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LONG RANGE WIDE AREA NETWORK (LORAWAN) AND ITS APPLICATIONS IN MONITORING SMART FARMS AND FORESTS

Sameer Ahmed Mohammed MOHAMMED

Master's Thesis

Supervisor
Asst. Prof. Dr. Ayça KURNAZ TÜRKBEN

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The thesis titled A NEW POWER LINE FAULT DETECTION USING ENHANCED MACHINE LEARNING TECHNIQUES prepared by NAWAR MAJID DHAHIR and submitted on 12/04/2023 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering.

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DEDICATION

I would like to dedicate this work to my dearest Mom, Dad and my beloved husband. I feel so honoured and blessed to have you all by my side and want to express my gratitude for your care and I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work. Sameer Ahmed Mohammed MOHAMMED support over the years, thanks for instilling me with a strong passion for learning and for doing everything possible to put me on the path to greatness, I will never forget the important values you have passed down to me particularly perseverance and honesty word cannot describe how important you are to me.

ABSTRACT

LONG RANGE WIDE AREA NETWORK (LORAWAN) AND ITS APPLICATIONS IN MONITORING SMART FARMS AND FORESTS

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Fires in forests and agricultural systems have devastating impacts and adversely affect human and animal lives, the economy, and the environment. The recent growth of IoT use-cases in a wide array of industrial, utility and environmental applications has necessitated the need for connectivity solutions with diverse requirements. We study the fundamentals and design principles of LPWAN technologies pertain to wireless networks tailored for low-power gadgets that demand broad coverage over a considerable distance, with LoRaWAN serving as a prime example."LPWAN technologies in both licensed and unlicensed bands have been considered to provide connectivity to a high density of devices over larger coverage areas. We design, implement, and test a fire detection system for forests and farms based on LoRaWAN technology. The proposed system offers more accurate fire detection capability in terms of determining actual fire presence and determining the position of fire. Also, the proposed design can detect fires under a higher number of possible conditions compared to other designs.

Keywords: Low-Power Wide-Area Networks, Internet of Things, LoRaWAN, Network Simulation.

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ABBREVIATIONS

CR	:	Code Rate
B	:	Bandwidth
BW	:	Modulation Bandwidth
WSN	:	Wireless Sensor Networks
SNR	:	Signal-to-Noise Ratio
LPWAN	:	Low Power Wide Area Network
LPWA	:	Low Power Wide Area
IoT	:	Internet of Things
Gp	:	Processing Gain
N	:	Average Noise of Interference Power
R_b	:	Bit Rate
R_c	:	Chip Rate
Rsc	:	Symbol Rate
SF	:	Spreading Factor
S	:	Average Received Signal Power

1. INTRODUCTION

Long-Range Wide Area Network (LoRaWAN) standard was among the first LPWAN technologies to be developed, specified, and adopted. It is one of the solutions that recent technological advancements offer to aid in agriculture management. These kinds of solutions aid in boosting the output of agricultural production. Therefore, intelligent farms, also known as smart farming, have emerged as a new technology sector due to incorporating sensors, actuators, smart devices, and an IoT infrastructures such as LoRaWAN [1]. LoRaWAN enables low-power, long-range communication, as stated in [2]. Because of these qualities, the technology can be combined with other technologies of smart agriculture. To that end, this study aims to suggest a novel, cost-effective wireless long-range communication system based on LoRaWAN for use in smart farm settings. When we discuss smart farming, we are referring to utilizing today's information and communication technology in farm settings. It can provide accurate and resource-efficient agricultural production that can last for long periods of time. Growers can monitor soil and air temperature, water and soil conductivity, and irrigation water and soil pH in real-time, thanks to sensors installed in agricultural farms. Soil attributes and recorded data, which may be transported to the cloud for further analyses, can be used with communication technologies to convey the necessary information to gateways [3][4]. LPWAN is becoming increasingly popular in the industry and research communities due to its low power consumption, extended range, and low communication cost. Its range is 10-40 km out in the countryside but just 1-5 km in the city [5]. The primary advantages of low-power wide-area networks (LPWANs) can be summarized as: LPWAN networks have long coverage range, from 5 km to 30 km. Because of their low power consumption, LPWAN devices have a greater lifespan about 10 years. LPWAN sensors and gateways are less expensive. To cover greater distances, LPWAN network needs a modest number of access points (also known as base stations or gateways). LPWANs can withstand challenging channel conditions relatively easily by operating in the sub-GHz frequency spectrums. LPWAN signals can efficiently pass-through buildings and reach underground locations. Through its intelligent design, it facilitates quick network setup and straightforward administration. Because of its usage of encryption methods, it allows for safe data transmission between nodes and Gateways. An IoT-based solution can let farmers keep tabs on their agricultural production from afar with the help of simple devices. If you need to transmit small amounts of data from several sensor modules over a vast area network quickly and cheaply, one of the best options is an LPWAN. In Fig. 1, we can see a number of the prominent technologies that fall under both licensed and unlicensed LPWAN categories. Using an LPWAN-based sensor network architecture, real-time data relating to agriculture can be sent to the end user. To transmit data across distances of many kilometres using devices that require low power consumption, long-range (LoRa) technology is an attractive option. The primary focus of this effort is the development of an Internet of Things-based infrastructure for the remote monitoring of forests and farms with the purpose of detecting fires early. The developed system (hardware and software) allows for real-time tracking of fires. It can analyse data supplied by numerous end nodes. The prototype built provides an inexpensive means of collecting data from the environment of nodes. This article's unique contribution is in its proposal of a LoRaWAN-based hardware and software platform that can provide accurate fire detection capability in terms of determining actual fire presence or determining the position of fire. Also, the proposed design can detect fires under higher number of possible conditions compared to other designs. Although comparable designs have been used in the past, much of the available literature focuses on designing a system that can detect fires but does not focus on the accuracy or the efficiency in achieving that objective.

Figure 1.1: Licensed and Unlicensed LPWAN Technology [6].

In the system we designed we aimed to minimize the consumption of available resources in terms of available battery energy or channel frequency bandwidth. Other systems we found in the literature use the system to continuously monitor the environment to calculate the probability of a fire or use the system for other purposes as well such as controlling the operation of monitored farms. As was shown in [7], in case of fire any nodes sensing any of the symptoms of fire will send uplink messages. In the case of the existence of many sensors, as it is expected to cover large areas with a suitable number of sensors, this can cause a condition where uplink messages might collide or create a bottleneck condition at the gateways [8][9]. This can degrade the performance of the system when it is needed the most. Also, designing the nodes to respond to any indication of fire can lead to a system that may produce a high percentage of false positive alarms or make it difficult to locate the positions of fire. The end nodes we designed do not use the available resources, battery or channel, unless sufficient evidence is found i.e. the values of sensors reach certain thresholds.

1.1 PROBLEM STATEMENT

In Ecuador, there is practically little agricultural application of intelligent sensors. At the moment, sensors are employed for variable counting, monitoring, and control [10]. These wireless sensors can be used to regulate energy effectively. They can be scaled. Dynamic network topologies can be implemented by adding new sensors without degrading performance [11]. Long Range Wide Area Network (LoRaWAN) is a wireless communication technology that has gained considerable attention in recent years due to its ability to provide low-power and long-range connectivity for Internet of Things (IoT) devices. This technology is particularly attractive for monitoring large-scale outdoor environments, such as smart farms and forests, where traditional wired communication systems are often impractical or too expensive. Despite its potential benefits, there are still different challenges to overcome associated with the implementation of LoRaWAN in monitoring smart farms and forests. Firstly, the deployment of LoRaWAN gateways, which serve as communication hubs for IoT devices, requires careful planning and optimization to ensure optimal coverage and connectivity. Secondly, there is a need for robust and reliable sensors that can tolerate harsh outdoor conditions and provide accurate data for decision-making. Thirdly, management and analysis of collected data are critical for making effective use of the vast amounts of data generated by IoT devices in smart farms and forests. Furthermore, there is a need for further research to explore the full potential of LoRaWAN in monitoring smart farms and forests. This includes investigating the use of advanced analytics and machine learning techniques to enable predictive maintenance and decision-making, as well as exploring the potential of LoRaWAN for environmental monitoring and conservation efforts. Targeting these challenges will be vital to the successful implementation of LoRaWAN in monitoring smart farms and forests, enabling more efficient and sustainable agriculture and forestry practices.

1.2 OBJECTIVE OF THIS STUDY

The aim of Long-Range Wide Area Network (LoRaWAN) is to provide a cost-effective and efficient wireless communication protocol for Internet of Things (IoT) devices. Its applications in monitoring smart farms and forests aim to improve the efficiency and sustainability of farming and forestry practices, as well as enhance environmental conservation efforts. Specifically, LoRaWAN aims to enable the creation of low-power, wide-area networks that can connect a large number of devices over a wide geographic area. This enables the collection of real-time data from sensors placed throughout a farm or forest, which can be used to optimize farming and forestry practices, reduce costs, and improve crop yields. In monitoring smart farms, LoRaWAN aims to provide farmers with the ability to monitor environmental factors such as temperature, humidity, and soil moisture in real-time, and use this data to make informed decisions about crop management. This can help farmers optimize their irrigation and fertilization practices, reduce water consumption, and increase crop yields. In monitoring forests, LoRaWAN aims to provide forest managers with the ability to monitor temperature, humidity, and wind conditions in real-time, and predict the risk of wildfires. This can help authorities take preventive measures and mitigate the impact of wildfires. Overall, the aim of LoRaWAN and its applications in monitoring smart farms and forests is to provide a sustainable and efficient solution for IoT devices, and to enable the collection of real-time data that can inform decision-making and improve environmental management practices.

1.3 THESIS ORGANIZATION

Part 1: Introduction: Presents the background, motivation, and problem statement. It also describes the aims of this study. Part 2: Related Work: Discusses related work, highlights some of the previous work and research done in our problem area. Describes some introductory background needed for this thesis. Part 3: Methodology: Explains system design. Part 4: Results and Discussion: Evaluates the performance of LoRaWAN in the proposed scenario i.e., in monitorıng smart farms and forests. Part 5: Conclusions: It provides a summary and conclusion of the results obtained in our study.

2. BACKGROUND

2.1 SMART AGRICULTURE

It has been noted that urbanization and an aging agricultural labour force [15], are two of the significant global trends and demands that pose new difficulties for contemporary agriculture and necessitate technical innovations. The population is estimated at 7.77 billion now [17], but the FAO predicts it will rise to 9.73 billion by 2050 and 11.2 billion by 2100 [16]. (March 2020). Increasing food production is, therefore, inevitable. Water shortages, land degradation, and deforestation are serious problems that will only worsen as the climate and our eating habits shift. Less healthy food will be produced due to the over-exploitation of natural resources and the effects of climate change, creating fertile ground for spreading food- and water-borne illnesses and increasing the demand for pesticides. Accordingly, digital technologies are the current and future frontrunners in combating these tendencies. Indeed, monitoring, measuring, and evaluating the agricultural sector's physical characteristics can help shed light on its inherent complexity, variability, and unpredictability. The implementation of the Internet of Things allows for this [18].

2.2 WIRELESS SENSOR NETWORKS AND INTERNET OF THINGS

Through the implementation of novel data-centric systems equipped with various sensors, required actuators, wireless network connectivity, platforms focusing on Fog and Cloud computing, and similar elements the Internet of Things (IoT) can assist the agricultural industry in the framework of Smart Agriculture. Agricultural production and farm management may be effectively monitored and managed with the help of IoT-oriented systems due to their ability to collect, transfer, process, and analyse essential data originating from agricultural activities. Systems with an Internet of Things (IoT) or smart agriculture (Smart Agriculture) focus should follow the multi-tiered structure of most IoT platforms. A popular three-layer decomposition is utilized for IoT applications, while many layered networking schemes can be used to illustrate an IoT platform [19][20]. Here are the specifics of each of the three levels (i) the perception layer, which consists of devices that collect data from the environment (ii) the network layer, that is used to communicate information among connected end nodes and Internet, with the availability of local processing also; and (iii) the application layer, which presents application layer services to end users (e.g., farmers). Local networks of end devices form the backbone of an IoT platform in agriculture. Once deployed, these devices interact with the monitored area's many parts and may spread across a broad area (e.g., a large farm). Connecting this IoT platform to the web (through Cloud infrastructures, for instance) or a local monitoring station enables more versatile functions (such as data real time analysis at the application layer). Wireless sensor networks (WSNs) are commonly used to monitor and record environmental variables since they are local networks at the network layer that consist of geographically distributed sensing nodes. Specifically, a WSN relies on many nodes, or sensor nodes, which may be outfitted with many sensors to gather data on various variables, such as temperature, sound, pollution levels, humidity, wind intensity, etc. A concentrator, sometimes called a "sink" or "gateway," saves sends the collected data to a location outside the WSN. This route may involve more than one hop. It is important to note that the sink is responsible for establishing a connection between the WSN and the outside world through a communication protocol that is not necessarily the same as that used by the sensor nodes. In practice, it is common to exchange information between end nodes and the IoT system components by combining long-range wireless technologies such as cellular NB-IoT, SigFox, LoRaWAN, or other similar technologies such as IEEE 802.11 or Bluetooth Low Energy (BLE) [21].

2.3 LORA WAN OVERVIEW

Low-Power Wide-Area Networks (LPWANs) are designed in order to provide long-range, low-cost, and low-rate connection to a large number of end devices limited in terms of available power supply and processing capacity), is another IoT technology that is helpful for Smart Agriculture use cases. LoRa [22], and LoRaWAN [23], two of the newest wireless network technologies in the realm of LPWANs, provide excellent possibilities for Smart Farming. The critical reason LoRaWAN is used as the foundation for LoRaFarM's low-level communications is its versatility. More specifically, LoRa and LoRaWAN are two different things: The LoRa protocol operates on the Physical (PHY) layer because it uses a proprietary modulation based on Chirp Spread Spectrum (CSS) that was developed and patented by Semtech Corporation (https://www.semtech.com). In contrast, LoRaWAN is an open network architecture that specifies the Medium Access Control (MAC) layer using the LoRa modulation for the Physical Layer (PHY) layer. In particular, the Spreading Factor (SF) regulates the signal length in LoRa modulation; the more significant the SF, the longer time of a symbol and the farther a signal may reach. In particular, the SF may be anywhere from 7 to 12, with SF = 12 giving the highest sensitivity, and, longest transmission range, but with the lowest data rate and highest energy consumption [24]. Intuitively, the busier the radio transceiver is, the longer the symbol duration. As SF is reduced by one unit, the transmission rate is doubled, the transmission time is halved, and the energy required for transmission is cut in half. Given a fixed frequency band, LoRaWAN gateways can receive message signals from multiple sources with distinct SFs since the chirps at these SFs have orthogonality.

LoRaWAN uses a "star-of-stars" network topology, depicted in Figure 1, consisting of ENs and GWs. The latter is linked to a Network Server (NS) through IP-based networks connected to higher-level applications. There are three classed of ENs in LoRaWAN A, B, and C, with the Class defining the ENs' behavior regarding downlink packets. Class A is the minimum standard that all LoRaWAN devices must meet, and it allows devices to receive downlink acknowledgement messages only after sending an uplink message. Once a time-synchronized signal is received from the GW, Class B devices open additional receive slots at predetermined intervals, making them ideal for applications demanding a higher volume of downlink data. In conclusion, Class C devices have the most significant energy consumption level but the lowest downlink delay since they are constantly ready to receive a downlink packet. As soon as a packet is obtained from a node within a GW's reception range, the GW will pass it to the NS, which is in charge of the whole LoRaWAN network. In most cases, a single NS will receive the identical packet (provided by ENs) from numerous GWs.

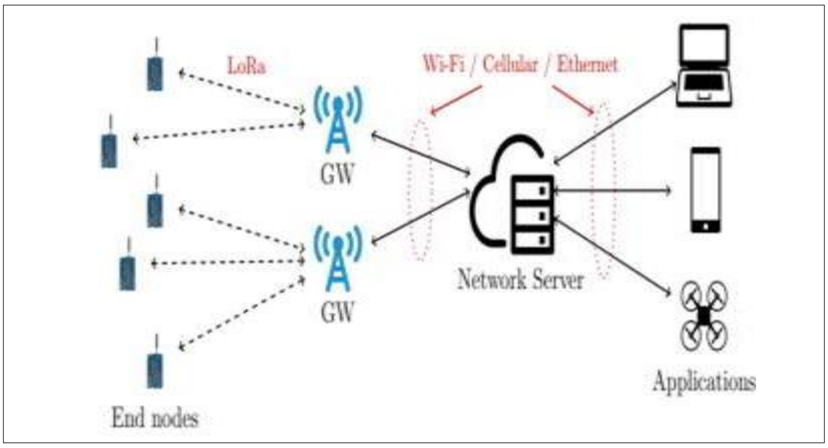

Figure 2.1 : LoRaWAN Architecture.

In LoRaWAN, the ALOHA protocol is used to get access to the radio spectrum: (i) an end node turns on and transmits a packet on a chosen radio channel; (ii) a single or more gateways within the node's coverage range receive the package; and (iii) the NS gets and processes the message. Because LoRaWAN works in Europe's unlicensed 868 MHz bands, all devices and gateways must adhere to the ETSI limits of the duty cycle (ranging from 0.1% to 10%, depending on the frequency) or risk interference. Due to this limitation, the Time on Air is determined every time a frame is sent, and the time the transmitter is prohibited from using the channel is computed as the Time off (TOFF). Registering and activating a LoRa-compliant node with the NS is required for the node to participate in LoRaWAN activities. LoRaWAN specifies two distinct activation procedures (i) Activation-by-Personalization (ABP), in this method an end device has all the required activation configuration parameters and there is no need for a join procedure, and (ii) Over-The-Air-Activation (OTAA), which is the safest because an end node sends a join-request frame to the NS, which in turn (potentially) sends a join-accept frame. For long-range, low-power communication, Cycle created LoRa, based on the Chirp Spread Spectrum (CSS) modulation technology and has its unique physical (PHY) layer. LoRaWAN is a MAC layer protocol developed on top of LoRa; its specifications are publicly published, and the LoRa Alliance has been approved.

2.3.1 Lora Physical Layer

LoRa operates in the lower ISM frequency bands of 433 MHz and 169 MHz without a license and the higher ISM bands of 863-870 MHz for Europe and 902-928 MHz for the US. By using free to use unlicensed ISM frequency bands, LoRaWAN reduces the cost of deployment but limits the highest data rate that can be achieved owing to per-device airtime allocation limits. In the widely used 863.000–869.00 MHz and 869.00–869.60 MHz frequency sub-bands, the required duty cycle is 1%. For a duration that is directly related to the packet's on-air time and the maximum allowable duty cycle [25], each sub-band must be "silent." If the duty cycle is 1% and the air duration is 1 second, then the sub-band must be silent for 99 seconds. This makes LoRa unsuitable for large data rate applications since the available air-time per device is limited to about 36 seconds per day. LoRa devices often employ channel-hopping algorithms that hop across channels (specified by distinct centre frequencies) to send data to overcome this limitation. Using the unlicensed ISM frequency spectrum reduces the cost of deployment but limits the highest data rate that can be achieved owing to per-device airtime allocation limits. In the widely used 863.000–869.00 MHz and 869.00–869.60 MHz frequency sub-bands, the required duty cycle is 1%. For a duration that is directly related to the packet's on-air time and the maximum allowable duty cycle [25], each sub-band must be "silent." If the duty cycle is 1% and the air duration is 1 second, then the sub-band must be silent for 99 seconds. This makes LoRa unsuitable for large data rate applications since the available air-time for each end node is limited to about 36 seconds per day. LoRa devices often employ channel-hopping algorithms that hop across channels (specified by distinct centre frequencies) to send data to overcome this limitation. Using lower frequencies compared to Wi-Fi and cellular, signals may travel further and penetrate more solid objects. According to different research results, this can be as far as 15 kilometres in open rural areas and 2 to 5 kilometres in built-up urban areas, with improved performance in the case of an uninterrupted line of sight between endpoints and access points. A variety of adjustable settings in LoRa provide the designer some leeway in determining the maximum range, power consumption, and data rate that may be attained by using the protocol.

a. The spreading factor (SF) is proportional to the number of chirps needed to modulate a single bit of information during the message's modulation. As the spreading factor grows, the signal-to-noise ratio (SNR) grows, allowing for a more excellent communication range but at the expense of slower transmission and more air time per packet.

b. The information transfer rate varies from 0.3 kbps to 27 kbps [25], depending on the SF used. The range of frequencies across which the LoRa chirp is broadcast is known as its bandwidth (BW). As bandwidth increases, packet rates increase, but communication distance decreases. Standard bandwidths range from 125 kHz to 500 kHz.

c. Coding Rate (CR), the additional bits in the packet header that can be changed to implement forward error correction. Higher coding rates improve interference tolerance but come at the expense of longer packets, more air time, and higher energy costs [26].

2.3.2 Lora Wan Mac Layer

LoRaWAN is a protocol developed on top of the LoRa MAC layer. Recently, it's gotten much attention because its features are well-suited to the Internet of Things (IoT). There are three primary parts to a LoRaWAN network:

a. Nodes: board-level sensors and actuator controllers that exchange data and control signals with gateways.
b. Gateways: Devices with Internet connection that operate as a logically transparent bridge between nodes and the network by forwarding packets from the nodes to a network server.
c. The network server responsible for de-duplicating incoming packets, discarding corrupted or undesirable ones, and allocating messages to be sent via gateways to the intended destinations.

In a typical LoRaWAN network, nodes do not communicate directly with any gateway but broadcast to all gateways in range. Fig. 2.2 depicts a sample topology for a hypothetical intelligent agricultural application in which various sensing nodes can exchange data via different types (fixed or mobile based on vehicles or drones) of gateways. This is in contrast to the mesh topologies generally used by WSN (wireless sensor networks), where groups of devices talk to a sink they must associate with directly and then transmit the message. These multi-hop topologies sacrifice efficiency in terms of power consumption in favor of increased range. Because of this restriction, a sensor node powered by a single battery LoRaWAN is predicted to last for years, resulting in lower costs for deployment and maintenance and a more straightforward network architecture [27][28]. With LoRaWAN, an unconfirmed uplink message has been sent as far as 702 kilometres. When a gateway gets data from many nearby nodes, it forwards that information to the respective network server. With two-way communication, devices may uplink data to the network and downlink commands. However, the uplink direction is greatly preferred. LoRaWAN does not allow for direct connection between nodes; instead, data must travel via a gateway in both directions. LoRaWAN cannot be used for time-sensitive, low-latency applications due to these constraints.

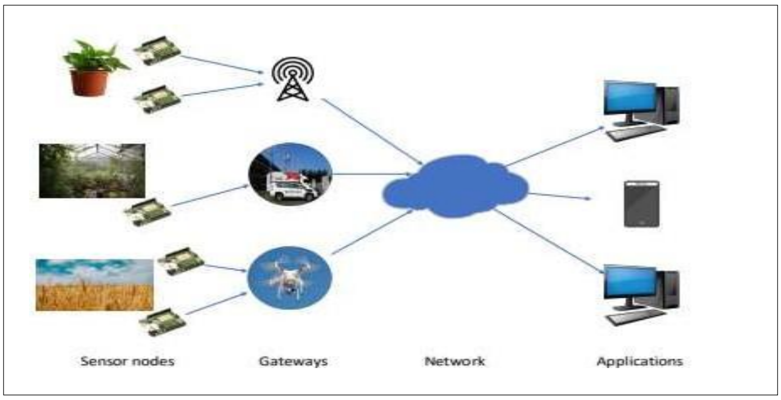

Figure 2.2: Typical Star-of-Stars Lorawan Network Topology.

The LoRa PHY layer can serve as a foundation for additional, specialized protocols. In order to build a multi-hop, robust, and low-latency network while maintaining energy consumption low, LoRaWAN was created. Another protocol that uses a variety of characteristics to address the scalability issues identified by many researchers is called Symphony LinkTM [29].

2.4 WHY LORAWAN

LoRaWAN is only one of several low-power wide-area networks (LPWAN) technologies in Internet of Things communication. Sigfox protocol [30], is one of these technologies; it has a broader coverage area than LoRaWAN and is working on expanding internationally. LoRaWAN's open protocol is a significant advantage over Sigfox's proprietary one. The high-frequency-band narrow-band (NB-IoT) protocol technology is another illustration. It shares many of the same capabilities as LoRaWAN. However, unlike LoRaWAN, NB-IoT is not a freely accessible protocol [31]. Bandwidth scalability, improved power economy, and adaptive data rate are just a few of LoRaWAN's benefits that NB-IoT doesn’t share. Typical LPWAN technologies are depicted in Fig 2.1, however, there are many more protocols with similar functionality, such as Weightless, NWAVE, OnRamp wireless, IEEE802.11ah, and Dash7 [32][33].

Figure 2.3: Low Power Wan (Lpwan) Technologies.

2.4.1 Advantages of LoRa Wan

a. Sensors that require little energy to operate can monitor a large region on the order of miles.
b. Uses the "ISM" (industrial, scientific, and medical) radio spectrum. It is not necessary to pay any upfront fees to utilize this technology because it operates on public or "unlicensed" frequencies.
c. The longer a device's battery may last, thanks to low power consumption. Batteries in sensors have a lifespan that can extend to five years (Class A and Class B)
d. With a single LoRa Gateway, you may manage thousands of nodes or end devices.
e. An ideal tool for keeping tabs on assets in the field.
f. It has widespread use in machine-to-machine and Internet of Things systems.
g. An organization known as an alliance oversees LoRaWAN's operations.
h. Smart solutions, such as innovative city applications, are made possible by long-range functionality.
i. Security: Security for both the network and the program itself using AES encryption.
j. Fully bi-directional dataflow.
k. LoRa operates on unlicensed frequencies and does not need a state license.

2.4.2 Disadvantages of Lora Wan

a. cannot support large data payloads, payloads are limited to 0.3 ~ 5.5 kBps per packet
b. Cannot be used for audio or video applications.
c. Cannot achieve continuous monitoring (except for class C devices) in limited cases.

d. Not optimal for real-time applications requiring lower latency and bounded jitter requirements.

2.5 HOW A LORAWAN-BASED FIRE DETECTION SYSTEM WORKS

Connectivity, real-time analytics, reporting, and extra features like geolocation are made possible by Semtech LoRa Technology.

a. Signs of (heat, smoke, gas, or "ames) data collected by a sensor embedded with LoRa Technology.”
b. Data from the sensor is periodically sent to a LoRa-based gateway.”
c. Gateway sends information to network server where an application server analyses the data.”
d. Application server sends alerts on or smoke to property managers or emergency personnel via mobile device or computer”.

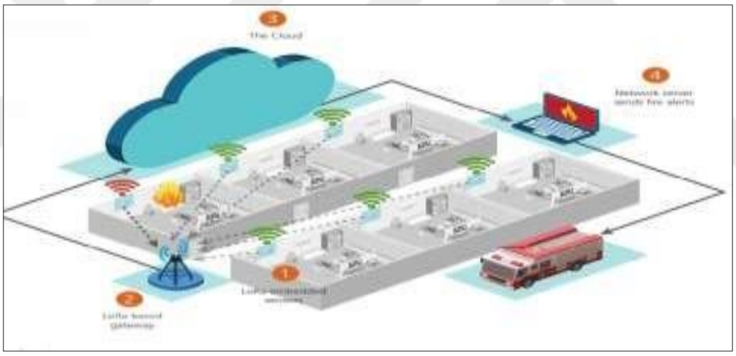

Figure 2.4: Application of Lora Wan Fire Safety and Agriculture.

a. Sensors installed throughout a business building can detect indicators of a fire including heat, smoke, gas, or “ames, enabling speedier reactions for the tenants” safety and preventing property damage.
b. Key features of semtech’s lora wireless of technology.”
c. Long Range Penetrates in dense urban and deep indoor environments, connecting to sensors 15-30 miles away in rural areas.”
d. Low power enables multi-year battery lifetime of up to 20 years or more
e. High Capacity Supports millions of messages per base station.”
f. Geolocation enables tracking applications without GPS or additional power consumed.”

g. Standardized LoRa WAN specification ensures interoperability among applications, IoT solution providers, and telecom operator.”
h. Secure embedded end-to-end AES-128 encryption of data ensuring optimal privacy and protection.”
i. Low cost reduces upfront infrastructure investments, as well as operating and end-node costs.”

2.6 RELATED WORK

Five 900 MHz mobile transmitters were used to calculate route loss [34]. We require data on the signal's observed intensity to calculate the actual signal loss caused by propagation. The Cost-231 Hata, SUI, and ECC-33 prediction models are explored. Cost-231 Hata is the best-fitting model. It is determined. The predicted accuracy is boosted using the Least Squares technique. Adjustments are made to the Cost-231 model's starting offset and slope, and new parameters are calculated. Mean square error; root mean squared error, standard deviation, and relative error are all used to assess its quality. Both forecasts and projected error values are calculated. According to the results, the Cost-231 and its adjusted variant produce the fewest mistakes among all the models tested.

Measured information was derived from the test results for the mobile communication network, and empirical PL models were evaluated in the rural and suburban settings in Batna, Indonesia [35]. Several empirical route loss models were compared using the root-mean-squared-error (RMSE) criteria. The results indicate that the data best fit by a COST231 Hata. In addition, three methods were used to fine-tune the COST 231 model parameters. They better matched the observed environment and provided ideal values for modelling the selected environment PL at the lowest cost (RMSE). Evaluation test approaches for determining PL in urban and suburban settings were analysed in [36]. The selected model was studied to assess the effectiveness of the present 2G and 3G mobile networks in Baghdad, Iraq. Data from the field was gathered by conducting a drive-and-walk test. Data from simulation and calculations show that the Cost231-Hata model is the best choice for the 2G and 3G networks case study. This study aims to refine a mathematical model for transmitting "LoRa" signals in the adapted environment of the Electrical Engineering Technical College in Baghdad, Iraq. We're carrying on an ongoing integrated effort to construct an IoT-ready LoRa network. To create and deploy IoT applications, modelling the spread of LoRa signals in a campus setting is essential. This paper presents two new contributions: determine which PL model works best in the used case study. In this context, we analysed the Ericsson Model, the Egli Model, the Okumura Model, and the Cost 231Hata Model—four of the most used mathematical models for propagation worldwide. The root-mean-squared error (RMSE) is calculated by comparing the actual data with the simulated predictions and is used to choose the best model. Second, a particle swarm optimization (PSO) technique is used to create a more accurate signal propagation model for future use.

Chaudhari et al. [37], recommended a LoRaWAN-based network for monitoring innovative sanitation systems in metropolitan areas. This paper presented the infrastructure required to keep tabs on maintenance hole covers and alert a main dedicated server in real-time. This server notifies the right people when problems occur, allowing for timely resolution. We include LoRaWAN into our workflow in addition to using it. Our method provides message and user tracking features compared to conventional monitoring. Like with Chaudhari et al. work. 's the information is stored in a database and evaluated to find ways to improve the service. The signal quality study for an Internet of Things catastrophe solution utilizing LoRaWAN was provided by Apriantoro et al. [38]. This study proposes deploying a LoRaWAN network with numerous gateways and verifying the system with a road test in a populated region. The findings indicated that the SNR ranged from -100 dBm to -13 dBm, and the RSSI ranged from -24 dBm to -131 dBm. The average RSSI was -100 dBm. A gateway was the sole node in the network we used to test the system. Various settings (urban, rural, and natural) were used for the validation process. Our study yields findings that are consistent with those of Apriantoro et al. The reconfigurable architecture was presented by Atutxa et al. [39], to facilitate multimedia services during rescue operations. An uncrewed aerial vehicle performs the necessary tasks (UAV). An uncrewed aerial vehicle with mobile radio and a video streaming server. They advocated leveraging Kubernetes for virtualization to facilitate rapid and versatile service deployment. In addition, they evaluated functionality by monitoring deployment and reconnect times. Because our network and UAV nodes may share the same frequency range, we see this effort as complementary to our system. Our network is built on low-power gadgets that help increase the UAVs' operational time, which is the system's primary limitation.

Mobile terminals inside a MANET network share sensor data in an emergency rescue evacuation assistance system designed by Hayakawa et al. [40]. When a calamity is detected, the system is set into action and begins looking for a safe escape route immediately. Furthermore, they investigated how individuals react in crises. The coordination of rescue teams is the primary focus of our activity. Using LoRaWAN technology, our system can offer messaging and team tracking services.

An innovative P2Pnet-based walkie-talkie communication system was developed by Lien et al. [41]. The network was constructed using a MANET P2P architecture and laptop PCs. In the event of a natural disaster, when outside aid is unavailable, this mechanism can step in to help. Thanks to the multi-hop mechanism, it's possible to maintain contact while scurrying around hazards. This way of thinking is intriguing. We propose a centralized, far-reaching LoRaWAN network. The equipment employed is efficient and economical, requiring little in the form of electricity. When the base station is relocated, the LoRaWAN coverage area may be altered, which is the key benefit. Liu et al. [42], looked at the impact on packet transmission performance in LoRaWAN networks under different conditions. Using data collected over the course of eight months in Shanghai, they give a comprehensive analysis of the local packet loss rate. The causes of data packet loss are also investigated in this study. Our approach uses a calculation that takes into consideration the different cases of packet loss. We also cantered our attention on signal strength analysis. It is crucial, then, that the signals reliably reach the receiver. Using LoRa technology [43], designed a network scheme that combines a long-range network. This LoRaWAN-based network is a multi-hop network. Data is sent between nodes in the linear network. Before sending them to the application server, they collect the packets modulated using LoRa and encapsulate them within the LoRaWAN network. An ad hoc routing protocol governs the behaviour of the intermediary nodes to maximize system uptime and minimize power consumption. However, packet losses are decreased by synchronizing the nodes. The outcomes proved that the suggested setup was reliable and would offer a lengthy uptime guarantee. The suggestion has potential. We recommend incorporating a distributed network of gateways capable of providing a broad service area into our ongoing research. Our primary proposal is to make the gateways mobile. A result of this is a shift in LoRaWAN's reach.

The system proposed in [44], researched how to create a multi-hop network within a LoRaWAN wireless network that only required one hop for data to go between gateways. Additionally, they inspected the potential and efficiency of the planned network. When it comes to analysis, our efforts are parallel. We recommend a narrower application domain here. We have developed this solution to facilitate communication in locations without mobile phone service. LoRaWAN networks do not employ multi-hop, however.

When it comes to mobile ad hoc networks, Sato et al. [45], presented a visualization system (MANETs). Packet flow visualization is implemented in this system to validate the MANET network's packet flow and routing effectiveness. In our work, we offer a visualization service for the network administrator. This service displays the network owner's emergency team's messages and whereabouts. It's important to highlight that our implementation uses LoRaWAN technology and that the work is done through a MANET network. The researchers in [46], emphasized aiding emergency rescue operations, particularly in cities dealing with building collapse. It is common for this kind of event to disrupt communication systems. The purpose of this study was to propose a MANET-based emergency communication network and information system to help in the rescue operations of victims in case of natural disasters. Both systems are comparable in use cases; however, while Lien et al. created a MANET network based on LoRaWAN for urban areas, our system a LoRaWAN network designed for farm and forest monitoring. To that purpose, our network is primarily designed for use in more remote and natural settings. The authors of [47], suggested a method of movement in which the coordination effort is handled by moving in all four directions simultaneously. It's assumed that communication is facilitated through MANET networks. The article compared three routing protocols: AODV (Always On, Best Distance-Via), DYMO, and LAR. Actual packet rate, end-to-end latency time, routing burden, and retransmissions were all estimated for each protocol. The emphasis of this book is on the role of communication in times of crisis. Although the system was designed for places without LoRaWAN service, we focused on this scenario in our work. We evaluate the system’s transmission rate and coverage area effectiveness.

Using LoRaWAN technology, Valente et al. [48], created a low-power node. Sensors used for monitoring agricultural processes were the main focus of their research. There were three unique nodes created. Through the gateway, the nodes communicate with a central server. One of the most significant findings was that the energy consumed by each node varied up to 400 A depending on the distance between the gateway and the quantity and types of sensors attached to it. In our experiments, we employ commercially available low-power gadgets. Like others, this effort takes advantage of LoRaWAN to transmit data periodically. Our plan calls for communications to be issued only in extreme circumstances.

3. DESIGNING THE SYSTEM

The proposed system consists of sensor nodes that collect readings from the surrounding environment and forwards the data to available gateways. The gateways will forward the collected data via the Internet to online servers which take care of authenticating and aggregating the received information and then present the data in a format suitable to be used or viewed by the users.

3.1 GENERAL STRUCTURE

The general structure of the system is shown in figure 2 below. As can be seen, the system consists of the following:

a. End sensor nodes: these nodes collect readings from the surrounding environment and send the data to receiving gateways. Each node consists of a microcontroller board, sensors, and a LoRa modulation unit.

b. Gateways: the gateways use LoRaWAN standard to receive uplink frames from sensor nodes within the coverage area. After receiving a frame, it will be forwarded using TCP/IP Internet to the corresponding servers.

c. Online servers: the servers are used to store, process, and access collected information from the nodes. In the designed system we use the things network (TTN) servers as they provide free, easy-to-use, reliable services with different functionalities.

d. Below, we will elaborate on the details of each part of the designed system.

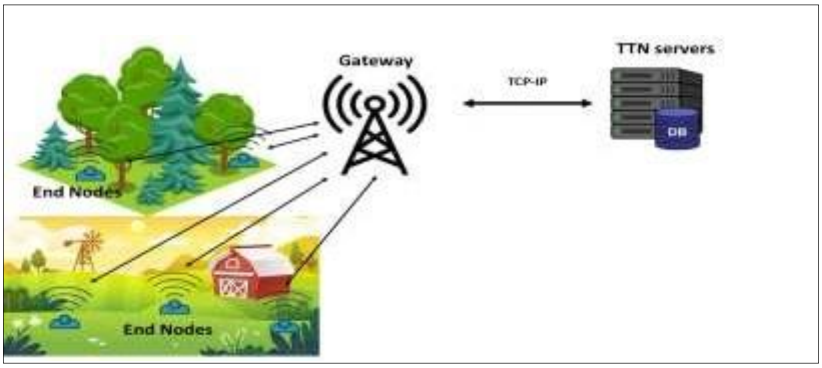

Figure 3.1: General Structure of the System.

3.2 END SENSOR NODES

The sensor nodes measure different parameters of their environment and then transmit the information to receiving gateways using LoRa modulation. Below, the details of designing and implementing end nodes for the proposed model are given. The sensor nodes consist of three main parts, the sensors, the control unit, and the LoRa modulation module. We present the specifics of each part and discuss the relevant details.

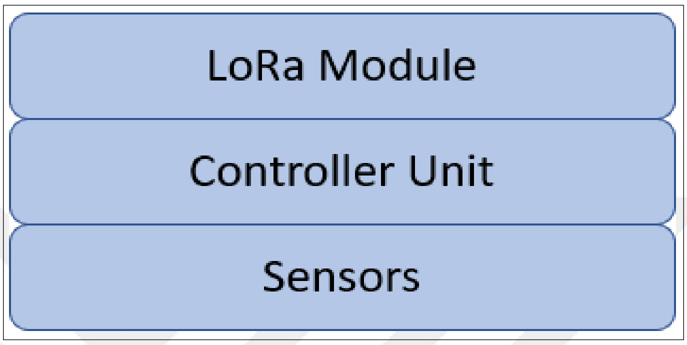

Figure 3.2: Long Range Wide Area Network Stack.

3.3 SENSORS

The end nodes of the proposed system employ the following sensors:

a. Smoke sensor: in order to detect the smoke that results from fires, we used the MQ2 sensor. It is a cheap and multi-purpose sensor that can detect liquid petroleum gas (LPG), smoke, hydrogen, alcohol, methane, carbon monoxide, and propane concentrations in the air. Its task is to measure the smoke concentration in the area surrounding the sensor node.

Figure 3.3: Smoke Sensor.

b. Temperature Sensor: The sensor DHT11 was used to measure the temperature. It is a low-cost and widely available sensor. Its task is to measure the temperature in the area surrounding the sensor node.

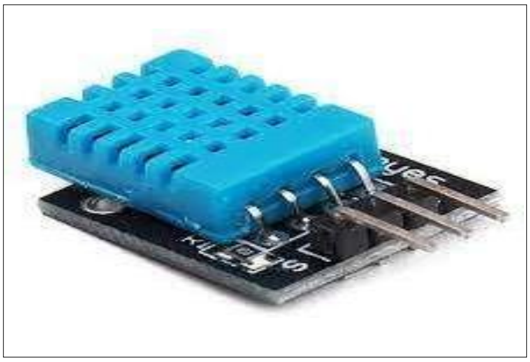

Figure 3.4: Temperature Sensor.

c. IR Flame Sensor: In order to detect the presence of flames near sensor nodes an IR flame sensor was used. It can play an important role in case the wind is blowing the smoke away from sensor nodes.

Figure 3.5: IR Flame Sensor.

The data of sensors is collected by the end nodes; however, the data will not be transmitted unless certain thresholds are reached indicating a high probability of the presence of fire.

d. Microcontroller Board: The microcontroller board provides the processing power for the end nodes. It collects the readings from the sensors, performs necessary computations, and organizes the information to fit in a single packet. Next, the data packets are relayed to the LoRa modulation module to be wirelessly transmitted. The microcontroller board stores and executes the LoRaWAN end node source code. It is responsible of controlling the operation of the nodes according to the desired LoRaWAN class. In the proposed system we used two types of microcontrollers, Arduino Nano and Arduino Uno.

3.4 LORA MODULATION MODULE

In a LoRaWAN network, for end nodes to send uplink messages and receive downlink messages, a LoRa modulation module is required. It handles the process of modulating and demodulating transmitted and received signals, respectively, using chirp spread spectrum (CSS) technology. In the implementation of the proposed systems two types of LoRa modules were used, RFM95W and Dragoon shield.

3.5 GATEWAY

In LoRaWAN networks, the gateways, also called base stations, act as a bridge between end sensor nodes and LoRaWAN servers. Using LoRa modulation, a gateway receives uplink messages from, and sends downlink messages to, sensor nodes, respectively. The messages are modulated using LoRa modulation. On the other hand, the gateways connect to LoRaWAN servers using TCP/IP Internet. They receive uplink messages from sensor nodes and relay them to the servers, and receive messages from servers and relay them as downlink messages to the end nodes.

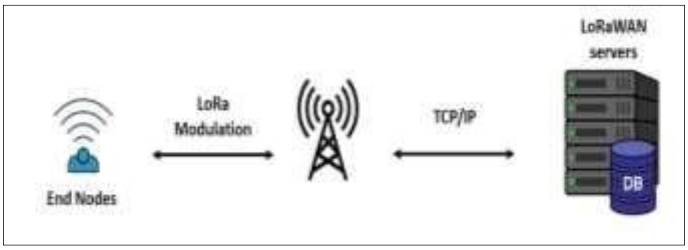

Figure 3.6: Gateway.

LoRaWAN gateways can support 8,16, or 64 channels concurrently. In the proposed system, an 8-channel gateway was used. It can receive and transmit on the eight channels simultaneously. However, each channel is half-duplex i.e., you can only transmit or receive on a given channel at a time. We used a gateway manufactured by RAKwireless as shown below in Figure 3.7. It can support 8 channels with a bandwidth of 125 kHz each in addition to a dedicated downlink channel. The transmitted power is 27 dBm with receiver sensitivity is -139 dBm at SF = 12.

Figure 0.7: Gateway Manufactured by RAK Wireless.

Figure 3.8: Gateway File System.

3.6 LORAWAN SERVERS

In a LoRaWAN network, local or online servers are required to organize the operation of the system, and in order to view, store, and retrieve the data sent by the end nodes. In the design of the proposed system, we used the servers provided by TTN. They provide a free and easy to use platform to set up the network, join, and application servers. The online console provided by TTN can be used to access and store the data of sensor nodes.

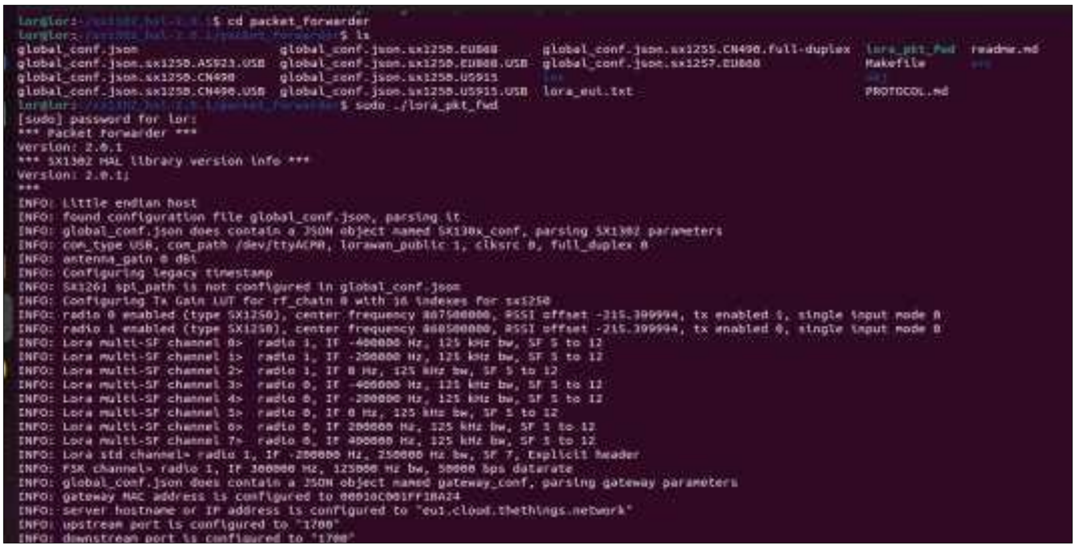

Figure 0.9: Gateway Lora Wan Parameters.

3.7 SYSTEM IMPLEMENTATION

As discussed earlier, the proposed system was implemented using two types of microcontroller boards, namely Arduino Nano and Arduino Uno. Figure 4 illustrates the system design using an Arduino Nano board. The diagram consists of the sensors: MQ2, DHT11, and IR flame sensor, the RFM95W module responsible for LoRa modulation, the antenna connected to RFM95W, and the microcontroller board.

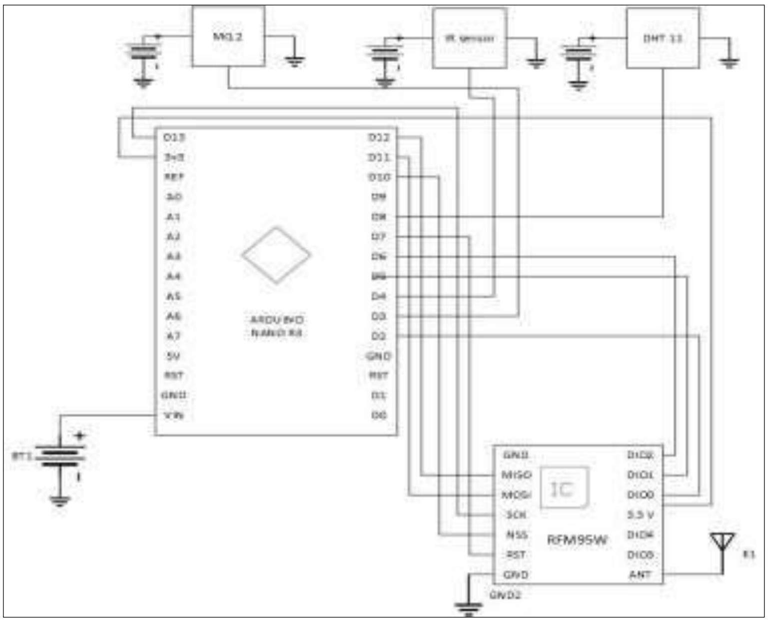

Figure 3.10: Illustrates the System Design Using an Arduino Nano Board.

The second system implementation utilizes an Arduino Uno board. The design uses the same sensors as the first one. However, the LoRa modulation process is handled by a specialized Arduino shield. Figure 5 shows the design of the second implementation of the proposed system consisting of an Arduino Uno board, MQ2, DHT11, and IR flame sensors, LoRa Arduino Dragino shield, and an antenna.

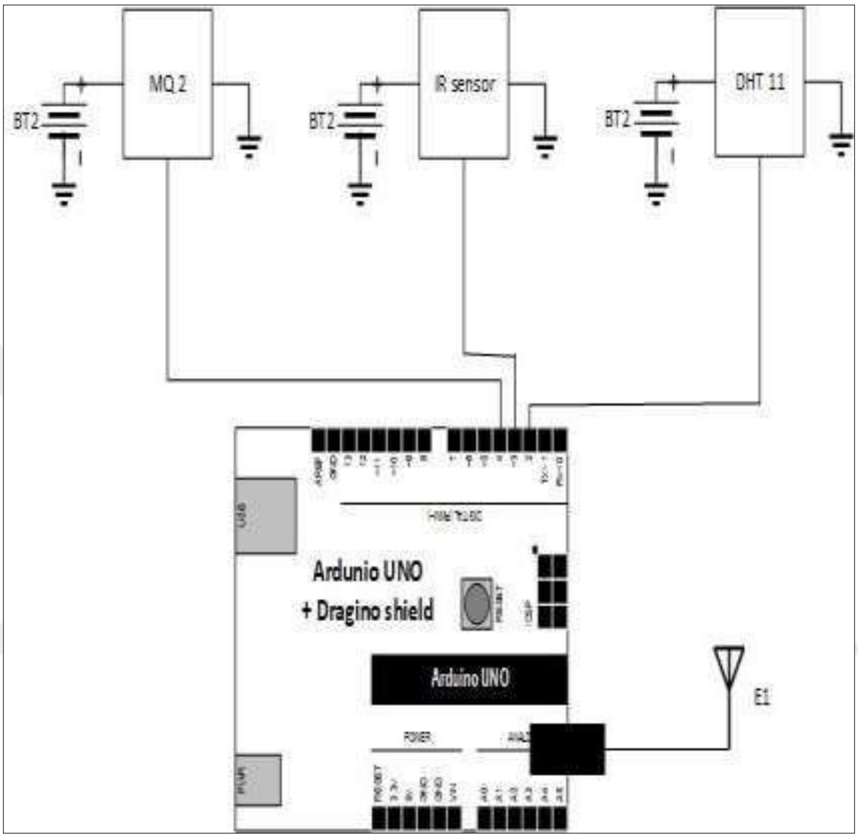

Figure 3.11: Design of the Second Implementation of the Proposed System.

4. TESTING AND RESULTS

This section discusses the tests that were performed to check the operation of the proposed system and the results obtained.

Figure 4.1: The Tests of Operation of the Proposed System.

Figure 4.2: Gateway Connected to TTN.

Figure 4.3: Receiving Sensor Data.

The main functionality required of the system is to correctly determine the presence of fires. In order to achieve this goal each node is equipped with three sensors. The first sensor is responsible for determining the presence of smoke in the air, the second sensor detects sudden increases in temperature, and the third sensor identifies infrared wavelengths between 760 nm and 1100 nm, which are emitted from fire flames. The readings of the latter sensor play an important role in case the wind is blowing the smoke away from a sensor node. The tests were performed as follows. Controlled fires were made to observe the response of the nodes through the LoRaWAN system. The graphs below show the readings of the sensors in the presence of a fire.

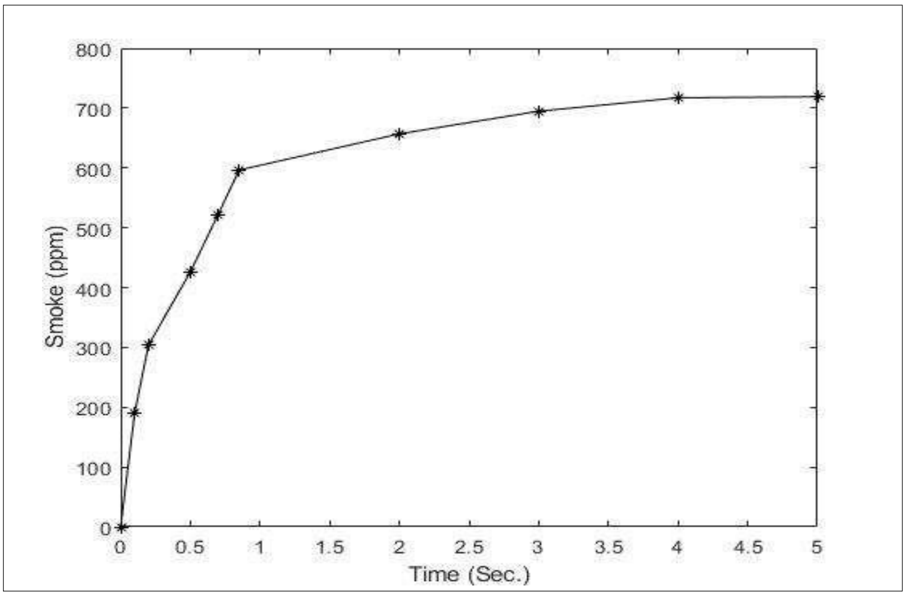

Figure 4.4: First Graph **of** Readings of the Sensors in the Presence of a Fire**.**

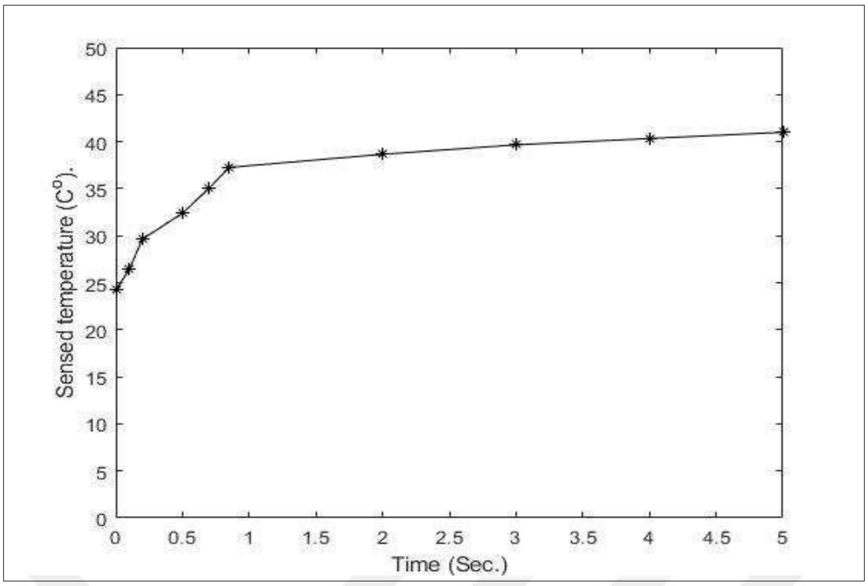

Figure 4.5: Second Graph of Readings of the Sensors in the Presence of a Fire.

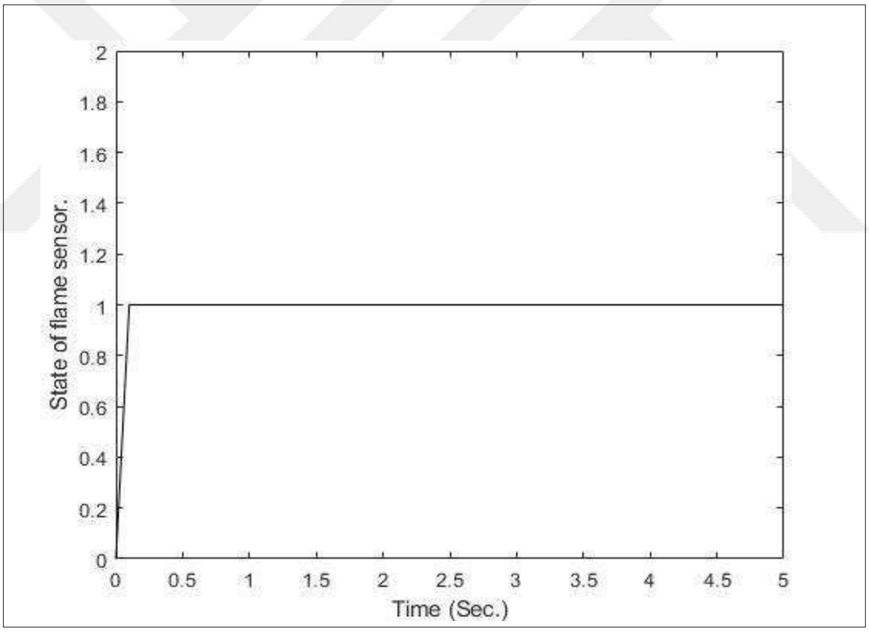

Figure 4.6: Third Graph of Readings of the Sensors in the Presence of a Fire.

The figures above show the response of the sensors as transmitted by the end node through the used LoRaWAN network. The readings are the results obtained from the sensors when a fire is present within the distance of (1.5 - 2.5 m) from a sensor node. The readings were successfully transmitted through the LoRaWAN network to the servers of TTN and then viewed on the online TTN console.

5. CONCLUSION AND FUTURE WORK

Fires in forests and farms cause considerable damage every year. Systems that can provide early and accurate fire detection are needed to deal with such fires and prevent or reduce the resulting damage. In this work, a LoRaWAN network, which is an LPWAN protocol, is used to design a fire detection system for forests and farms. The proposed system is designed to cover large areas which is a feature provided by LPWAN networks. Another factor carefully considered in the design of the proposed system is the method of processing and interpreting sensor readings. Three types of sensors are used: temperature, smoke, and IR flame sensors. The readings are processed to provide correct and early fire detection, and also give accurate fire position.

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