Development of a LoRa Based IoT-Enabled Communication System for Long-Range Data Acquisition

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Abstract*- This paper presents a modular and energy-efficient Internet of Things (IoT) based environmental monitoring system employing long-range (LoRa) and Long Range Wide Area Network (LoRaWAN) communication protocols. The proposed system enables real-time, long-range acquisition of environmental parameters, including temperature, humidity, air quality, and global positioning system (GPS) data, from geographically distributed sensor nodes. A novel multi-wireless environmental sensing architecture based on a LoRa network is introduced, in which individual LoRa-enabled sensor nodes are interfaced with a temperature–humidity sensor, a gas sensor, and a GPS module, respectively. A dedicated LoRa module operates as a LoRaWAN gateway accountable for receiving and decoding data transmitted from the sensor nodes. The gateway locally displays the acquired measurements on a display screen and simultaneously uploads the data to the ThingSpeak IoT cloud platform. In addition, a web dashboard is implemented, incorporating embedded Google Maps for real-time geolocation tracking of sensor nodes. The system operates in the 868-MHz LoRa frequency band and demonstrates reliable wireless communication over distances of up to 1.0 km. Experimental evaluations conducted at multiple locations around the gateway confirm stable long-range communication and accurate sensing performance. The results validate the effectiveness of the proposed system in achieving robust data transmission, seamless cloud integration, and real-time visualization. Owing to its low power consumption, scalability, and long communication range, the system is well-suited for environmental monitoring applications in infrastructure-limited environments and remotely operated mobile robotic systems.

Keywords- *LoRa, Wireless sensor nodes, LoRaWAN, IoT, Cloud etc.*

I. INTRODUCTION

In recent years, long-range (LoRa) and low-power wireless communication technologies have emerged as critical enablers for Internet of Things (IoT) applications. These technologies are particularly valuable in scenarios where traditional communication infrastructures such as Wi-Fi or cellular networks are either limited or unreliable available [1]. By offering extended coverage, low energy consumption, and the ability to connect a large number of devices, they support the deployment of IoT solutions in remote, rural, and resource-constrained environments, thereby expanding the scope and impact of IoT in diffrent sectors [2]. For developing energy-efficient sensor networks, the protocols such as LoRa and LoRaWAN (Long Range Wide Area Network) can be utilised for transmitting small packets of data across several kilometers while consuming minimal power, making them ideal for remote monitoring, smart agriculture, environmental sensing, and industrial IoT systems [3]. Multiple research efforts have explored the use of LoRa for environmental data acquisition. Hanaffi et al. [4] proposed a single-channel LoRaWAN gateway for indoor monitoring, highlighting the impact of node placement and obstacles on signal quality and packet delivery ratio. Gowrishankar et al. [5] developed a smart electric meter that utilizes LoRa and ThingSpeak for real-time monitoring, showcasing LoRa's capability for long-distance telemetry. Similarly, Rahman et al. [6] introduced a multi-sensor LoRa-based disaster response system that combines gas, temperature, and GPS sensing to support emergency monitoring and early warning systems. In the domain of smart agriculture, Dang et al. [7] designed a sensor tag based on LoRaWAN for tracking livestock behavior, demonstrating the reliability of LoRaWAN in rural deployments. Other researchers have addressed system scalability and power efficiency. Bhusal et al. [8] designed a self-powered LoRa node using solar energy, allowing sustainable long-range environmental sensing. Jouhari et al. [9] analyzed LoRaWAN performance in high-density deployments and proposed techniques like adaptive data rate and gateway densification to improve network scalability. Recent studies have also explored deeper architectural, performance, and modulation innovations. Marini and Cuozzo [10] analysed the operation of LoRaWAN in EU868 MHz and 2.4 GHz bands, revealing that the 2.4 GHz version improves throughput in dense node environments at the expense of coverage. Gaddam and Rai [11] reviewed various technologies such as low-power, wide-area network (LPWAN), emphasizing LoRa's advantage in battery life and scalability. UAV-based LoRa networks have also gained attention. Ghazali et al. [12] systematically reviewed real-time deployments and showed that UAV-LoRa systems can dramatically extend coverage and support emergency or hard-to-reach zones. In terms of physical layer parameters, Khanderay and Kemkar [13] and Turcinovic et al. [14] both analyzed the effect of spreading factor (SF) and time-on-air (ToA) on LoRa signal quality, especially in noisy environments. Aslam et al. [15] demonstrated LoRaWAN's suitability for remote medical IoT systems, showing reliable long-range, low-power transmission for vitals monitoring. To enhance data capacity, Elshabrawy et al. [16,17] introduced ICS-LoRa, a modulation scheme that interleaves chirp signals to increase data rate with minimal bit error degradation. In another practical application, Jaleel et al. [18] implemented a smart energy metering system using LoRa, capable of transmitting consumption data over a 10 km range to cloud dashboards. These studies reflect the growing demand for resilient, autonomous IoT systems capable of operating under real-world constraints. Recent advancements further extend the applicability of LoRa in diverse domains. Wang et al. [19] introduced Pyramid, a real-time concurrent LoRa decoding approach that mitigates packet collisions and improves network throughput, thereby enhancing scalability in dense deployments. Yu et al. [20] explored the feasibility of LoRa-based satellite using a geometry framework, providing insights into access probability and system design for global coverage. Chidolue and Iqbal [21] demonstrated a LoRa-based real-time monitoring system for remote solar-powered oil wells, emphasizing its effectiveness in environments lacking conventional internet connectivity. Similarly, Sulaiman et al. [22] proposed an innovative LoRa-enabled forest fire detection system integrating temperature, humidity, and smoke sensing, showcasing LoRa's role in critical environmental monitoring and disaster mitigation. These works collectively highlight LoRa's versatility, from terrestrial deployments to satellite-based IoT and environmental safety applications. At the same time, lightweight IoT communication protocols such as MQTT and CoAP have been widely explored for enabling efficient, low-latency, and reliable control of mobile robotic systems, remote monitoring, and inspection tasks. For instance, researchers proposed MQTT-based mobile robotic systems for industrial inspections, utilizing IoT cloud platforms to improve wireless communication speed and reliability compared to conventional HTTP protocols by Das and Jain [23]. Further, Sarkar et al. [24] have designed a CoAP-based protocol to reduce power consumption, achieve faster machine-to-machine (M2M) communication, and ensure high reliability in remote robotic systems. These works highlight the diversity of IoT protocol adoption across domains, emphasizing trade-offs between communication range, power efficiency, and latency.

To contribute to advancements in this field, this paper presents the design, development, and performance evaluation of a modular, low-cost, and long-range environmental monitoring system that consists of LoRa and LoRaWAN protocols. The proposed system is designed to offer reliable data transmission over extended distances while maintaining minimal power consumption, making it suitable for real-world deployment in remote and resource-constrained environments. The system consists of three LoRa modules acting as transmitter nodes, each interfaced with a different sensor, such as temperature and humidity, multi-gas air quality, and a GPS module for geolocation data. A LoRa module is configured as a central receiver that receives data over LoRa, displays it on a screen, uploads it to the ThingSpeak IoT cloud, and hosts a mobile-friendly web dashboard with integrated Google Maps for real-time geospatial monitoring. The novel architecture is designed to support real-time data acquisition, low-latency local visualization, and cloud analytics. Sensor readings are transmitted every 10 seconds and were experimentally validated over an outdoor line-of-sight (LOS) distance of 1.0 km. The web dashboard provides live environmental readings and geolocation updates, while ThingSpeak ensures continuous cloud-based data logging.

The key contributions of this paper are as follows:

i. Design and implementation of a distributed, multi-sensor IoT system using LoRa-based communication for long-range and low-power environmental monitoring.
ii. Integration of real-time local and cloud-based data visualization through a display, a mobile-responsive web dashboard, and ThingSpeak cloud channels.
iii. Performance evaluation of signal quality using received signal strength indicator (RSSI) and signal-to-noise ratio (SNR) for long range communication in a real-world.

This paper is structured as follows: Section II presents the design and methodology of system acrthciture for the LoRa based sensor network, wireless sensor node, and LoRa gateway. Section III discusses the experimental setup along with the obtained results. Finally, Section IV summarizes the conclusions and highlights the key findings of the study.

II. DESIGN AND METHODOLOGY OF IOT BASED PROTOCOL USING LORA AND LORAWAN FOR LONG RANGE COMMUNICATION

The proposed methodology of this research is structured into three principal components to ensure a systematic development and evaluation of the LoRa communication–based IoT-enabled sensing system. These components collectively address the network architecture, sensor node design, and gateway configuration required for reliable long-range environmental data acquisition. The first component focuses on the design of the LoRa network architecture. The proposed network comprises multiple LoRa-based environmental sensor nodes, specifically three distributed sensing units, and a single LoRa gateway acting as the master receiver node. The network topology follows a star configuration, wherein all sensor nodes communicate directly with the gateway using LoRa wireless links. This section details the overall system-level architecture, including node deployment strategy, communication parameters, and data transmission flow. Emphasis is placed on the utilization of LoRa's long-range, low-power characteristics to enable reliable data communication over extended distances while maintaining minimal energy consumption. The wireless communication framework also defines packet structure, transmission intervals, and acknowledgement mechanisms to ensure data integrity and robustness. The second component addresses the design of the wireless sensor nodes. Each node is developed as a self-contained sensing unit incorporating environmental sensors, a LoRa transceiver, a microcontroller, and a power management module. The integration of multiple environmental sensors enables real-time monitoring of key parameters, while the embedded firmware ensures efficient data handling and periodic communication with the gateway. Power-efficient operation is achieved through optimized duty cycling and low-power sleep modes, making the sensor nodes suitable for long-term field deployment. The third component presents the configuration of the LoRa gateway, which serves as the central data aggregation and processing unit. The gateway is responsible for receiving data from multiple sensor nodes, processing the received information, and forwarding it to the cloud platform for storage and visualization. Cloud integration enables remote access, data analytics, and real-time monitoring through a web-based interface. The complete system architecture and data flow are illustrated in **Figure 1**.

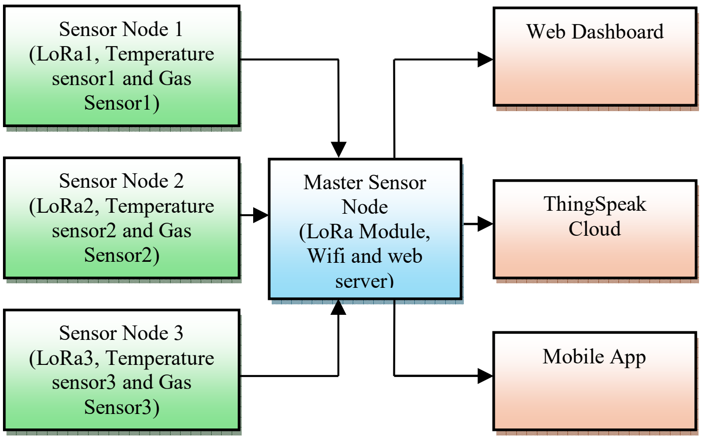
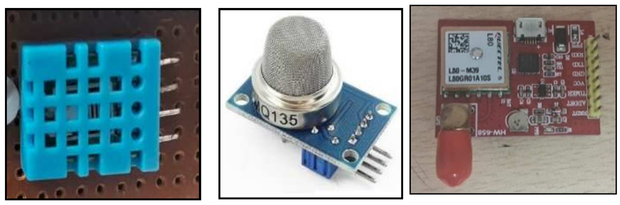


Figure 1. Schematic diagram of a novel configuration of system architecture for real-time geolocation tracking using LoRa and LoRaWAN communication protocols

A. LoRa Network Design

The proposed long-range sensor network is designed using four LoRa modules. Three modules are configured as transmitter nodes, each collecting a specific environmental parameter (temperature/humidity, air quality, and GPS location), while one module acts as a centralized receiver gateway. Each transmitter node is located in a different physical location and is equipped with the dedicated sensors such as temperature and humidity (Model: DHT11, Make: China), air quality (Model:MQ135, Make: China) and GPS module (Model: L80-M39, Make: China) as shown in **Figure 2**. These nodes collect sensor data and transmit it using the 868 MHz LoRa frequency band. The central receiver, also a Heltec LoRa module, receives all incoming LoRa packets and interfaces with Wi-Fi (2.4 GHz) to forward the data to the ThingSpeak IoT cloud platform. An OLED screen is also included for immediate visual feedback. Each sensor node runs custom firmware developed using the Arduino IDE. The firmware handles the sensor initialization, data acquisition, formatting, and LoRa transmission. On the receiver side, the firmware decodes incoming LoRa module, parses the data, updates the display, uploads the readings to ThingSpeak via HTTP, and hosts a live web dashboard using the ESPAsyncWebServer. The dashboard visualizes the temperature, humidity, air quality, RSSI values, and GPS coordinates in real time.



(a) Temp.& Humidity *sensor (b)Gas sensor* (c) *GPS sensor*

Figure 2. Sensors used in the proposed systems

B. Sensor Node Design

Each wireless sensor node in the network includes a microcontroller (Model:Heltec LoRa 32 V3, Make China), power source and sensor nodes. All nodes are powered via an onboard battery or USB. The data is transmitted every 10 seconds via LoRa to the central receiver. Each node uses libraries such as DHT.h, MQUnifiedsensor.h, and TinyGPS++ for sensor interfacing. The data is encoded into a structured format and transmitted using the LoRa.h or LoRaWan_APP.h libraries. The software is optimized for modularity, and individual nodes can operate independently, thereby making the network scalable.

C. LoRa Gateway Design

The receiver node uses a Heltec WiFi LoRa 32 V3 module with an OLED display. It acts as a gateway by receiving LoRa signals from all sensors, parsing the data, and uploading it to ThingSpeak via Wi-Fi. It also hosts a local web dashboard that can be accessed using any browser over the same Wi-Fi network. The receiver uses an ESPAsyncWebServer to display real-time environmental data and GPS location on a dynamic HTML/JavaScript-based web interface. It also includes a health monitoring feature for detecting and displaying the connectivity status of each sensor node. GPS data is plotted live using Google Maps API integration.

III. RESULTS AND DISCUSSIONS

A LoRa network with multi wireless sensor nodes system has been experimentally tested in an outdoor semi-urban environment. The system consisted of three Wi-Fi LoRa transmitter nodes equipped with environmental sensors and a single LoRa gateway acting as the receiver. Key hardware specifications are detailed in **Table 1.**

Table 1. Hardware Specifications

Component	Specification
Transmitter Node 1	Heltec WiFi LoRa 32 (V3) + DHT11 Sensor (Temperature & Humidity, ±1°C, ±1% RH)
Transmitter Node 2	Heltec WiFi LoRa 32 (V3) + MQ135 Sensor (CO, CO_2, NH_4, Alcohol, Toluene, Acetone)
Transmitter Node 3	Heltec WiFi LoRa 32 (V3) + GPS L80-M39 Module (Latitude, Longitude, Satellite Count)
Receiver (Gateway)	Heltec WiFi LoRa 32 (V3) + OLED Display + ESP32 Wi-Fi (Web Dashboard + ThingSpeak)
Frequency Band	868 MHz ISM Band (LoRa) + 2.4 GHz Wi-Fi

	(Cloud Upload)
Transmission Interval	10 seconds
Range Tested	0-1.0 km
Power Supply	Onboard Battery / USB Power (5.0 V)

The process flow chart for LoRa-based sensor monitoring system is shown in **Figure 3**. The process begins with system start and all sensors are initialized, followed by the initialization of the LoRa gateway. Once initialization is complete, the system proceeds to read sensor data. A decision step then verifies whether the LoRa gateway has been successfully initialized. If initialization is successful, the sensor data are transmitted to the LoRa gateway for further processing. The system subsequently uploads the processed sensor data to the ThingSpeak IoT cloud platform for storage and analysis. Another decision stage checks for LoRa node timeout conditions. If no timeout is detected, the system continues normal operation by repeatedly reading and transmitting sensor data. In the event of a timeout, the real-time sensor data are visualized through a web application.

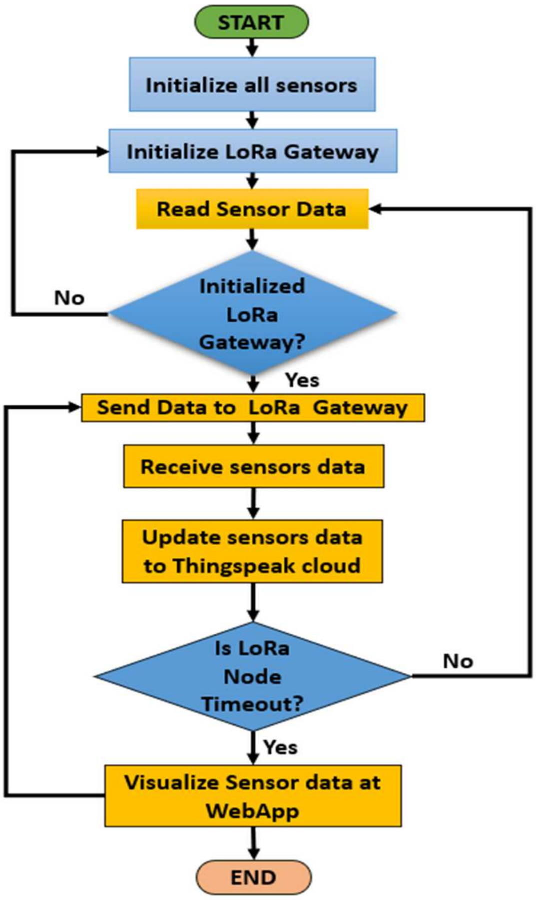
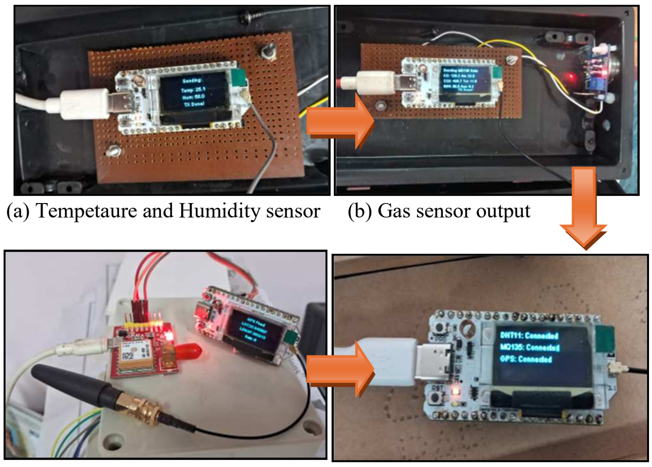


Figure 3. Flowchart showing the working operations

All nodes communicate wirelessly over the 868 MHz ISM band. The LoRa gateway is connected to a mobile data over the 2.4 GHz WiFi band to enable cloud communication via ThingSpeak. The complete experimental setup is shown in **Figure 4**. Each sensor node is deployed at distinct locations to mimic real-world conditions. The sensor nodes are installed in an open/shaded area with minimal obstructions. The GPS module is also fixed. These variations in topology helped analyze performance under different NLOS conditions. The results showed that all nodes successfully transmitted data up to 1.0 km. Environmental data was transmitted every 10 seconds from each node and validated against standard instruments. For example, temperature and humidity readings were cross-verified with different weather apps, while air quality readings from sensor node were compared with calibrated gas detectors. The GPS readings were monitored for satellite fix stability and accuracy. **Figure 5** displays the web dashboard snapshot hosted by the receiver, illustrating temperature, humidity, air quality, and GPS coordinates. **Figure 6** displays the corresponding ThingSpeak graphs for each sensor and **Figure 7** displays the RSSI values over time. The Google Map embedded in the dashboard dynamically updated the GPS node's real-time location.



(a) Tempetaure and Humidity sensor (b) Gas sensor output

(c) GPS sensor (b) LoRa Gateway output

Figure 4. Communication between Sensors and LoRa gateway

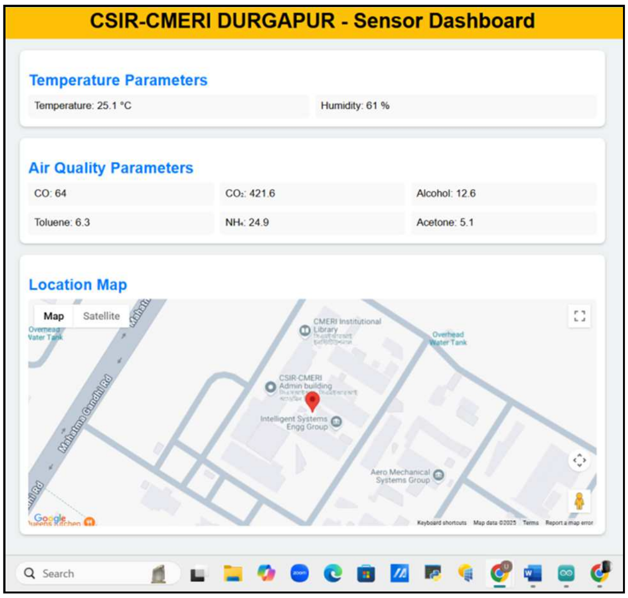


Figure 5. Web Dashboard

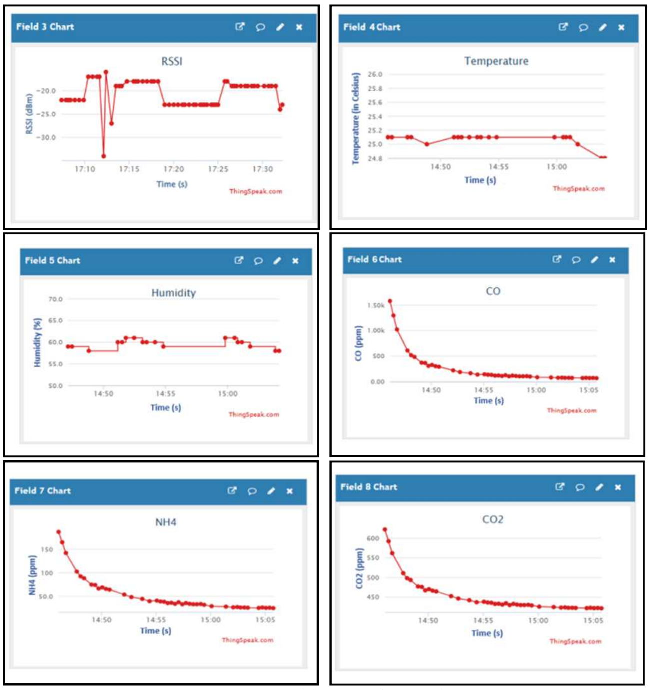


Figure 6. ThingSpeak Graphs

Tables 2 and 3 summarizes a sample RSSI and SNR data obtained from the field test by conducting different trials (T1,T2,T3,T4 and T5) with distance ranging from 0 to 1 km which indicates a degradation in signal strength with increasing distance as shown in **Figures 7 and 8.**

Table 2. Temperature and Humidity data

S. No.	Distance (m)	Temperature (in degree)					Humidity (in %RH)				
		T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
1.	0	24.6	24.7	24.6	24.8	24.6	51	52	51	58	52
2.	100	24.9	25	25	24.9	25.2	59	54	61	60	57
3.	200	25.9	26	26.1	26	26.3	50	48	47	46	48
4.	300	27.2	27.5	27.8	27.5	27.9	51	69	70	69	49
5.	400	28	28.1	28.1	28.2	28.9	48	44	70	70	75
6.	500	29.1	29.2	29.4	29.7	29.8	77	76	80	81	84
7.	600	30	30.1	30.6	30.7	30.8	83	83	83	83	83
8.	700	31.1	31	31.5	31.7	31.5	84	83	75	85	81
9.	800	31.3	31.2	31.1	31.5	31.5	79	84	83	75	75
10	900	32.3	32.2	32.4	32.7	32.2	77	78	91	76	78
11.	1000	34.3	34.4	34.5	34.3	34.8	72	70	69	68	70

Table 3. RSSI and SNR data

S. No.	Distance (m)	RSSI(dBm)					SNR(dB)				
		T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
1.	0	-37	-38	-40	-39	-41	11	10	12	9	13
2.	100	-102	-98	-103	-94	-99	9	8	10	7	11
3.	200	-104	-108	-106	-105	-103	7	6	8	5	9
4.	300	-109	-112	-117	-114	-106	5	4	6	3	7
5.	400	-116	-115	-114	-118	-117	3	2	4	1	5
6.	500	-117	-123	-119	-113	-118	1	0	2	-1	3
7.	600	-123	-125	-116	-125	-122	-2	-1	0	-3	1
8.	700	-121	-119	-123	-126	-120	-4	-3	-2	-5	-1
9.	800	-126	-125	-129	-122	-128	-6	-5	-7	-8	-4
10	900	-127	-126	-123	-125	-132	-9	-7	-10	-8	-11
11.	1000	-125	-132	-128	-124	-122	-13	-12	-14	-15	-11

The experimental performance of LoRa communication mapping under real-time conditions has been evaluated as show in **Figure 9**. The different node of the LoRa-based environmental monitoring system are tested in CSIR-CMERI campus. The network consists of three distributed sensor nodes and a centralized LoRa gateway arranged in a star topology. Each sensor node is equipped with a specific environmental sensor and an integrated GPS module, enabling both data collection and a location tracker. The temperature, humidity, and gas sensor nodes are tested at different locations around the gateway and communicate wirelessly up to approximately upto 1.0 km.

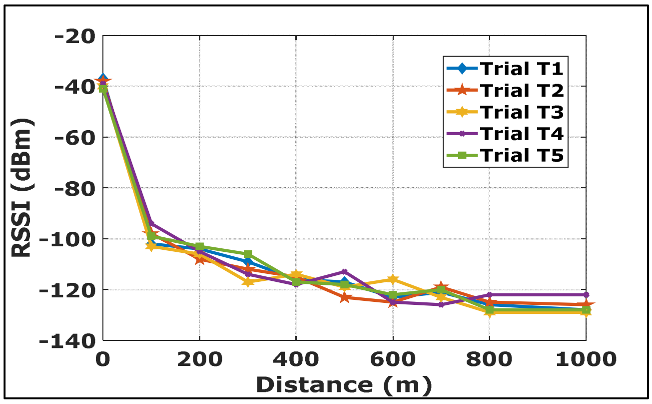


Figure 7. Plot of RSSI Vs Distance

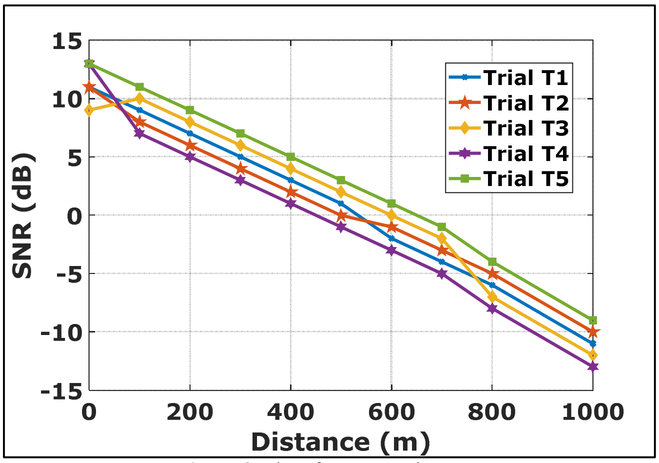


Figure 8. Plot of SNR Vs Distance

Figure 9. Experimental performance evaluation of LoRa communication mapping under real-time conditions

These validate the system's communication for long range data in real conditions. Furthermore, the receiver autonomously uploaded environmental data to ThingSpeak cloud storage, maintaining two separate channels for sensor data readings, RSSI and GPS data. The results confirm the operational feasibility of a LoRa-based distributed environmental monitoring system for remote deployment. With modular hardware and open-source software, the setup is scalable and can be extended for larger-scale applications such as smart agriculture, industrial air quality monitoring, robotic inspection system etc. The proposed system is experimentally validated over a limited range up to 1.0 km under diverse environmental conditions. The limitation of the proposed architecture is that the probability of packet collisions in sensor nodes may occur.

IV. CONCLUSION

A novel LoRa network-based multi-sensor wireless node system has been developed and implemented to enable real-time environmental monitoring. The system is designed to integrate multiple sensing capabilities within a LoRaWAN gateway for continuous monitoring in different environmental conditions. The system integrates three dedicated LoRa transmitter nodes equipped with temperature and humidity, air quality, and GPS sensors, along with a centralized LoRa receiver that acts as a LoRaWAN gateway. Each LoRa transmitter node is responsible for sensing environmental parameters and wirelessly transmitting the data to the LoRaWAN gateway using the 868 MHz frequency band. The gateway performs as a data logger for local visualization using an onboard display and web dashboard as well as a data transmitter that uploads sensor data to ThingSpeak IoT cloud for monitoring and analysis. Field experiments were conducted outdoors in NLOS scenarios to evaluate transmission reliability. Sensor data received from all LoRa nodes is validated and visualized in a web app dashboard and ThingSpeak IoT cloud platform. The temperature, humidity, and gas sensor nodes are tested at different locations around the LoRa gateway and communicate wirelessly approximately upto 1.0 km. The results confirm the feasibility and effectiveness of using LoRa and LoRaWAN based real time long range environmental monitoring systems. In the future, by incorporating edge computing and AI, the LoRaWAN gateway can perform anomaly detection, thereby reducing the volume of data uploaded to the IoT cloud, saving bandwidth, and minimizing latency.

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