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DESIGN AND IMPLEMENTATION OF LONG-RANGE ENVIRONMENT MONITORING SYSTEM

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ABSTRACT

Long-range communication and low power consumption are essential characteristics for IoT-enabled devices. The field of machine-to-machine (M2M) communication within the Internet of Things (IoT) is examined in the Design and Implementation of Low Power Wide Area Network for Internet of Things. Determining which LPWAN technology is best for a given use case has become cumbersome, and the majority of monitoring systems use short-range and higher power consuming networks. Through this work, the research aims to leverage LPWAN technology, specifically LoRa network, to achieve continuous real-time data transmission to a monitoring station. To achieve this Arduino microcontroller and SX1278 which serves as the LoRa node was integrated to sensors for real-time monitoring. Data acquired from the sensors was delivered to the LoRa gateway. The LoRa gateway was registered on The Things Network (TTN). An application was developed and integrated to the TTN to visualize the data. The received signal strength Indicator (RSSI), Signal to Noise Ratio (SNR) and Packet Delivery Ratio(PDR) were used to analyze the performance of various spread factors of the LoRa transmission. The finding from this research shows that LoRa network is suitable for deployment in monitoring temperature, humidity, Nitric Oxide(NO) gas level with range of 0.5to 25ppm and flame in Nigeria amongst other LPWAN technologies. This system successfully detects four environmental parameters: temperature, humidity, gas level and flame level, transmits the data to a base station over distances ranging from 10 to 500 meters, and securely stores the data in the ThinkSpeak IoT cloud platform. The data are displayed on LCD and web via ThingSpeak.

Keyword: Sensors, Gateway, Spreading Factor, LoRa, IoT, ThingSpeak, Battery lifetime

1. INTRODUCTION

The term "Internet of Things" (IoT) refers to the networking of individually identifiable objects within the current Internet infrastructure. These objects gather information from their surroundings and disseminate it online for use in a variety of intriguing applications, such as energy-efficient buildings, smart cities, smart homes, and electronic-health. IoT aims to improve and simplify our daily lives while increasing business and employee productivity and efficiency. Low Power Wide Area Network (LPWAN) is seen as one of the enablers for Internet of Things (IoT) where billions of devices will be networked, in addition to the existing short-range wireless systems using technologies such as Bluetooth, Zig-Bee etc. (Ma, et. Al., 2019). LPWAN offers wide area coverage for numerous IoT applications that require low power and due to its low-cost of operation, and its better power efficiency, as compared to the traditional mobile network systems, it can be considered as the future solution in Industrial IoT (Raza, Kulkarni and Sooriyabandara, 2017).

The last fifteen years have seen an exponential increase in the number of Internet of Things (IoT) devices, which has fuelled the development of LPWAN, a new wireless communication technology. The low power, long range, and low cost of LPWAN communication make it more and more popular among industrial and research communities. More specifically, it can communicate over a distance of up to 10-15 km in rural areas and 2–5 km in urban areas (Raza, Kulkarni and Sooriyabandara, 2017). It is also very affordable and energy efficient, with an industry target of 10 years for battery life and an operating cost of $1 per device annually for radio chipsets costing less than $2. Sigfox, Narrow Band Internet of Things (NB IoT), and Category M1 (CAT-M1) are examples of emerging technologies that can be used to realize LPWAN.(Gaddam and Rai, 2018; Yousuf, Rochester and Ghaderi, 2018). However, adopting IoT requires consideration of factors like battery life, latency, mobility, and deployment methods (Ma, *et. al.*, 2019).

By 2025, an estimated 75 billion IoT devices are projected to be connected, contributing to an annual economic impact of $11.1 trillion (Shafique *et. al*., 2020). While many devices use Wi-Fi and Bluetooth, a fraction relies on Low Power Wide Area Networks (LPWAN). LPWAN, exemplified by technologies like LoRa, Sigfox, and NB-IoT, addresses the needs of battery-powered sensor nodes, emphasizing the significant role LPWAN networks play in advancing IoT applications (Islam, Ray and Pasandideh, 2020; Chilamkarthy *et. al.,* 2022). LPWAN is recognized for its long-range communication capabilities, providing cost-effective and energy-efficient solutions for industrial and research applications (Qadir, *et.al*., 2018).

2. LITERATURE REVIEW

Several research efforts have explored environmental monitoring systems using different technologies and platforms. Recent studies have explored LPWAN performance in various environments (Milarokostas *et. al*, 2023; Perez *et. al*, 2022; Chall, Lahoud and Helou, 2019). LoRaWAN, a networking protocol, enhances device connectivity on a global scale, addressing key IoT requirements like security and mobility (Madhumitha and Singh, 2019). LoRa, the physical layer of LoRaWAN, minimizes interference with other technologies like Wi-Fi and Bluetooth, employing spread spectrum modulation derived from Chip Spectrum Spreading (CSS) technology (Ayoub *et.al*., 2019).

A study by Nikhade (2015) developed a system utilizing an Xbee module and Raspberry Pi to manage data from multiple sensor nodes at a base station, employing ZigBee radio transceivers for multi-hop transmission. However, due to ZigBee's limitations, long-distance data transmission from deployed sensors was not achievable. In another study conducted by Deshmukh and Shinde (2015), a low-cost environmental monitoring system comprised of a Raspberry Pi, sensors, and Arduino with ZigBee was developed. The sensor nodes were connected to a Raspberry Pi base station and an Arduino Nano, managed by the ATMega328. While the ARM11 microprocessor on the Raspberry Pi tracked greenhouse gas emissions, the system lacked cloud connectivity, limiting its data storage and accessibility. A water monitoring system, demonstrated by (Taru and Karwankar, 2017), employed Arduino and LabVIEW, featuring an Arduino UNO R3 board with an Atmega328 processor and a temperature sensor. The system converted analog values into voltage, calibrated them, and used LabVIEW as the display unit. The system can be expanded to include more environmental monitoring sensors for various applications, including house, agriculture, and industry. The escalating impact of climate change, evidenced by heat waves, intense rainfall, and other phenomena, necessitates monitoring environmental variables such as temperature and relative humidity, particularly in remote areas. Existing environmental monitoring systems face limitations in terms of latency, range, complexity, power consumption, and user-friendliness.

A LoRa technology-based environmental monitoring system was investigated by Azmi and Abdullatif (2019), It comprises a microcontroller with a LoRa radio shield and sensors transmitting data to a gateway over long distances with low rates and power consumption. Although the data was analysed using signal quality indicators like RSSI and SNR, the system lacks a reliable network design tool to represent its performance before physical deployment. Also, the system only measured temperature and relative humidity.

A system presented by Hartalkar *et.al (*2020) used air quality sensors: MQ-135 and MQ-7 connected to an Arduino Uno R3 for monitoring air quality. Equipped with a buzzer for red alert notifications and an LCD display, the system allowed data access via an Android phone, online storage, or printed in PDF format. Further research is needed to improve real-time data display on web-based and android applications.

To address the challenges raised, a low-power, long-range, LoRa-based environmental monitoring system was developed. Sensor nodes acquire measured values, sending information to a base station. The data is then transmitted to an Internet cloud service via a backhaul gateway, accessible to end-users or clients.

3. METHODOLOGY

The proposed environment monitoring system design comprises of both hardware and software aspects. The components of the designed LoRa-based monitoring system are depicted in Figure 1. The sensor nodes, also known as edge or end nodes, acquire one or more measured values before sending the information to the base station or Gateway. The data is sent from the base station to an Internet cloud service. The acquired data from cloud services might be used by the end user or clients

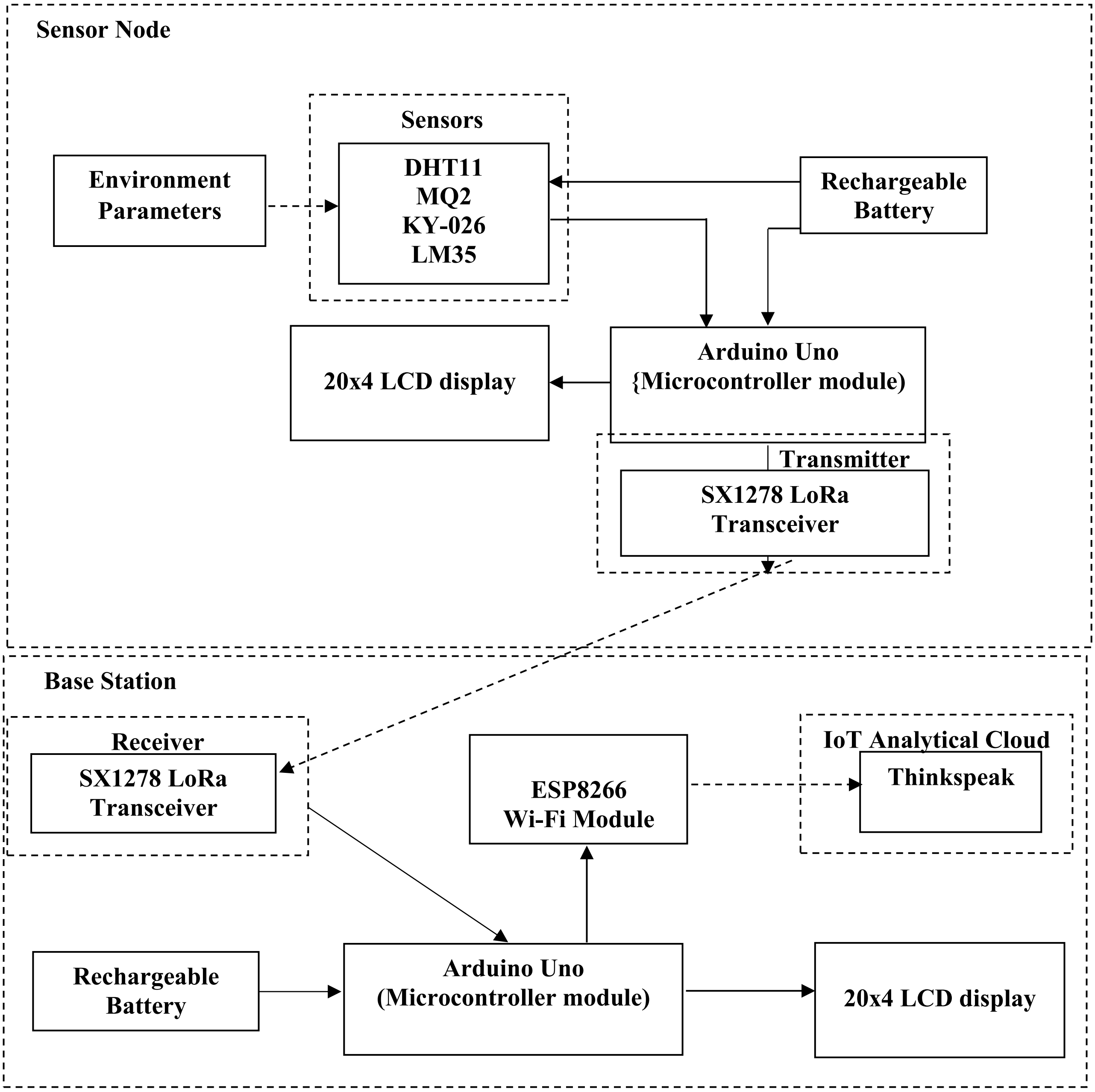

Figure 1: Block Diagram of the system

3.1 Hardware Design

The schematic diagram of the sensor node is depicted in Figure 2. It comprises the SX1278 LoRa Module, 20x4 LCD display, LM35 temperature sensor, KY-026 flame sensor, DHT11 humidity sensor, and MQ2 gas sensor, which are interfaced to the Arduino Uno Microcontroller. Overall, the sensor node is designed to continuously acquire the temperature, humidity, flame, and gas level of the surrounding environment while displaying the current readings on the LCD screen and also transmitting same wirelessly using the SX1278 LoRa module to the Base station which serves as the Gateway.

Figure 3 depicts the circuit for the Base station. The sensor node's data is initially received by the SX1278 LoRa module on the Base circuit from the LoRa module of the sensor node. This module wirelessly captures data transmitted by the sensors. The Arduino Uno processes the received data through tasks like Analog-to-Digital Conversion (ADC) and computation. The Arduino uno organizes the information, and the results are displayed on the connected LCD. The environmental monitoring system base station (Gateway) uses the LoRa protocol to communicate with the sensor node. Devalal and Karthikeyan (2018) discuss an overview of LoRa technology. The received data is then processed by the Arduino and sent to the ESP8266 module, which is responsible for uploading it to ThingSpeak via Wi-Fi communication.

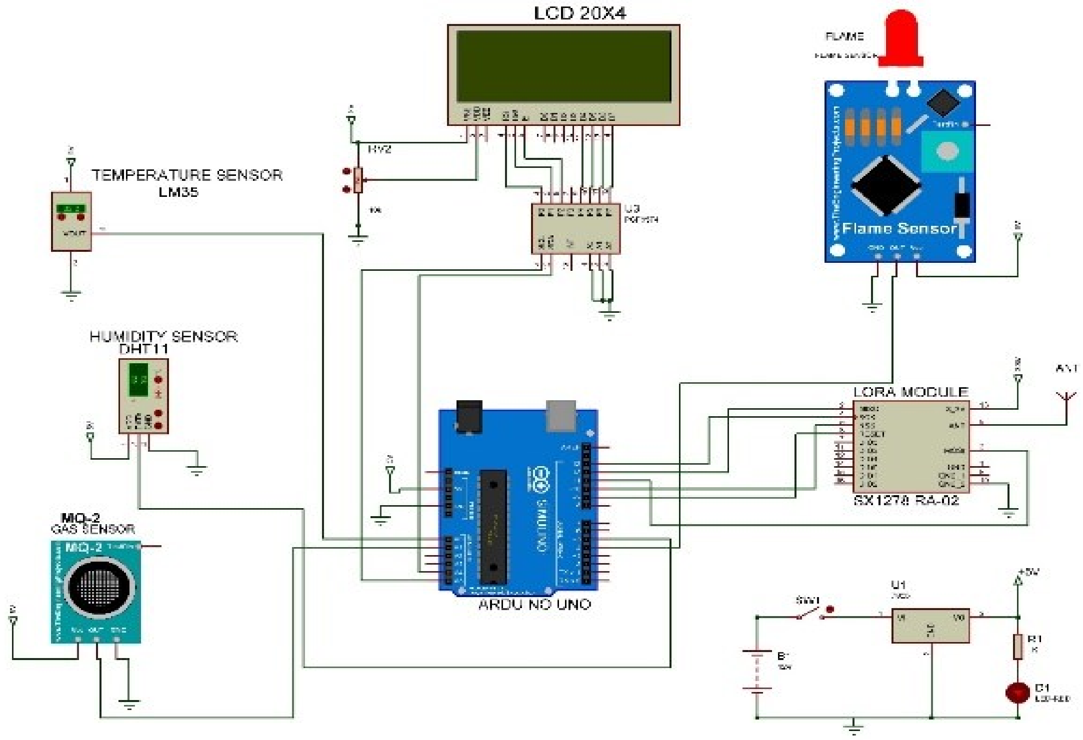

Figure 2: Sensor Node Circuit

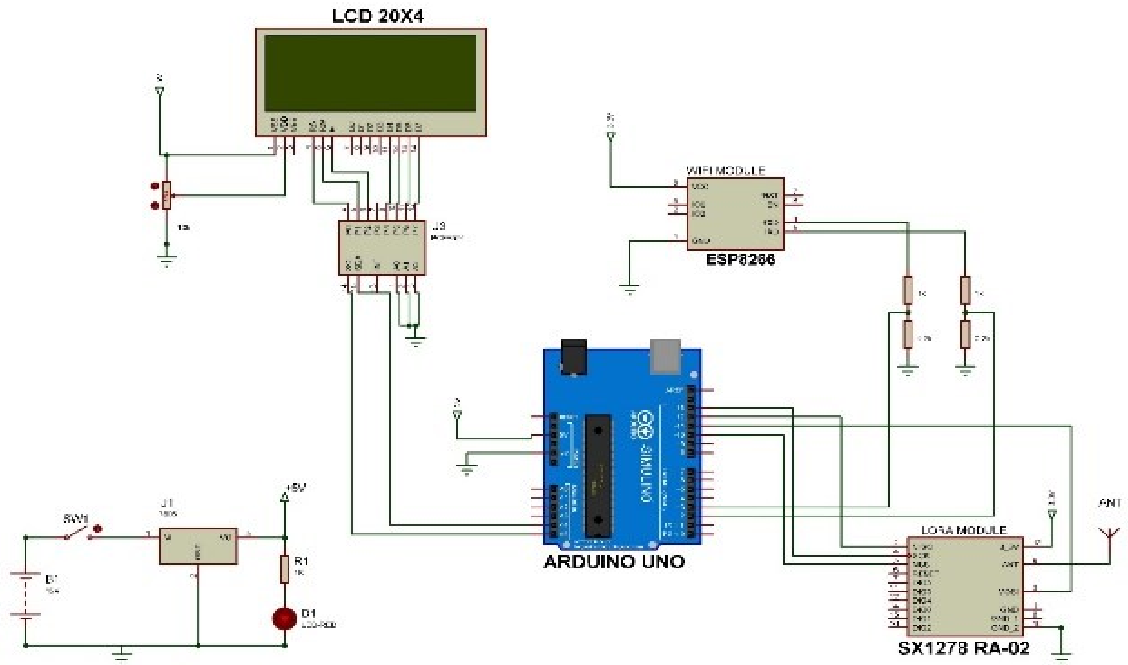

Figure 3: Base Station Circuit

3.2 Software Design

The flowchart of the system software is depicted in Figure 4 which shows the flow of instructions for the program developed in C++ for the system. The acquired data is sent via wifi to the IoT platform for storage and analysis. Thingspeak offers integrated tools for visualizing and interpreting the stored data through graphs and charts. This research work involves storing the acquired data -temperature, humidity, air quality and flame data in cloud. The channel Stats system was developed using IDE and Thingspeak, streamlining the transmission of sensor data to an IoT platform. Access is open to authorized users though a username and password on the IoT cloud platform at https://thingspeak.com

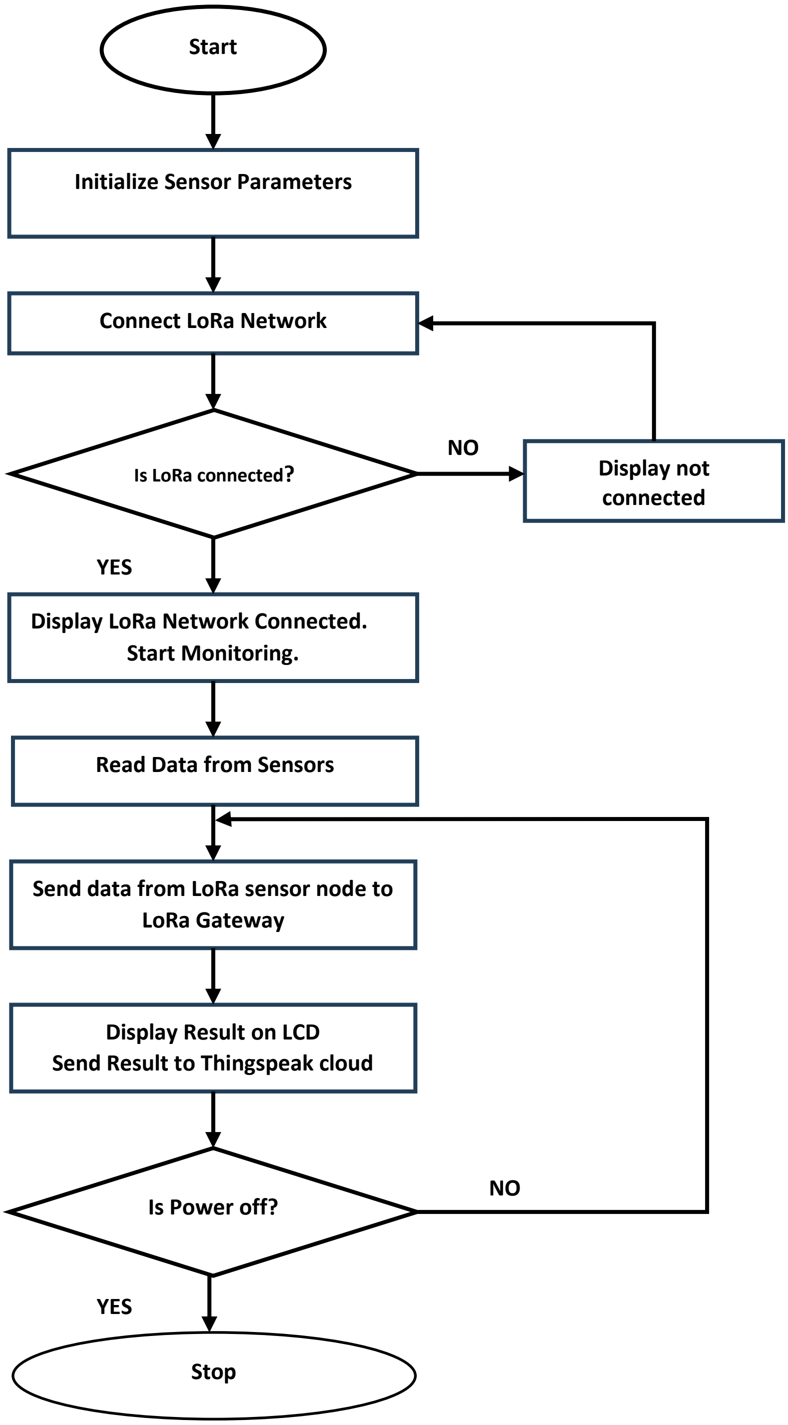

Figure 4 Flowchart of the LoRa Environment Monitoring System

4. RESULTS AND DISCUSSIONS

Lorawan Test

This test was conducted to determine the Received Signal Strength Indicator against distance. Values were then gotten from the TTN by changing the Spread Factor and repositioning the LoRa nodes at different distances.

Table 1 provides an overview of the parameters and system configuration used in the test. The connectivity range between the LoRa test device and the gateway is displayed by the coverage areas. Spread Factor (SF).

Table 1 LoRa system parameters

Parameters	Values/Settings
Transmission	uplink
Acknowledgment	Yes
Activation method	OTAA
Code rate	4/5
Gateway transmit power	14 dB
Spreading factors	7,8,9,10
Bandwidth	125 kHz
Packet Size	21 bytes
End-device output power	+14 dBm
End-device Antenna gain	+5 dBi
Carrier Frequency	EU868 MHz

The spread factors (SF) play a crucial role in determining the communication characteristics of a LoRa network. The choice of SF is a way to control the trade-off between communication range and data rate. The SF-7 offers the fastest data rate but has the shortest range while the SF8 offers a balance between data rate and range. The SF9 further increases the range at the expense of data rate. SF10 offers even more extended range compared to SF9, making it suitable for applications that require communication over very long distances. SF11 and SF12 are designed for ultra-long-range communication but at the slowest data rates. The performance test carried out for the different SFs was carried out by observing the Received Signal Strength Indicators, SNR and PDR of the LoraWAN device More than 200 packets of data were sent from the LoRa device to Gateway and their average as in Table 2. The values from Table 2 were used to plot the RSSI versus distance in Figure 5.

Table 2: RSSI at Different Spread Factors(SF)

Distance	RSSI (dBm) at different SF				
	SF7	SF8	SF9	SF10	SF11
40m	-31.5	-42.9	-39.6	-33.3	-47.85
50m	-27.1	-26.0	-30.5	-27.3	-31.15
55m	-25.7	-26.7	-36.8	-25.3	-32.1
155m	-50.2	-48.8	-47.3	-46.5	-44.9

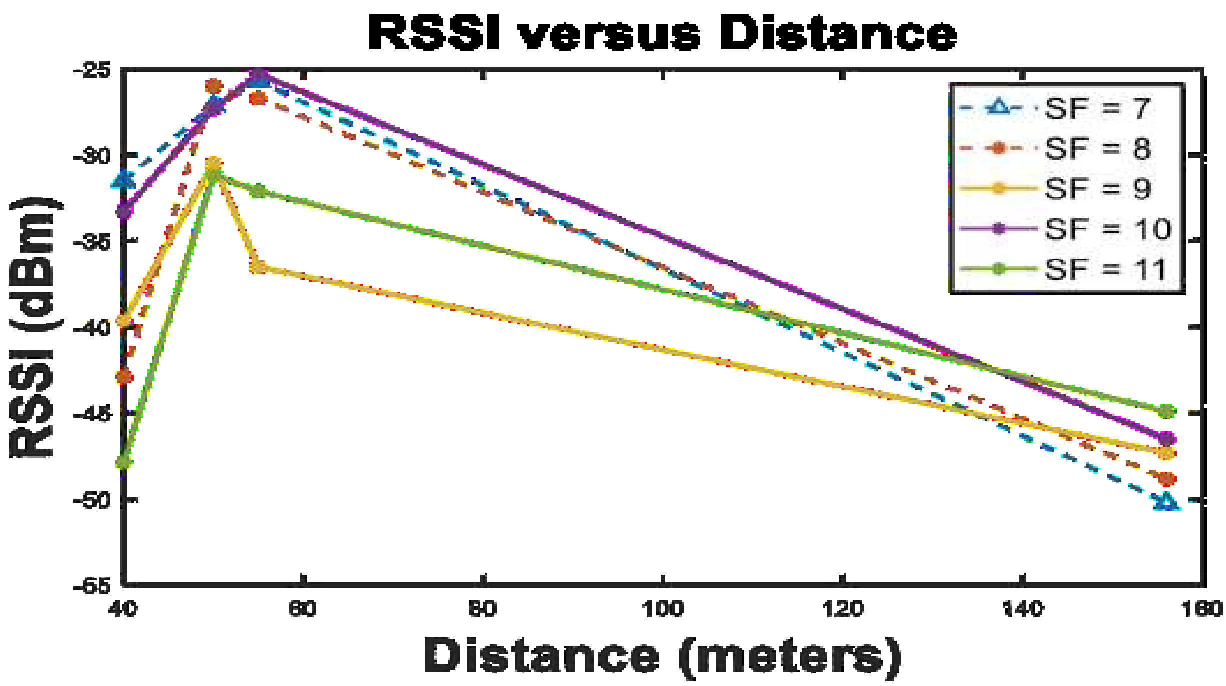

Figure 5: A graph of RSSI versus distance

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PP. 29- 37

A stronger RSSI is observed for the SF-7 to SF-11 when the LoRa Node is closer to the LoRa gateway. As the distance increases the RSSI values begins to degrade. The SF-11 offers a higher RSSI value compared to the other SFs at a distance of 160 meters while the SF-7 offered a better RSSI value at a distance of 40 meters. The above test is important in order to determine the right SF to use for the application of environment monitoring. The RSSIs for all the SFs tested shows that the fall is within acceptable limit of -110dBm. Hence, there will be minimum packet losses in data transmission. For RSSI values that were above -110dBm there are high chances of packet losses because of PDR below 70%. Table 2 shows the distances for the different SFs at which RSSI equals -110dBm.It was observed that at SF 10 no packet losses were experienced at long distances up to 850m.

Table 3: Coverage Limits

Spread Factor	Distance
SF7	415m
SF8	420m
SF9	780m
SF10	850m
SF11	855m

Plate 1 shows LCD screen for acquired data from the monitoring, while plate 2 shows the data from Thingspeak for SF 10 at a distance 0f 150m. The four environment quantities being observed were adequately measured, read and transported to the IoT cloud.

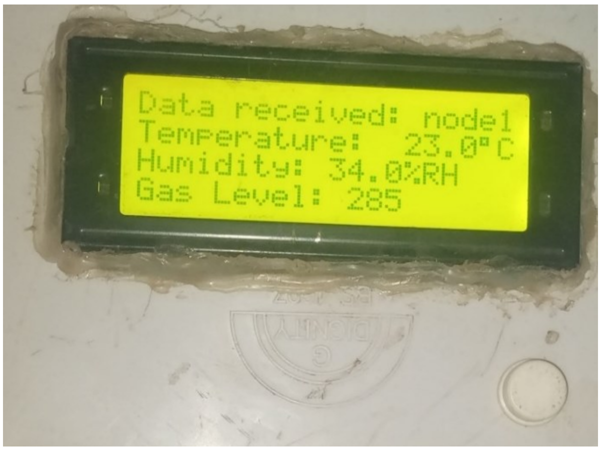

Plate 1: Environment measured Readings as displayed on LCD

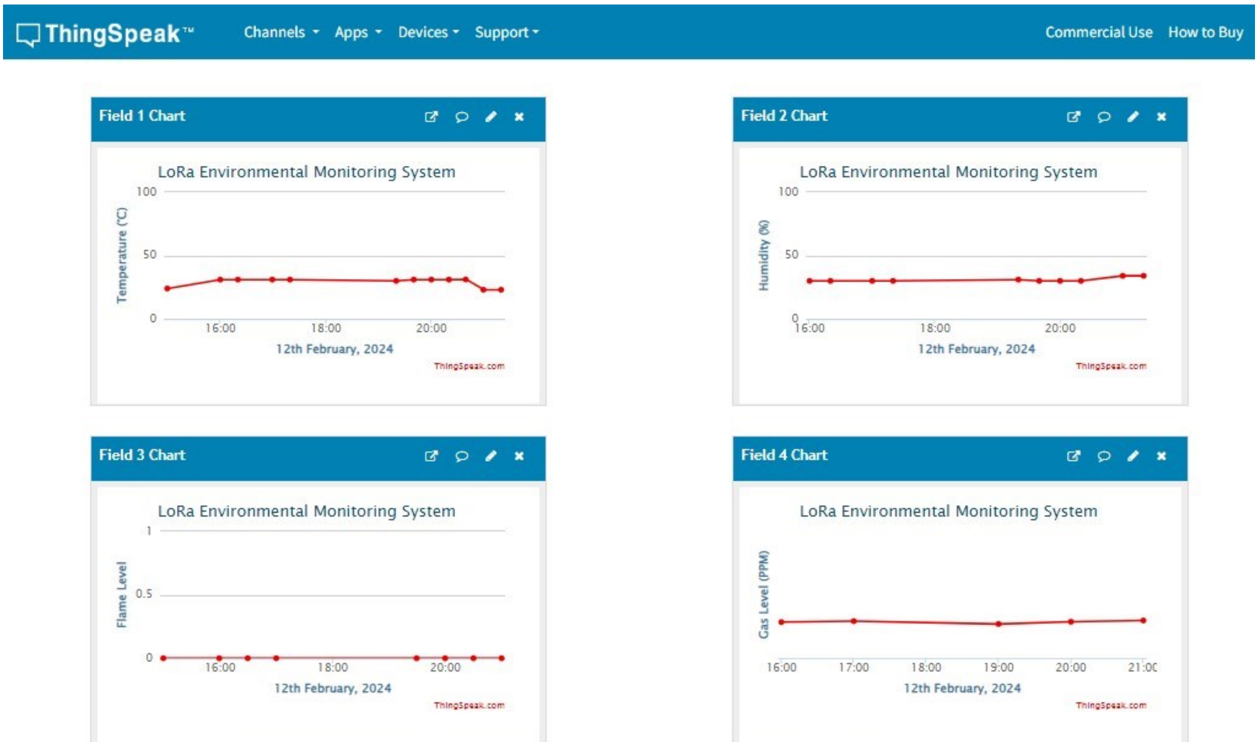

Plate 2: A snapshot of measured environmental parameters for distances of 100 meters on ThingSpeak dashboard

Power Usage: Analysis of Battery Power Lifetime

The battery used was 3.6V, 20,000mAh

Battery lifetime estimation can be obtained as

$$Time(hours) = \frac{Battery\ capacity[mAh]}{Sensor\ node\ current\ [mA]}$$

The overall Sensor nodes current consumption for the devices is summed up in Table 4

Table 4:Current Consumption

Arduino Uno	50mA
DHT11	1.5-2.5mA
KY-026	15mA
LM 35	60µA
MQ2	150mA
SX 1278 – Transmitting	29mA
SX 1278 – Receiving	12.6mA
SX 1278 - Sleep	1.6mA

Using a 20000mAh Lithium Battery and assuming the Node sensor sends data to Gateway every 15 minutes with less than 2s to send the data.

Total Current = 50mA + 2.5mA + 15mA + 150 +29mA = 241.5mA

Note that this current is consumed during data collection for a period less than two seconds and for four times in an hour for this research work.
Therefore,

$$Time(in\ Hours) = \frac{20000x3600}{241x8} = 37{,}344Hrs$$

Converting the time from hours to years gives 4.26years.

Key findings include temperature measurements from -55°C to +150°C, humidity from 0% to 100%, flame state on a boolean (0 for no flames, 1 for flames), and gas levels in ppm, with 0.5 to 25ppm indicating Nitric Oxide gas. At 10 meters, temperatures ranged from 25°C to 41°C, humidity from 25% to 35%, and gas levels from 187 ppm to 287 ppm, with no flames detected. At 100 meters, temperatures ranged from 22°C to 43°C, humidity from 22% to 25%, and gas levels from 0.5 ppm to 25 ppm, with no flames detected. Beyond 500 meters, communication challenges and diminishing RSSI values limited the system's effective range, highlighting practical range limitations for environmental monitoring.

5. CONCLUSION

A LoRa-based environmental monitoring system was developed through simulation, design, and implementation phases. Coverage assessment was carried out. The paper successfully achieved its objectives, employing Arduino Uno microcontrollers programmed in C++ to manage LoRa modules, Wi-Fi modules, and sensors. The system acquired environmental data on sensor nodes, transmitted it to a Wi-Fi-equipped base station, and forwarded it to an IoT cloud dashboard on ThingSpeak, enabling effective monitoring of environmental conditions. Also, for a 20,000mAh battery the lifetime was calculated to be 4.26 years.

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