values were present.


Figure 9. April 30, 2026 test path

The extended range test evaluated whether the LoRa link could remain usable beyond the shorter 833 m route used in the mixed-terrain test. Measurement points extended from approximately 723 m to 1.44 km from the gateway. The route included open field conditions, farm structures, a wooded obstruction region, and longer-range points beyond the tree line. Testing was performed on both the outbound and return paths, and field notes were matched with packet logs to separate radio-link behavior from application-layer sensing behavior.

The results showed that LoRa communication remained possible beyond 1 km, but packet reception became less reliable as distance and obstruction increased. Several points between approximately 879 m and 1.3 km still showed packet reception, indicating that the system was not limited to the shorter 833 m route. However, the farthest points showed clear degradation. At P12, approximately 1.44 km from the gateway, no connection was recorded during the test window. On the return path, no connection was also recorded at several of the farthest points, including P10 through P12. This suggests that the extended route approached the practical communication limit for this deployment configuration.

The radio-link behavior was not perfectly symmetric between the outbound and return paths. Some points showed connection on one direction of travel but not the other. This is consistent with a marginal LoRa link where small changes in node orientation, body position, antenna angle, vegetation, terrain, or local multipath can determine whether a packet is successfully received. Therefore, the extended range result should not be interpreted as a fixed maximum range value. Instead, it shows that packet reception was possible beyond 1 km under some conditions, but reliability decreased near the farthest region; it should be noted that this was achieved with the gateway at 4 feet elevation.

Application-layer sensing remained less consistent than radio-link reception. Heart rate and SpO2 values were sometimes available but were also missing or zeroed during parts of the test. Fall-event tests produced mixed results, with some successful detections but several failed attempts.

Overall, the extended range test showed that the prototype could communicate at distances greater than 1 km in rural mixed terrain, but the link became intermittent near the farthest measurement points. The results support the feasibility of LoRa for low-rate rural monitoring beyond typical Wi-Fi range, while also showing that reliable deployment would require careful attention to gateway placement, antenna height, vegetation, terrain, and node orientation.

A summary of these results can be found in Table 2.

| Point | Distance | Environment | Radio-link result | Application-layer result | Interpretation |
|---|---|---|---|---|---|
| P1–P3 | 723–804 m | Open field / near farm structures | Mostly weak or intermittent packet reception; P1 had no connection on the way out but reception on return | HR/SpO2 mostly inconsistent; one fall pass at P3 outbound and return | Communication was possible at this range, but not fully stable. Missing biometric data likely reflected sensor/contact issues plus weak link conditions. |
| P4–P6 | 879–1054 m | Open field approaching vegetation/wooded region | Packets still received at several points, including connection notes through P6; link quality degraded | Fall tests mixed: P5 and P6 had at least one pass, but several failed attempts; HR/SpO2 sometimes available | LoRa remained usable beyond 1 km, but fall detection remained inconsistent. |
| P7–P9 | 1156–1238 m | Near/through wooded obstruction and field edge | Intermittent reception; connection noted at P7/P8 outbound and P9, with skipped or failed return tests | HR/SpO2 sometimes available; fall tests mostly failed except one pass at P9 outbound | Communication was still possible beyond 1.2 km, but reliability was inconsistent. Vegetation and distance likely reduced robustness. |

| | | | | | |
|---|---|---|---|---|---|
| P10–P12 | 1271–1440 m | Farthest open-field / beyond wooded section | Outbound packets still received at P10–P11; P12 recorded no connection. Return path showed no connection at P10–P12 | Fall tests failed or were not recorded; HR/SpO2 unavailable or inconsistent | The farthest region approached the practical limit for this deployment. Packet reception became unreliable, especially on the return path. |

Table 2. April 30th, 2026, Test 2 results

See Figure 10 for the data collected. The benchmark test had a strong, stable signal, with high RSSI and positive SNR. The extended-range test had a much weaker and more variable signal, especially while walking through the woods. Most packets were around −110 to −95 dBm RSSI, with SNR ranging from about −15 to +3 dB. LoRa communication still worked through wooded, obstructed terrain at long range, but the link was much closer to its practical limit and less reliable than the benchmark test.

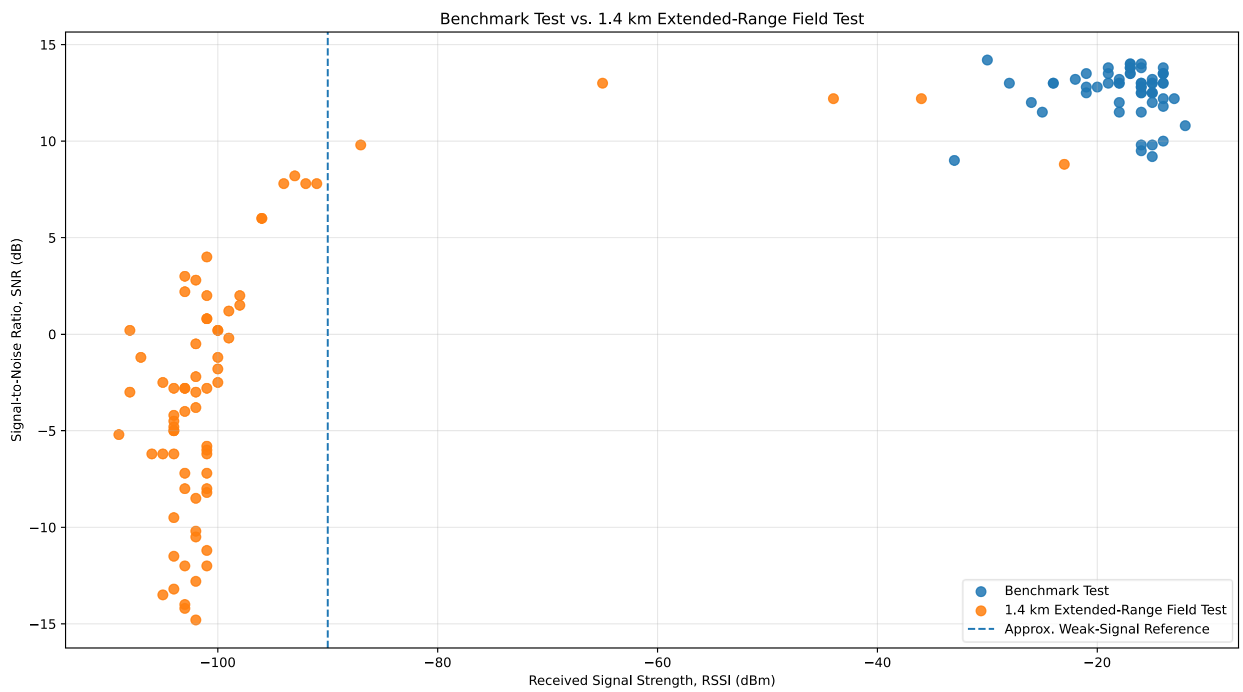


*Figure 10 RSSI vs SNR*

### 3.6 Fall-Only Test

A fall-only test was conducted on May 8th, 2026 to evaluate the fall-event portion of the prototype separately from the broader biometric and mixed-terrain tests. Earlier field tests showed inconsistent fall-test behavior, but those tests also included biometric sensing and enclosure effects. The purpose of this test was therefore to determine whether fall-event flags could be generated and transmitted over LoRa at each marked distance point along the route.

The route extended from the gateway to a farthest point of approximately 833m and then returned toward the gateway which can be seen in Figure 11. Fall tests were performed at marked points along both the outbound and return paths. For each expected fall test, the packet log was matched to the corresponding test time so that the fall-event flag, RSSI, and SNR could be interpreted relative to distance from the gateway.

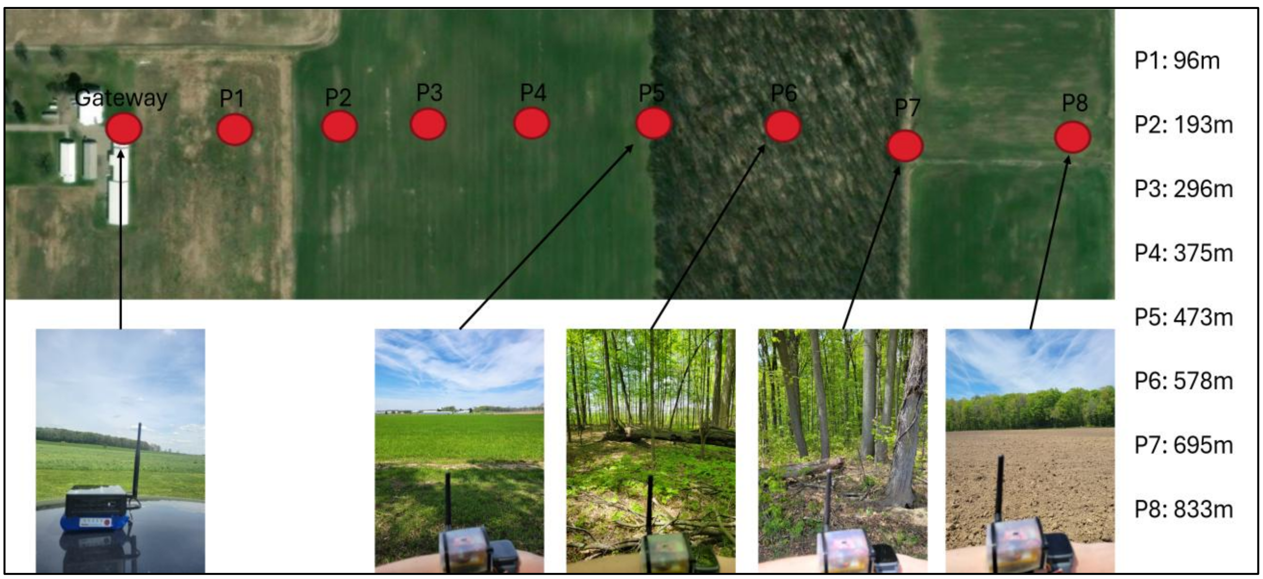


Figure 11. May 8th, 2026 test path

### 3.6.1 Fall-Only Test Results

The received packet log showed that at least one positive fall-event flag was received at each marked distance out to 833 m. This does not mean that every individual fall attempt was successful. Several test points included both successful and failed fall attempts. Figure 12 therefore summarizes the result at the distance-point level.

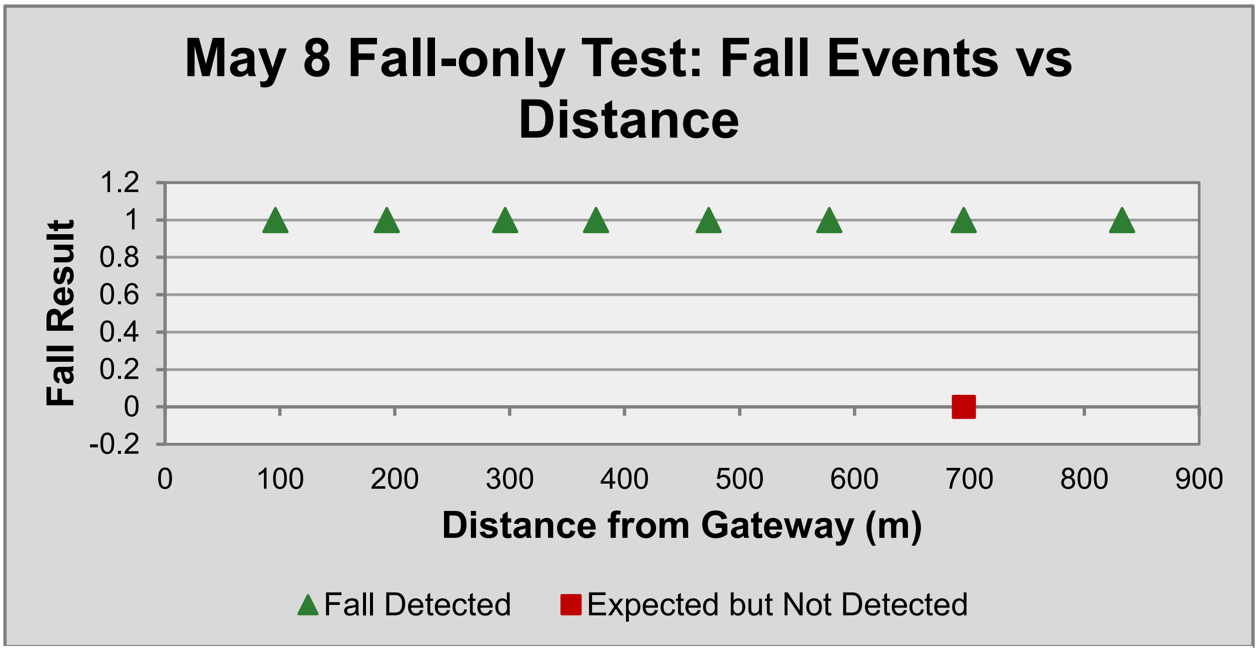

Figure 12. Fall-event results during the May 8th fall-only test.

A green triangle indicates that at least one expected fall test at that distance produced a positive fall-event flag, while a red square indicates a test window where an expected fall did not produce any positive fall-event flag. The plot does not include every raw packet where fall_event = false.

Figure 13 shows RSSI and SNR values matched to the fall-test timeline and plotted against distance from the gateway. Link quality varied across the route, with weaker RSSI and lower SNR appearing near the farther points. Fall-event packets were received at every marked distance, although not every individual fall attempt produced a positive event flag. One expected return-path fall test near 695 m produced no positive fall-event flag.

This test helps separate communication performance from prototype fall-detection behavior. In earlier field tests, missed fall events may have resulted from enclosure shock absorption, IMU orientation, threshold timing, cooldown behavior, or inconsistent physical test motion. In the focused fall-only test, positive fall-event flags appeared at every marked distance point, supporting the conclusion that the communication layer was capable of transmitting fall alerts. Remaining inconsistencies are more likely associated with mechanical packaging, sensor coupling, and fall-detection logic than with LoRa's ability to transmit a binary event flag.

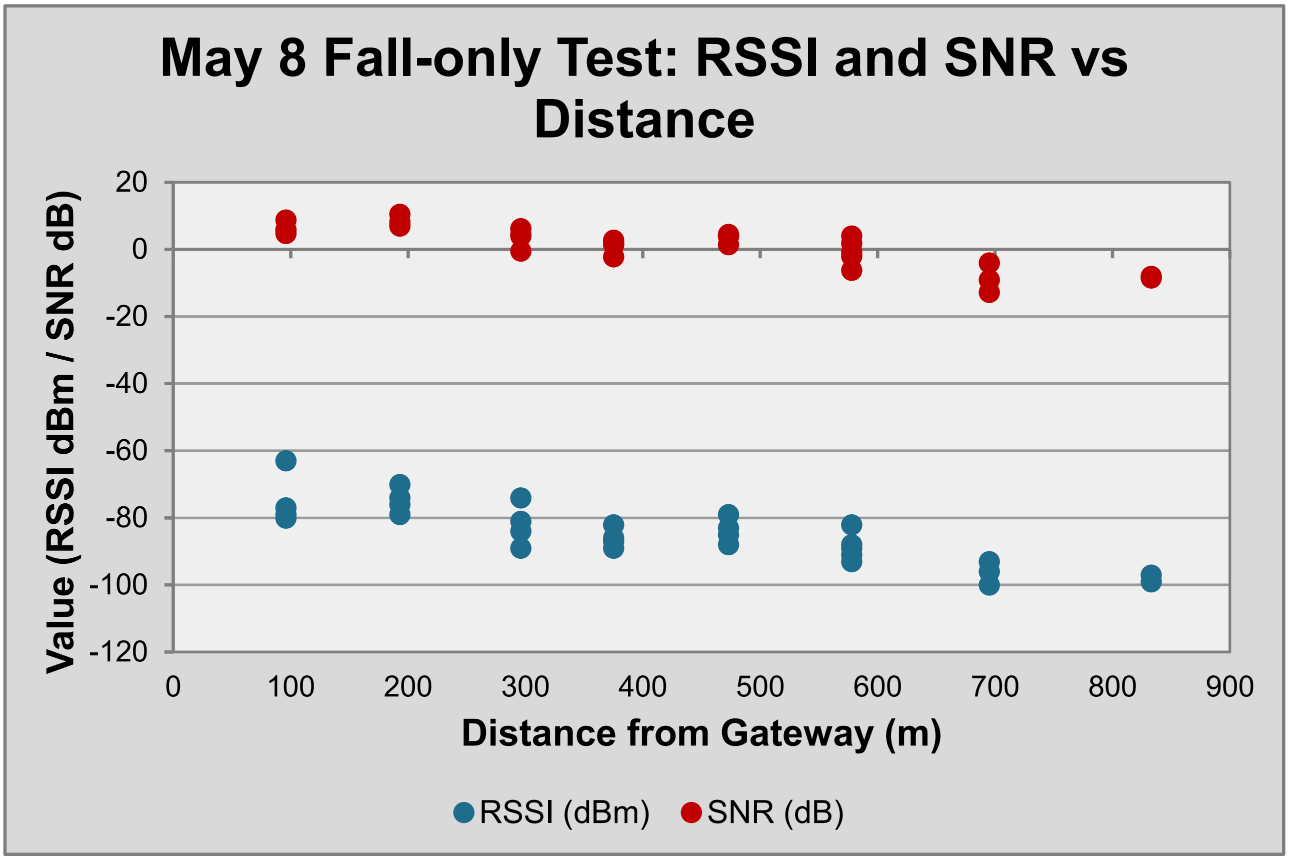


Figure 13. RSSI and SNR during the May 8th fall-only test.

Overall, the May 8 fall-only test supports the feasibility of transmitting low-bandwidth safety alerts over LoRa. A fall event requires only a small payload field, making it well matched to LoRa's low-data-rate communication model. However, this test should be interpreted as prototype event-flag validation, not as a clinical fall-detection accuracy study.

### 3.7 Antenna Configuration Tests

Additional testing was conducted on May 8 to compare antenna configurations along the same farm route used for the fall-only test. The purpose was to evaluate whether a directional (concentrated signal one way) gateway antenna improved practical LoRa communication performance compared with the omnidirectional (360 degree horizontal coverage) antenna gateway setup.

The omnidirectional configuration used the RSSI and SNR results from the May 8 fall-only test, which used a one-half wavelength base antenna at the gateway and a one-quarter wavelength antenna on the wearable node. The directional configuration used a rectangular directional gateway antenna with a one-half wavelength antenna on the node. Both tests followed the same route out to approximately 833 m and back toward the gateway, as shown in Figure 14.

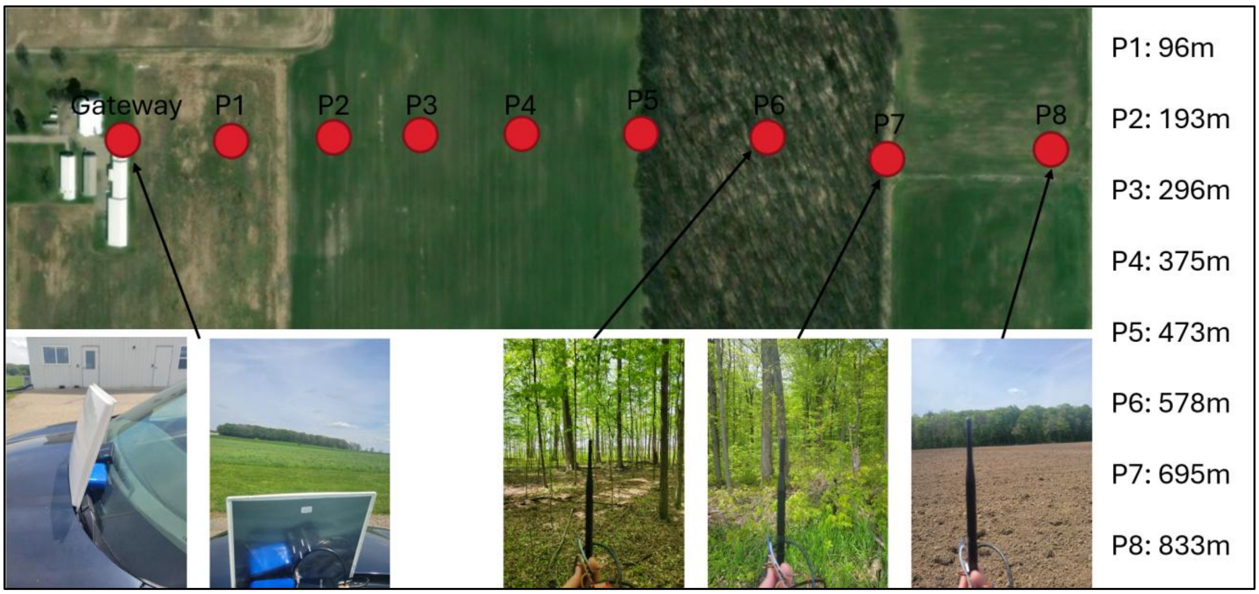


Figure 14. Directional antenna configuration and route for the May 8th antenna comparison.

Because the tests were conducted on the same day and along the same route, the comparison reduces day-to-day environmental variation. However, the comparison should still be interpreted as a practical comparison between complete antenna configurations rather than a controlled isolation of one antenna variable, because both the gateway antenna and node antenna changed between configurations.

RSSI and SNR were plotted separately against distance from the gateway. Only received packets are shown in the RSSI and SNR plots. No-signal windows are omitted because RSSI and SNR are only available when a packet is received. Therefore, missing directional values at farther points indicate communication failure during those test windows rather than missing numerical data.

The RSSI comparison showed that the omnidirectional configuration maintained measurable packet reception across the full route, including the farthest point at approximately 833 m. In contrast, the directional configuration produced measurable RSSI only through the early-to-mid route. The directional setup began with weaker RSSI than the omnidirectional setup and did not maintain received packets across the full route. This indicates that the directional configuration did not provide a practical received-signal-strength advantage for this moving-node test.

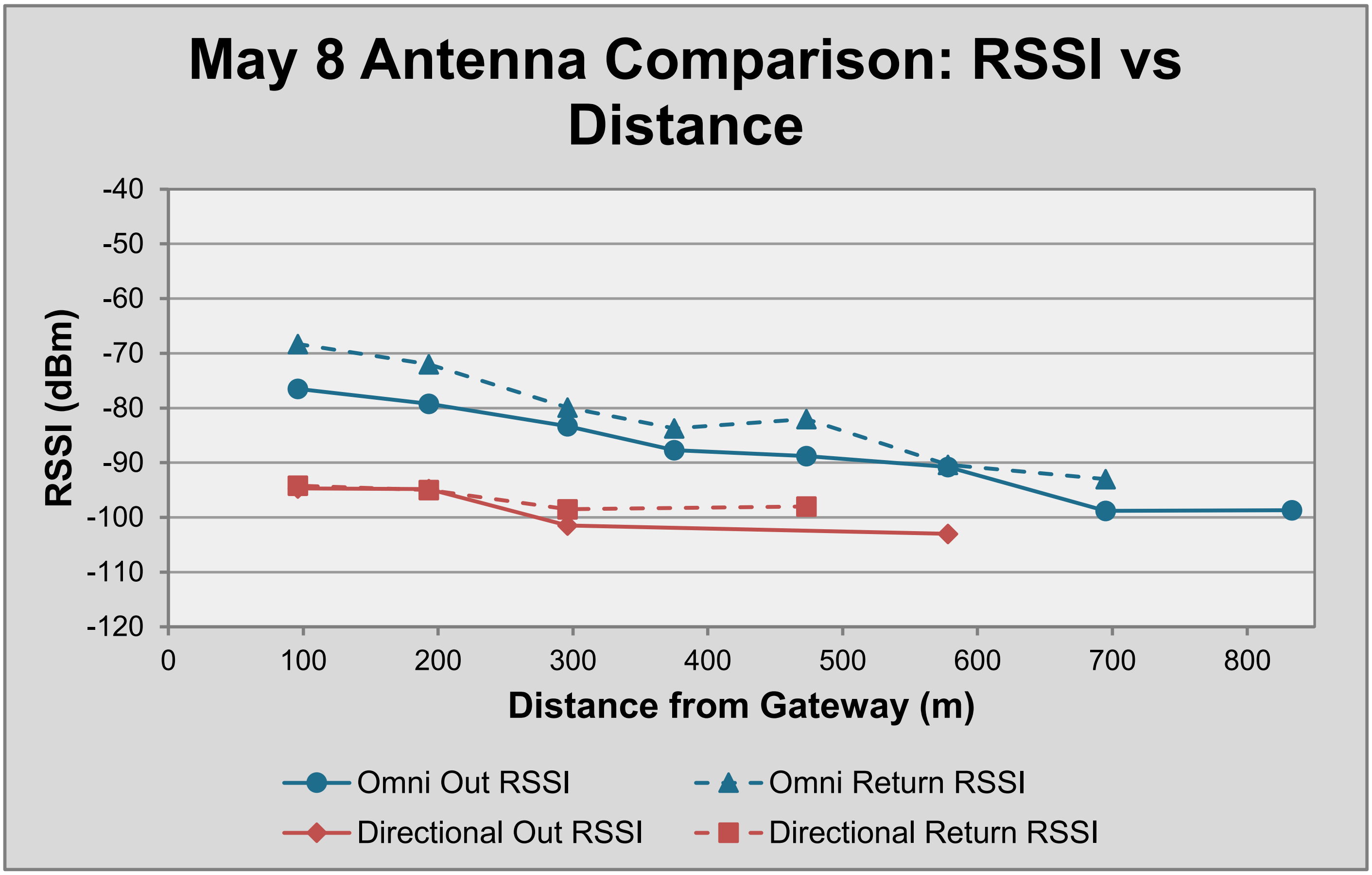


Figure 15. RSSI values are plotted against distance from the gateway for the omnidirectional and directional antenna tests. Only received packets are shown; no-signal windows are omitted because RSSI is only available when a packet is received.

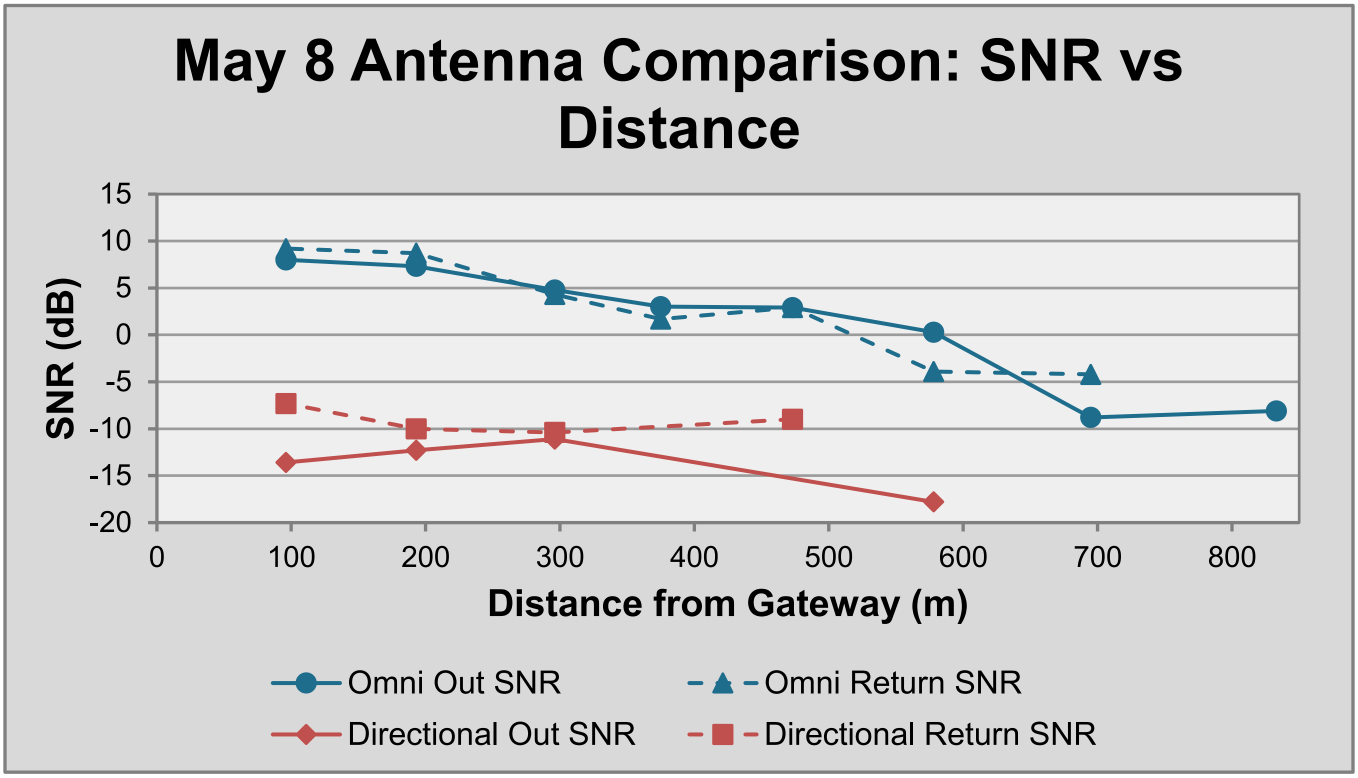


Figure 16. SNR values are plotted against distance from the gateway for the omnidirectional and directional antenna tests. Only received packets are shown; no-signal windows are omitted because SNR is only available when a packet is received.

The SNR comparison showed the difference more clearly. The omnidirectional setup maintained positive SNR through the early and middle portions of the route and continued to produce measurable packets at longer distances. The directional setup showed negative SNR at all measured distances, indicating reduced link margin even when packets were received. At farther route points, no SNR value was available because no directional packets were received.

Figure 16. SNR values are plotted against distance from the gateway for the omnidirectional and directional antenna tests. Only received packets are shown; no-signal windows are omitted because SNR is only available when a packet is received.

This result is important because the directional test used a one-half wavelength node antenna, which would generally be expected to perform better than a one-quarter wavelength node antenna. However, the overall directional configuration still performed worse than the omnidirectional configuration. This shows that node antenna gain alone did not determine link quality. The complete RF path mattered more, including gateway antenna pattern, antenna alignment, node orientation, polarization, route geometry, terrain, and vegetation.

The directional antenna likely required more precise alignment with the node path than the field route allowed. Directional antennas can provide gain when the receiver is located within the antenna's main "beam", but that advantage can be lost if the node moves outside the beam, changes orientation, or experiences polarization mismatch. In this test, the node was mobile and followed a route that changed direction as it moved away from and back toward the gateway. Under those conditions, the omnidirectional base antenna's broader coverage pattern was more effective.

The comparison does not mean that directional antennas are worse in general. A directional antenna may still be useful for fixed point-to-point links where the node location is known, and the antenna can be carefully aimed. However, for this wearable monitoring route, the omnidirectional setup was more robust. The results suggest that orientation tolerance and coverage pattern mattered more than nominal antenna gain for a moving wearable node in mixed rural terrain.

One important note is that the gateway was placed 4 feet from the ground, which increased communication difficulty compared to a taller gateway placement.

Overall, the antenna comparison showed that the omnidirectional one-half wavelength base antenna with the one-quarter wavelength node antenna produced more reliable field performance than the directional base antenna with the one-half wavelength node antenna. The directional setup had more theoretical gain available, but its performance was limited by alignment and route geometry.

For rural wearable monitoring, this suggests that broad gateway coverage may be more practical than directional gain unless the node location and antenna orientation are fixed and controlled.

## 4. Additional Applications Tested

Although the primary focus of this work was wearable rural monitoring, the same low-power communication approach was also evaluated in an agricultural sensing application. During the later stages of the project, LoRaWAN soil-monitoring sensors were deployed in the Michigan State University Plant Resilience Institute greenhouses to investigate the feasibility of low-cost environmental monitoring.

The sensors transmitted several data points relevant to agricultural monitoring, including air humidity, air temperature, and soil moisture using analog-to-digital conversion, along with battery voltage, packet count, RSSI, SNR, and time.

Figure 17 presents the soil moisture measurements collected throughout the deployment. Variations between sensor nodes reflected differing local watering conditions and soil environments within the greenhouse. Several intervals of missing data are visible throughout the dataset. These gaps correspond to periods when the LoRaWAN gateway temporarily lost power or network connectivity while being relocated within the greenhouse and therefore represent missing measurements rather than sensor values.

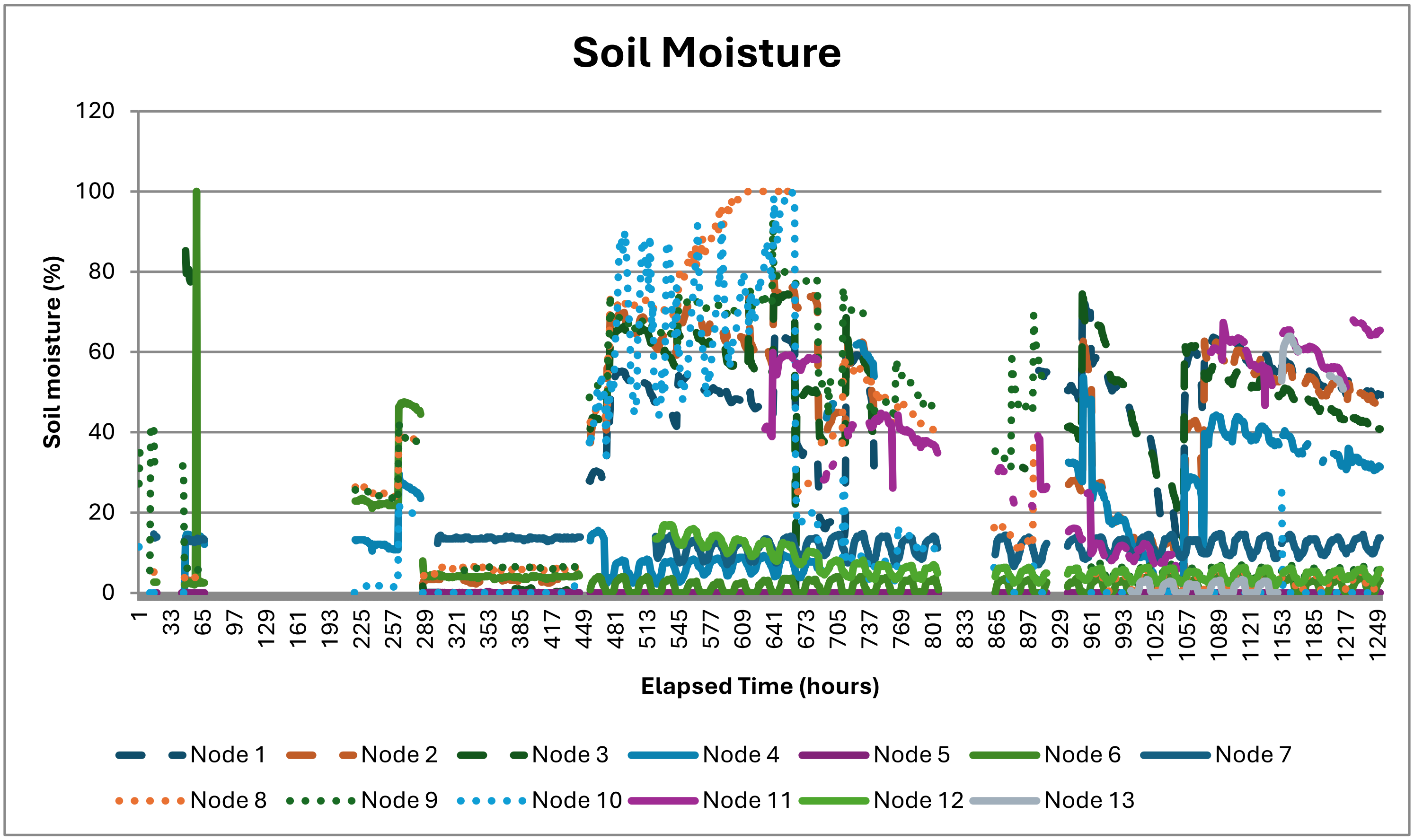


*Figure 17. Soil moisture measurements collected from the deployed greenhouse sensor nodes over the monitoring period. Data gaps correspond to temporary gateway outages.*

Figure 18 shows the measured air temperature for all deployed sensor nodes. The sensors exhibited consistent daily temperature cycles, with measurements generally tracking one another throughout the deployment. Temperature fluctuations corresponded to normal greenhouse environmental conditions and demonstrate consistent operation of the distributed sensing network.

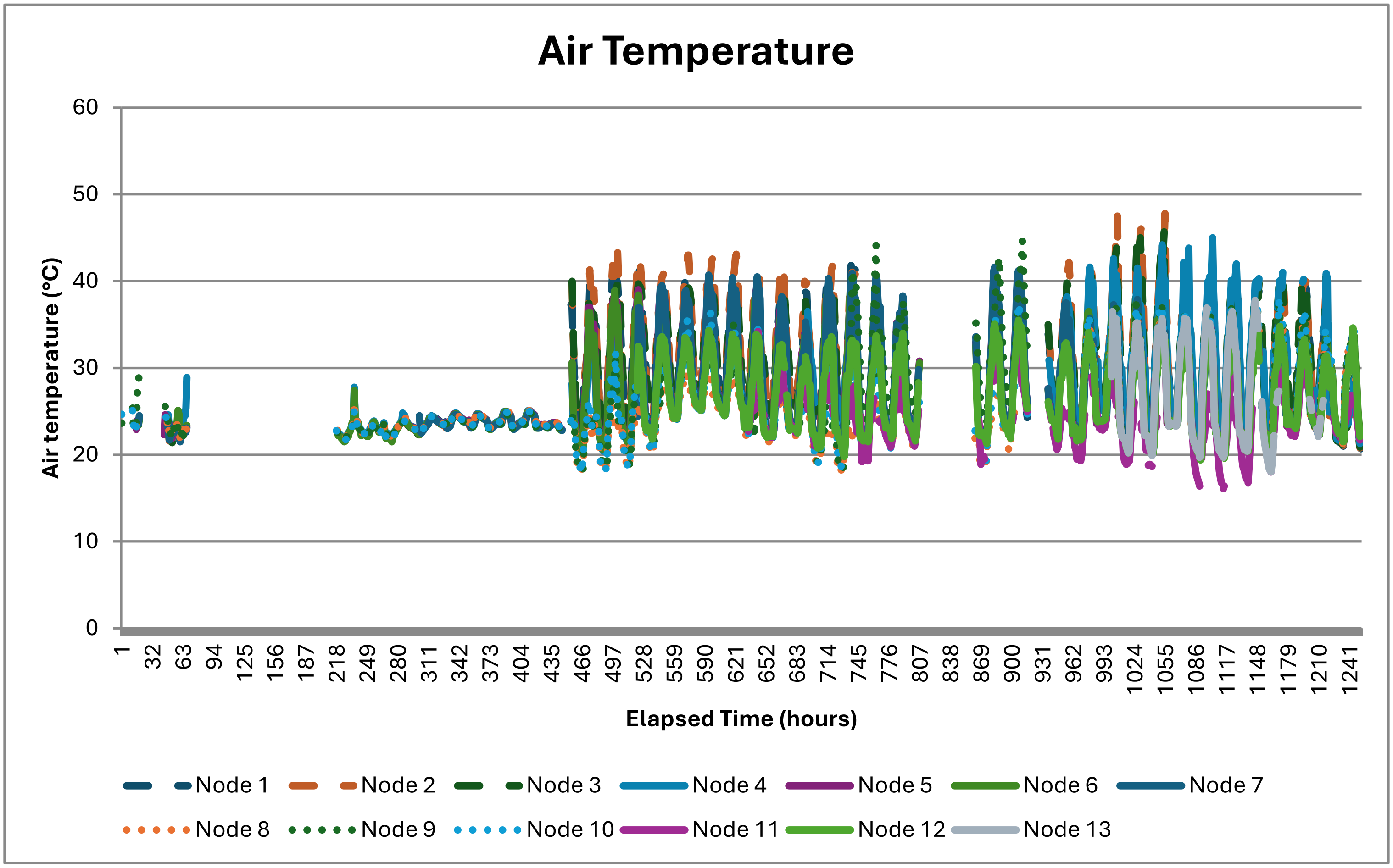


*Figure 18 Air temperature measurements recorded by each greenhouse sensor node.*

Figure 19 presents the measured relative humidity. As expected, humidity exhibited periodic variations throughout the deployment and generally followed trends inverse to air temperature during daily heating and cooling cycles. The close agreement between sensor nodes demonstrates reliable environmental monitoring across the greenhouse.

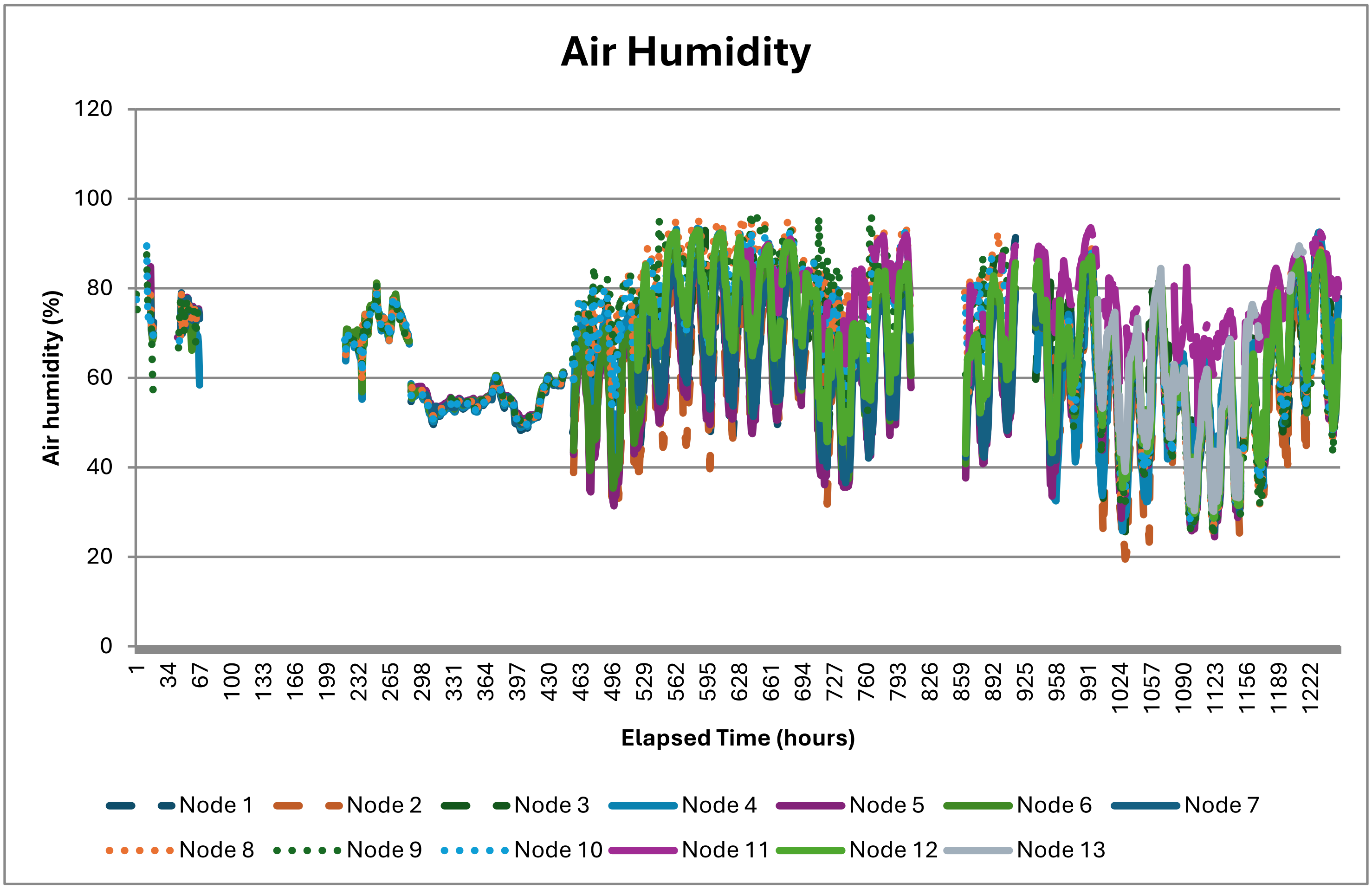


*Figure 19 Relative humidity measurements recorded by each greenhouse sensor node.*

Figure 20 summarizes the received signal strength indicator (RSSI) values for all deployed nodes. Most received packets were observed between approximately −100 dBm and −120 dBm, indicating relatively weak but stable radio links within the greenhouse environment. Despite the varying signal strengths, the network maintained reliable communication during normal gateway operation.

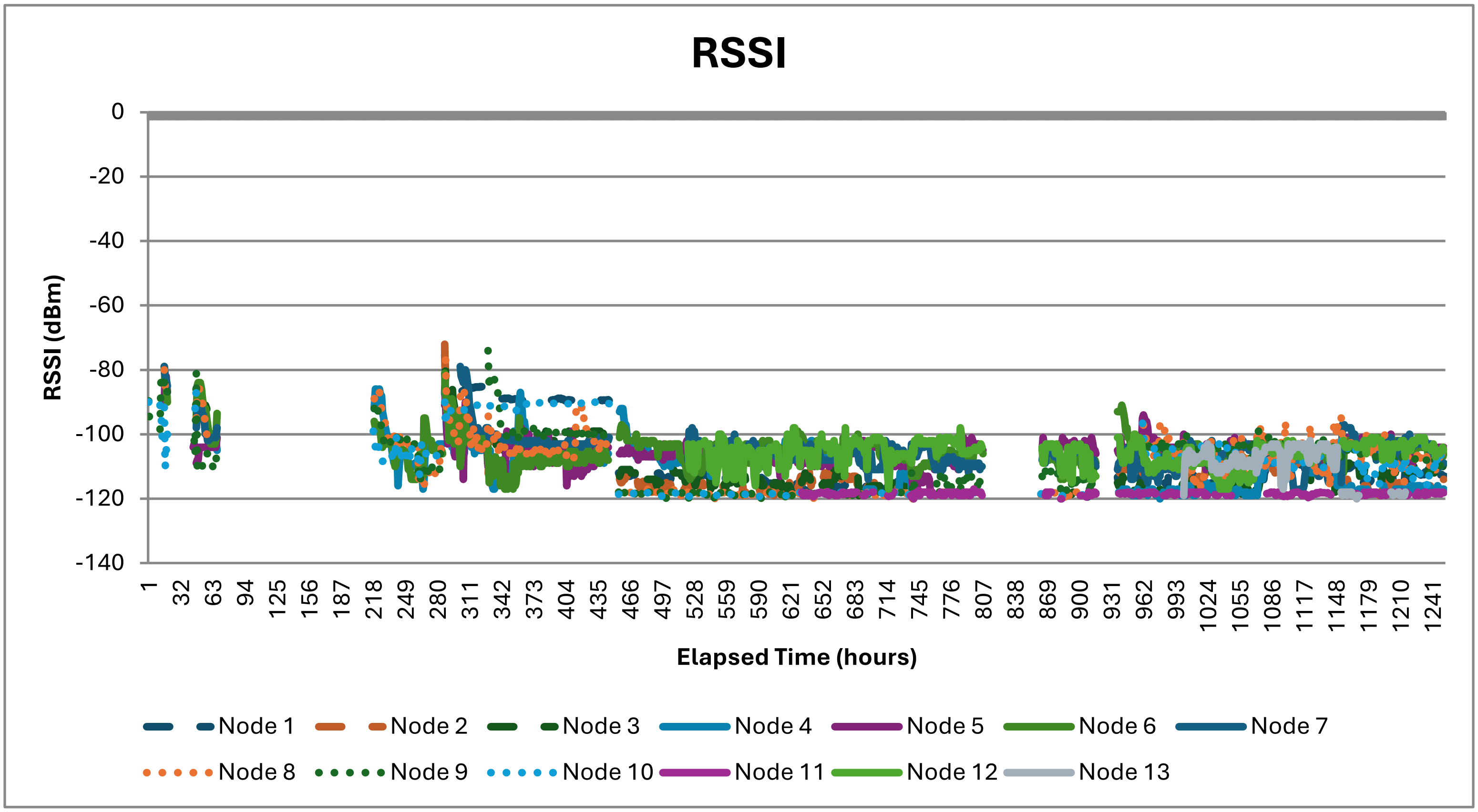


*Figure 20 RSSI measurements recorded from all greenhouse sensor nodes.*

Figure 21 presents the signal-to-noise ratio (SNR) measurements throughout the deployment. SNR varied considerably among sensor locations due to differences in propagation paths and local environmental conditions. Several nodes operated successfully with negative SNR values, demonstrating LoRaWAN's ability to maintain communication even under challenging radio conditions.

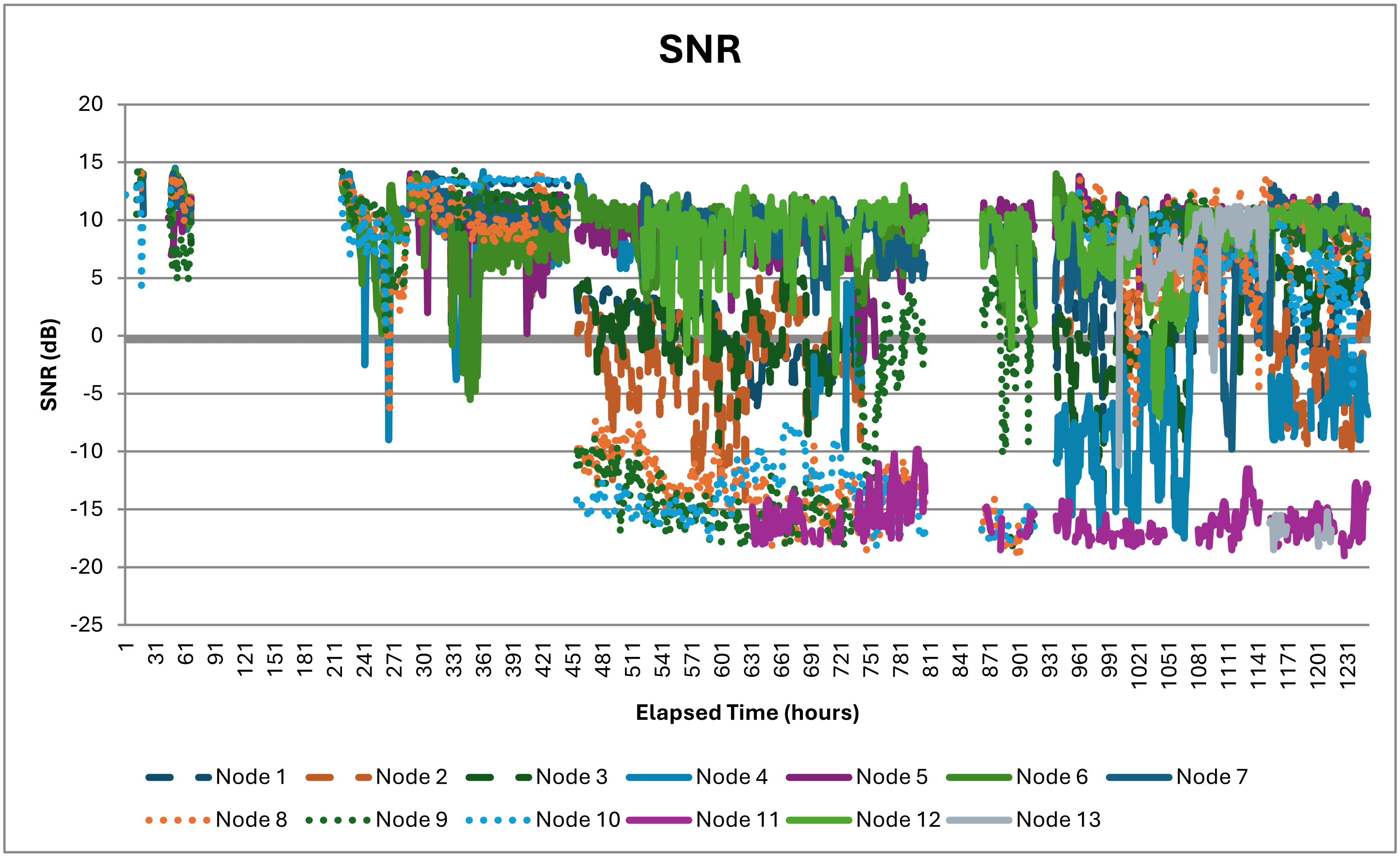


*Figure 21 SNR measurements recorded from all greenhouse sensor nodes.*

### 4.1 Summary of Greenhouse Deployment

The greenhouse deployment showed that the LoRaWAN architecture could support multiple distributed environmental sensing nodes over an extended monitoring period. The system collected soil moisture, air temperature, humidity, RSSI, and SNR data from 13 nodes during normal gateway operation.

Temporary gateway outages introduced periods of missing data during relocation and maintenance. Normal data collection resumed after gateway power and connectivity were restored without requiring sensor reconfiguration.

These results support the use of the communication architecture for low-cost distributed environmental monitoring. However, sensor accuracy, calibration, packet-delivery rate, or long-term reliability were not validated.

**5. Overall Assessment**

Across the field tests, the LoRa link successfully transmitted low-bandwidth packets beyond typical Wi-Fi range under realistic rural conditions, including obstructed terrain, mixed farm routes, wooded areas, and distances exceeding 1 km. Because testing was limited by available line-of-sight locations, accessible routes, terrain, and gateway height, these results represent the communication performance observed under the available rural test conditions rather than the maximum achievable range.

The results also showed that radio-link performance and application-layer sensing must be evaluated separately. In several tests, packets were successfully received even when heart rate, SpO2, or fall-event behavior was inconsistent. This suggests that many biometric and fall-test failures were caused by sensor contact, enclosure effects, IMU orientation, or prototype packaging rather than LoRa communication failure.

The greenhouse deployment further demonstrated that the same communication architecture could support long-term agricultural sensing. Temporary gaps observed in several datasets resulted from planned gateway relocation and power interruptions.

Future work should include controlled line-of-sight range testing, battery-life characterization, improved enclosure design, better sensor mounting, repeated controlled fall trials, and longer-term unattended field testing.

## 6. Conclusion

This project demonstrated a low-cost LoRa-based rural monitoring prototype and characterized its field performance under realistic Michigan rural conditions. The system successfully transmitted compact sensor and environmental data across multiple environments, including obstructed terrain and distances exceeding 1 km, while also supporting greenhouse environmental monitoring using soil moisture, air temperature, and humidity sensors.

The results demonstrate that LoRa provides a practical communication layer for low-bandwidth rural IoT applications when combined with appropriate gateway placement, antenna selection, and reliable application-layer sensing. This prototype was developed for communication and field-characterization research only and is not intended or validated for real health, safety, or emergency monitoring without substantial redesign, validation, regulatory review where applicable, and long-term reliability testing.

References:

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MICHIGAN STATE UNIVERSITY

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