

Next generation LoRa-based resilient communication system for disaster mitigation and relief operations

Al-Baraa Ebad¹, Mohammed Abaker¹, Bilal A. Khawaja¹, Arshad Karimbu Vallappil¹, Sameer Qazi²,
Muhammad Mustaqim³

¹Department of Electrical Engineering, Faculty of Engineering, Islamic University of Madinah, Madinah, Saudi Arabia

²Department of Computer Science, Faculty of Engineering, Science and Technology, IQRA University, Karachi, Pakistan

³Department of Electronic and Power Engineering (EPE), PN-Engineering College (PNEC), National University of Sciences and Technology (NUST), Karachi, Pakistan

Article Info

Article history:

Received Jul 10, 2025

Revised Dec 10, 2025

Accepted Jan 30, 2026

Keywords:

Chirp spread spectrum
Disaster communication
Long range
Range test
Software defined radio

ABSTRACT

This paper presents the development of a long range (LoRa) based communication system meant for off-grid environments. It aims to send data over long distances with minimal power consumption. Using Arduino boards, LoRa transceiver modules, and Bluetooth modules, an analysis of LoRa devices was carried out, focusing on their performance in terms of signal strength and range. LoRa technology is recognized for its low-power consumption and extended range capabilities. The experiments were conducted at the Islamic University of Madinah (IUM), Madinah, Saudi Arabia. The readings of the received signal strength indicator (RSSI) and signal-to-noise ratio (SNR) are collected at various distances. The study involved testing with a 2.15 dBi antenna, and the results indicated that the device achieved a maximum range of 240 m with RSSI = -128 dBm and SNR = -20 dB. This work explored LoRa modulation using software-defined radio (SDR) and demonstrated the feasibility of LoRa technology for off-grid communication. The system offers long-range text messaging capabilities with user-friendly features, serving as a valuable solution where traditional network infrastructure is unavailable.

This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.



Corresponding Author:

Bilal A. Khawaja
Department of Electrical Engineering, Faculty of Engineering
Islamic University of Madinah
Madinah 42351, Saudi Arabia
Email: kjbmohammed@iu.edu.sa

1. INTRODUCTION

Communication infrastructure is a critical lifeline during natural disasters, yet it is often one of the first casualties. For instance, the 2011 Eastern Japan earthquake resulted in the destruction of approximately 29,000 mobile base stations, severed fiber optic and submarine cables, and the shutdown of 120 television stations and two radio stations [1], [2]. These events underscore the sensibility of centralized communication systems in the face of large-scale disasters. When such systems fail, affected populations are left isolated, hindering rescue and recovery efforts.

To address this sensibility, researchers are increasingly exploring off-grid communication solutions that function independently of conventional infrastructure. These systems aim to ensure reliable communication when power grids and networks fail. Long range (LoRa) technology [2]-[4] emerges as a promising solution in these circumstances, known for its ability to transmit data over long distances with minimal power consumption. Depending on each region's regulations, LoRa operates in unlicensed

industrial, scientific, and medical (ISM) frequency bands. i.e., 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia [5]. Based on the National Frequency Plan of Saudi Arabia, the 433.05–434.79 MHz band is designated for ISM applications [6].

– LoRa as a solution for disaster communication

LoRa has gained significant attention in wireless communication, particularly for its application in internet of things (IoT) networks. Its low-power, long-range capabilities make it an attractive option for off-grid communication in disaster-stricken areas. Augustin *et al.* [7] conducted a foundational study on LoRa's performance, demonstrating that it can reliably decode signals at power levels as low as -125 dBm using chirp spread spectrum (CSS) modulation. Their experiments in suburban Paris revealed that LoRa can achieve communication distances of up to 3.4 km, depending on the spreading factor (SF).

In addition to its range capabilities, LoRa's adaptability in diverse environments has been explored by Wixted *et al.* [8], who tested long range wide area network (LoRaWAN) in urban settings, and Baumgartner *et al.* [9], who evaluated it for environmental monitoring applications. Both studies confirmed that LoRa remains reliable over distances ranging from 2.2 km in dense urban areas to 6.5 km in rural environments. This adaptability positions LoRa as a versatile technology for disaster communication, given the diverse terrain and conditions that must be taken into account.

Beyond basic LoRa deployments, several approaches have explored enhanced architectures for disaster scenarios. Syed *et al.* [10] demonstrated mesh networking capabilities using Meshtastic-based systems integrated with amphibious rovers, achieving reliable communication in flood-affected areas. Vithayathil *et al.* [11] proposed a hybrid wireless fidelity (Wi-Fi)/LoRa infrastructure with captive portal functionality, enabling both local device connectivity and long-range data transmission. For highly disrupted environments, Schmidt *et al.* [12] developed a delay-tolerant networking (DTN) system over LoRa, demonstrating that store-and-forward mechanisms can maintain communication even when direct links are unavailable. Performance considerations are critical in disaster deployments; Lopes *et al.* [13] identified key network parameters, including collision handling, node density, and transmission intervals, that significantly impact reliability under stress conditions, with data extraction rates (DER) dropping below 95% when certain thresholds are exceeded.

– Alternative low-power wide area network (LPWAN) technologies for disaster communication

Complementary to LoRa-based approaches, other LPWAN solutions have been explored for emergency communication. Narrowband internet of things (NB-IoT) achieves a stable signal strength (RSSI: -55.6 to -74.6 dBm) up to 458m with zero packet loss [14], but critically depends on functional cellular base station infrastructure, which is frequently compromised during disasters. ZigBee offers low-power mesh networking (2 mW transmission) but is severely range-limited, maintaining connectivity only up to 40 m on the same floor, with complete failure beyond two floors [14], making it unsuitable for disaster zones spanning hundreds of meters. Wireless smart ubiquitous network (Wi-SUN) provides robust mesh capabilities with 298 m outdoor range [15], but requires complex multi-node deployment and mesh coordination infrastructure. In contrast, LoRa combines long-range, low power consumption, and complete infrastructure independence, characteristics essential for off-grid disaster communication.

– Emergency communication challenges

Post-disaster communication poses unique challenges due to the potential for damaged infrastructure and unreliable power sources. Deepak *et al.* [16] identified three primary network scenarios in post-disaster settings: congested networks, partial networks, and isolated networks. In isolated networks, where traditional communication infrastructure is unavailable, mobile ad-hoc networks (MANETs) or drone-assisted communication systems can be deployed to establish temporary wireless coverage. The redundancy and fault tolerance offered by MANETs make them particularly suitable for these situations.

Furthering this idea, Lieser *et al.* [17] proposed a delay-tolerant communication network based on MANET architecture, which enables resilient communication without relying on fixed infrastructure. This approach is particularly relevant in disaster scenarios, where flexible, civilian-centered communication systems are paramount. Mobile applications that integrate the public into emergency communication infrastructure have also become increasingly common, as highlighted by Tan *et al.* [18], who noted that these apps are increasingly focused on facilitating on-site collaboration between civilians and emergency responders.

– Contributions

The primary contribution of this study is the design and evaluation of a bi-directional LoRa-based texting communication system optimized for off-grid disaster scenarios. Despite leveraging an accessible technology like LoRa, a well-known communication protocol in IoT applications, the presented walkthrough analysis, along with the practical implementation, enriched the discussion on using LoRa for wireless messaging while supporting collapsed infrastructure. The proposed prototype was evaluated through range test experiments and software-defined radio (SDR) analysis. In addition, including the SDR in the analysis adds another dimension to understanding the system's functionality from the perspective of wireless

communication principles, which links theoretical concepts with reality. The device is compatible with most Windows and Android operating systems and supports communication among multiple users within the same LoRa network through a custom addressing scheme. A key advantage of this design is that even if one device is not connected to a mobile phone, the user can still trigger a buzzer to notify the recipient, ensuring critical communication is maintained during emergencies. Starting with LoRa as the communication protocol, these features were incorporated to provide a comprehensive solution that addresses disaster situations and connectivity issues, thereby supporting rescue and relief operations.

2. METHODOLOGY

Our methodology comprises the following key steps: system design, range test experiment with data collection, SDR analysis, and a discussion of the results, including the determination of the received signal strength indicator (RSSI) equation. The goal of this work is to build a device utilizing LoRa technology to facilitate bi-directional text messaging over long distances. Since the application of the system is to build communication devices for emergency cases, the proposed design should have the following specifications:

- The device operates with a minimum amount of power
- The device is user-friendly in terms of prototyping and usage
- The device is compatible with most operating systems, including Windows and Android

The evaluation of the communication system was made possible through range-test experiments considering the environmental factors. RSSI and signal-to-noise ratio (SNR) measurements were performed, and the data were collected and visualized for better understanding. We observed the transmitted LoRa signals over the frequency spectrum using SDR. This gives more insight into the signal's behavior.

A discussion of the results is as follows. The log-distance path-loss (LDPL) model is a propagation model suitable for indoor and outdoor environments, which considers the path-loss value that occurs for the distance between the transmitter (Tx) and receiver (Rx) [19].

$$PL(d) = PL(d_0) + 10n \log \left(\frac{d}{d_0} \right) \quad (1)$$

Where $PL(d)$ is the path-loss at distance d (meters) in the outdoors, whereas $PL(d_0)$ is the reference path-loss at distance d_0 with free space conditions obtained from measurements close to the Tx. It is often considered to be 1 meter in various studies [20], [21]. Moreover, d is the distance between Tx and Rx in meters, and n is the path-loss exponent (PLE) adjusted to the test environment, as summarized in Table 1.

Table 1. PLE for different environments [22]

Environment	PLE, (n)
Free space	2
Urban area cellular radio	2.7–3.5
Shadowed urban cellular radio	3–5
In-building line of sight (LoS)	1.6–5
Obstructed in building	1.6–1.8
Obstruction in factories	4–6
Indoor office	2–3

So, the RSSI calculation is as follows [22]:

$$RSSI = P_T + PLo + 10n \log \left(\frac{d}{d_0} \right) + X\sigma \quad (2)$$

Where RSSI and P_T , which refer to the Tx transmitted power, are both considered in dBm, respectively.

2.1. Proposed design

In this section, the design of the proposed system is discussed. The LoRa-based communication system is made of two devices. These devices establish an off-grid LoRa-based network. Once the smartphone is connected to one of the devices, the user can use the mobile phone for text messaging via the LoRa network. This approach to off-grid communication demonstrates the practical application of LoRa technology in overcoming the limitations of traditional GSM networks.

In our design, we used an Arduino Nano board with ATmega328P microcontroller, a LoRa Transceiver (Ra-01) module with Semtech's (SX1278) integrated circuit (IC), a Bluetooth module (HC05), a 5 V buzzer, a switch, and a single 9 V AAA alkaline battery. The system block diagram is shown in Figure 1.

After installing the Serial Bluetooth Terminal app, the user can connect to the device via Bluetooth using their mobile phone. Each device has a predefined address, such as 0xBB and 0xFF. Therefore, it is feasible for multiple users to communicate within the same LoRa network. The messages are then sent via LoRa transceiver to the recipient device, where the recipient can read them in the app, as shown in Figure 2. The user can send a call signal that triggers the buzzer. Even if one of the devices was not connected to any mobile phone, the user can still activate the buzzer to notify the recipient. In the presented work, for analysis purposes, the “LoRa.h” library was used in the code, which provides physical-layer control for LoRa radio chips (SX127x), such as sending/receiving raw packets and setting frequency, bandwidth, and SF. The library supports Coding Rate, which is additional data added to the packet to allow for error correction. While the “LoRa.h” library does not have built-in retransmission or routing mechanisms, it can still be hard-coded for better scalability.

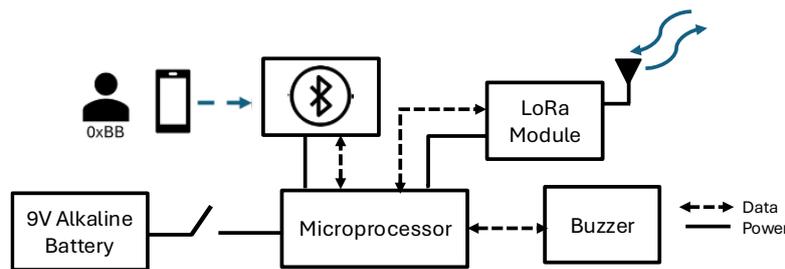


Figure 1. Block diagram of the proposed system design

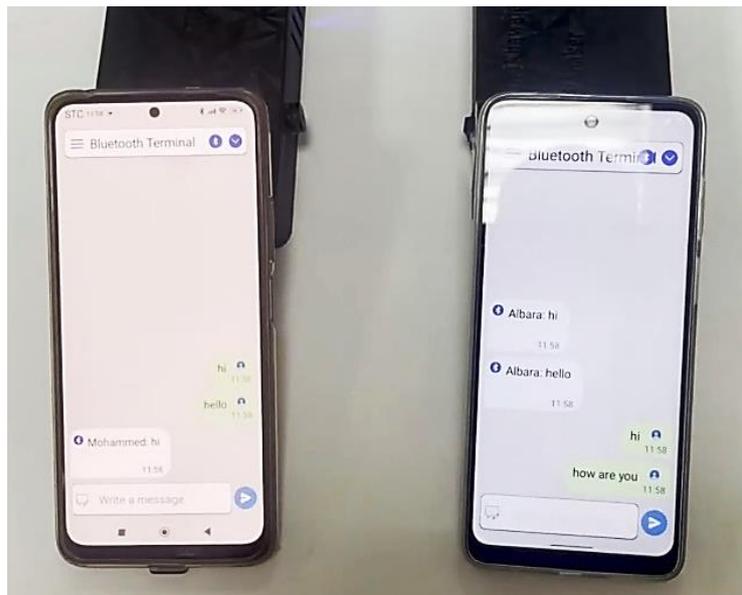


Figure 2. Bluetooth terminal app showing the received messages

Figure 3 shows the device layout of the proposed design. A 433 MHz nickel-plated spring antenna is used for signal transmission. The antenna is 36 mm in length, with a gain of 2.15 dBi [23]. Additionally, computer-aided design (CAD) software is used to design the device’s enclosure. Based on the power demand as discussed in Table 2, we choose a 9 V alkaline battery to power the circuit. It is an ideal choice since it supplies up to 800 mA. This alkaline battery has high energy density and voltage stability. The LoRa devices in this study utilize Bluetooth low-energy modules, allowing only one smartphone to pair with each LoRa device at a time. However, the physical layer of LoRa operates independently of Bluetooth, which leverages long-range communication. It enables multiple LoRa devices to coexist in the same network by implementing a custom addressing scheme at the application layer. Each device is assigned a unique identifier (ID) to manage data routing and avoid packet collisions [18]-[23].

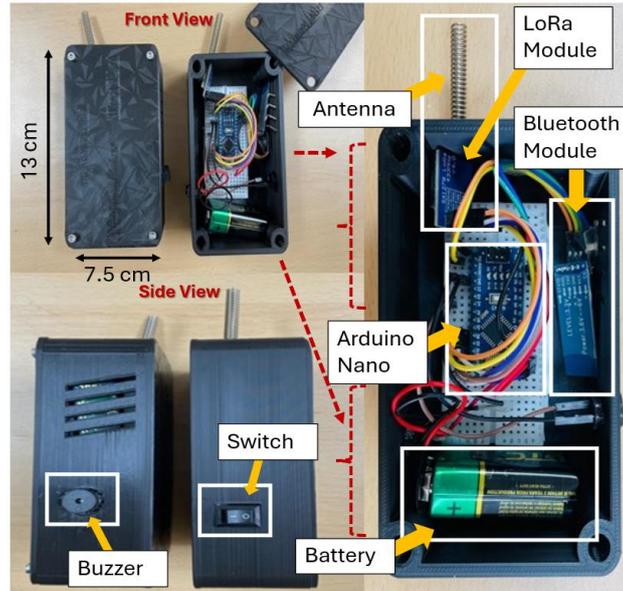


Figure 3. Device layout showing the front and side views (on the left); also highlighting the antenna, LoRa module, Bluetooth module, Arduino Nano, and battery in the Zoomed-in version (on the right)

Table 2. Power requirements for the proposed system

Item name	Voltage (V)	Stand-by current (mA)	Active current (mA)
HC05 Bluetooth module [24]	3.3	8	25
LoRa module [25]	3.3	1.6	Tx = 93, Rx = 12.15
Arduino Nano [26]	5	19	200
Buzzer	5	0	25
Total		28.6	355.15

Within the context of emergency communication, hypothetical scenarios were considered, along with active time assumptions, to provide a comprehensive picture of the situation. Firstly, the on-demand scenario is a typical type where the user activates the device in response to active coordination or SOS signals. This case assumes that there are four sessions, each lasting 30 minutes, with 12 messages/session. In the code, the duration of the tone for the buzzer feature was set for 1 second. On the other hand, latency increases with longer distances and under specific conditions, such as obstructions. Therefore, the active communication time is approximately 12-20 seconds, depending on the scenario and the surrounding environment. For example, the first scenario would have a total of 13 seconds, consisting of 12 seconds for transmission and 1 second for the buzzer. The active time is obtained by multiplying the number of messages by the total active time. Secondly, the device can be deployed to continuously listen for incoming emergency messages, allowing it to remain idle and in standby mode. The third scenario involves coordination and periodic updates, where the message frequency is six messages/hour. However, the worst-case scenario occurs in high-activity mode. In search-and-rescue missions, intensive coordination among multiple rescue teams is critical, with an average of 12 messages/hour. Battery life is a significant factor in designing emergency communication systems. While the 9 V battery is replaceable and accessible, changing it can be challenging at times, especially during stressful moments. Thus, a long battery life is advisable and recommended. To assess the energy consumption of the developed LoRa device, calculating the duty cycle is the first step. The duty cycle is driven by user behavior and how long the device is active. By following hourly active time calculations, the cycle appears to be 3600 seconds. Hourly basis metrics are more relevant to emergency applications. As the intensity of the activity increases, the active time duration becomes 0 seconds, 16 seconds, 78 seconds, and 252 Seconds, respectively. Once the active time of the device in each scenario is known, the duty cycle and the average draw current can be calculated by using (3) and (4). Since the capacity of the recommended 9 V alkaline battery is 580 mAh, the battery lifetime equation can be solved, as in (5) [27].

$$\text{Duty Cycle (\%)} = \frac{T_{\text{Active}}}{T_{\text{Cycle}}} \times 100\%, T_{\text{Cycle}} = 3600 \text{ Sec} \quad (3)$$

$$\text{Average Current Draw}(mA) = \frac{(I_{Active} \times T_{Active}) + (I_{Stand-by} \times T_{Stand-by})}{T_{Cycle}}, T_{Cycle} = 3600 \text{ Sec} \quad (4)$$

$$\text{Battery Lifetime (Hr)} = \frac{\text{Battery Capacity (mAh)}}{I_{avg}(mA)} \quad (5)$$

The results show that in the last four scenarios, battery life is less than a day, as shown in Table 3. Switching the device off and using it only when necessary will save a significant amount of energy. The 28.6 mA standby current remains the dominant energy consumer, and such efficiency measures will extend battery life to 8 days, as in the first scenario. Additionally, the medium activity mode sustains 16.2 hours of operation with periodic emergency messaging, representing only a 20% reduction from idle mode. Even in high-activity mode, the system spends 93% of its time in stand-by, making stand-by the current primary determinant of battery life. Only a 37% reduction from idle to high activity mode, which is sufficient for most emergency responses. In a nutshell, looking for other alkaline battery options with higher capacity is expected to extend the lifetime of the battery. Nevertheless, the primary purpose is not to run the device continuously, as the chemistry of the alkaline 9 V battery is optimized for long-term applications.

Table 3. Energy consumption analysis under various scenarios

Scenarios	Duty cycle/hour (%)	Average current draw (mA)	Battery life
On-demand	8.33	2.98	8.1 Days
Idle	0	28.6	20.3 Hr
Medium	2.17	35.7	16.2 Hr
Heavy	7	45.6	12.7 Hr

The efficiency of the proposed LoRa-based communication system and the maximum transmission distance are determined by the SF and the bandwidth (BW), denoted by the RSSI and SNR parameters. Moreover, better stable communication is determined by a higher value of SNR. Environmental factors can affect LoRa communication. For instance, cold weather improves the SNR, while warm weather suggests selecting lower SFs to minimize latency [28].

2.2. Network architecture and measurement settings

The long-range communication with low-power consumption between the two devices is the key concern. The configuration of the data transmission line is point-to-point. When more users are exchanging messages, the network shifts into a mesh topology. Due to the properties of LoRa modulation, a higher SF leads to a longer communication range but a lower data transmission rate. The ideal LoRa configuration depends on the application type. In fact, the transmission distance can be extended with a bandwidth of less than 125 KHz, but at the cost of increased transmission latency. The receiver has a specified capture frequency range, which is the allowable percentage difference between its frequency and the transmitter's frequency. This range determines how much the transmitter and receiver frequencies can differ while still allowing the receiver to successfully detect the signal. Typically, the percentage is 25% of the bandwidth. To illustrate, if the bandwidth were 10 KHz, the receiver would need to be on or between 433.9975 MHz and 434.0025 MHz. On the other hand, the SF defines the noise performance below. SF6 and SF12 give a -7.5 dB and a -20 dB below noise performance, respectively. The larger SFs, therefore, provide a wider range; the trade-off is that higher SF packets take longer to transmit. In the case of an SF of 12 and a BW of 125 KHz, the maximum transmission distance is attained with the least package loss [28]. The coding rate can also result in small signal gains at the limit of reception, and it varies between 4/5 and 4/8. Yet, the higher 4/8 rate will result in longer packets [25]. A coding rate of 4/5 was chosen because it means that for every 4 bits of data, 1 redundant bit is added for forward error correction. Hence, the proposed LoRa devices used in this work were set at a frequency of 433 MHz, a bandwidth of 125 KHz, a coding rate of 4/5, and a transmitting power of 17 dBm. Since these parameters can be adjusted in the software, the range test results are effective in determining the optimal settings. A summary of these settings is shown in Table 4.

Regarding the network architecture, it can be described as a custom packet-based protocol over LoRa at the physical layer. In the meantime, a serial-based application protocol is running over Bluetooth for user chatting. In Figure 4, the Bluetooth link handles local communication between the user and the device, while the LoRa link handles long-range wireless communication between devices. Together, they form a two-hop system. Although mesh topology leads to an increase in network traffic, mesh networks can reconfigure themselves in the event of a loss of connectivity to a node or group of nodes.

Table 4. Measurement parameters and settings

Parameter name	Parameter values
Frequency	433MHz
SF	12=4096 chips/symbol
Transmitter height	5 m
Receiver height	1.2 m
Transmitted power	17 dBm
Antenna gain	2.15 dBi
Bandwidth	125 KHz

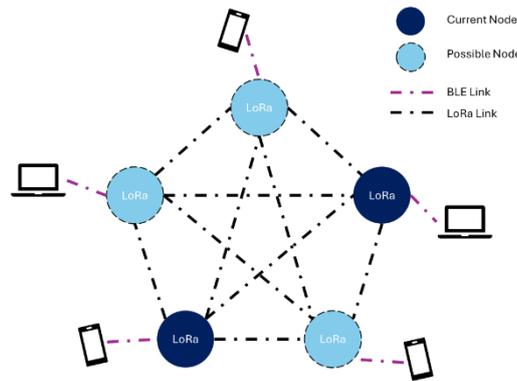


Figure 4. Diagram of the network architecture shows the potential of scalability, forming a two-hop mesh topology network

On the other hand, the routing of messages is straightforward since every LoRa device sends a message to a particular LoRa device using a specific address. Besides broadcasting, messages from different addresses are ignored. The device username is what appears in the application layer, whereas the physical layer addresses are represented in hexadecimal. For example, 0xBBB is the actual address of User 1, as shown in Figure 1, and 0xFF is set for broadcasting. Additionally, the counter is reset at the start of every session, making it useful for troubleshooting. Likewise, the message length in bytes provides insight into cases of mismatch and data corruption. Afterward, over-the-air transmission occurs once the packet is ended after writing to the internal buffer, as shown in Figure 5.

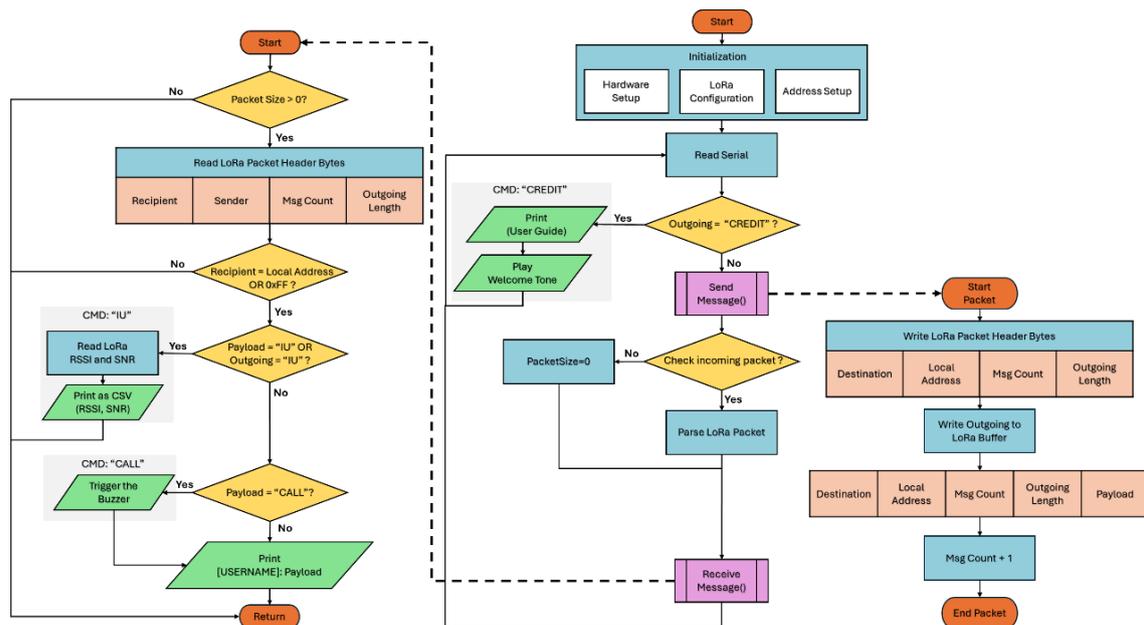


Figure 5. Flowchart of the LoRa communication protocol showing the data flow in the software

During the experiments, the measurements were performed by fixing the Tx at a specific location, and the Rx was placed at different distances. Tx was placed at a height of approximately 5 m. Measurements were taken at several locations until the maximum distance was reached, or the Rx could no longer receive the message sent by the Tx, as indicated by the RSSI level. Afterward, RSSI, SNR, and distance readings were retrieved in CSV format for further analysis.

2.3. Range test experiment

The experiments were carried out in the Islamic University of Madinah (IUM) campus in Madinah, Saudi Arabia. The location chosen for the range test was the university campus parking lot, as shown in Figure 6. The site is flat with a complete LoS, and it is surrounded by some buildings. These experiments took place in the Madinah environment during June. During this time of the year, the temperatures are in the range of 40 °C with a humidity of 8%. The maximum transmission distance couldn't exceed 80 m due to the extremely high ground temperatures.



Figure 6. LoS range test with Tx and Rx for the maximum distance of 237.5 m

Therefore, another experiment was conducted in which the Tx was placed near a window on the third floor of a building facing the direction of the Rx. The temperature was 30 °C, and the humidity was 13%. As a result, the research team achieved a maximum transmission distance of 237.5 m, as shown in Figure 6. This implies that the transmission distance can be further increased as the transmitter altitude increases. For empirical analysis, we conducted two range tests under a similar setup where RSSI and SNR readings were recorded. While the first experiment was at a 5 m interval, the second test was for every meter to capture the fine variations.

3. RESULTS AND DISCUSSION

The PLE value is used as a reference for calculating the LDPL. The linear regression is applied, which is modeled with the path-loss equation empirically [13].

$$Y = a + bX \quad (6)$$

$$PL(d) = PL(d_0) + 10n \log \left(\frac{d}{d_0} \right) \quad (7)$$

$$PL = a + bX \quad (8)$$

With the variable a as the initial value of path-loss, which is free-space loss at a reference distance, d_0 and b is the PLE value multiplied by 10, and X is the logarithmic value of the receiver distance divided by the reference distance, so that the PLE value is $b/10$.

The post-experiment datasets were merged, with overlapping data points averaged to mitigate spatial sampling bias and enhance measurement accuracy. Figure 7 shows the RSSI and SNR values in LoS conditions, where the signal from the transmitter is directed towards the receiver. The signal experiences reflection, refraction, diffraction, absorption, and scattering, which affect the received signal strength. This can be ascribed to the surrounding buildings or the dry, hot weather, as the latency is more [29]. In both measurements and calculations, the received signal strength decreases logarithmically with distance. The graphs demonstrate reliable communication up to 165 m, with consistent RSSI/SNR trends and minimal packet loss. Beyond 165 m, the system can maintain connectivity for the maximum distance, but it exhibits severe packet loss, which may affect the results.

SNR degradation correlated strongly with RSSI decline, suggesting that the noise floor is a key limiting factor at LoRas, as seen in Figure 7(a). However, SNR is a more accurate measure of signal quality than RSSI. At distances greater than 100 m, the SNR approaches the LoRa demodulation threshold, typically -20 dB, which explains the increased packet loss beyond this range [25].

The SNR plot follows a logarithmic-like trend, dropping sharply within the first 40 m, which suggests that the environment introduces significant interference. This behavior is consistent with fundamental wireless propagation theory, where the signal power typically decays logarithmically with distance due to free-space path-loss. The RSSI plot exhibits a rapid logarithmic decay from -115 dBm at 1 m to -126 dBm at 20 m, as shown in Figure 7(b). This steep decline aligns with free-space path-loss ($n = 2$) but is mitigated by ground reflection and constructive interference in the near field, typical of open LoS environments. RSSI converges to a noise-limited floor of -128 dBm to -129 dBm, persisting until communication fails at a distance of 165 m. Typically, the noise floor represents the physical limit of sensitivity; however, LoRa operates below this level [25]. This exemplifies resilience, unlike commonly used communication protocols.

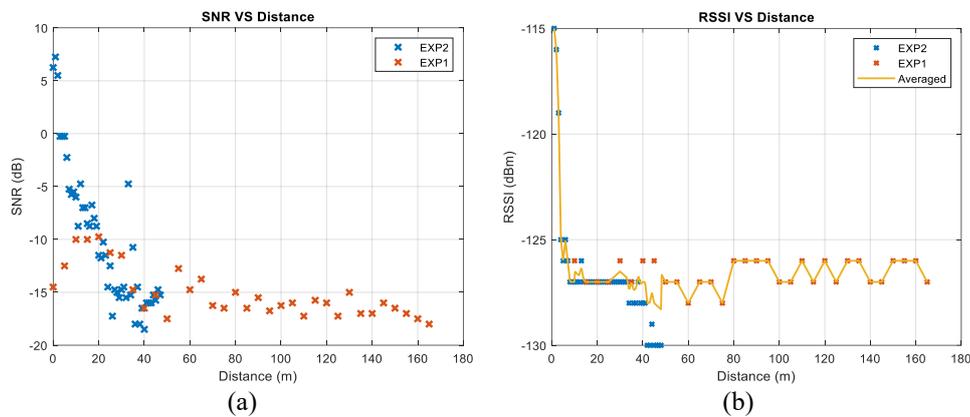


Figure 7. The outdoor experiment measurements in LoS conditions of (a) SNR (dB) and (b) RSSI (dBm)

Figures 8(a) and (b) illustrates the standard deviation error bars, which underscore the variability of readings caused by the multipath fading and interference. Each data point represents the mean value at a specific distance, whereas the error bars indicate the standard deviation across repeated measurements. The standard deviation decreases as the distance increases, making trends more observable. For example, the standard deviation of SNR measurements goes as low as ± 0.35 . It implies that the signal should travel enough distance for a better description and analysis of the path. By excluding the first value, the average standard deviation of SNR is ± 2.3 , while the average standard deviation of RSSI is ± 0.86 .

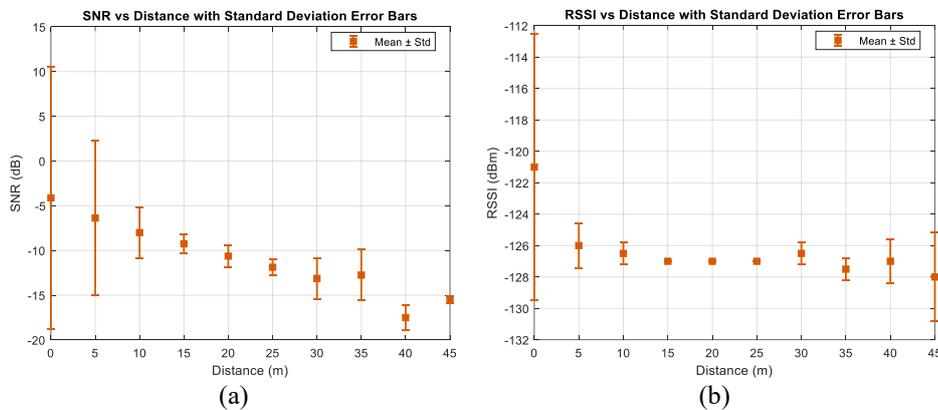


Figure 8. Standard deviation error bars for the repeated tests of (a) SNR and (b) RSSI, which highlight the measurement variability due to the path loss

Furthermore, RSSI measurements collected outdoors display significant signal fluctuations, which are common in outdoor scenes due to multipath fading. The signal in the outdoor environment suffers from noise, resulting in increased interference and creating a challenging environment for testing and analysis. Subsequently, the Kalman filter is utilized by isolating the true signal from the noise-induced variance, as shown in Figure 9. In this research, Kalman filter parameters are tuned to fit the RSSI filtering application. Firstly, noise within the system is examined through two parameters: R reflecting measurement noise, and Q representing internal process noise.

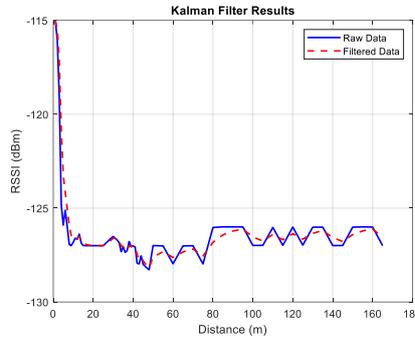


Figure 9. Kalman filter results that isolate the true signal from the noise-induced variance

Furthermore, as the height of Tx increases, the quality of communication would increase. Additionally, when temperatures are low, the noise power is reduced. Thus, better SNR values are achieved. Although hot weather may slow down processing due to overheating components, cold weather tends to drain batteries more quickly than warm weather [29]. As shown in Figure 10 (a), the PLE is plotted as a function of distance. The results show that when the distance is less for the LoS setup, the value of the PLE value is at its highest, closer to $n = 2$. As expected, the research team found that when the Rx is displaced in outdoor conditions, the PLE decreases, violating the idealized free-space value. This discrepancy arises from ground reflection effects, which introduce constructive interference between the direct and reflected signal paths.

For meaningful results, the focus was placed on the pre-saturation region (1–20 m), where signal dynamics dominate. The observed logarithmic decay aligns closely with the LDPL model. After averaging RSSI raw data and applying a filtration technique, the LDPL model was estimated. The LDPL model relies on the relationship between the RSSI and the logarithmic scale of distance, as shown in Figure 10(b). The regression estimation line yields the following (9).

$$RSSI \text{ (dBm)} = -12.6 \log\left(\frac{d}{d_0}\right) - 115 \tag{9}$$

- Estimated PLE (n) = 1.26
- Intercept (RSSI at reference distance) = -115 dBm

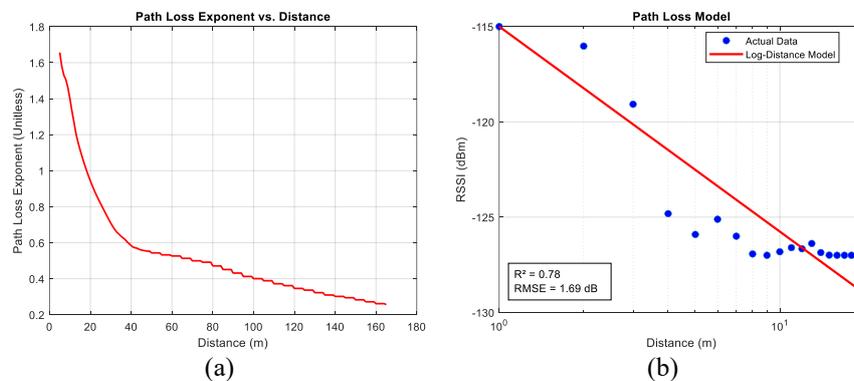


Figure 10. Path-loss characterization of the environment for meaningful insights on the signal behavior: (a) PLE vs. distance and (b) LDPL model for the first 20 m

This mathematical analysis was explored using MATLAB. To assess the accuracy of the linear regression, the coefficient of determination (r^2) was employed, which is a useful statistical measure representing the proportion of the variance in the dependent variable. It shows an acceptable value of 0.78, which is close to 1.

3.1. Software-defined radio-based analysis

LoRa is defined within the physical (PHY) layer based on a chirp CSS modulation technique, which allows long-range, low-power data transmission [30]. Additionally, the carrier frequency is swept linearly over time, which improves signal resilience to interference [30]. This is illustrated in Figure 11. Recently, computers have become powerful enough to perform the required mathematical calculations to decode and process radio signals. This has led to advanced radios that previously required complicated analog hardware now being easily implemented in software.

This has reduced the cost of advanced radio capabilities such as wideband tuning and waterfall displays. For analysis purposes, the research team utilized an RTL-SDR dongle in conjunction with SDR# software [31]. The RTL-SDR is a low-cost SDR that is based on DVB-T TV (Digital-HD TV) universal serial bus (USB) receiver dongles [31]. Using a dipole antenna, we were able to observe the frequency spectrum to validate the performance of the LoRa devices. The SDR dongle was set to a bandwidth of 225 KHz, a central frequency of 433 MHz, narrowband frequency modulation (FM), and a 1.4 MS/s sample-rate. The device was set up close to the antenna, while the research team captured the sent sequences. The complete measurement setup is shown in Figure 12.

By observing the waterfall plot, the transmitted signal can be distinguished because its power is higher than that of the noise signal. Hence, this experiment demonstrates that the devices are successfully transmitting the signal at a frequency of 433 MHz. This is true since we are using an SX1278 LoRa module, which operates at this frequency, as shown in Figure 13(a). LoRa messages are transmitted using the CSS modulation scheme. To enable precise observation of the modulation dynamics, the sample-rate was adjusted to 2.56 MS/s. This adjustment enabled real-time visualization, as shown in Figure 13(b).

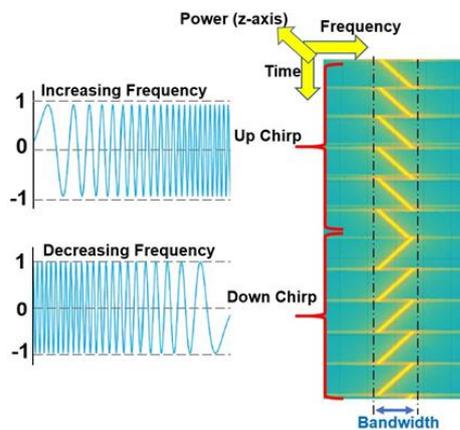


Figure 11. CSS scheme [18]

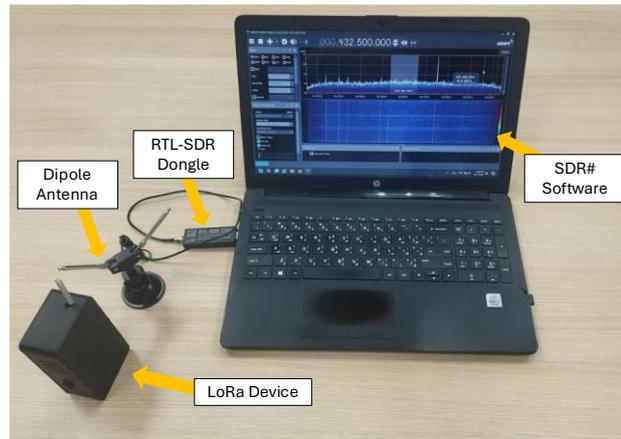


Figure 12. Measurement setup of LoRa Tx with RTL-SDR Rx

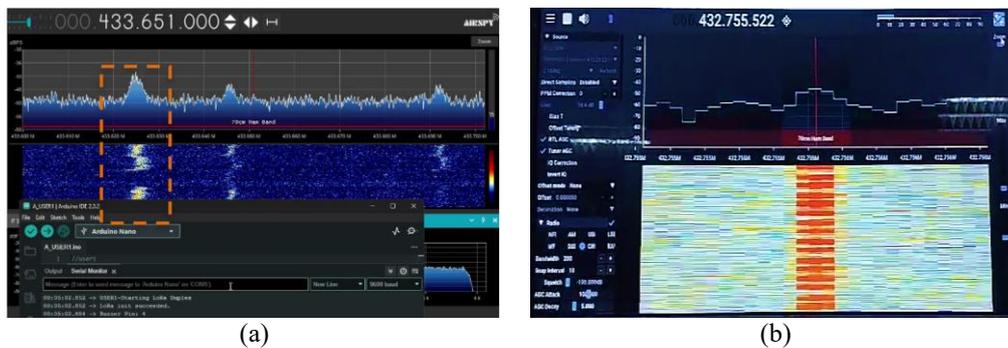


Figure 13. The waterfall results by the SDR showing LoRa signal transmission: (a) successful transmission at 433 MHz and (b) chirps were observed as the sample rate was adjusted

3.2. Comparative study

The proposed design has several significant advantages over the other designs presented by other researchers, as summarized in Table 5 (see in Appendix) [7]-[9], [14]-[17], making it especially suitable for disaster mitigation and relief operations in off-grid emergency applications. It functions completely offline, eliminating the need for internet or mobile networks, which is crucial for maintaining functionality in emergency scenarios. To ensure that critical communications are received even when a device is not connected to a mobile phone, the system features an emergency notification capability with buzzer alerts. Its compact design and energy efficiency enable it to be deployed in off-grid or remote locations with minimal infrastructure and low power consumption. Furthermore, the design has been validated through real-world testing, including SDRs and range tests, which demonstrate its ability to sustain reliable communication in various situations.

4. CONCLUSION

This paper aims to enhance the discussion on strengthening infrastructure during disaster situations by utilizing off-grid solutions with LoRa protocol technology through engineered deployment. After designing the prototype, LoRa devices were analyzed based on the principles of wireless communication. The authors successfully proposed and developed a point-to-point communication system utilizing LoRa technology in the Madinah, Kingdom of Saudi Arabia, environment. The findings of this research study indicate that the maximum achievable distance is approximately 240 m when using a 2 dBi gain antenna. This limitation is largely due to the presence of various buildings and trees along the signal propagation path, as well as the proximity of the receiving (Rx) device, which is positioned 1.6 m above the ground. Using an SDR, we were able to observe the transmitted signals of LoRa and validate the modulation process. This investigation led us to explore CSS, a modulation technique used in LoRa technology. The PLE value of the measurement results was determined using the readings of the RSSI value via the LDPL model, whose results closely match the RSSI values of the measurement data. Through regression of RSSI measurements, the equation parameters were defined. The range tests were conducted using 2.15 dBi gain antennas. Our work sheds light on the various analysis techniques that can be implemented for LoRa devices. While LoRa has been around for a while in several IoT applications, it is not conventional to use it for texting and human communication. The prototype demonstrated in this work makes a practical contribution to disaster communication systems, utilizing accessible technologies like LoRa. The innovation lies in creating custom hardware with features that address the unique disaster challenges, namely, access to power, warning triggers, and user flexibility.

Using similar developed analysis, researchers can explore the capabilities of other novel wireless protocols and their potential for rescue and relief. For future work, it is also necessary to conduct all useful experiments in various environments to estimate the received signal power by varying the level of transmitted power. Although the range tests of LoRa devices were conducted outdoors in an open environment within the campus under line-of-sight conditions, it is advisable to carry out similar experiments in indoor, rural, or obstructed terrain environments, or even under interference or out-of-sight conditions. Different frequency ranges and the influence of certain types of walls can also be explored through further range tests. This topic can also be discussed from a networking perspective, including the encryption of messages, retransmission, redundancy recovery techniques, and overall architecture. Although the proposed system features Coding Rate, message counter, and payload length indicator for reliable data handling, a detailed discussion on failover logic and backup algorithms provides a significant contribution.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Al-Baraa Ebad	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			
Mohammed Abaker	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			
Bilal A. Khawaja	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓	
Arshad Karimbu		✓	✓	✓	✓		✓			✓	✓	✓		
Vallappil														
Sameer Qazi		✓			✓			✓		✓	✓	✓		
Muhammad Mustaqim	✓		✓	✓		✓		✓		✓	✓			

C : Conceptualization	I : Investigation	Vi : Visualization
M : Methodology	R : Resources	Su : Supervision
So : Software	D : Data Curation	P : Project administration
Va : Validation	O : Writing - Original Draft	Fu : Funding acquisition
Fo : Formal analysis	E : Writing - Review & Editing	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

- [1] Z. A. Smith, M. Z. Mumtaz, H. Kislal, and S. L. Baglione, "Disasters and impact estimation the great East Japan earthquake and the tsunami in Tohoku," *Natural Hazards*, vol. 121, no. 7, pp. 8587–8611, Apr. 2025, doi: 10.1007/s11069-025-07107-4.
- [2] M. Joughari, N. Saeed, M. -S. Alouini and E. M. Amhoud, "A Survey on Scalable LoRaWAN for Massive IoT: Recent Advances, Potentials, and Challenges," in *IEEE Communications Surveys & Tutorials*, vol. 25, no. 3, pp. 1841-1876, thirdquarter 2023, doi: 10.1109/COMST.2023.3274934.
- [3] A. K. Vallappil, B. A. Khawaja, M. K. A. Rahim, M. N. Iqbal, H. T. Chattha, and M. F. bin M. Ali, "A Compact Triple-Band UWB Inverted Triangular Antenna with Dual-Notch Band Characteristics Using SSRR Metamaterial Structure for Use in Next-Generation Wireless Systems," *Fractal and Fractional*, vol. 6, no. 8, p. 422, Jul. 2022, doi: 10.3390/fractalfract6080422.
- [4] M. Uzair, R. D. Dony, M. Jamil, B. A. Khawaja, and M. N. Khan, "A no-reference framework for evaluating video quality streamed through wireless network," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 27, no. 5, pp. 3383–3399, Sep. 2019, doi: 10.3906/elk-1811-173.
- [5] J. P. Lousado and S. Antunes, "Monitoring and support for elderly people using lora communication technologies: Iot concepts and applications," *Future Internet*, vol. 12, no. 11, pp. 1–30, Nov. 2020, doi: 10.3390/fi12110206.
- [6] Communications and Information Technology Commission (CITC), *National Frequency Plan in the Kingdom of Saudi Arabia*, Riyadh, Saudi Arabia, 2008. [Online]. Available: <https://docslib.org/doc/11024856/national-frequency-plan-in-the-kingdom-of-saudi-arabia>. (accessed Oct. 08, 2025).
- [7] A. Augustin, J. Yi, T. Clausen, and W. M. Townsley, "A study of Lora: Long range & low power networks for the internet of things," *Sensors (Switzerland)*, vol. 16, no. 9, p. 1466, Sep. 2016, doi: 10.3390/s16091466.
- [8] A. J. Wixted, P. Kinnaird, H. Larijani, A. Tait, A. Ahmadinia, and N. Strachan, "Evaluation of LoRa and LoRaWAN for wireless sensor networks," in *Proceedings of IEEE Sensors*, IEEE, Oct. 2016, pp. 1–3, doi: 10.1109/ICSENS.2016.7808712.
- [9] L. Baumgartner, A. Penning, P. Lampe, B. Richerzhagen, R. Steinmetz, and B. Freisleben, "Environmental Monitoring Using Low-Cost Hardware and Infrastructureless Wireless Communication," in *GHTC 2018 - IEEE Global Humanitarian Technology Conference, Proceedings*, IEEE, Oct. 2018, pp. 1–8, doi: 10.1109/GHTC.2018.8601883.
- [10] D. S. Syed, S. B. Hossain, A. Islam, T. A. I. Jim, and M. S. R. Zishan, "Design and Feasibility Analysis of a LoRa Based Communication System for Disaster Management," *AIUB Journal of Science and Engineering*, vol. 23, no. 2, pp. 135–144, Aug. 2024, doi: 10.53799/ajse.v23i2.1055.
- [11] A. Vithayathil, A. Mohamed, A. Jacob, C. M. Raju, and J. Jacob, "LoRa Based Wireless Network for Disaster Rescue Operations," in *10th International Conference on Advances in Computing and Communications, ICACC 2021*, IEEE, Oct. 2021, pp. 1–7, doi: 10.1109/ICACC-202152719.2021.9708218.
- [12] D. Schmidt, F. Kuntke, M. Bauer, and L. Baumgartner, "BPoL: A Disruption-Tolerant LoRa Network for Disaster Communication," in *2023 IEEE Global Humanitarian Technology Conference, GHTC 2023*, IEEE, Oct. 2023, pp. 440–447, doi: 10.1109/GHTC56179.2023.10354717.
- [13] I. R. Lopes, P. R. da S. L. Coelho, R. Pasquini, and R. S. Miani, "Evaluating the Performance of LoRa Networks: A Study on Disaster Monitoring Scenarios," *Internet of Things*, vol. 6, no. 1, p. 14, Feb. 2025, doi: 10.3390/iot6010014.
- [14] T. Inthasuth, Y. Kaewjumras, S. Somwong, and W. Boonsong, "Comparative analysis of ZigBee, LoRa, and NB-IoT in a smart building: advantages, limitations, and integration possibilities," *International Journal of Reconfigurable and Embedded Systems (IJRES)*, vol. 14, no. 1, p. 165, Mar. 2025, doi: 10.11591/ijres.v14.i1.pp165-175.
- [15] B. Shilpa, R. K. Jha, V. Naware, A. Vattam, and A. M. Hussain, "Design and implementation of hybrid low power wide area network architecture for IoT applications," *Journal of Ambient Intelligence and Smart Environments*, vol. 16, no. 2, pp. 201–213, Jun. 2023, doi: 10.3233/ais-230146.
- [16] D. C. Deepak, A. Ladas, Y. A. Sambo, H. Pervaiz, C. Politis, and M. A. Imran, "An Overview of Post-Disaster Emergency Communication Systems in the Future Networks," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 132–139, Dec. 2019, doi: 10.1109/MWC.2019.1800467.
- [17] P. Lieser, F. Alvarez, P. Gardner-Stephen, M. Hollick, and D. Boehnstedt, "Architecture for responsive emergency communications networks," in *GHTC 2017 - IEEE Global Humanitarian Technology Conference, Proceedings*, IEEE, Oct. 2017, pp. 1–9, doi: 10.1109/GHTC.2017.8239239.
- [18] M. L. Tan, R. Prasanna, K. Stock, E. Hudson-Doyle, G. Leonard, and D. Johnston, "Mobile applications in crisis informatics literature: A systematic review," *International Journal of Disaster Risk Reduction*, vol. 24, pp. 297–311, Sep. 2017, doi: 10.1016/j.ijdr.2017.06.009.
- [19] T. S. Rappaport, *Wireless Communications*. Cambridge University Press, 2024, doi: 10.1017/9781009489843.
- [20] M. Rademacher, H. Linka, T. Horstmann, and M. Henze, "Path Loss in Urban LoRa Networks: A Large-Scale Measurement Study," in *IEEE Vehicular Technology Conference*, IEEE, Sep. 2021, pp. 1–6, doi: 10.1109/VTC2021-Fall52928.2021.9625531.
- [21] H. Vo, V. H. L. Nguyen, V. L. Tran, F. Ferrero, F. Y. Lee, and M. H. Tsai, "Advance Path Loss Model for Distance Estimation Using LoRaWAN Network's Received Signal Strength Indicator (RSSI)," *IEEE Access*, vol. 12, pp. 83205–83216, 2024, doi: 10.1109/ACCESS.2024.3412849.

- [22] A. Vazquez-Rodas, F. Astudillo-Salinas, C. Sanchez, B. Arpi, and L. I. Minchala, "Experimental evaluation of RSSI-based positioning system with low-cost LoRa devices," *Ad Hoc Networks*, vol. 105, p. 102168, Aug. 2020, doi: 10.1016/j.adhoc.2020.102168.
- [23] G-NiceRF, "433MHz nickel plated spring antenna SW433-TH32DN." Accessed: Oct. 09, 2025. [Online]. Available: https://www.laskakit.cz/user/related_files/433mhz_nickel_plated_spring_antenna_sw433-th32dn_v2-2.pdf
- [24] S. V. S. V. P. D. Kumar, S. Akashe, and V. Kumar, "Advanced Control of Switching Ignition by Smart Helmet," *International Journal of Image, Graphics and Signal Processing*, vol. 10, no. 2, pp. 34–42, Feb. 2018, doi: 10.5815/ijigsp.2018.02.04.
- [25] V. Bonilla, B. Campoverde, and S. G. Yoo, "A Systematic Literature Review of LoRaWAN: Sensors and Applications," *Sensors*, vol. 23, no. 20, p. 8440, Oct. 2023, doi: 10.3390/s23208440.
- [26] N. Yusop, N. A. Moketar, and S. F. N. Sadikan, "Development of Arduino applications for IoT applications in software engineering education: a systematic literature review," *Bulletin of Electrical Engineering and Informatics*, vol. 13, no. 3, pp. 1824–1831, Jun. 2024, doi: 10.11591/eei.v13i3.4506.
- [27] Duracell, "MN9100-1 alkaline manganese dioxide battery datasheet." <https://assets.rs-online.com/v1698853671/Datasheets/ba8f7897330b3cde9ea853ad61fb6fa5.pdf> (accessed Oct. 09, 2025).
- [28] S. De *et al.*, "Interleaved Reception in LoRa Using IFT: A Hardware-Efficient Architecture for Fast and Low-Power Image Transmission," *IEEE Internet of Things Journal*, vol. 12, no. 19, pp. 39777–39787, Oct. 2025, doi: 10.1109/JIOT.2025.3588064.
- [29] O. Elijah *et al.*, "Effect of Weather Condition on LoRa IoT Communication Technology in a Tropical Region: Malaysia," *IEEE Access*, vol. 9, pp. 72835–72843, 2021, doi: 10.1109/ACCESS.2021.3080317.
- [30] V. H. L. Chalacan, "Performance Evaluation of Long Range (LoRa) Wireless RF Technology for the Internet of Things (IoT) Using Dragino LoRa at 915 MHz," University of North Florida. School of Engineering, 2020. [Online]. Available: <https://digitalcommons.unf.edu/etd/986>
- [31] R. Yagoub, M. Benaissa, and B. Benadda, "Nearby Carrier Detection Based on Low Cost RTL-SDR Front End," *Wireless Personal Communications*, vol. 108, no. 4, pp. 2341–2358, Oct. 2019, doi: 10.1007/s11277-019-06524-6.

APPENDIX

Table 5. Comprehensive performance comparison of the proposed LoRa-based system with alternative LPWAN technologies and existing LoRa implementations

Ref.	Technology/focus area	Environment tested	Key features and comparison to our design
[7]	Performance analysis of LoRa	Suburban (Paris)	<ul style="list-style-type: none"> - Range: up to 3 km, data rate: low, power consumption: low, cost: low - Infrastructure requirements: minimal (LoRa only) - Deployment complexity: low, latency: low, bandwidth: narrow (~125 khz) - Comparison to our design: our design adds real-world deployment, mobile support, and practical usability, including a buzzer for emergency notifications.
[8]	Evaluation of LoRaWAN	Urban environments	<ul style="list-style-type: none"> - Range: up to 2.2 km, data rate: low, power consumption: low, cost: low - Infrastructure requirements: lorawan gateway - Deployment complexity: moderate, latency: low, bandwidth: narrow - Comparison to our design: our prototype focuses on off-grid disaster communication with buzzer support, ideal for emergency response in isolated regions, without the need for external gateways.
[9]	Environmental monitoring	Rural areas (up to 6.5 km)	<ul style="list-style-type: none"> - Range: up to 6.5 km, data rate: low, power consumption: low, cost: low - Infrastructure requirements: none (infrastructure-less) - Deployment complexity: low, bandwidth: narrow - Comparison to our design: our system focuses on human-to-human communication, providing more interactive functionality for disaster scenarios, whereas theirs is sensor-based deployments.
[14]	NB-IoT (Quectel BC95)	Multi-floor building (1 st , 5 th , 10 th floors),	<ul style="list-style-type: none"> - Range: 458 m (stable), data rate: 25.2 kbps downlink (DL), 15.6 kbps uplink (UL), power consumption: high (~199.5 mW @ 23 dBm) - Infrastructure requirements: cellular base stations and core network - Deployment complexity: high, latency: moderate, bandwidth: wide (licensed long-term evolution/LTE spectrum) - Comparison to our design: NB-IoT offers excellent coverage and zero packet loss, but relies on cellular infrastructure, which is often damaged during disasters. Our LoRa system operates entirely off-grid, maintaining communication continuity when cellular networks fail.

Table 5. Comprehensive performance comparison of the proposed LoRa-based system with alternative LPWAN technologies and existing LoRa implementations (*continued*)

Ref.	Technology/focus area	Environment tested	Key features and comparison to our design
[14]	ZigBee (XBee series 2, IEEE 802.15.4)	Multi-floor building (8 th -10 th floors)	<ul style="list-style-type: none"> - Range: 40 m (same floor), no link beyond 2 floors, data rate: 250 kbps, power consumption: low (30–50 mA active) - Infrastructure requirements: mesh coordinator nodes - Deployment complexity: moderate, latency: low, bandwidth: high (2.4 GHz band) - Comparison to our design: ZigBee fails beyond 40 m indoors and cannot cover multi-building zones. Our LoRa prototype achieves 240 m range in urban LoS conditions, over six times longer, providing a practical solution for campus-scale disaster operations.
[15]	Wi-SUN (IEEE 802.15.4g) mesh network for smart city IoT	Outdoor LoS/ non-line of sight (NLoS), indoor LoS/NLoS	<ul style="list-style-type: none"> - Range: 298 m (LoS), 180 m (indoor NLoS), data rate: \approx 50 kbps, power consumption: moderate (8 mA Rx, 14 mA Tx @ 10 dBm) - Infrastructure requirements: mesh network with a border router and multiple router nodes - Deployment complexity: moderate to high, latency: very low (\approx 0.02 s), bandwidth: up to 300 kbps - Comparison to our design: Wi-SUN provides self-healing mesh and low latency, but needs multi-node infrastructure and mesh configuration. Our point-to-point LoRa design is simpler, consumes less power (28.6 mA standby vs. Wi-SUN mesh overhead), and can be deployed within minutes for rapid disaster response.
[16]	Post-disaster network scenarios	Theoretical	<ul style="list-style-type: none"> - Range: varies, data rate: varies, power consumption: moderate, cost: high (due to drone/manet infrastructure), - Infrastructure requirements: manets, drones - Deployment complexity: high, latency: varies, bandwidth: variable - Comparison to our design: our work presents a simpler, real-world-tested design with off-grid usability, focusing on low-cost, low-complexity deployment for civilian use.
[17]	Delay-tolerant mobile ad hoc network (MANET)	Emergency communication	<ul style="list-style-type: none"> - Range: wide, data rate: low to moderate, cost: moderate - Infrastructure requirements: none (ad-hoc MANETs) - Deployment complexity: high, latency: high, bandwidth: variable - Comparison to our design: our system offers lower latency and faster communication via buzzer alerts, ensuring faster response during emergencies, with much lower deployment complexity.
Proposed design (this work)	Bi-directional LoRa texting system	Madinah, Kingdom of Saudi Arabia (urban with obstructions)	<ul style="list-style-type: none"> - Range: up to 240 m, data rate: low, power consumption: very low, cost: very low - Infrastructure requirements: none (self-contained), - Deployment complexity: very low, latency: low, bandwidth: narrow - Comparison to other designs: real-world tested in an urban environment with sdr analysis; ideal for off-grid disaster zones, with a buzzer for alerting and multi-user support. Unlike other designs, it works completely offline without needing external infrastructure.

BIOGRAPHIES OF AUTHORS



Al-Baraa Ebad     received the B.Sc. degree in Electrical Engineering with First-Class Honors from the Islamic University of Madinah, Madinah, Kingdom of Saudi Arabia, in 2025. During his studies, he completed a research internship at Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia. He can be contacted at email: 421018293@stu.iu.edu.sa.



Mohammed Abaker    received the B.Sc. (Hons.) in Electrical Engineering from the Islamic University of Madinah, Saudi Arabia, in 2025. He completed a research internship at the Interdisciplinary Research Center for Intelligent Manufacturing and Robotics, KFUPM, where he co-authored a conference paper on autonomous inspection robots. He secured second place in the best graduation project competition for his SLAM-based indoor navigation system. His research interests include IoT, LoRa-based communication, embedded systems, and robotics. He can be contacted at email: 422039063@stu.iu.edu.sa.



Bilal A. Khawaja    holds a B.S. in Computer Engineering from Sir Syed University (2002), an M.Sc. in Communication Engineering from the University of Plymouth, UK (2005), and a Ph.D. in Electrical Engineering from the University of Bristol, UK (2010). He served as an Assistant Professor at NUST, Pakistan (2010-2016), and as a Visiting Post-Doctoral Researcher at Queen's University, Canada (2015), contributing to the NSERC-funded next generation optical network project. In 2016, he joined the Islamic University of Madinah, Saudi Arabia, where he is now a Professor in the Department of Electrical Engineering. His research interests include antenna and array design for 5G, IoT, and UAVs, millimeter-wave communication, metamaterials and metasurfaces, and the application of AI and blockchain in 5G, 6G systems, as well as smart cities. He has authored more than 70 journal articles and conference papers. He can be contacted at email: kjbmohammed@iu.edu.sa.



Arshad Karimbu Vallappil    received his B.Tech. degree in Electronics and Communication from the University of Calicut (2009), India, M.Tech. in Electronics Engineering from Pondicherry University (2013), India, and Ph.D. in Electrical Engineering from Universiti Teknologi Malaysia (2021), Malaysia. He has worked as a lecturer and now serves as Assistant Professor at the Islamic University of Madinah, Saudi Arabia, with prior research experience at the Institute of Space Sciences, Barcelona. His interests include RF/microwave systems, antenna arrays, beamforming, metamaterials, and metasurfaces. He can be contacted at email: kvarshad@iu.edu.sa.



Sameer Qazi    received his B.E. from NUST, Pakistan, in 2001, and his M.S. and Ph.D. from the University of New South Wales, Australia, in 2004 and 2009, respectively. He is the Director of ORIC and Associate Professor of Computer Science at Iqra University, Pakistan. Previously, he served as Head of Electrical Engineering at Karachi Institute of Economics and Technology (2016–2024) and held faculty positions at DHA Suffa University and NUST-PNEC. His research focuses on IoT, wireless networks, and AI applications. He has published extensively and leads research projects funded by Pakistan's Higher Education Commission and NCGSA. He can be contacted at email: sameer.hashmat@iqra.edu.pk.



Muhammad Mustaqim    received his B.S. in Electrical Engineering from the University of Central Florida, USA (2007), and M.S. from PAF-KIET, Pakistan (2012). He is pursuing his Ph.D. and serves as an Assistant Professor in the Department of Electronics and Power Engineering at NUST, Karachi. His research focuses on software-defined radio, RF/microwave design, spectrum sensing, and wireless networks. He has published over 25 articles and is active in RF education and SDR outreach. He can be contacted at email: mmustaqim@pnec.nust.edu.pk.