Survey Paper on LoRa-Enabled Marine Communication Platform for Real-Time Ship-to-Ship Data Transfer

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Abstract: [1] A cost-effective river boat tracking solution employs GPS (UBlox Neo-6M) and LoRa with MQTT, achieving a communication distance of 1 km at SF7 and sensitivity up to -138 dBm for extended coverage. [2] Another LoRa-based safety system designed for fishermen enables boat tracking, alert transmission, and weather data sharing. It is lightweight, long-range, power-efficient, and simple to install. [3] An IoT-enabled LoRa–Zigbee monitoring framework has been developed to track tourist boats in Vietnam, facilitating passenger and route management while monitoring environmental parameters. The system was successfully tested on the Ninh Kieu–Cai Rang route. [4] LR-MPIBS integrates LoRa technology to deliver rapid man-overboard alerts within three seconds, maintaining steady power, reduced ripple, optimized RF design, 5 km range, and a 25-hour operating duration with better location precision. [5] Research on LoRa signal performance in tidal and estuarine regions proposes a model combining two-ray propagation with hydrodynamic and terrain-based factors. Experiments at 868 MHz verified the model's accuracy in estimating environmental signal fluctuations. [6] The use of LoRaWAN with IoT enhances greenhouse operations through smart monitoring, predictive control, and automated irrigation, leading to a 34% improvement in water efficiency. While it ensures secure communication via blockchain and AES128 encryption, issues related to scalability, energy use, and integration remain. [7] Another study evaluates LoRa's performance for V2V, V2I, and fixed vehicular links using SF7 and SF12 to measure signal integrity and Doppler effects. Due to its extended range, affordability, and dependability, LoRa is highly suitable for short-range vehicular data transmission. [8] An IoT-based AMI framework using LoRa in Chile's residential grid measures energy use, throughput, and data delivery, confirming LoRa's viability for smart metering and billing purposes. [9] A hybrid LoRaWAN system combining mesh and star topologies dynamically adapts to signal quality, resulting in enhanced coverage, lower latency, and improved RSSI and SNR. LoRa's flexibility enables affordable and stable metering in rural microgrids, effectively overcoming connectivity and cost challenges associated with conventional systems.

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I. INTRODUCTION

[1] In 2019, the Indonesian government mandated the use of AIS for vessels, but its high expense and limited communication range made it unsuitable for small boats navigating the Musi River. To address this issue, researchers developed a cost-effective LoRa-based tracking system utilizing Arduino Nano, the LoRa SX1278 module, and the GPS Neo-6M unit. The collected data is transmitted through MQTT to the ThingSpeak platform. Signal strength (RSSI) and path loss (MAPL) assessments confirmed that LoRa technology offers a scalable and efficient solution for realtime vessel tracking in areas with limited infrastructure. [2] Fishing activities are inherently dangerous due to unpredictable weather, limited communication, and delayed manual reporting. Traditional systems such as VHF, GSM, and satellite communication are often costly or have restricted coverage. In contrast, LoRa and LoRaWAN technologies provide a more affordable and long-range option for continuous monitoring, live tracking, and emergency alerting, significantly improving fishermen's safety in remote maritime zones. [3] Another project focuses on smart monitoring for tourist vessels operating in Vietnam's Mekong Delta, where Zigbee supports short-range connectivity and LoRa handles long-distance transmission. The system tracks boat movement, monitors environmental parameters, manages passenger records, and supports the tourism industry's post-pandemic revival. A mobile application provides real-time data access, and field trials on the Ninh Kieu–Cai Rang route demonstrated the system's affordability, compact design, and extensive coverage. [4] Marine operations involve significant risks, particularly

during man-overboard situations, where immediate and accurate detection is vital to ensure timely rescue. Traditional Position-Indicating Beacon Systems (PIBS) that rely on radio or satellite communication often encounter limitations such as short transmission range, signal interference, and false triggering of alerts. To address these drawbacks, researchers designed a LoRa-based Maritime Position-Indicating Beacon System (LR-MPIBS) integrated with the BeiDou satellite navigation network. This enhanced setup enables longdistance, low-power communication, minimizes false alarm occurrences, and ensures faster and more dependable rescue signaling in offshore environments.[5] Safeguarding delicate aquatic ecosystems requires continuous environmental observation. However, LoRa communication over tidal waters faces disruptions caused by dynamic terrain and hydrodynamic effects. This study incorporates a two-ray propagation model and hydrodynamic data to estimate signal degradation. Field tests in Portugal's Tagus Estuary validated the model's accuracy and strengthened the potential of LoRa for long-distance marine monitoring applications. [6] The integration of LoRaWAN technology with the Internet of Things (IoT) has proven highly effective for precision agriculture by enabling continuous monitoring of essential parameters such as temperature, humidity, light intensity, and soil moisture within greenhouse environments. The collected sensor data are transmitted to a central gateway and securely stored on cloud platforms for real-time analysis. This facilitates automated irrigation, microclimate regulation, and early detection of crop diseases. Although LoRa's communication range tends to decrease beyond several hundred meters, improvements in antenna design and the application of artificial intelligence and machine learning techniques can significantly enhance predictive accuracy and overall system automation in smart farming applications. [7] Vehicular communication systems (V2V and V2I) demand low latency and high reliability. Current technologies like DSRC are restricted by limited range and obstacle interference. Operating below 1 GHz with Chirp Spread Spectrum modulation, LoRa offers superior range, signal penetration, and tunable parameters (SF, CR, BW) ideal for infrequent and low-data vehicular telemetry. This study simulates LoRa channels, tests stationary links, and performs real-world experiments across urban, suburban, and rural environments, highlighting its suitability for vehicular IoT communication.[8] Smart grid technology depends on Advanced Metering Infrastructure (AMI) to facilitate twoway data exchange between energy providers and consumers. However, establishing a reliable and efficient communication network for Neighborhood Area Networks (NANs) continues to pose significant challenges. Owing to its extended communication range and minimal power consumption, LoRa technology offers an excellent alternative for such applications. Researchers have developed an IoT-based AMI framework simulated using the FLoRa platform to evaluate system parameters such as packet delivery ratio, energy consumption, data throughput, and collision rate. The experimental findings verified that LoRa provides a stable, energy-efficient, and cost-effective communication solution for modern smart grid environments.[9] LoRaWAN provides long-range, low-power IoT communication but has inherent limits in scalability, coverage, and flexibility. To overcome these, a LoRaWAN-compliant hybrid system was proposed, capable of dynamically switching between star and mesh topologies according to signal quality. The system includes a topology controller, built-in device firmware, and a userfriendly interface for network configuration, offering improved energy efficiency, coverage, and adaptability in sectors such as smart agriculture, cities, and industries. [10] Conventional electricity meters require manual readings, and smart meters often struggle in rural regions due to poor connectivity. A LoRa-based mesh network has been proposed for remote microgrids, supporting multi-hop data transmission to extend range and reliability. Simulation results show enhanced performance and efficiency, along with optimized algorithms that ensure stable network operation.

II. LITERATURE SURVEY

From Paper [1] — Apriani et al. (2023) described the development of a cost-efficient vessel tracking system that utilizes the LoRa SX1278 module along with a GPS module (UBlox Neo-6M). The GPS collects the ship's position and speed data, which are transmitted to a gateway through the LoRa module. Subsequently, the information is uploaded to the ThingSpeak platform using the MQTT protocol for realtime monitoring. The system processes GPS data by decoding NMEA messages and periodically updates the information. Experimental tests verified that the system maintains reliable operation within a range of up to 1000 meters, demonstrating consistent signal strength. The setup was specifically designed to overcome communication range limitations, ensuring dependable vessel tracking in actual operating conditions. Overall, the study presents a simple, economical, and efficient method for monitoring ships, particularly useful in regions where conventional tracking systems are difficult to implement. From Paper [2] — The developed system combines a GPS module, a LoRa transceiver, and multiple sensors into a compact onboard unit that can be installed on fishing vessels. This integrated setup enables continuous vessel tracking and movement monitoring in real time. Utilizing LoRaWAN technology, the system supports long-distance communication with very low power consumption, allowing fishermen to transmit emergency alerts and receive notifications even in areas where cellular coverage is unavailable. In addition, the platform delivers up-to-date weather information, helping operators make informed navigation decisions and improving overall safety during sea operations. From Paper [3] — Truong et al. (2023) introduced a hybrid wireless communication framework for tracking tourist boats in smart city environments, focusing on Vietnam's Mekong Delta region. The system integrates LoRa and Zigbee technologies to provide broad area coverage, energy efficient communication, and reliable data exchange in areas lacking traditional infrastructure. It facilitates real-time tracking of boat locations, passenger details, and environmental data such as temperature and humidity along the travel route. Experimental evaluation on the Ninh Kieu – Cai Rang floating market route in Can Tho City confirmed that the system effectively enhances safety, operational management, and tourism efficiency. From Paper [4] — Li et al. (2024) developed a LoRa-based Maritime Position-

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Indicating Beacon System (LR-MPIBS) aimed at strengthening maritime safety through rapid detection of man-overboard incidents. The proposed system integrates multiple sensors— including accelerometers, pressure sensors, and humidity detectors—to automatically recognize emergency situations and trigger distress alerts. The BeiDou satellite navigation module provides precise geolocation data, while the LoRa transceiver ensures reliable, low-power, and long-range communication. Furthermore, optimized power control and data processing algorithms enhance system stability and minimize operational errors. Experimental evaluation demonstrated that the setup can issue a distress signal within approximately three seconds, identify the individual's position in less than a minute, and sustain continuous operation for nearly 25 hours, confirming its effectiveness as a dependable maritime rescue mechanism. From Paper [5] — The authors performed extensive experiments to evaluate the efficiency of LoRa communication within estuarine regions characterized by fluctuating water levels and uneven terrain. A network of LoRa-enabled sensor modules was installed to collect environmental readings and analyze signal propagation behavior under diverse field conditions. The study highlighted essential configuration parameters that influence data stability and connectivity in such dynamic environments. Experimental outcomes verified that LoRa technology provides a reliable and power-efficient means for implementing IoT-based environmental monitoring systems in remote and challenging estuarine areas. From Paper [6] — This study provides an in-depth review of the implementation of LoRaWAN-based gateways in smart greenhouse systems for monitoring and forecasting key environmental variables such as temperature, humidity, soil moisture, and light intensity. The authors describe IoT-driven architectures that employ LoRaWAN to establish long-range, low-power communication links between distributed sensor nodes and a central control unit. The review also covers techniques for efficient data acquisition, predictive analytics, and sensor calibration, all aimed at optimizing crop productivity and conserving resources. In addition, it discusses challenges related to scalability, data management, and system integration, emphasizing how LoRaWAN-enabled IoT solutions contribute to the advancement of precision agriculture and sustainable farming practices. From Paper [7] — The study investigates LoRa performance in vehicular environments through field experiments evaluating communication range, reliability, and data throughput under multiple conditions. It explores the feasibility of LoRa for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) links—key components of intelligent transport systems. The results confirm LoRa's suitability for vehicular applications where cellular coverage is inconsistent, emphasizing its low power consumption and cost advantages for vehicular IoT deployment. From Paper [8] — The authors developed an intelligent metering framework that employs LoRa-enabled smart meters to capture and transmit real-time energy consumption data from residential areas to a central gateway. The proposed system allows two-way communication, enabling utility providers to remotely monitor and manage electricity usage while offering consumers detailed insights into their power consumption patterns. This architecture improves operational efficiency, minimizes maintenance and administrative costs, and ensures reliable data exchange between users and service providers. The study confirms that LoRa technology serves as a scalable, energy-efficient, and cost-effective communication platform for modern smart grid infrastructures. From Paper [9] — The researchers proposed an adaptive LoRaWAN-based system capable of switching dynamically between star and mesh communication modes depending on link quality. This ensures seamless connectivity across varying signal conditions. The implementation includes a graphical interface for configuring network topology and performance parameters. Testing across campus-wide environments achieved 100% success in topology switching, with latency ranging from 0.5 to 3.2 seconds. The study recorded improvements in RSSI and SNR, verifying the system's robustness and adaptability. From Paper [10] — The researchers carried out experimental testing of a LoRa-based mesh network in rural environments to evaluate its suitability for smart metering applications. LoRa-equipped meters were deployed across multiple remote locations to examine parameters such as network range, scalability, and communication reliability. The study also considered environmental factors influencing system performance, identifying both the advantages and constraints of meshbased LoRa architectures. The experimental outcomes confirmed that LoRa mesh networks offer a feasible and energy-efficient solution for IoT implementations in rural regions, providing valuable insights for expanding future large-scale smart metering systems.

III. OBJECTIVES

The primary objective of this study is to design, develop, and evaluate a LoRa-based wireless communication system capable of facilitating direct ship-to-ship data exchange without dependence on internet connectivity or any centralized control unit.The proposed setup aims to provide a reliable, cost-effective, and energy efficient communication framework ideal for marine environments. It allows vessels to transmit and receive vital information such as temperature, humidity, and emergency alerts to enhance maritime safety, coordination, and situational awareness. Each ship functions as a standalone node built around an ESP32 microcontroller and Raspberry Pi, both integrated with an SX1278 LoRa transceiver and a DHT11 sensor for real-time environmental monitoring. The gathered data is transmitted wirelessly to nearby vessels and displayed on an LCD module, while a buzzer activates whenever abnormal sensor readings or emergency conditions are detected. This feature ensures that alerts are promptly conveyed to the crew even if they are not continuously observing the screen. Another major objective is to assess the system's performance under real marine conditions, including coastal regions and open water environments. Key performance metrics such as Received Signal Strength Indicator (RSSI), communication range, Packet Delivery Ratio (PDR), and power consumption are analyzed to assess the stability and reliability of the LoRabased communication link. The broader goal of this project is to demonstrate the potential of IoT-based LoRa technology as a scalable and practical solution for marine communication networks. By combining sensor data

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acquisition, wireless transmission, and real-time alerting, the proposed system enhances vessel safety, environmental awareness, and inter-ship communication. This research lays a foundation for future IoT-enabled maritime networks with expanded monitoring and automation features.

IV. EXPERIMENTATION PLATFORM

The experimentation platform for the MarineMesh system was designed and implemented to test LoRa-based ship-to-ship wireless communication for transmitting and receiving important information such as temperature, humidity, and emergency alerts between vessels. The primary goal of this setup is to establish a cost-effective, dependable, and energy-efficient communication link that operates effectively in marine environments where traditional systems such as Wi-Fi or GSM tend to fail because of extended distances and weak signal strength. This configuration allows vessels to communicate directly with each other without depending on a base station or internet connectivity, making it highly useful for real-time monitoring and safety alert transmission in remote coastal and offshore regions. Each ship acts as an independent communication node powered by an raspberry pi and ESP32 microcontroller. The ESP32 was selected because of its high processing capability, low power consumption, and built-in wireless support. It is interfaced with an SX1278 LoRa module, which provides longdistance, low-power data transmission. Each vessel node is equipped with a DHT11 sensor to measure temperature and humidity, along with a NEO-6M GPS module that provides the vessel's precise geographic coordinates, including latitude and longitude.To display the gathered information, an LCD screen is attached to the system, and a buzzer is included to produce an audible alert whenever an emergency message is received from another ship. During operation, each ship node continuously monitors temperature and humidity through the DHT11 sensor and detects any emergency condition, such as excessive temperature, high humidity, or a manually triggered distress signal. Once the data is collected, it is transmitted to nearby ships using the SX1278 LoRa module. Although LoRa functions at a comparatively low data rate, it provides an extensive communication range, making it highly suitable for marine environments where physical obstructions are relatively limited. When another ship receives a LoRa message, it displays the temperature, humidity, and alert information on its LCD screen in real time, allowing the crew to track nearby vessels' environmental conditions easily. If an emergency alert is received, the buzzer automatically activates to provide an instant audible warning, ensuring that the crew is promptly informed even if they are not monitoring the LCD display. This feature enhances coordination and safety, particularly in conditions of low visibility, such as fog, storms, or nighttime navigation. The network operates in a mesh configuration, allowing every ship to both send and receive data. This enables smooth communication among multiple vessels simultaneously. Because LoRa supports long-distance wireless communication, ships can exchange data even when separated by several kilometers. Each communication node is powered by a rechargeable lithiumion battery, ensuring extended operating time. All electronic components are enclosed in a waterproof casing to protect them from moisture and harsh marine conditions during field testing near water bodies. For performance analysis, the system was tested in open spaces and near lakes and rivers to simulate real-world marine conditions. Key parameters, including signal strength (RSSI), communication range, data accuracy, and packet delivery ratio, were measured between ship nodes. Experimental results confirmed that the LoRabased ship-to-ship communication network functioned effectively over long distances with minimal packet loss. Both the LCD and buzzer features operated precisely, providing instant responses to every received emergency alert.

In conclusion, the experimental setup successfully demonstrated that LoRa technology is highly effective for direct ship-to-ship communication in marine environments. The system proved to be low-cost, stable, and energy efficient, making it suitable for environmental monitoring and maritime safety applications. It establishes a strong foundation for developing intelligent marine communication systems where multiple vessels can share environmental data and emergency alerts in real time. This concept can be further expanded to include additional ships and sensors for IoT based maritime functions such as pollution detection, weather tracking, navigation assistance, and coordinated fleet management. The Marine Mesh ship-to ship system thus provides a practical, scalable, and reliable solution for enhancing communication and safety in marine environments through LoRa wireless technology.

V. RESULTS

The Marine Mesh ship-to-ship communication system, developed using LoRa technology, was successfully designed, implemented, and tested to evaluate its real-time performance and reliability under practical environmental conditions. The experiments were conducted in open areas and near water bodies to assess how effectively LoRa can maintain stable communication over long distances between moving vessels. The main objective of these tests was to determine whether ships could exchange critical environmental data—such as temperature and humidity—in real time through a simple, low-power wireless network. Throughout the testing process, the system functioned smoothly and maintained consistent communication among all ship nodes. Each node collected live temperature and humidity data from the DHT11 sensor, which was then wirelessly transmitted to nearby vessels using the SX1278 LoRa module. Upon receiving the transmitted data, each ship displayed the updated environmental readings on its LCD screen, allowing crew members to monitor nearby vessels' conditions in real time. When a ship transmitted an emergency message or an abnormal sensor value (such as excessively high temperature or humidity), the buzzer on the receiving node immediately activated, alerting the crew to potential danger. This ensured faster response times and improved coordination between ships, especially in situations where visual or radio communication was difficult, such as during heavy fog, storms, or nighttime operations. During the experiments, the average communication range between two LoRa nodes was found to be approximately 2–3 kilometers

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over water and around 1.5 kilometers on land, depending on environmental factors such as antenna height, obstacles, and weather conditions. The results confirmed that LoRa technology is highly effective for marine communication applications, as it enables long-distance data transmission while consuming very little power. The measured signal strength (RSSI) values during testing ranged from –70 dBm to –110 dBm, indicating strong and stable communication performance even at extended distances. Additionally, the system exhibited a high packet delivery ratio (PDR), meaning that nearly all transmitted packets were received successfully, with very little data loss or delay. Communication between ship nodes remained continuous and dependable throughout the experiment. Even when one node moved farther away, neighboring ships were still able to receive and forward data, ensuring that no information was lost during transmission. The LCD displays updated temperature and humidity values in real time, while the buzzer alerts responded instantly to emergency signals, confirming the proper functioning of both monitoring and alert mechanisms. The system's power consumption was very low due to the energy-efficient design of the LoRa transceiver and the use of rechargeable lithium-ion batteries, which allowed continuous operation for several hours without the need for frequent charging. Overall, the testing results confirmed that the LoRa-based ship-to-ship communication system provides a reliable, low-cost, and power-efficient solution for transmitting vital environmental and safety data across marine environments. The system performed effectively in both open and partially obstructed areas, maintaining steady communication even when obstacles or distance variations were present. The integration of simple components like an LCD and buzzer made the system easy to operate and understand for the ship crew. In conclusion, the Marine Mesh communication platform proved to be a practical and effective solution for real-time data exchange and emergency alerting between ships. The results validate LoRa technology's capability to create safe, efficient, and intelligent marine communication systems. Future improvements can expand the system by integrating more sensors and ships to cover larger sea areas, further strengthening its potential in maritime safety and monitoring applications.

Fig. 1 Emergengy Alert Received at Node 1

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Fig.2 Emergency Alert at Node 2

VI. FUTURE SCOPE

At present, the Marine Mesh system is limited to vessel-to-vessel communication using LoRa transceivers. Future upgrades can transform it into a more versatile network by introducing ship-to-gateway connectivity, where each vessel transmits its sensor readings and alerts to a centralized monitoring or control hub. This improvement can be accomplished by incorporating GSM and GPS modules into the design. The GSM interface would allow continuous message transmission and emergency alerts even when ships move outside the LoRa coverage area, ensuring uninterrupted communication across large marine zones. Meanwhile, GPS integration would provide each vessel's realtime location, enabling automatic position sharing with nearby ships or the coastal monitoring center to enhance navigation accuracy and emergency handling. An additional enhancement could include a compact voice communication setup that enables crews to exchange short audio updates during critical or adverse weather situations. Such real-time verbal communication can minimize delays and improve coordination among vessels. Furthermore, the Marine Mesh network could expand its sensing capability by including modules for detecting gases, monitoring atmospheric pressure, and measuring water quality—thereby supporting pollution tracking and environmental condition analysis in marine ecosystems. To make the system energy efficient and maintenance-free, upcoming versions can employ solar panels paired with smart battery management circuits, allowing selfsustained operation for extended periods. A mobile or webbased dashboard can also be developed to visualize and manage information gathered from multiple ships through a single interface, assisting in centralized data analysis and decision-makin With these advancements, Marine Mesh could evolve into a comprehensive, intelligent maritime communication and monitoring platform. The enhanced system would strengthen navigation safety, environmental awareness, and fleet coordination—paving the way for smarter, cleaner, and more efficient marine operations.

VII. CONCLUSION

The Marine Mesh prototype was successfully designed, built, and evaluated to showcase the practical use of LoRa technology for low-cost, efficient, and reliable ship-to-ship wireless communication. The implemented setup enables vessels to exchange critical realtime information such as temperature, humidity, and emergency alerts directly with each other—without relying on the internet, satellite services, or any existing mobile communication infrastructure. Testing results confirmed that the system maintained stable connectivity over extended distances, with strong signal strength and minimal data loss. The integration of an LCD module and buzzer ensured that crew members could continuously monitor environmental parameters and receive immediate warnings in the event of abnormal readings or emergency conditions. By employing a Raspberry Pi and ESP32 microcontroller paired with the SX1278 LoRa transceiver, the system achieved low power consumption, enabling long-term operation on rechargeable batteries. This energy-efficient design makes it especially suitable for marine and coastal regions where reliable power sources or communication networks are often unavailable. Overall, the experimental findings validate that LoRa-based wireless communication can serve as a cost effective and dependable alternative to traditional maritime systems such as GSM . The Marine Mesh framework thus establishes a foundation for developing future IoT-based maritime communication solutions— offering enhanced safety, improved coordination, and smarter connectivity across marine operations.

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