

A Portable IoT and Lora-Enabled Safety and Communication Framework for Small-Scale Fishing Vessels

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ABSTRACT

Communications is still a concern for small-scale fishing vessels that don't have expensive satellite systems. This paper describes geolocation, Environmental Sensing, and resilient, two-way LoRa communications. In addition, it presents a portable IoT framework that revolves around an ESP32-S3 microcontroller and an SX1278 transceiver. Within a dashboard supported by Firebase, it synchronizes the data collected during internet inactivity. The system is active during internet outages. Active two-way messaging is possible in the proposed system, which is an improvement over existing systems that emphasize one-way telemetry. This allows for real-time safety communications and monitoring. Shackelford and Schoch, in their field trials, noted reliable messaging across two kilometers inland and four kilometers offshore, proving its alignment with near-shore fisheries operations. The practicality is enhanced by the system's portability, modularity, and low price, which also allows for scalability into larger fleets and the national fisheries monitoring system. Planned future improvements involve AES-based encrypted messaging, energy management for multi-day voyages, mesh relay systems to extend communications, and a community-level safety tool. This enhances and strengthens the proposed system as a national-scale safety solution.

Keywords: LoRa, ESP32, IoT, Fisheries safety, Marine communication

INTRODUCTION

Coastal communities continue to rely on fishing for a living. In Sri Lanka however, it is common for P Class vessels to have to function without expensive commercial AIS or VMS AIS, widget is classed for the industrial fishing fleet. Given those constraints, small vessels do have a form of satellite communications, either through a mobile network, VHF radio, or even worse ad-hoc communications. Both of which (mobile and radio- VHF) are utterly useless offshore and can create life threatening situations when they fail.

Recent studies have shown that LoRa and similar low power wide area networks have the potential to be used in maritime communication [1–4]. Although distance and certain environmental factors impact signal performance, LoRa allows for low cost and low power communication, making it favorable for fisheries monitoring. Previous work [5] implements low-cost tracking systems and IoT dashboards utilizing ESP32 for various industrial and emergency uses [6–8]. However, the most critical systems these works are based on emphasize passive telemetry, primarily to locate or monitor environmental data, fundamentally ignoring the much-needed active bi-directional communication systems that are essential at sea.

This study tackles the gap by offering a compact IoT system with two-way messaging over LoRa, environmental sensing, and cloud sync. For a fraction of the cost and without the modular and bulky design portability of AIS or VMS systems, the proposed kit exists to minimize onboard fixation. Of note, this device loss of internet connectivity will still be honored, as the device will continue to sync the data to the firebase dashboard once internet connectivity is re-established. The system strikes a balance between low cost, compact, and durable, providing an effective communication and safety device for small scale fisheries in the country with large community level deployment and even state wide use.

SYSTEM DESIGN AND METHODOLOGY

Sender Node Block Diagram

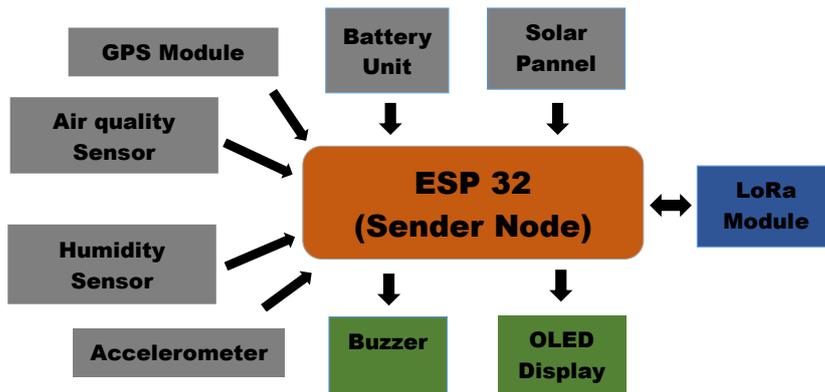


Figure 1. Block diagram of the sender node showing ESP32-S3 microcontroller, LoRa SX1278 module, GNSS, sensors, OLED display, buzzer, and power system. This illustrates the portable on-boat design.

The block diagram of the sender node is described in Figure 1. The anchor of the system is the ESP-32 Microcontroller owing to its dual core architecture capable of performing WIFI transactions and its proven ability to integrate with Lora modules. The microcontroller in the schematic is surrounded by other essential components that make the system robust in monitoring and safety. The vehicle's location and speed are continuously provided via NMEA sentences to the ESP32 from an integrated GNSS module. The environmental sensors lie within an MQ-2 detector and a DHT11 Sensor which are responsible for monitoring temperature, humidity, and detecting the presence of hazardous combustive gases that are of fuel leak on board. The 6-axis MPU6050 is an accelerometer, and a gyroscope helps in detecting tilt and motion which is critical when monitoring abnormal heel during a storm or other accidents. Approximately User feedback is conveyed and processed with the help of a 0.96" OLED display and a buzzer to signal alarms. The system is powered with the help of a rechargeable lithium-ion battery pack, along with additional solar battery for long hours at sea.

The sender node has been made with portability features; hence it can be taken onboard almost any small fishing boat with no need for physical installation. The modular block design minimizes couplings between subsystems, so the failure of a sensor or a module does not disable the whole system. The LoRa transceiver (SX1278) directly interfaces with the ESP32 over SPI, allowing comfortable and fast communication. This setup shows the value of the low-cost IoT for fisheries - the built system features more IoT devices and physical reliability than system elegance [1–3].

Receiver Node Block Diagram

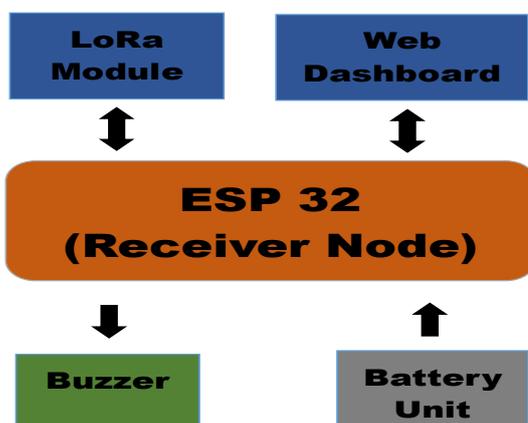


Figure 2. Block diagram of the receiver node with ESP32-S3 and LoRa SX1278 interfaced to Wi-Fi backhaul, highlighting its role as a gateway between sea and cloud.

The receiver node is presented in a block diagram in Figure 2. In its LoRa interface it has the same functions as the sender, but its sensing functions are simplified. As before, the ESP32 microcontroller functions as the computing center, while the SX1278 LoRa module is connected through SPI (serial peripheral interface). The circuitry is powered by a battery pack, and whenever the ESP32 has Wi-Fi connectivity, it sends recorded LoRa payloads to the cloud. The receiver has also a buzzer for local signaling, and it can be used on shore in ports, or on larger support vessels.

In contrast with the sender, the receiver is free from GNSS and environmental sensors, which simplified the design, and lowered the power consumption. The receiver's main task is to function as a bridge from the LoRa domain to the internet. The system has division of function which enhances reliability. The Wi-Fi backhaul could be superfluously disconnected, and the LoRa channel peers in a native mode, which means messaging continues uninterrupted.

Sender Circuit Diagram

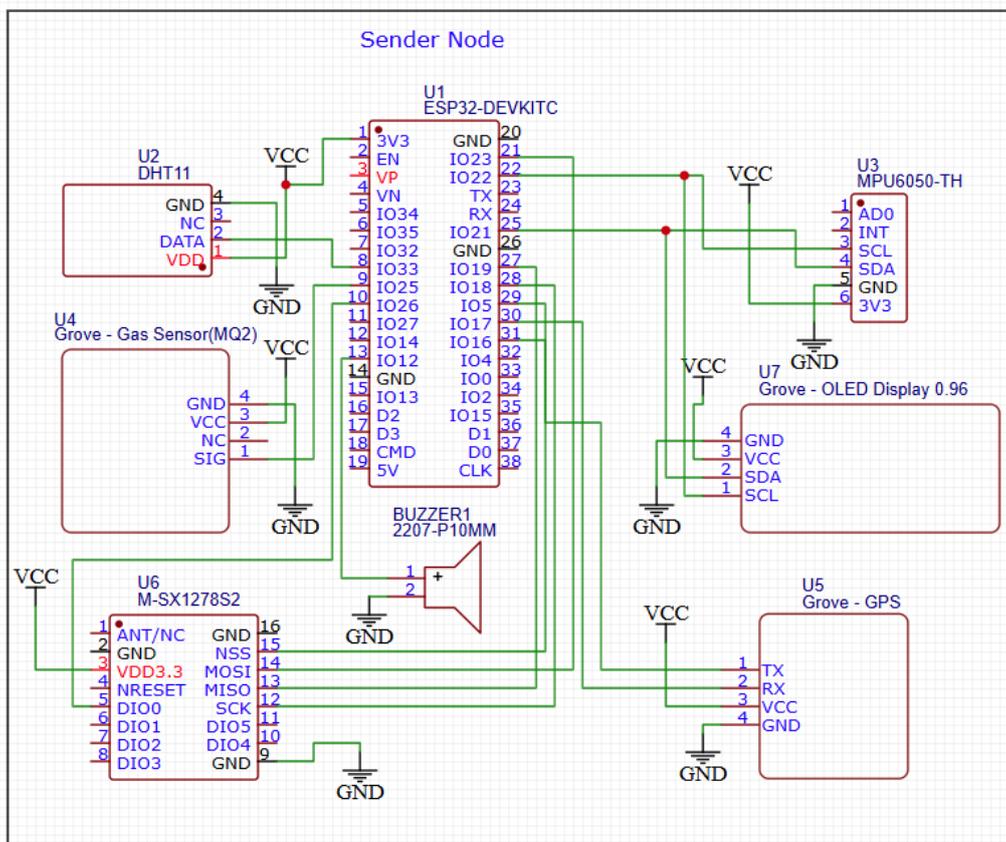


Figure 3. Circuit schematic of the sender node detailing pin connections between ESP32, LoRa, GNSS, sensors, and power rails.

The circuit diagram showing the details of the sender node is illustrated in Figure 3. The other peripherals managed by the ESP32 in different buses are: GNSS (UART), DHT11 Sensor and Buzzer (GPIOs), MQ-2 gas sensor (ADC channel), and the Buzzer and DHT11 sensor (GPIOs) with the DHT11 sensor. The LoRa SX1278 module is wired over SPI with Chip Select (CS) pin and allocated the reset and ESP32 pins the IRQ. Careful pin mapping enables seamless the real-time GPS parsing and LoRa packet processing of the receiver node.

The power distribution section takes in power from a 12V portable battery and/or solar panel and protects sensitive components by regulating the output power to 5V and 3.3V rails. The decoupling capacitors and pull-up resistors that were added to the I2C bus and sensor lines are designed to stabilize the signals. Loosely coupled modular designs in which the basic circuit boards have standard sockets to interconnect to other circuit boards to which modular replacement of components is the design a high priority for small rural communities to repair.

Receiver Circuit Diagram

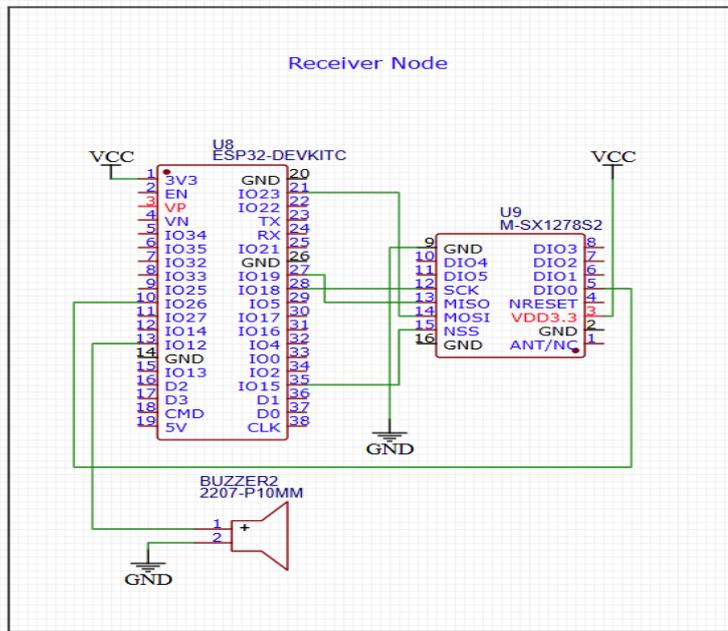


Figure 4. Circuit schematic of the receiver node showing ESP32 interfaced with LoRa transceiver, buzzer, and regulated power system.

In this diagram figure 4 shows the receiver circuit schematic. Loosely compared to the sender the wiring is more straightforward. The ESP32 communicates with the SX1278 LoRa transceiver over SPI and interfaces with a buzzer for alert tones. The ESP32 embeds the Wi-Fi subsystem therefore there is no additional hardware. Again, power is supplied through a rechargeable battery unit with regulated 3.3 V rails powering the MCU and LoRa module.

This deliberate decision is a result of the design's intention. The stripped receiver design minimizes the additional peripherals and therefore within the receiver will itself theoretically being more useful when used at coastal locations bases, as the receiver design will cost lower as well using mor personnel and power. When positioned at a coastal harbor with a clear line of sight to operational zones the receiver provides uninterrupted packet capture with cloud streaming and LoRa link as a backup communication line for seamless cloud integration of packet bursts.

Dot-Board Implementations



Figure 5. Prototype sender node assembled on a dot-board with sensors, OLED display, and upright LoRa antenna for portable boat-side operation.

The integrated sender's DOT board in Figure 5 demonstrates the incorporation of an ESP32 module alongside GNSS, an IMU, a gas, and a humidity sensor enabling it to track its position in space, detect movement, and monitor the environment. To facilitate unobstructed monitoring and alerting, the crew can access the board's ends where OLED panels and a buzzer are mounted. To prevent corrosion and saltwater intrusion, all connecting wires were bundled into a harness, which was insulated and shielded. For optimal antenna throughput, an attached LoRa antenna via an SMA connector is positioned upright for proper signal commanding communication.

The integrated receiver DOT board in Figure 6 demonstrates the node's intact communication and data receiving capabilities starting from the sender unit. Like the sender, it is built around the ESP32 and integrates supporting hardware for stable operation in marine conditions. The rugged layout of the board was designed to durability, user signal access, and sensitive reception, providing reliable performance in field deploy scenarios.

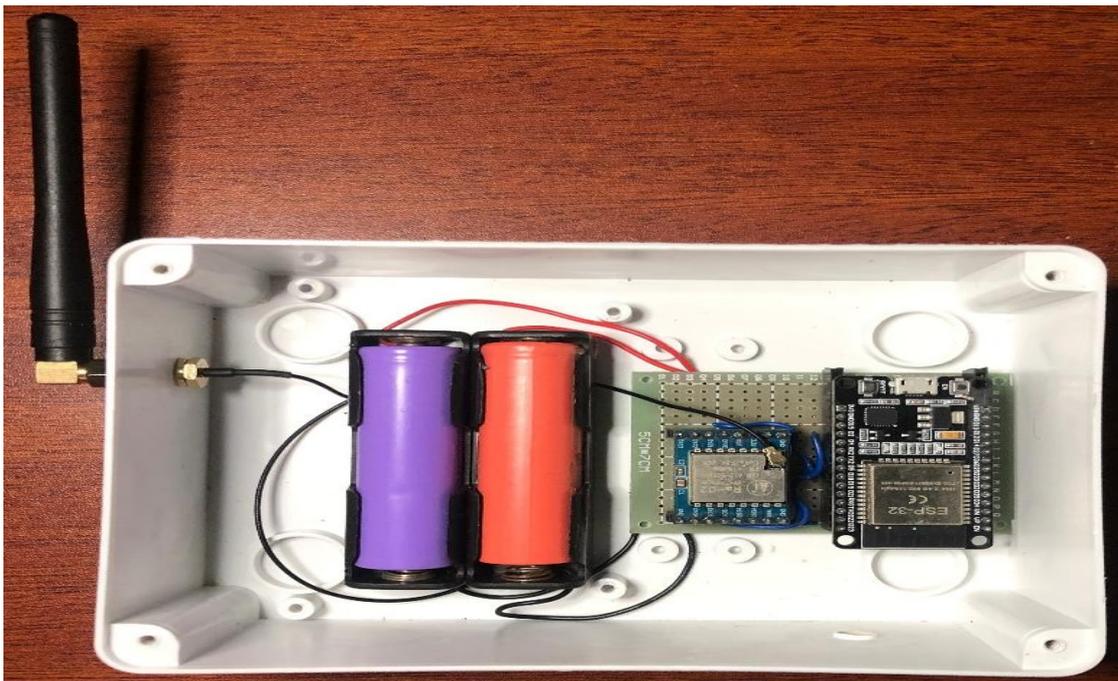


Figure 6. Prototype receiver node on a dot-board demonstrating stable LoRa reception and Wi-Fi forwarding.

Web Dashboard and Cloud Integration

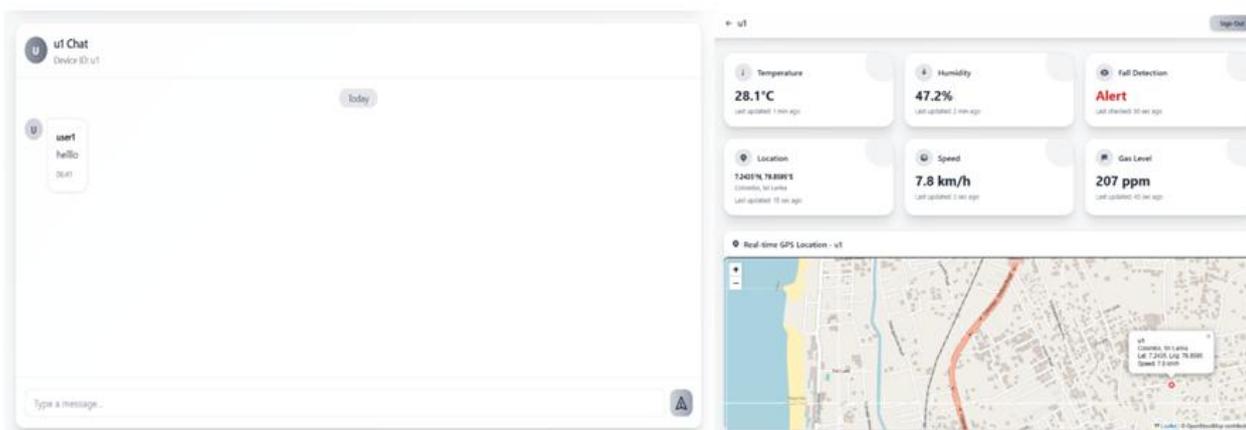


Figure 7. Firebase-based web dashboard with real-time telemetry, GNSS tracking map, fall-detection alerts, and two-way chat.

As shown in Figure 7, the web dashboard interface displays live information on the web. The dashboard updates in real-time and is connected to the Firebase Realtime Database, receiving new payloads as they arrive. There are three panes on the interface: (i) Realtime data readings of temperature, humidity, location,

speed and gas index value. Each data is depicted in rounded boxes and hazardous alerts are popping up. (ii) A breadcrumb map that captures time in synchronization with the GNSS position over time. (iii) A chat window with the crew and coordinators with the ability to send and receive messages.

With role-based access control, the operation can be carried out securely: Authenticated coordinators are able to send commands like force updates of the GNSS, whereas standard users are restricted to only telemetry and chat functions. Firebase's push-based model is essential to minimizing latency and bandwidth, particularly with poor backhaul connectivity. The interface provides actionable insights from the telemetry data and turns the data into useful information, which serves as the safety platform for the crews, coordinators, and families.

Range-Test Methodology

The device was tested inland along a rural corridor with partial vegetation obstruction. Text messages were transmitted using the LoRa long-distance radio transmitter, and acknowledgment messages, together with RSSI values, were recorded by the receiver at fixed distance intervals. The distance at which the last acknowledgment was received was defined as the practical "messaging reach." This operational metric was selected over raw path-loss modeling, as it provides a more accurate representation of user experience regardless of message delivery success. RSSI measurements were plotted against distance, producing empirical coverage curves consistent with previous studies on LoRa propagation.

RESULTS AND DISCUSSION

Dashboard and Telemetry Performance

The interface provided situational awareness during both bench and field trials in real time. Sensors were refreshed from acquisition in 1–3 seconds, consistent the latency of LoRa packets at spreading factor 9–12. Temperature and humidity readings were stable after warm-up, while gas sensor values reliably responded to controlled smoke exposure. IMU tilt data was accurately captured although there was an attempt to filter out the false alarms generated from wave motion. Sustained heel angles were still sustained.

These were consistent with the previous IoT dashboards using ESP32 and Firebase that demonstrated sub-second update propagation in ideal backhaul conditions [6,7]. The tested system, however, proved resilient irrespective of backhaul strain. LoRa text still operated independently.

Two-Way Messaging Functionality

The chat system was validated under both static and mobile trials. In every case, messages were prioritized above telemetry, maintaining conversational flow. Application-layer acknowledgements reassured users of delivery; a feature not present in most fisheries tracking solutions [5]. Crew members expressed confidence when the OLED display confirmed message exchange, improving usability and trust.

Sender Hardware Evaluation

Like Figure 5 indicates, the sender dot-board has sustained functionality when used outdoors. The OLED were prescriptive, and articulated GNSS locks, and showed sensor readings and confirmations of chat messages. The buzzer was activated on the spikes of gas concentration, illustrating the working of the life-saving warnings. The unit's modularity was, however, able to be achieved, and was able to be placed inside a waterproof box.

Receiver Hardware Evaluation

The receiver node proved reliable as a gateway. Its simple architecture reduced points of potential failure and the independent battery supported prolonged operation. Data streamed to Firebase without interruption when Wi-Fi was connected; when Wi-Fi was dropped, data streamed over LoRa chat without interruption. This dual pathway architecture has proven the benefits of separating local from cloud communication, as the local and cloud communication channels can be decoupled.

Field Test Results with Map and RSSI Graph

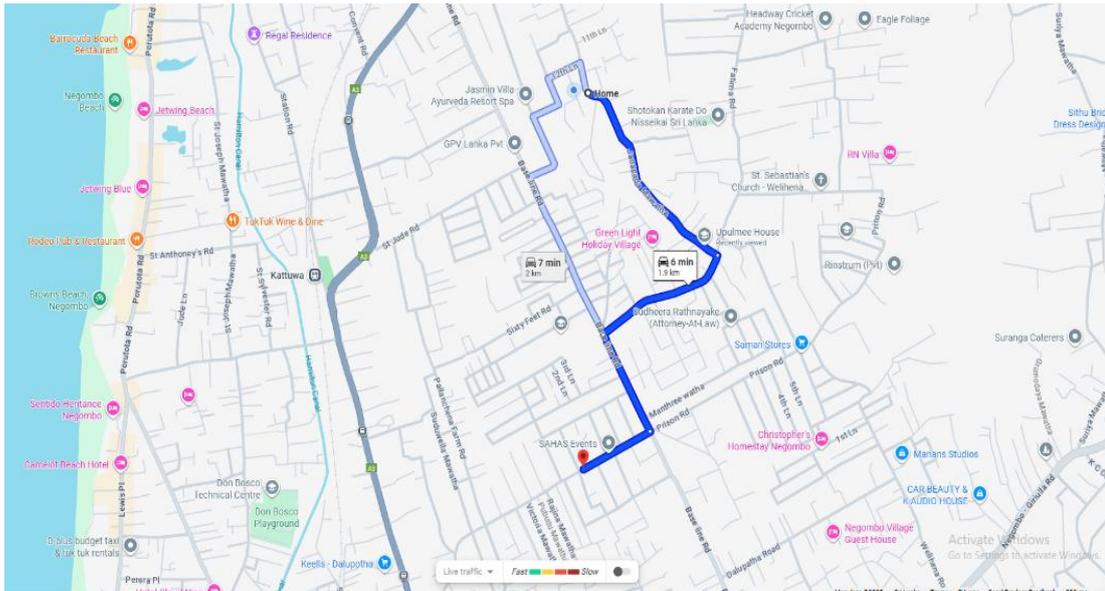


Figure 8. Mapped inland test paths showing message reliability across vegetation-obstructed environments.

The actual range of the system functionality has been verified in field trials. Land based routes achieved reliable messaging of approx. 2 km, as beyond that, acknowledgements were lost attributable to vegetation and other obstructions. Shoreline routes to the North, on the other hand, ranged 4 km under clear Fresnel conditions. These outcomes are brought to Figure 8, which shows the test routes and emphasizes points of loose and stored message exchanges. This sure indicates that the near-shore fisheries, which are assumed to operate within 10 km of the harbor, are able to utilize communication based on LoRa technology. [2-4].

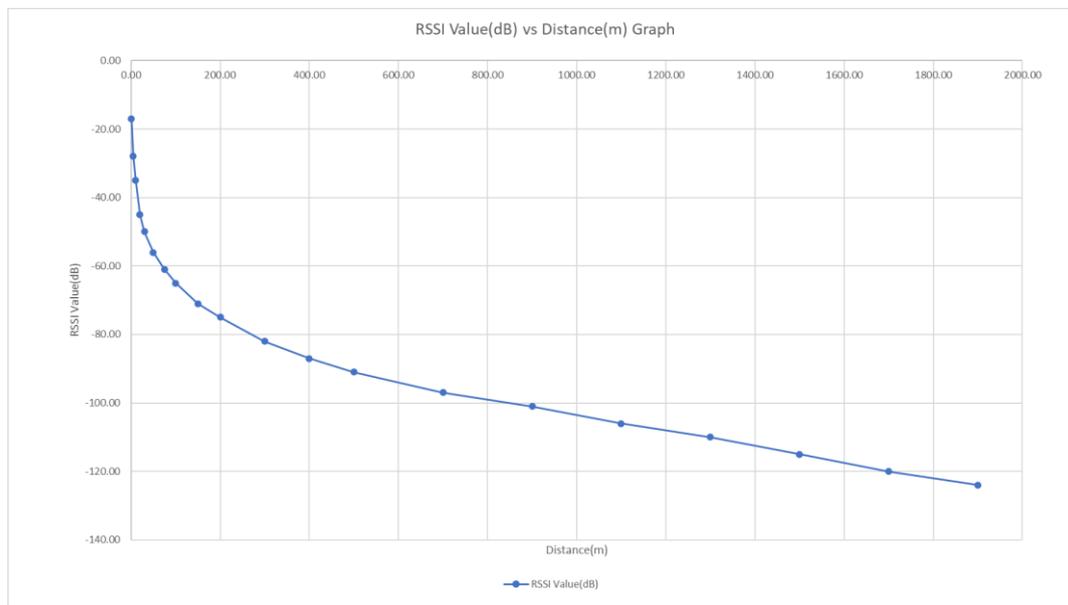


Figure 9. RSSI vs distance graph from inland and shoreline trials, showing gradual signal loss and confirming prototype reliability.

In Figure 9, the RSSI measured with respect to distance did not show a decline with distance. This increasing distance did not show a drop off which proves the prototype has good resilience and baseline coverage for the area. This also holds true for other marine LoRa studies. The prototype still needs to validate the accuracy for storms and other weather as well as long distance travel with varying antenna configurations for multi day trials. Much of this has already been accomplished with the results serving well for any further work in this regard.

Reliability and Security Considerations

Managing energy usage Wisely is important for keeping sailing operations going over a long period of time without the need to constantly recharge. Both deep-sleep modes of the ESP32 and the low duty cycle of LoRa minimize energy expenditure, while the system also integrates solar recharging for multi-day sailing operations. Other still adaptive duty cycling on slowdown cycles telemetry versus chat modes could prolong battery life even more.

Firestore auth is used for the secure dashboard of the system and will be complemented in the future with AES-128 encryption in LoRa for messages. This will ensure message confidentiality. Protection on the two layers is important for state level use and trust that will be used for private and commercial fishing use.

For fishing safety and monitor, it will also meet broader policy objectives that support it will also be suited for grassroots and centralized deployment for the whole country. It could cover borderless deployment due to the modular, low-cost design which is easy to replicate for community fleets. This improves construction based on the use of mesh relays or drone repeaters placed in the offshore waters.

CONCLUSION

The study presented here has developed a lightweight Internet of Things (IoT) based safety and communication system for small-scale fishing vessels. The system balances real-time telemetry and resilient two-way text messaging by integrating an ESP32-S3 Microcontroller with an SX1278 LoRa transceiver along with GNSS and environmental sensors. The field trials documented in this study show reliable communication within ~2 km of the land and 4 km of the shore and confirm the system's ability to meet the communication needs of near-shore fisheries with limited communication infrastructure.

The design's key features of portability, low cost, and lack of satellite-based AIS and a VMS make the system ideal for primary fishing communities. The structure of the prototype was proved to be compliant with the day-boat conditions and modular construction promotes ease of repair and extended use for the system.

In the future, it will also be necessary to evaluate the system performance on long continuous voyages with geo-fencing and rough weather with long-range communications. Multi-day operations will be sustained through optimized energy management that incorporates solar-assisted charging, duty cycling, and super deep-sleep modes. The backbone of the system may also include a LoRa module with AES-128 encryption to strengthen secured data policies, on top of the existing Firestore authentication on the cloud dashboard. Measures of scalability with drone-based mesh relay repeaters will extend coverage to offshore fleets, allowing for seamless integration with the national fisheries monitoring system.

The technical and operational components of these systems provide compelling evidence for their ability to enhance the safety of individual fishing crews, while simultaneously expanding the framework for community-level fisheries management and beyond.

ACKNOWLEDGEMENTS

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