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*Faculty of Science and Technology*
***Department of Electronics***

# *Memoire*

*Presented for obtaining*
**THE MASTER'S DIPLOMA**
FILIERE: Telecommunication
**Specialty:** Telecommunications System
By
Mr. SEGUENI Oussama
Mr. MERABET Mohamed El Amine
**Entitled**

# ***Design and Implementation of a Communication System Using Lora for IoT Applications***

**Supported on:** 29/05/2024

***Before the jury composed of:***

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# Dedication

To my **grandparents**, may God rest their souls.

To my **parents**,

Your Endless love and sacrifices have been the cornerstone of my journey. I am forever grateful for your unwavering support and guidance.

To my **Sisters**,

You have been my pillars of strength and companions throughout life's ups and downs. Your love and support have been my source of inspiration.

To my **friends**,

Your friendship and camaraderie have been a source of joy and strength. Thank you for standing by me through thick and thin.

Special thanks to my work partner, **MERABET Mohamed El Amine**,

Your collaboration and dedication have been instrumental in our shared accomplishments.

In conclusion, I thank God Almighty for His blessings and guidance, and I extend my heartfelt appreciation to everyone who has played a role in my life, whether family, friends, or colleagues. Your support has been invaluable, and I am truly grateful for each and every one of you.

**SEGUENI OUSSAMA**

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**MERABET Mohamed El Amine**

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# Acronyms and Abbreviations

| | |
|---|---|
| **ABP** | Activation By Personalization |
| **ACK** | Acknowledgment |
| **AES** | Advanced Encryption Standard |
| **ADR** | Adaptive Data Rate |
| **AQI** | Air Quality index |
| **BER** | Bit Error Rate |
| **BPSK** | Binary Phase Shift Keying |
| **BW** | Bandwidth |
| **CF** | Carrier Frequency |
| **CRC** | Cyclic Redundancy Check |
| **CR** | Coding Rate |
| **CSS** | Chirp Spread Spectrum |
| **DL** | Downlink |
| **DR** | Data Rate |
| **ETSI** | European Telecommunications Standards Institute |
| **FHDR** | Frame Header |
| **FSK** | Frequency Shift Keying |
| **GFSK** | Gaussian Frequency Shift Keying |
| **GHz** | Gigahertz |
| **GMSK** | Gaussian Minimum Shift Keying |
| **GSM** | Global System for Mobile Communications |
| **iHENs** | Intelligence, Healthcare, Environment, Network, Safety |
| **IP** | Internet Protocol |
| **IoT** | Internet of Things |
| **ISM** | Industrial, Scientific, and Medical |
| **ITU** | International Telecommunication Union |
| **Kbps** | Kilobits per second |
| **LAN** | Local Area Network |
| **LPWAN** | Low-Power Wide-Area Network |
| **LoRa** | Long Range |
| **LoRaWAN** | Long Range Wide Area Network |
| **MAC** | Medium Access Control |
| **MHDR** | MAC Header |
| **MIC** | Message Integrity Code |
| **MHz** | Megahertz |
| **MSK** | Minimum Shift Keying |
| **NB-IoT** | Narrowband Internet of Things |
| **NFC** | Near Field Communication |
| **NLOS** | Non-Line-of-Sight |

| | |
|---|---|
| **NS** | Network Server |
| **OAA** | Over-the-Air Activation |
| **OTAA** | Over-the-Air Activation |
| **OSI** | Open Systems Interconnection |
| **PHY** | Physical Layer |
| **PCB** | Printed Circuit Board |
| **PER** | Packet Error Rate |
| **QAM** | Quadrature Amplitude Modulation |
| **QoS** | Quality of Service |
| **QPSK** | Quadrature Phase Shift Keying |
| **RFID** | Radio-Frequency Identification |
| **RSSI** | Received Signal Strength Indicator |
| **SC-FDMA** | Single Carrier Frequency Division Multiple Access |
| **SF** | Spreading Factor |
| **SNR** | Signal-to-Noise Ratio |
| **TP** | Transmission Power |
| **UL** | Uplink |
| **USA** | United States of America |
| **WSN** | Wireless Sensor Network |
| **Wi-Fi** | Wireless Fidelity |

# Abstract

Our thesis revolves around studying and implementing the LoRa communication system in Internet of Things (IoT) applications and its use in smart poultry farming. The system includes the use of Sender Device (End-Node) composed of Arduino, sensors, actuators and LoRa, and a Receiver Device(Gateway) composed of ESP32 and LoRa, along with the development of Android and iOS applications for data monitoring and securing through Firebase. The system is divided into three parts: LoRa communication technology, system establishment and implementation with a database, and system programming with different modules. Functions include sending environmental data from the poultry house to a Wi-Fi network area, providing a smartphone application for monitoring the poultry's living environment.

**Keywords:** LoRa, IoT, unidirectional communication, cloud, wireless sensor.

# الملخص

تتمحور مذكرتنا حول دراسة وتنفيذ نظام الاتصالات LoRa في تطبيقات إنترنت الأشياء (IoT) واستخدامه في تطبيق الدواجن الذكية. يتضمن النظام استخدام جهاز ارسال (End-Node) مكون من اردوينو ,حساسات ,منفذات و LoRa، وجهاز استقبال (Gateway) مكون من ESP32 و LoRa، بالإضافة إلى تطوير تطبيق لأجهزة Android و iOS لمراقبة البيانات وتأمينها عبر Firebase. يُقسم النظام إلى ثلاثة أجزاء: تقنية الاتصال LoRa، إنشاء وتنفيذ النظام وقاعدة البيانات، وبرمجة النظام بوحدات مختلفة. تتضمن الوظائف إرسال بيانات بيئية من منزل الدواجن إلى منطقة موصولة بشبكة Wi-Fi، مع توفير تطبيق هاتف ذكي لمراقبة الوسط الحيوي للدواجن.

**الكلمات المفتاحية** LoRa- : شبكة إنترنت الأشياء- اتصال أحادي الاتجاه- سحابة - مستشعر لاسلكي.

# Résumé

Notre mémoire porte sur l'étude et la mise en œuvre du système de communication LoRa dans les applications Internet des objets (IdO) et son utilisation dans l'élevage intelligent de volailles. Le système comprend l'utilisation d'un appareil d’émission (End-Node) composé d'Arduino, capteurs, actionneurs et de LoRa, et un appareil de réception (Gateway) composé d'ESP32 et de LoRa, ainsi que le développement d'applications Android et iOS pour la surveillance et la sécurisation des données via Firebase. Le système est divisé en trois parties : la technologie de communication LaRa, l'établissement et la mise en œuvre du système avec une base de données, et la programmation du système avec différents modules. Les fonctions incluent l'envoi de données environnementales depuis le poulailler jusqu'à une zone du réseau Wi-Fi, fournissant une application smartphone pour surveiller l'environnement de vie des volailles.

**Les mots clés :** LoRa, IdO, Cloud, communication unidirectionnelle, capteurs sans fils.

# General Introduction

# General Introduction

The future is poised to change dramatically, fueled by the emergence of IoT, which aspires to connect every element of the environment to the ubiquitous Internet and make communication between its various elements efficient and seamless. The exponential growth of IoT has led to many research initiatives, and as such, it has evolved and grown in terms of optimization. It’s a network of interconnected devices that includes electronics, software, sensors, and wireless communication protocols. These devices collect and send information via wireless networks connected to the internet. Most experts expect the number of connected devices to grow, and it is estimated that 25 billion or more IoT devices will be alive by 2025, making IoT an exciting topic for many industries and services - smart buildings, smart agriculture, and more. However, the proliferation of connected devices poses significant challenges related to connectivity technology that needs to be upgraded to address and solve the following challenges Energy consumption of connected devices must be optimized, and these devices must allow for long-range connectivity, and maximize efficiency with packet collisions.[1], [2]

Although traditional wireless networking technologies are ubiquitous, they do not meet the unique requirements of the IoT, especially low-mobility communication devices responsible for the intermittent transmission of short messages. Low-Power Wide-Area Network (LPWAN) is a new paradigm designed to precisely address this gap by providing low-power, long-range, low-bit error rate, and cost-effective connectivity. LPWAN, epitomized by the LoRaWAN (Long Range Wide-Area Network) protocol, is a milestone in IoT connectivity, enabling seamless interconnection between IoT devices without the need for complex local infrastructure.[3], [4], [5]

Our aim for the research project is to establish a LoRa communication system based on IoT. The system will comprise of a LoRa (Long Range) Node that will function as an End device, a gateway that will receive and transmit data using Wi-Fi, and an application that will enable remote monitoring and control.

This project consists of two chapters. The first Chapter gives a general background on IoT and LPWAN, explains the basic concepts of LoRa technology, briefly touches on LoRa modulation technology and its important parameters, and reviews IoT applications that use LoRa. Chapter 2 explains the design phases of the iHENs (Intelligence, Healthcare, Environment, Network, Safety) system, and before testing it, first, a LoRa Heltec HTCC AB01 device will be implemented and tested to design our iHENs system and compare it with the results of study included in reference [6]. Then, our iHENs system will be tested, the results obtained will be discussed, and finally, conclusions and future work will be defined at the End of the project.

# Chpater 1

# Fundamental Concepts of LoRa Technology

## 1.1 Introduction

Currently, the world is witnessing a radical shift towards what is known as the Internet of Things era, where technology is making significant advancements in the field of IoT, leading to various applications such as smart homes, smart cities, and smart agriculture. This transformation has made communication between things an essential part of daily life, enabling individuals to remotely control and monitor.

The IoT is of great importance, it connects various things such as sensors, electronics, and communication devices, enabling the continuous exchange and control of data. However, Classical technologies such as GSM, 3G, Wi-Fi, and Bluetooth are no longer suitable for low-power mobile communication devices, which are an important part of the IoT, especially regarding energy and battery life challenges. Therefore, the LPWAN Wireless Communication, specifically LoRa technology, comes as a promising alternative, as this new wireless technology is ideal for battery-powered integration systems that require transmitting small amounts of data over long distances.

In This Chapter, we will Introduce the Overview of IoT and LPWAN. In addition, The Fundamental Concepts of LoRa Technology such as Definitions, Features, architecture, Security, and more. Moreover, we will compare it with some traditional wireless technology. Finally, we discover the five most popular IoT Applications using it.[3], [7]

## 1.2 Internet of Things Overview

The term "IoT" has been around since 1998 when it was introduced by Kevin Ashton, who suggested that this innovation could change the world as much as the Internet did. The idea was officially approved in 2005 by the International Telecommunication Union (ITU), making it an essential part of modern technology infrastructure. Since then, the idea of IoT has undergone remarkable evolution that makes it more relevant to the practical world, leveraging the rapid growth of mobile devices and embedded communications, the availability of cloud computing, and data analytics. This evolution has made it a tangible and important realization in various sectors. [1], [2]

In its common definition, the IoT is a comprehensive network of various objects, from personal electronic devices to vehicles, home appliances, industrial tools, and more. This network includes everyday objects that we may not expect to be smart, such as food, clothing, furniture, etc. These objects can interact and communicate intelligently without direct human intervention, enhancing the comfort and efficiency of human life and facilitating many daily operations and tasks in an innovative and sophisticated manner. This intelligent interaction between physical objects comes through the use of specific protocols that enable these objects to exchange information, improve security, and better manage data, making the IoT more than just a network of computers but a comprehensive system for intelligent interaction between physical objects.

Through the use of advanced communication technologies such as WSN and RFID, the exchange of information between people and things can be realized easily and efficiently, allowing people and devices to be connected anywhere and anytime, mediated by any network or service, enhancing interaction and communication between various elements (See Figure 1.1).[1], [2]

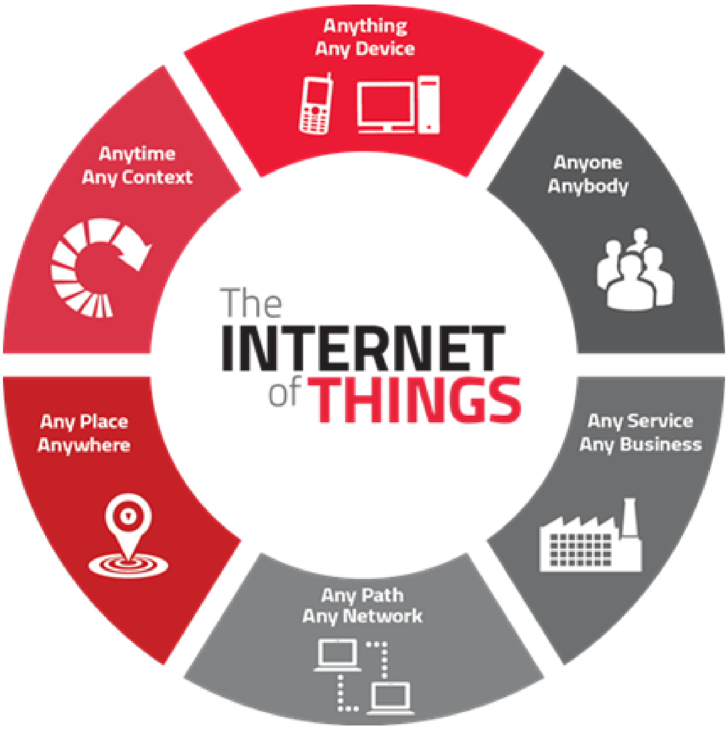


Figure 1.1 : Internet of Things [2]

## 1.3 LPWAN Network

LPWAN is an advanced and popular technology in the field of large-scale wireless communications, with several features that efficiently meet the needs of the IoT. This technology stands out for its low power consumption, wide coverage, and efficient use of bandwidth, which help it to be implemented at reasonable costs. Figure 1.2 shows a comparison of energy efficiency and cost, as well as range and data rate, for a number of wireless communication systems, and demonstrates the attractiveness of LPWAN as an ideal choice due to its low deployment cost and energy efficiency. This technology enables M2M (Machine to Machine) communication for IoT devices, allowing them to interact with the environment anywhere and anytime. [8]

Additionally, LPWAN provides wide coverage of up to 40 km in rural areas and 10 km in urban areas, with a battery life of at least 10 years. The cost of the device is typically less than 5$, with network maintenance costs of only 1$ per year per device, but it often comes with long latency (in seconds or minutes). The many technologies based on the LPWAN concept include LoRa, Sigfox, NB-IoT, and others.[8]

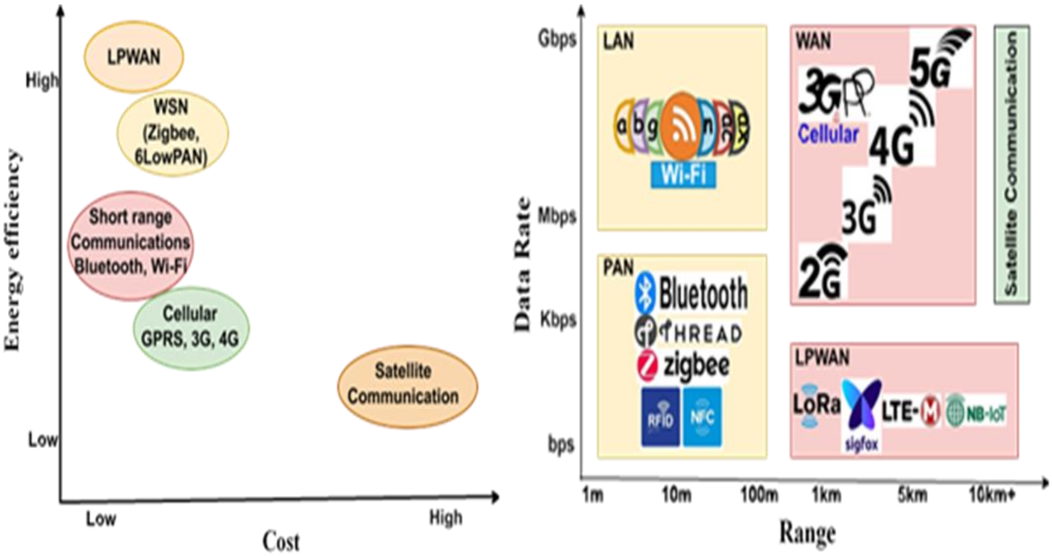


Figure 1.2 : Comparison Different Wireless Communication Technologies [8]

## 1.4 LoRa and LoRaWAN

### 1.4.1 Definition

LoRa, invented French startup Cycleo, developed and patented by Semtech in 2012, is a wireless communication technology that utilizes proprietary spread spectrum modulation technology. It operates in the ISM (Instrumentation, Scientific, and Medical) Bands, enabling long-range communication capabilities. LoRa technology is based on Frequency Spread Spectrum Modulation, which helps maintain low-power characteristics while ensuring increased communication range.[9], [10]

As for LoRaWAN is a communication protocol overseen by the LoRa Alliance. It utilizes LoRa modulation technology and operates within the MAC layer of the OSI model. LoRaWAN is designed to provide a standardized, cost-effective, and secure solution tailored to meet the requirements of the IoT industry. It manages communications between End Nodes and gateways in a star topology, where gateways relay messages between End Nodes and a centralized network server. This topology minimizes information redundancy and conserves battery life, making it suitable for long-range communication scenarios. [9], [10]

### 1.4.2 ISM Bands

The ISM bands represent frequency bands regulated by specific legislation aimed at ensuring access to communication without requiring prior authorization. These standards define the conditions for using these frequencies, which vary by continent. In Europe, for example, the ISM band uses frequencies of 868 MHz, while in the United States, it operates at 915 MHz (See Table 1.1). LoRa devices typically transmit on these frequency bands, benefiting from their license-free availability. However, transmission power and duty cycles are regulated, limiting the frequency and duration of transmissions. For example, the LoRaWAN network imposes duty cycle restrictions in line with European Telecommunications Standards Institute (ETSI) regulations, thereby ensuring fair and efficient use of available channels. Additionally, LoRa devices must adhere to operational standards, such as adding additional channels upon network request, while staying within established limits to maintain spectrum integrity and avoid interference.[8],[10], [11]

Table 1.1 : LoRaWAN Frequency [MHz] Band per Region [12]

| **Region** | Frequency band (MHz) |
|---|---|
| **Europe** | 433 and 863-870 |
| **North America** | 902-928 |
| **China** | 470-510 and 779-787 |
| **Japan** | 920-923 |
| **India** | 865-867 |
| **Australia** | 915-928 |

### 1.4.3 LoRa Features

LoRaWAN boasts many features and characteristics, including QoS, Flexibility, low power consumption, network coverage, cost-effective policies, easy deployment, high scalability, enhanced throughput, and strong security. These unique attributes significantly affect the performance of IoT technology, as they are all critical factors affecting its effectiveness and efficiency. Table 1.2 represents these characteristics with their descriptions.[7]

Table 1.2 : LoRaWAN Features and Descriptions [7]

| Feature | Description |
|---|---|
| Quality of Service | • LoRaWAN operates on an asynchronous protocol within unlicensed spectrum.<br>• Its modulation technique, known as CSS, effectively manages interference, multipath, and fading challenges. |
| Flexibility | • LoRaWAN functions as an open protocol within unlicensed spectrum.<br>• It offers adaptable solutions to optimize data rate adjustment and supports scalable bandwidth through bidirectional communication. |
| Power Consumption | • End Node devices in LoRaWAN can enter sleep mode for varying durations, extending battery life.<br>• Particularly suitable for low-latency applications, it efficiently manages power consumption and enhances device longevity. |
| Network Coverage | • Utilizing a star topology, LoRaWAN provides extensive coverage in both indoor and outdoor environments.<br>• Its long-range capabilities surpass those of cellular networks, with a single gateway capable of covering entire cities. |
| Cost Policy | • LoRaWAN deployment requires minimal infrastructure and employs cost-effective End Node devices.<br>• Suited for budget-friendly network deployment, it minimizes expenses related to spectrum, network setup, deployment, and End Node devices. |
| Deployment | • Deployment of LoRaWAN network infrastructure is straightforward and can be implemented nationwide with ease.<br>• Existing cellular networks can be seamlessly upgraded and repurposed to accommodate LoRaWAN technology. |
| Scalability | • LoRaWAN's star network topology efficiently accommodates the exponential growth of IoT devices.<br>• Highly scalable, a single gateway can support numerous End Node devices, assuming low traffic loads per device. |
| Throughput | • LoRaWAN network performance is enhanced through increased subbands, resulting in a higher overall duty cycle.<br>• It delivers superior throughput compared to alternative technologies, all while maintaining minimal complexity. |
| Security | • Security is paramount in LoRaWAN to ensure uninterrupted IoT device operation.<br>• Employing encryption algorithms, it provides a robust security framework.<br>• Dual-layer security measures safeguard both network integrity and End-to-End communication. |

## 1.5 Comparison of LoRa and Existing Technologies

LoRa technology stands out as one of the prominent solutions in the IoT world compared to other technologies such as cellular networks, LAN, ZigBee, and NB-IoT. While cellular networks offer wide coverage and high-speed data transfer, they consume a lot of power, making them unsuitable for IoT applications that require low power consumption. On the other hand, LAN technology via Wi-Fi provides speed but with limited range and low security, while ZigBee relies on overlapping networks that consume power and serve short distances. NB-IoT technology offers responsiveness and high data rates but consumes more power, making it unsuitable for low-power applications. In contrast, LoRa comes with multiple benefits including low power consumption, long range, and high security, making it the optimal choice for IoT applications requiring long-range connectivity and low power consumption. Table 1.3 illustrates a comparison between LoRa and some various wireless communication technologies.[3], [13], [14]

Table 1.3 : Comparison of Technologies used in IoT [14]

| Parameters | Technology | | | | |
|---|---|---|---|---|---|
| | LoRa | Wi-Fi | ZigBee | SigFox | NB-IoT |
| Standard | LoRa Alliance | IEEE802.11 | IEEE802.15.4 | SigFox (Owner) | 3GPP |
| Frequency | 868 MHz (EU); 915 MHz (USA); 433 MHz (Asia) | 2.4 GHz and 5 GHz | 868 MHz (EU); 915 MHz (USA); 433 MHz (Asia); 2.4 GHz | 868 MHz (EU); 915 MHz (USA), 433 MHz (Asia) | Depends on the frequency licensed to LTE |
| Coverage | 5 km (urban),20 km (rural) | 50 m (indoor), 40 km (outdoor) | 10–100 m | 10 km (urban), 40 km (rural) | 1 km (urban), 10 km (rural) |
| Modulation | LoRa, FSK, GFSK | BPSK, QPSK, (16, 64, 256, 1024) QAM | BPSK, OQPSK | BPSK, GFSK | QPSK, OFDM (DL, SC-FDMA (UL) |
| Power consumption | Low | High | Medium-Low | Low | Low |
| Theoretical Data Transfer Rate | 22 kbps (LoRa), 100 kbps (GFSK) | 2.4 Gbps (IEEE802.11 ax, 2 streams with 1024 QAM) | 250 kbps at 2.4 GHz, 20 kbps at 868 MHz, 40 kbps at 915 MHz | 100 bps | 10 Mbps |

## 1.6 LoRaWAN Network Architecture

LoRa technology relies on LoRaWAN as an additional layer to define the network architecture and communication protocol, providing a standardized, open-source specification through the LoRa Alliance. LoRaWAN features a star topology that allows devices with LoRa chipsets to connect to gateways and transmit data to a network server over the Internet. Subsequently, the data is forwarded to application servers for processing, thereby facilitating energy efficiency and prolonging battery life. These characteristics make LoRaWAN well-suited for applications requiring wide coverage and low power consumption. LoRaWAN comprises LoRa Nodes, gateways, network servers, and application servers, with data efficiently routed between them. Communication from Node to gateway is based on LoRa or FSK modulation with different channels and data rates. Furthermore, gateways connect to the network server via standard IP technology, as depicted in Figure 1.3. [3], [9], [15], [16]

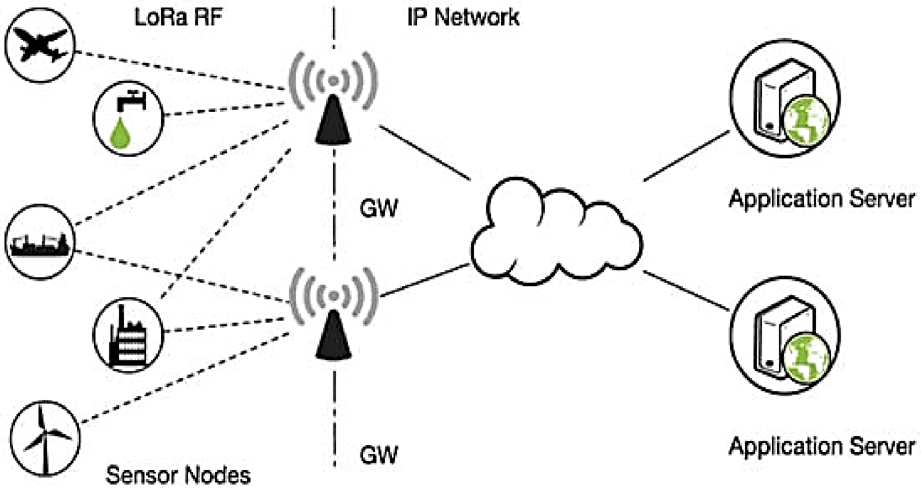


Figure 1.3 : LoRaWAN Network Architecture[15]

## 1.7 Layers of the LoRaWAN

The LoRaWAN structure is integrated and coherent, based on the Open Systems Interconnection (OSI) model, which consists of three main layers: The Physical Layer, the Medium Access Control Layer, and the Application Layer. This structure is clearly illustrated in Figure 1.4.

This part primarily focuses on two layers: LoRa PHY and LoRa MAC, which significantly influence LoRa's performance. The terms LoRa PHY and LoRa MAC are employed to denote the PHY and MAC layers, respectively.[9], [14], [17]

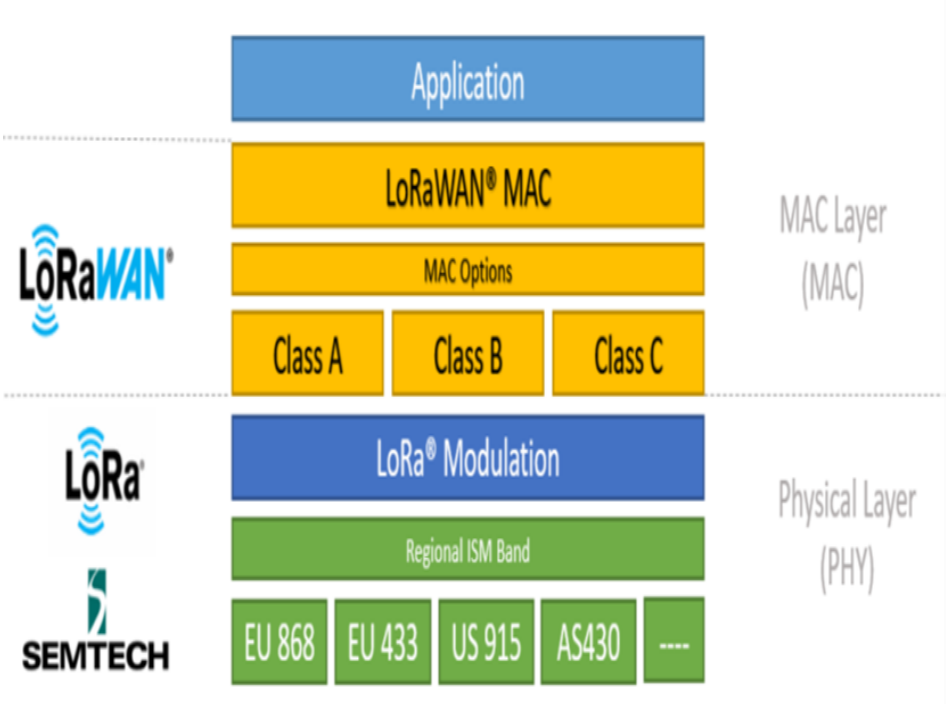


Figure 1.4 : LoRaWAN layers [17]

### 1.7.1 The Physical Layer

The LoRa physical layer utilizes LoRa modulation and demodulation to transmit UL (Uplink) and DL (Downlink) packets between devices and network servers via a Chirp-coded sequence. This technique spreads the data sequence signal over a wider bandwidth using coded CSS (Chirp Spread Spectrum) modulation, which helps bypass noise, improve energy efficiency, and increase the available bandwidth. Moreover, LoRa devices feature Adaptive Data Rate (ADR), which can improve power usage and long-term communication performance.[9], [18]

#### 1.7.1.1 Modulation

The modulation is a crucial process in communication systems where information is embedded onto a carrier signal for transmission. LoRa, a physical layer technology, employs CSS modulation, characterized by linear frequency modulation chirp pulses. These pulses, either up-chirps or down-chirps, enable efficient encoding of information with high bandwidth, accommodating multiple users within one channel. It simplifies receiver design by ensuring equivalent timing and frequency alignment between transmitter and receiver through these chirp signals. Error correction mechanisms, such as transmitting a parity bit for every four bits of information, further enhance signal robustness. [14], [15] In LoRa modulation, chirp pulses serve as symbols representing discrete units of information. The duration of each symbol, known as symbol time ($T_s$), determines the number of bits encoded within it. Symbol time is influenced by the spreading factor, where higher SF values allow more bits to be encoded per symbol. LoRa supports spreading factor values ranging from 7 to 12, impacting the symbol rate ($R_s$), which is inversely proportional to SF and bandwidth. The symbol rate ($R_s$) can be calculated using the formula: [14], [15]

$$R_s = \frac{R_c}{2^{SF}} = \frac{BW}{2^{SF}} \tag{1.1}$$

Where $R_c$ represents the chirp rate .Higher SF values result in lower symbol rates, impacting the efficiency of data transmission. Bit rate ($R_b$) in LoRa modulation is influenced by SF, BW, and the CR, determining the proportion of non-redundant bits used for Forward Error Correction. Different CR values, such as 4/5, 4/6, 4/7, and 4/8, offer flexibility in optimizing data throughput. The formula for bit rate ($R_b$) is: [14], [15]

$$\mathrm{R_b} = \frac{\mathrm{SF} \times \mathrm{BW}}{2^{\mathrm{SF}}} \times \frac{4}{4 + \mathrm{n}} \tag{1.2}$$

Symbol duration ($T_s$) increases with higher SF values and BW, leading to longer transmission times (ToA) and increased power consumption. However, longer symbol durations enhance noise robustness, improving coverage range. The symbol duration can be calculated as: [14], [15]

$$T_s = \frac{2^{SF}}{BW} \tag{1.3}$$

Finally, LoRa modulation allows for the adjustment of SF and transmit power based on gateway distance, enabling the deployment of networks with multiple gateways. Additionally, LoRa is immune to the Doppler Effect, minimizing the impact on the modulated signal caused by slight frequency shifts induced by motion. [14], [15]

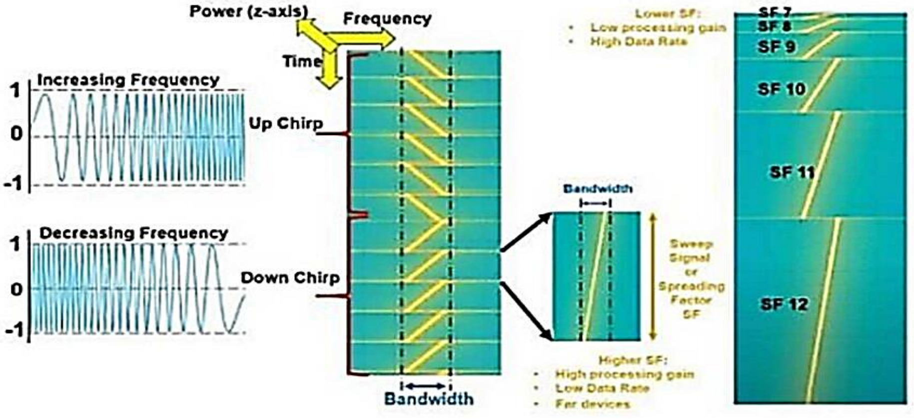


Figure 1.5 : LoRa Chirp Spread Spectrum Illustration [14]

#### 1.7.1.2 Transmission parameters

The radio transmission in LoRaWAN is characterized by several configuration parameters that directly influence energy consumption, transmission range, and system robustness. These parameters are SF, TP, CR, BW, and CF.[4], [18]

- **Spreading Factor:** Controls how chirps are spread. A lower SF decreases the SNR, thereby reducing sensitivity and range, but also transmission time. Conversely, a higher SF provides better immunity against interference but increases energy consumption.
- **Transmission Power:** Varies between $-4\ dBm$ and $20\ dBm$, influencing the probability of frame reception. Higher TP improves reception but increases energy consumption and interference level.
- **Coding Rate:** Represents the proportion of error correction code added to a frame before transmission. A higher CR offers better error protection but increases transmission time and thus energy consumption.
- **Bandwidth:** Determines the width of frequencies used for transmission. A higher BW allows for higher data rates but lower sensitivity. Only BWs of 125 kHz, 250 kHz, and 500 kHz are used in LoRaWAN.
- **Carrier Frequency**: Is the central frequency modulated for transmission. It can be adjusted between 137 MHz and 1020 MHz, influencing coverage and signal penetration.

#### 1.7.1.3 Adaptive Data Rate

Adaptive Data Rate, also known as ADR mechanism in the context of LoRaWAN, is a crucial functionality aimed at dynamically adjusting the data rate of connections to optimize network efficiency and minimize Node energy consumption. By manipulating key parameters of the LoRa physical layer, such as SF and TP, ADR enables more efficient utilization of available resources. For example, a Node close to a gateway can transmit with a low spreading factor to reduce transmission duration and thus energy expenditure. However, for distant Nodes, a higher spreading factor is necessary (As shown Table 1.4). This dynamic adaptation of the data rate is achieved asynchronously between the LoRa Node and the network server, with the latter using the downlink to transmit necessary adjustments based on signal quality. [5], [18] The primary objective of ADR is to enhance network performance and reliability while conserving device battery energy. Furthermore, it provides effective control of transmission parameters for better adaptation to network conditions. Although the signaling scheme for transmission parameters is specified in LoRaWAN, the ADR calculation algorithm is left to the discretion of network operators, offering flexibility in its implementation.[5], [18]

Table 1.4 : LoRa modulation data rates used in ADR [18]

| Data Rate (DR) | Spreading Factor (SF) | Bandwidth (BW) | Bit Rate (bit/s) | Max. App. Payload (bytes) |
|---|---|---|---|---|
| 0 | SF12 | 125 | 250 | 51 |
| 1 | SF11 | 125 | 440 | 51 |
| 2 | SF10 | 125 | 980 | 51 |
| 3 | SF9 | 125 | 1760 | 115 |
| 4 | SF8 | 125 | 3125 | 242 |
| 5 | SF7 | 125 | 5470 | 242 |
| 6 | SF7 | 250 | 11000 | 242 |

### 1.7.2 The MAC Layer

The LoRaWAN layer offers three classes of service A, B, and C. Class A is centralized, while Classes B and C are extensions of the Class A specification. LoRaWAN serves as a MAC layer, facilitating medium access for End devices across multiple frequencies. It is an open standard developed and maintained by the LoRa Alliance. [9], [15]

The protocol incorporates uplink optimizations and operates on the principle that any message sent from an End device will be received by the receiving gateway, thereby minimizing unnecessary messages. Although acknowledgment messages can be managed through receive windows, the ACK transmission system was not a primary concern during the protocol's design phase. Instead, the focus was primarily on enhancing performance and providing various power usage strategies for peripherals. [9], [15]

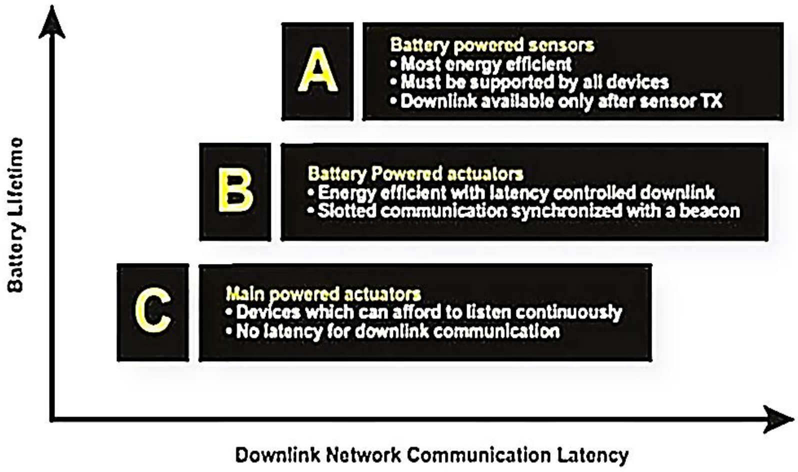


Figure 1.6 : LoRaWAN terminal classes [5]

### 1.7.2.1 Class A

All terminals in a LoRaWAN network must adopt the Class A implementation, where Class A communication is always initiated by the terminal that sends an uplink message at any time, and after this transmission is completed, the terminal opens two short receive windows (RX1 and RX2) to listen to the downlink, and there is a delay between the End of the uplink transmission and the beginning of the two receive windows (RX1 and RX2, respectively). The uplink server can respond during the first (RX1) or second (RX2) receive slot, but it does not use both slots and if the transmitter does not respond during these slots, the initial transmission on the downlink will not be available before the initial transmission (As Shown in Figure 1.11). This pattern is the default that all End Nodes in a LoRaWAN network should follow. Due to the short listening windows, Class A is the most energy efficient and provides bidirectional communication, where data from the End device to the gateway is sent randomly over the UL, and then two short receiving windows (RX1 and RX2) are opened to receive the transmission from the gateway to the End device (DL). RX1 uses the same frequency and data rate used in the UL, while RX2 is pre-configured with a fixed frequency and data rate.[4], [9], [17]

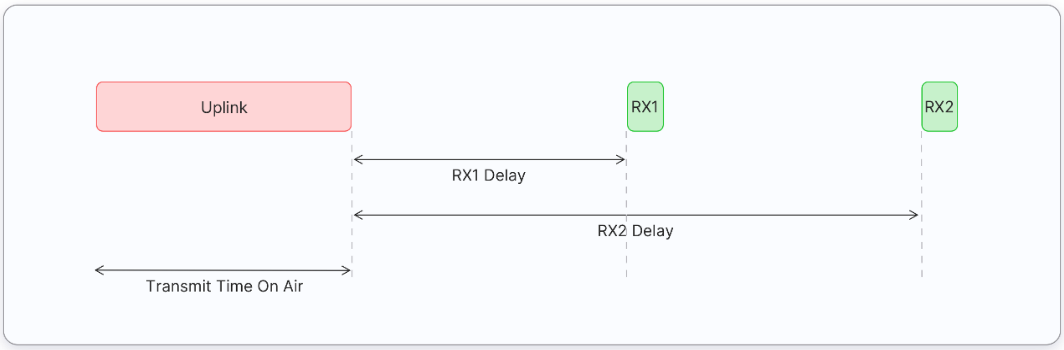


Figure 1.7 : Class A reception windows [17]

### 1.7.2.2 Class B

Class B terminals provide synchronized receive slots to receive messages incoming from the network server, in addition to the receive slots opened by Class A terminals. These slots are regularly opened using synchronized signals transmitted by the gateway, with a specified period between each pair of signals known as the beacon period. Furthermore, additional receive windows are opened after transmitting the uplink frame from Class B terminals, resulting in higher energy consumption compared to Class A due to the increased number of communication slots.

Additionally, Class B implements Class A's operational mode, executing operations similarly to Class A but with the addition of regularly scheduled receive windows alongside the random ones (as shown in Figure 1.12). The network regularly broadcasts a synchronization eacon to provide synchronization references, and the terminals need to receive these signals regularly to align their internal clocks with the network, leading to higher energy consumption in Class B compared to Class A. [4], [9], [17]

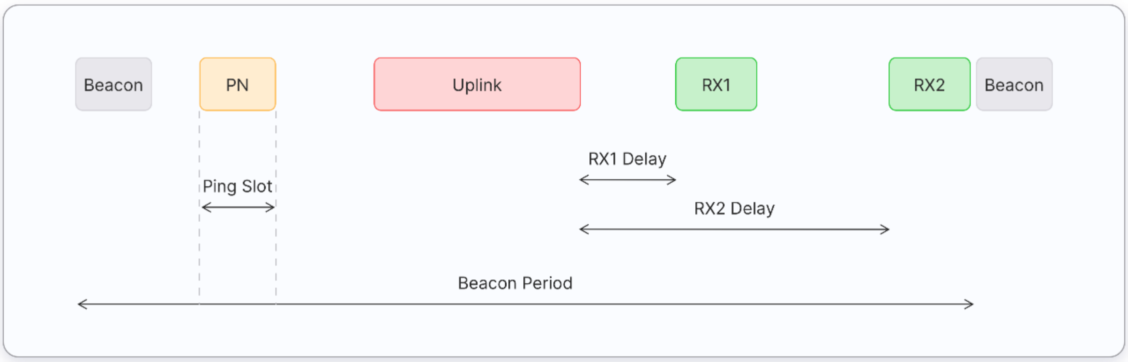


Figure 1.8 : Class B reception windows [17]

### 1.7.2.3 Class C

Class C terminal stations employ a low-latency communication strategy, despite consuming more energy compared to Class A terminal stations. This strategy involves continuous channel listening to receive messages from the network server. Activating terminal stations from both Class C and B within the terminal station must be carefully coordinated. While Class A terminal stations periodically open reception windows, Class C terminal stations keep RXC windows open for continuous listening (as shown in Figure 1.13).[4], [9], [17] Additionally, Class C terminal stations open RX2 window directly after transmitting the UL link, before opening RX1 window. They remain in continuous listening mode when not transmitting. This approach is suitable for devices with ample power supply and no energy constraints, allowing them to achieve excellent performance in wireless communications.

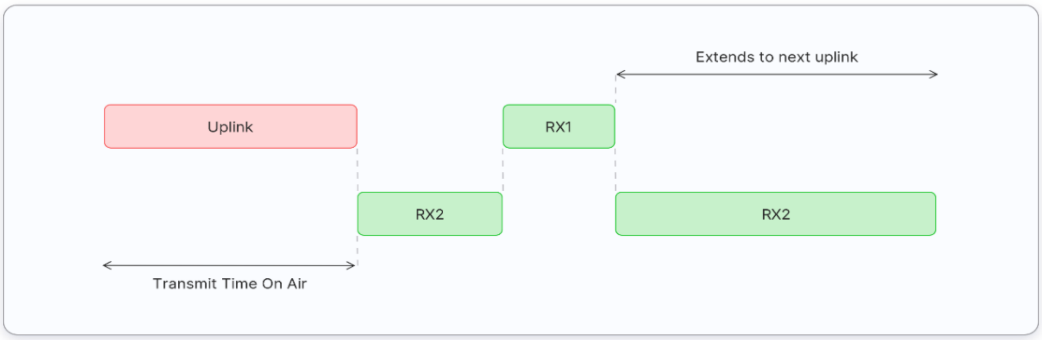


Figure 1.9 : Class C reception windows [17]

## 1.8 LoRa Frame

LoRa technology offers remarkable flexibility thanks to its explicit and implicit frame formats. In the former case, each frame consists of a detailed header containing crucial information such as payload length, CR, and the use of a 16-bit CRC. In contrast, the implicit format does not include these elements, leaving it to the transceiver's responsibility to configure them manually. This simplified approach significantly reduces transmission time. However, within the LoRaWAN specification, the explicit frame format is preferred for UL and DL communications, ensuring increased compatibility and consistency in data exchanges. [9]

### 1.8.1 LoRa Frame Format

LoRa frame format (as shown in Figure 1.14) is characterized by several configurable elements. Firstly, the length of the preamble can vary from 6 to 65,535 symbols. This preamble is crucial as it acts as a locking signal for the receiver, enabling the LoRa signal to be synchronized. Furthermore, to ensure this synchronization, the LoRa modem adds 4.25 symbols, representing a synchronization word, to the End of the preamble. Next, the LoRa frame header has a fixed FEC rate of 4/8 to improve communication reliability. As for the payload, its length can vary from 1 to 255 bytes, offering flexibility in data transmission. [9]

In addition, the LoRaWAN protocol, an 8-symbol preamble is used. This preamble is initiated by a constant chirp, followed by two inverted chirps acting as synchronization words, indicating the End of the preamble. This method ensures that the receiver can actually detect the presence of a LoRa frame, which is essential for successful reception.[9]

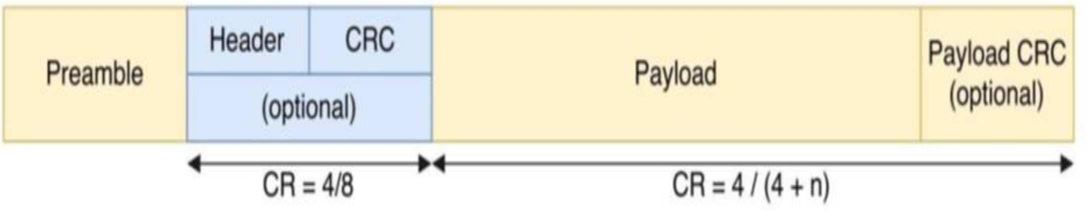


Figure 1.10 : LoRa frame format [9]

### 1.8.2 LoRaWAN Frame Format

LoRaWAN frame format (as shown in Figure 1.15), by defining a set of MAC message types, establishes an efficient protocol for data transmission via physical layer messages. Three main types of MAC messages are specified: Join message, confirmed data message, and unconfirmed data message. Each of these messages follows a defined format, including a MAC header (MHDR) to indicate the message type, a MAC payload to carry data or a Join message, and a MIC to ensure the integrity of the received message. [9]

Data messages may also contain MAC commands, which are intended to adjust radio and MAC layer parameters. The FPort field, present when the frame payload contains data, determines the maximum size of the MAC Payload field. The frame header (FHDR) field can vary in size, ranging from 7 bytes without options to 22 bytes with options, thus allowing flexibility in managing messages and exchanged data. [9]

An essential sub-field of the FHDR further allows acknowledgment of the last received confirmed data message, thus enhancing reliability and traceability of exchanges within the LoRaWAN network.[9]

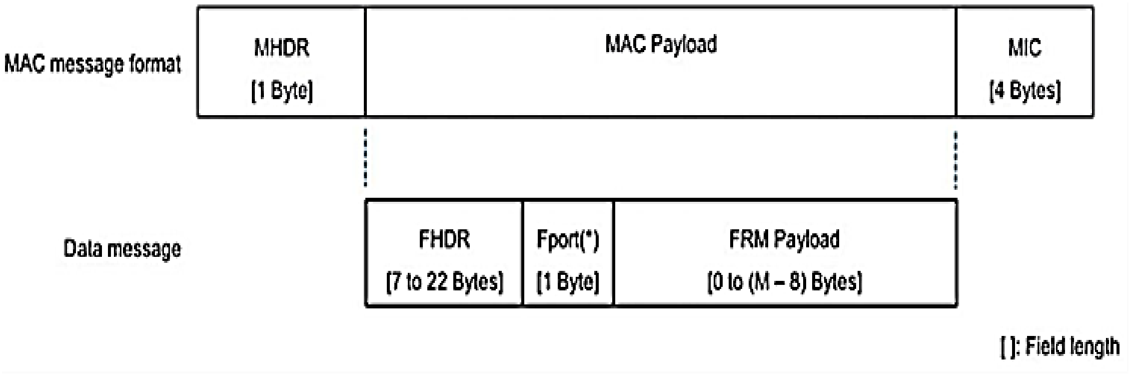


Figure 1.11 : LoRaWAN frame format [9]

## 1.9 Types of Modulation in LoRa Devices

In the Physical layer, we introduced the principal modulation used in LoRa, known as LoRa Modulation or CSS Modulation. Additionally, some LoRa devices provide FSK, GFSK, MSK, and GMSK modulation for legacy use cases. These modulation types add flexibility to their usage and enhance transmission performance.[19]

### 1.9.1 (G)FSK Modulation

Binary FSK is a modulation technique employing two distinct frequencies to convey binary symbols '0' and '1', devoid of amplitude variations. The information is solely encoded within the frequencies utilized. Mathematically, it can be described as follows: [19]

$$S_1 = Acos(2\pi f_1 + \phi)\ , kT \leq t \leq (k+1)T\ for\ 1 \tag{1.4}$$

$$S_2 = Acos(2\pi f_2 + \phi)\ , kT \leq t \leq (k+1)T\ for\ 0 \tag{1.5}$$

Here, $(A)$ represents the signal amplitude, ( $f_1$ ) and ( $f_2$ ) denote the frequencies corresponding to symbols '1' and '0' respectively, ( $\phi$ ) can be either shared, termed as continuous phase, or distinct, known as non-coherent modulation. The graphical representation of the signals in FSK modulation is depicted in Figure 1.16. [19]

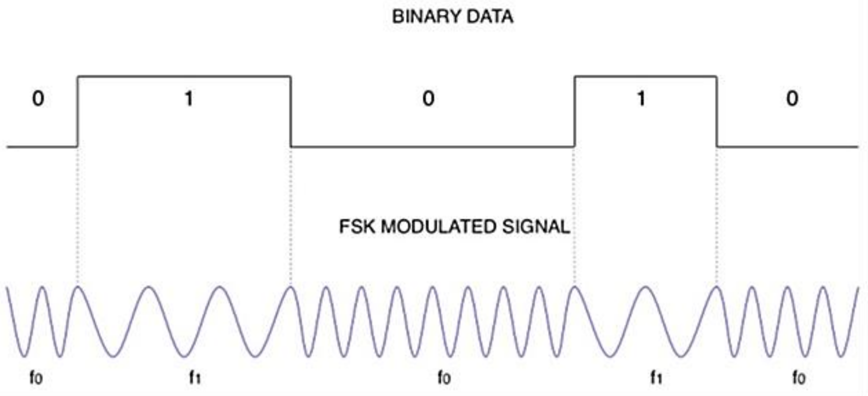


Figure 1.12 : FSK signals [19]

Conventional Binary FSK, employing fixed frequencies for symbols '0' and '1', often leads to inefficient bandwidth usage due to abrupt frequency transitions caused by rectangular input data. GFSK addresses this issue by applying a Gaussian filter to pre-modulate the input data signal. This filtering action minimizes abrupt frequency changes, enhancing spectral efficiency over the transmission duration. [19]

### 1.9.2 (G)MSK Modulation

MSK is a form of continuous phase modulation characterized by a carrier devoid of phase information, with frequency changes occurring precisely at the zero crossings of the carrier. In MSK, the frequency disparity between symbols '0' and '1' is set to half the data rate, ensuring coherent orthogonality between FSK signals, thereby preventing interference during detection processes. Mathematically, the modulation index (m) of MSK is expressed as: [19]

$$m = \Delta t \times T \tag{1.6}$$

Where:

$$\Delta t = f_1 - f_0 \tag{1.7}$$

$$T = \frac{1}{Bit\ Rate} \tag{1.8}$$

As illustrated in Figure 1.17, MSK signals exhibit a peak-to-peak frequency shift equivalent to half of the bit rate. Both FSK and MSK yield constant envelope carrier signals, which remain immune to amplitude variations. This characteristic proves advantageous for transmitter power efficiency, as constant-envelope signals mitigate nonlinearities in amplifier amplitude-transfer functions, thereby reducing spectral regrowth and adjacent channel power. Moreover, GMSK evolves from MSK by passing the modulating waveform through a Gaussian filter, further compressing the required bandwidth while minimizing instantaneous frequency variations. GMSK's spectral efficiency, constant envelope, favorable BER performance, and self-synchronization features render it highly suitable for mobile radio systems. [19]

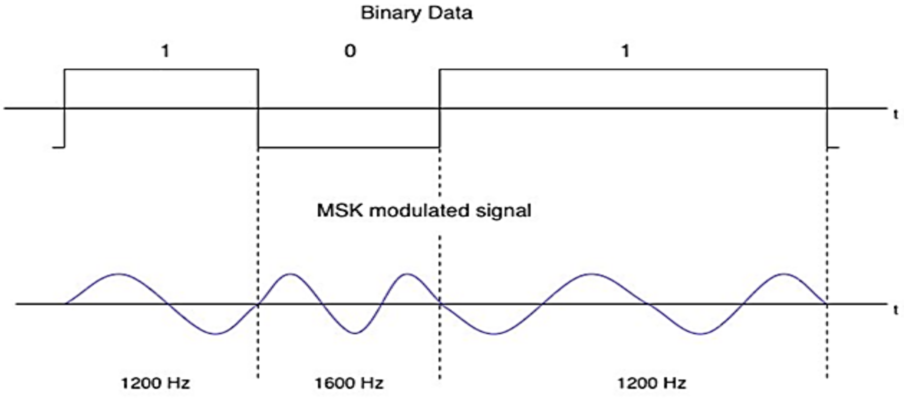


Figure 1.13 : MSK signals [19]

## 1.10 Security in LoRaWAN

Security is a paramount concern in the development of future IoT networks, ensuring uninterrupted operation and safeguarding sensitive data from external threats. LoRaWAN, a prominent solution in this domain, implements a robust security mechanism combining encryption and message integrity verification. In LoRaWAN 1.0.x specification, terminals utilize 16-byte encryption keys derived from the AppKey root key, while the LoRaWAN 1.1 specification employs both NwkKey and AppKey root keys. These keys, represented as gray and green keys (as shown Figure 1.18). [3], [13], [17]

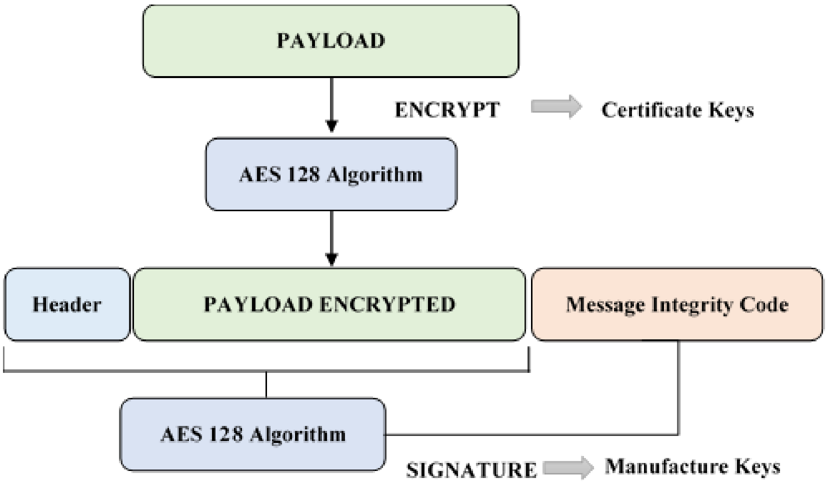


Figure 1.14 : AES-128 encryption scheme

Focusing primarily on the LoRaWAN 1.1 specification, the AppKey encryption key (depicted as the blue key in Figure 1.19) yields a 16-byte session encryption key known as AppSKey. This AppSKey is subsequently utilized for encrypting application payload data at both terminal and application server levels, ensuring confidentiality throughout data transmission. [3], [13], [17]

Table 1.5 : Abbreviation of safety keys. [17]

| Abbreviation | Meaning |
|---|---|
| AppKey | Application Key |
| NwkKey | Network Key |
| AppSKey | Application Session Key |
| FNwkSIntKey | Forwarding Network Session Integrity Key |
| SNwkSIntKey | Serving Network Session Integrity Key |
| NwkSEncKey | Network Session Encryption Key |

Conversely, the NwkKey encryption key (illustrated in red in Figure 1.19) generates FNwkSIntKey, SNwkSIntKey, and NwkSEncKey, forming a security layer between terminals and network servers. These session keys serve various purposes, including MIC calculation and media access control command encryption, bolstering the security of LoRaWAN networks. [3], [13], [17]

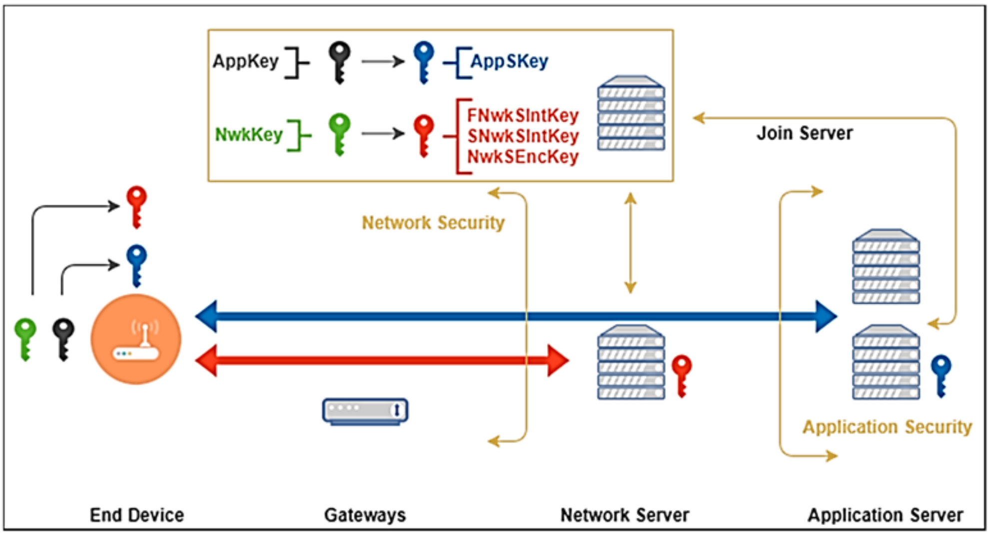


Figure 1.15 : Architecture for LoRaWAN [17]

LoRaWAN's security framework is structured into two layers: network security and application security, as depicted in Figure 1.19. This bifurcation allows for distinct authentication and encryption processes, enhancing the overall security posture of the system. Unlike some other systems, LoRaWAN employs separate keys for encryption and authentication, enabling packet authentication and integrity protection. [3], [13], [17]

Utilizing AES-128 encryption and IEEE 802.15.4/2006 Annex B, LoRaWAN ensures robust security and authentication mechanisms. While conventional technologies typically incorporate single-layer security, LoRaWAN stands out by implementing dual-layer security: network security, for Node authentication, and application security, safeguarding End-user application data from network operators' access. [3], [13], [17]

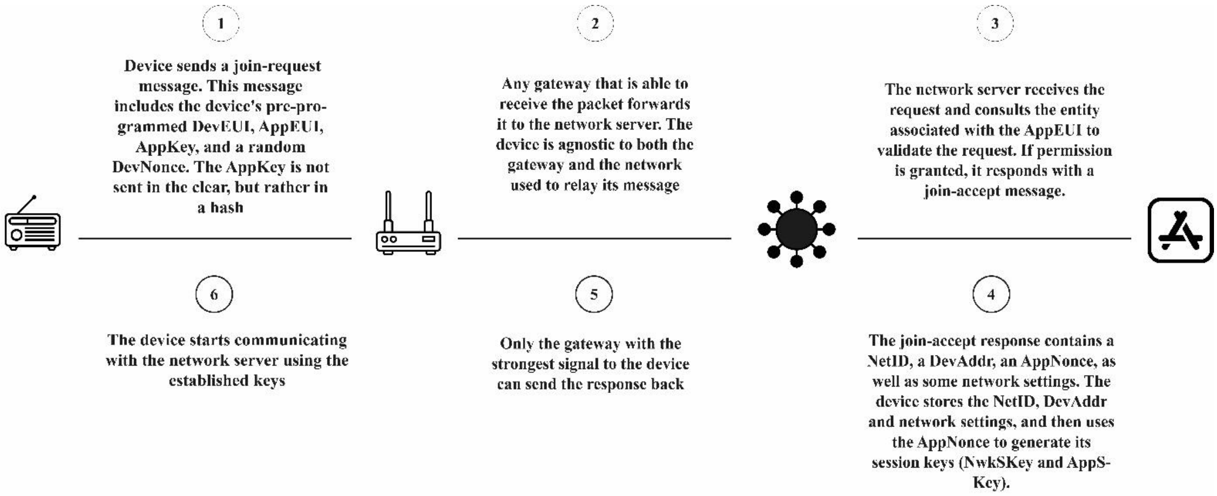
The deployment of NwkSKey and AppSKey underscores LoRaWAN's commitment to security and authenticity. End devices must undergo activation and authentication processes to participate in the network, facilitated through OAA or ABP methods, ensuring secure and authenticated connections. [3], [13], [17]

### 1.10.1 Over the air activation

Over-the-air activation is a method employed for End-device activation in networks, enabling devices to join any network without prior personalization. This approach involves a joint procedure where devices are loaded with necessary information before network entry, facilitating roaming across different service providers. Unlike methods tying devices to specific service providers, OAA allows for network flexibility.[3], [9]

The operation of OAA involves an exchange of MAC messages between the terminal and the network server, as depicted in Figure 1.20. To authenticate and activate devices within a LoRaWAN network using the OTAA method, several steps are followed. Initially, the device initiates a JOIN REQUEST, incorporating pre-programmed identifiers and a random value. Gateways receiving this request forward it to the network, regardless of the gateway or network used for relaying the message. [3], [9]

Upon receiving the request, the network server validates it by consulting the entity associated with the provided identifier. If the request is authorized, the server responds with a JOIN ACCEPT message, containing essential network parameters. Notably, only the gateway with the strongest signal to the device returns this response. Subsequently, the device stores the received information and utilizes it to generate session keys, enabling secure communication within the network. This streamlined process of OAA ensures seamless device activation and integration into networks, promoting efficient communication and interoperability across various service providers and network environments. [3], [9]



1 Device sends a join-request message. This message includes the device's pre-programmed DevEUI, AppEUI, AppKey, and a random DevNonce. The AppKey is not sent in the clear, but rather in a hash

2 Any gateway that is able to receive the packet forwards it to the network server. The device is agnostic to both the gateway and the network used to relay its message

3 The network server receives the request and consults the entity associated with the AppEUI to validate the request. If permission is granted, it responds with a join-accept message.

4 The join-accept response contains a NetID, a DevAddr, an AppNonce, as well as some network settings. The device stores the NetID, DevAddr and network settings, and then uses the AppNonce to generate its session keys (NwkSKey and AppS-Key).

5 Only the gateway with the strongest signal to the device can send the response back

6 The device starts communicating with the network server using the established keys

Figure 1.16 : Over the air activation

### 1.10.2 Activation by personalization

Activation by personalization presents a targeted approach to device activation, distinct from more widespread methods like OTAA. It optimizes network integration by pre-loading vital data onto devices, streamlining setup processes and enhancing efficiency. It configures devices with session keys, eliminating the need for additional identifiers like DevEUI and AppKey. This pre-programming allows seamless communication and bypasses join procedures (as shown in Figure 1.21). [3], [9]

Beyond activation, ABP bolsters network security by minimizing device-network interaction, ensuring authenticity. Each device's unique session keys, NwkSKey and AppSKey, bolster individualized security, emphasizing a personalized and secure network environment.

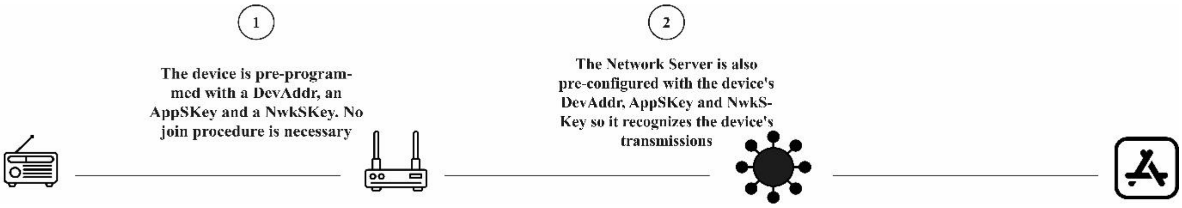


Figure 1.17 : Activation by personalization

## 1.11 IoT Applications

LoRaWAN, well-known for its extensive range and cost-effectiveness, has emerged as a cornerstone in the IoT sector, driving innovation across diverse industries. Its versatility and reliability make it indispensable in various applications, including smart city projects, industrial IoT, and outdoor solutions. In addition, there Many Domains will be used such as Urban areas, Industrial, Agriculture, and more. (as shown in Figure 1.22).

However, there are five popular applications of LoRaWAN, each leveraging its unique features to address specific requirements following as: [20]

- **Intelligent Infrastructure Management:** LoRaWAN is deployed in smart buildings and infrastructure to streamline operations and maintenance, significantly reducing manual efforts. With LoRaWAN, monitoring parameters such as temperature, humidity, occupancy, and detecting events like fires or floods becomes seamless across large areas, owing to its scalability and low energy consumption. [20]

- **Smart Parking Solutions:** In densely populated urban areas, smart parking solutions powered by LoRaWAN offer a solution to parking challenges. These systems optimize parking space usage, alleviate traffic congestion, and automate reservation management. Moreover, the cost-effectiveness of LoRaWAN deployments enables parking space owners to efficiently monetize their assets. [20]
- **Structural Health Monitoring for Smart Cities:** City administrations benefit from LoRaWAN-enabled structural health monitoring systems. By deploying long-range sensors on critical infrastructure such as bridges, authorities can identify anomalies and proactively address potential risks. LoRaWAN's extensive coverage and minimal maintenance requirements make it ideal for ensuring the structural integrity of urban assets.
- **Smart Waste Management with LoRaWAN:** Waste management, a fundamental requirement, finds a reliable partner in LoRaWAN. By monitoring waste container fill levels and optimizing collection routes, cities can enhance operational efficiency and resource utilization. LoRaWAN enables timely waste collection while reducing fuel costs and operational downtime. [20]
- **Smart Metering Solutions for Sustainable Cities:** Promoting sustainability is crucial for smart cities, and LoRaWAN plays a pivotal role in achieving this objective. Through smart metering solutions, LoRaWAN facilitates efficient monitoring of electricity, gas, and water consumption. By automating billing processes and gathering usage data, cities can minimize wastage and promote responsible resource management. [20]

Figure 1.18: IoT Application using [20]

## 1.12 Conclusion

In this chapter, we have discussed the general concept of LoRa technology in IoT, its pivotal role and applications as well as its history that began unexpectedly in 2015. Apart from Architecture, LoRa has grown into a global leader with outstanding battery life, wide coverage and strong security which is underpinned by AES128 encryption. Our research highlights the adaptability of LoRa to various IoT deployments where it can work with different needs and setups seamlessly. We also brought forward other ideas like CSS Modulation and the LoRaWAN framework that contribute towards making LoRa flexible.

# Chpater 2

## Design and Implementation

## 2.1 Introduction

In the previous chapter, we discussed IoT and LPWAN and introduced the fundamental principles of LoRa technology and its various applications in IoT.

This chapter will delve into the implementation of a LoRa communication system in IoT, focusing specifically on its use in healthcare and poultry farming. We will cover the entire process, from hardware and software selection to design, deployment, operational procedures, and testing. Additionally, we will present a case study involving a smart poultry model to showcase the functionality of the application and the crucial role of the LoRa communication system. The system can be accessed and managed through a user-friendly app on Android or iOS devices, as well as through a web interface.

## 2.2 Problematic and Objectives

The current advancements in technology and wireless communication systems have the potential to forecast environments and enhance healthcare and lifestyle in various sectors such as industry, urbanization, agriculture, and specifically, poultry farming, commonly referred to as "Smart Poultry". Smart poultry involves the connection of smart devices throughout poultry facilities, forming a network that assists poultry farmers with their daily tasks. Monitoring and tending to poultry is a significant part of a poultry farmer's routine, making improvements in poultry security and healthcare economically, socially, and health-wise crucial. This helps protect poultry farmers from losses due to poultry mortality or diseases, while also reducing the effort and time required to monitor and protect them from various hazards such as high temperatures, humidity, theft, and declining air quality. However, like any other field, the Internet of Things presents some challenges that need to be addressed, including information security, network availability in remote areas, construction costs, energy consumption, and data transmission.

Our main objective is to develop and implement “iHENs” system for controlling and monitoring smart poultry using a LoRa communication system. Additionally, we aim to create multiple applications for accessing the system (web page, Android or iOS mobile app). Furthermore, we have designed a smart poultry prototype that utilizes a transmitter inside the poultry house and a receiver in an internet-connected location. Our iHENs system addresses several challenges in the field and provides solutions to some of the questions raised in the industry:

- How can data be transmitted from off-grid areas to locations with available networks?
- What is the anticipated cost of implementing remote data transmission solutions?
- How can internet outages be managed in the context of data transmission?

## 2.3 Architecture of Our System

The iHENs System targets IoT applications that require low power consumption, such as Smart poultry. It is designed to enhance the care and safety of Smart Poultry, enabling users to remotely monitor and manage Poultry, including controlling various aspects and sensors. The associated application can be accessed via Smartphones, Tablets, and Computers, facilitating unidirectional communication for sending instructions and receiving information.

Our system prioritizes energy efficiency and data transmission improvement, using LoRa technology within an LPWAN network to transmit data quickly and efficiently, especially in areas with limited infrastructure or weak signals. Figure 2.1 illustrates the overall structure of the system, and the iHENs system provides the following features:

- Ensuring the safety of Smart Poultry from potential risks.
- Securing data exchange using advanced authentication and encryption techniques.
- Ensuring system connectivity even in case of internet disconnection.
- Increasing transmission range and improving data transmission efficiency using LoRa technology.
- The iHENs system can transmit data over distances of up to 15 kilometers in rural areas and 5 kilometers in cities.

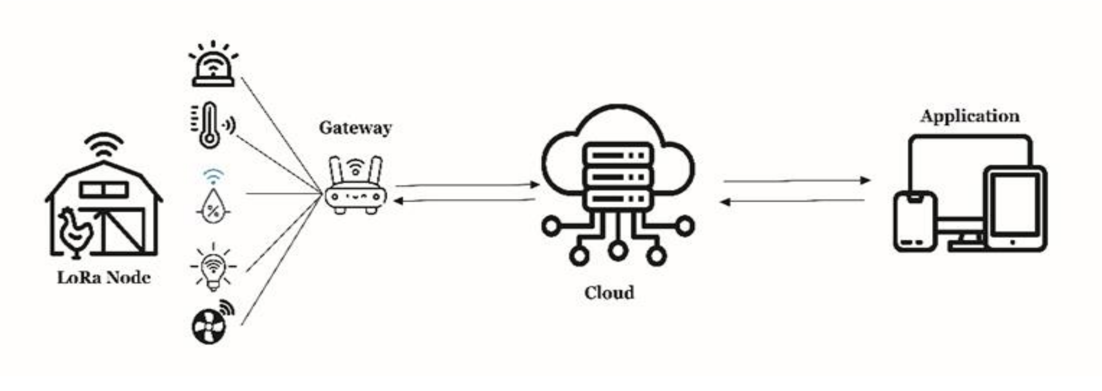


Figure 2.1 : Architecture of our "iHENs" system

## 2.4 System Functionalities

In this section, we will explore the functionality provided by our iHENs.

- **Notification:**

Users will receive notifications in case of temperature or humidity increase, activation of the fan, or poor air quality detected in the poultry house.

- **Maximum Temperature and Humidity Control:**

The system is equipped with a built-in feature enabling control over the maximum temperature and humidity within the poultry house. Upon activation, the maximum temperature is preset to 30°C, and the maximum humidity to 60%. It dynamically adjusts these parameters as required, while preserving the user's last-defined settings in case of power outages and subsequent restoration.

Designed to keep you informed, the system sends notifications when the temperature or humidity exceeds your set limits. Moreover, it automatically activates the fan once the temperature or humidity surpasses the predefined thresholds.

- **Air Quality Detection:**

Our system uses the MQ135 gas sensor to detect the presence of ammonia gas. If the air quality exceeds the permissible values outlined by the AQI, as depicted in Table 2.1, the system reacts promptly. It notifies users of the poor air quality and initiates automatic fan operation to improve the air quality.[21]

Table 2.1 : Breakpoints of NH3 (µg/m3) – 24hr [21]

| AQI Category | Breakpoint Concentration (µg/m$^3$) |
|---|---|
| Very Good (0-50) | 0 - 200 |
| Good (51-100) | 201 - 400 |
| Moderate (101-200) | 401 - 800 |
| Poor (201-300) | 801 - 1200 |
| Very Poor (301-400) | 1201 - 1800 |
| Severe (401-500) | 1800+ |

- **Light Control**

The function for controlling lighting allows users to conveniently handle and adjust lighting by pressing the dedicated button on the End-Node, and its status can be observed using the iHENs app.

## 2.5 Implementation

After presenting the system's architecture and functionality in the previous sections, we will now present the hardware and software environment required to develop and build the system.

### 2.5.1 Hardware Environment

In this section, we'll review all the physical components, including sensors and controllers, that were utilized in our project. We employed the following materials to carry out our work:

- **Arduino Nano**

Arduino Nano is a compact electronic development board based on the ATmega328 microcontroller, measuring just 1.85 cm by 4.3 cm. Despite its small size, it features 14 digital input/output pins and 6 analog inputs, facilitating versatile connectivity for sensors and devices. With an on-board USB interface, it seamlessly integrates with computers for programming and data exchange. Compatible with various shields and modules, it offers expanded functionality for diverse projects. Its compatibility with serial communication protocols enables seamless integration into multi-device setups. Programming is simplified with the "Wiring Language" and Arduino IDE. Additionally, it can be powered via USB or an external source (7-12 volts), making it suitable for a wide range of applications.

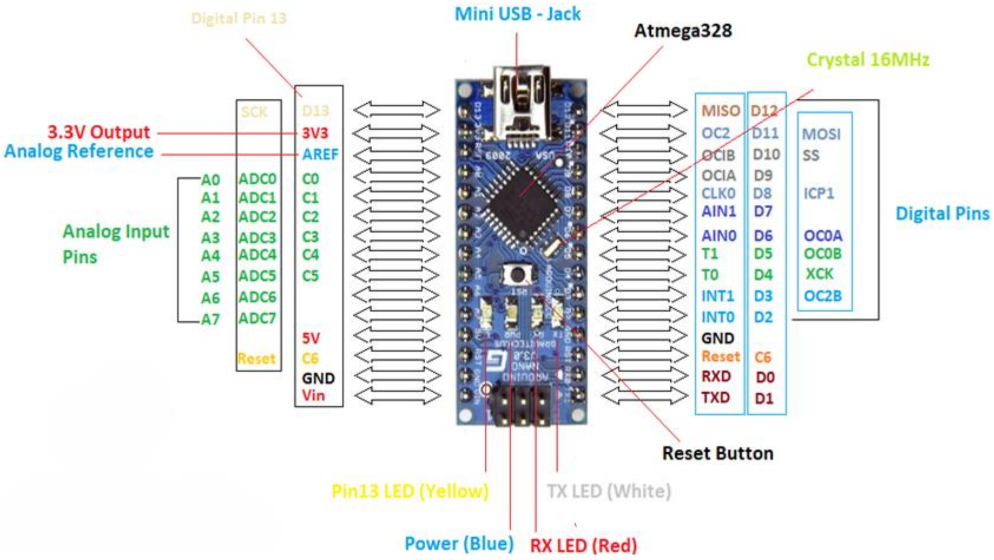


Figure 2.2 : Arduino Nano board Diagram

- **Heltec Cub Cell HTCC-AB01 (LoRa Module)**

The Heltec CubCell HTCC-AB01 is a compact LoRa module designed for IoT applications. Figure 2.3 shows the HTCC-AB01 schematic.[22]

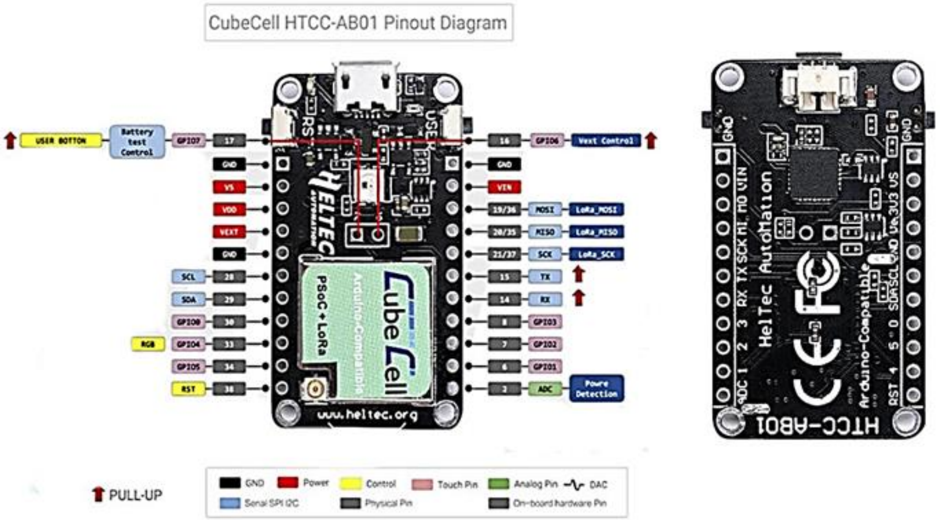


Figure 2.3 : HTCC-AB01 Board Diagram [22]

It operates in sub-GHz ISM bands and provides long-range communication using the LoRaWAN protocol. Integrated with a LoRa transceiver, MCU, and sensors, it enables precise environmental monitoring and asset tracking. It is compatible with Arduino, facilitating easy programming and integration. Table 2.2 shows the general specifications.

Table 2.2 : General specifications [22]

| Parameter | Description |
|---|---|
| Master Chip | ASR6501 (48 MHz ARM Cortex M0+ MCU) |
| LoRa Chipset | SX1262 |
| USB to Serial Chip | CP2102 |
| Frequency | 470510 MHz, 863923 MHz |
| Max TX Power | 22dB ± 1dB |
| Receiving sensitivity | -135 dBm |
| Solar Energy | 5.5～7V solar panel |
| Low Power Deep Sleep | 3.5µA |
| Hardware Resources | UART x 1; SPI x 1; I2C x 1; SWD x 1; 12-bits ADC input x 1; 8-channel DMA engine; GPIO x 8 |
| Memory | 128KB internal FLASH; 16KB internal SRAM |
| Interface | Micro USB x 1; LoRa Antenna interface (IPEX) x 1; 11 x 2.54 pin x 2 + 2 x 2.54 pin x 1 |
| Battery | 3.7V Lithium (SH1.25 x 2 socket) |
| Operating temperature | -20 ~ 70 ℃ |
| Dimensions | 41.5 x 25 x 7.6 mm |

- **ESP-WROOM-32**

The ESP-WROOM-32, as shown in Figure 2.4, is a versatile Wi-Fi and Bluetooth module designed by Espressif Systems. Powered by the ESP32 microcontroller, it boasts a dual-core Xtensa LX6 processor with a maximum clock speed of 240MHz. This module is perfectly suited for a wide range of IoT applications due to its seamless integration of both 2.4 GHz Wi-Fi (802.11 b/g/n) and Bluetooth 4.2 (Bluetooth Low Energy). Plus, it comes equipped with various peripheral interfaces, such as GPIOs, UART, SPI, I2C, ADC, DAC, and PWM, making the integration of sensors and actuators a breeze. It can be programmed through Arduino IDE, Espressif IDF, or other development environments. Its affordability, low power consumption, and robust feature set make it a popular choice for IoT, home automation, wearable technology, and industrial automation projects.

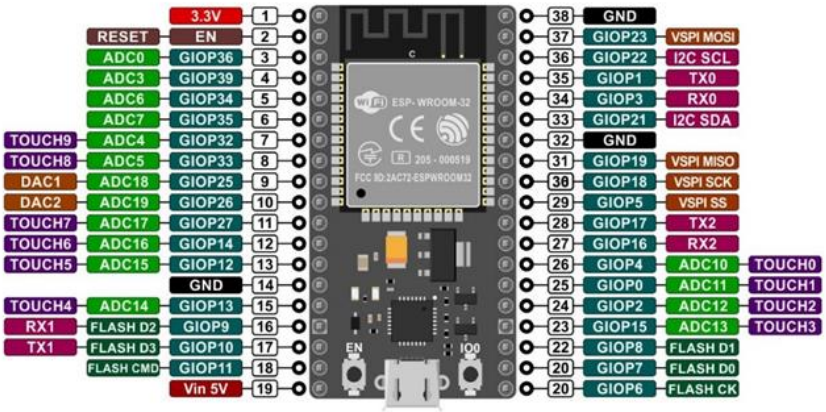


Figure 2.4 : ESP-WROOM-32 Board Diagram

- **DHT22 Sensor**

The DHT22, also referred to as a digital temperature and humidity sensor, is an affordable and highly precise tool for measuring the surrounding temperature and humidity levels (Figure 2.5).

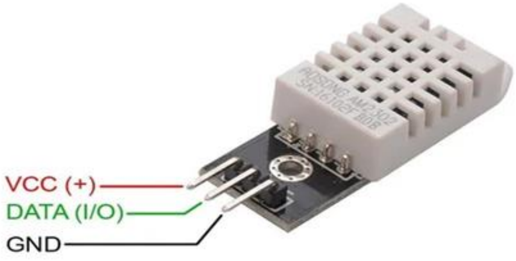


Figure 2.5 : DHT22 Sensor

By utilizing a capacitive humidity sensor and thermistor, this device is able to acquire this information digitally, with updates occurring every two seconds. Utilizing the OneWire protocol, the DHT22 communicates with the microcontroller through a single pin, guaranteeing both high reliability and long-term stability, with rapid response times. Its versatility makes it a popular choice for a range of applications, including weather monitoring, climate control, irrigation systems, and indoor environmental management. Table 2.3 provides further details on the features of DHT22 technologies.

Table 2.3 : Technical Specifications of DHT22

| Parameter | Description |
|---|---|
| Power Supply | 3.3 to 6 VDC |
| Consumption | Idle: 50 µA / Maximum 1.5 mA |
| Temperature Measurement Range | -40°C to 80°C |
| Humidity Measurement Range | 0% to 100% RH |
| Accuracy | +/- 2°C and +/- 5% RH |
| Maximum Measurement Frequency | 2Hz (2 measurements per second) |
| Dimensions | 25×15×9 mm |
| Long-Term Stability | +/- 0.5% per year |

- **MQ-135 Sensor:**

The MQ-135 serves as an analog sensor that effectively detects gases like ammonia, NOx, benzene, smoke, and CO2, and various atmospheric pollutants, as shown in Figure 2.6.

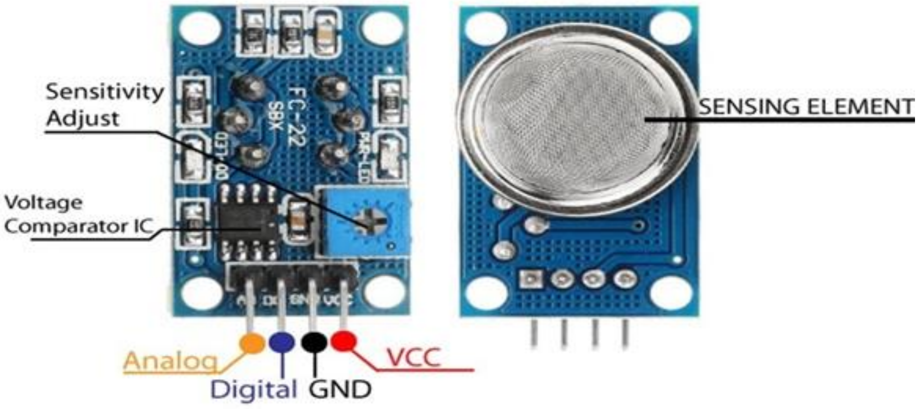


Figure 2.6 : MQ-135 Sensor

It provides an analog output voltage that corresponds to the concentration of the detected gas, making it a popular choice for air quality monitoring systems, indoor air quality monitoring, and gas leak detection. Before accurate readings can be obtained, the unit requires a warm-up time. It can be easily paired with microcontrollers like the Arduino Nano for efficient data acquisition and analysis. The MQ-135 is an ideal option for our air quality monitoring project, thanks to its high sensitivity and prompt response time. You can find a detailed account of the technical specifications of the MQ135 Sensor in Table 2.4.

Table 2.4 : Technical Specifications of the MQ135

| Parameter | Description |
|---|---|
| Power Supply | 5 V |
| Output | Analog (and a digital output) |
| Detection Range | 10 to 1000 PPM |
| Gases Detected | NH3, NOx, alcohol, benzene, smoke, and CO2 |
| Response Time | ≤ 1 second |
| Dimensions | 32x22x27 mm |
| Lifespan | 5 years |

- **OLED SSD 1306 I2C**

The SSD1306 is a high-tech 0.96" 128 x 64 monochrome OLED display (Figure 2.7) that uses organic light-emitting diodes (OLEDs) to produce breathtaking images with incredible contrast and power efficiency.

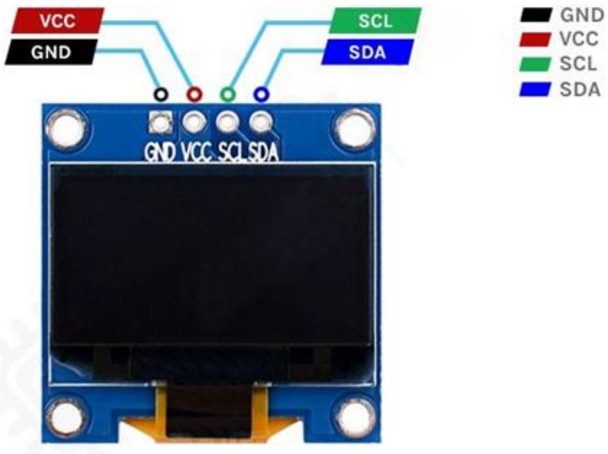


Figure 2.7 : OLED SSD 1306 I2C Display

This display is renowned for its slim, lightweight design and boasts wide viewing angles and lightning-fast response times. It's incredibly versatile and can seamlessly integrate with microcontrollers like the Arduino Nano via the I2C protocol. The SSD1306 driver streamlines system design by combining features such as contrast control and display RAM, and it offers a range of interface options, including parallel, SPI, and I2C. Table 2.5 shows the technical Specifications of the OLED SSD1306 I2C.

Table 2.5 : Technical Specifications of the OLED SSD 1306

| Parameter | Description |
|---|---|
| Driver | SSD1306 |
| Screen size | 0.96” |
| Screen dimensions | 22 x 11 mm |
| Resolution | 128 x 64 pixels |
| Supply voltage | 3 – 5 V |
| Module size | 27 x 27 x 3.5 mm |

- **Relay modules**

Relay modules, as depicted in Figure 2.8, play a crucial role in electronics by enabling the control of high-power devices through low-power signals. These modules comprise electromechanical switches called relays, which facilitate the management of electrical current to external devices.

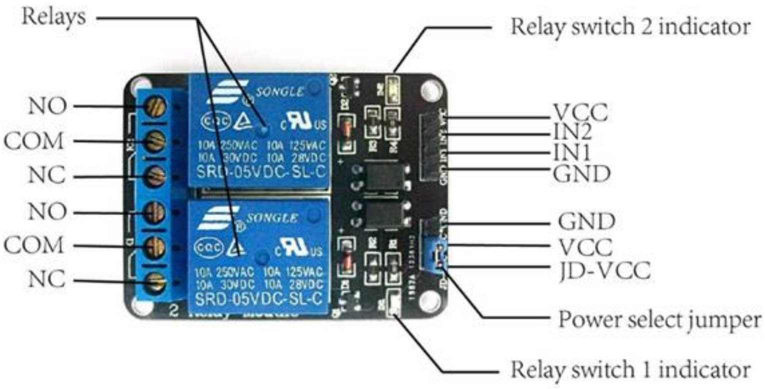


Figure 2.8 : Relay modules

Widely utilized across automation, robotics, and industrial control systems, relay modules ensure the separation between control circuits and loads, protecting delicate components from voltage surges. Available in various configurations such as single and multi-channel relays, they accommodate diverse voltage and current needs. Moreover, their compatibility with microcontrollers like the Arduino Nano streamlines their integration into projects. You can find a detailed account of the technical specifications of the Relay Module in Table 2.6.

Table 2.6 : Technical Specifications of the Relay Module

| **Parameter** | **Description** |
|---|---|
| Normal Voltage | 5V DC |
| Normal Current | 70mA |
| Maximum Load Current | 10A/250V AC, 10A/30V DC |
| Maximum Switch Voltage | 250V AC, 30V DC |
| Operate Time | ≤ 10ms |
| Release Time | ≤ 5ms |

- **Cooling Fan**

The Cooling Fan (Figure 2.9) consists of a small electric motor that turns the blades, generating an air current that lowers the temperature of the coolant. Its operation is controlled by the cooling switch.

Figure 2.9 : Cooling Fan

### 2.5.2 Software Environment

In this section, we will be discussing the various programs and Platforms utilized in our project to program the transceiver system and create the control and monitoring application, as well as the Cloud. The following programs and Platforms were used to carry out our work:

- **Arduino IDE**

Arduino IDE is an electronics platform that offers user-friendly software and hardware solutions for amateurs and experts alike. The Arduino Software (IDE), supporting all Arduino boards along with other board add-ons like ESP32, LoRa, and more. Additionally, the IDE interface boasts an uncomplicated design, featuring a code editor, syntax highlighting, a toolbar, an advanced functions menu bar, and a console for real-time feedback.

Figure 2.10 : Arduino IDE Logo

- **MIT App Inventor**

The MIT App Inventor is a user-friendly interface including two main editors: the design editor and the block editor. The design editor or the designer, users can drag and drop any of the elements they want effortlessly to create the UI of their app. On the other hand, the blocks editor gives app developers an environment in which they can plan of their apps' logic using color-coded blocks that are snapped together like puzzle pieces to build the program. As well it offers an app for Android or iOS for development and testing which gives developers an opportunity to fix and study the behavior of the applications in real-time.

Figure 2.11 : MIT App Inventor

- **Firebase Platforms**

Firebase is an advanced Backend as a Service (BaaS) platform created by Google. It provides all the necessary tools and services to make backend development for web and mobile apps easy. The system eliminates the need for difficult setup of backends through features such as cloud database integration, messaging, service authentication, analytics etc., thereby simplifying establishment of backend systems and shortening development time. Firebase is built to enable programmers build successful applications which can generate income and drive business growth using an intuitive, affordable platform.

Figure 2.12 : Firebase Platforms

## 2.6 System Presentation

In order to implement our iHENs system (Figure 2.13) that we designed earlier (Figure 2.1), we utilized the hardware components that were explained in the Hardware Environment section to develop the transmitter (End-Node), and the receiver (Gateway). Moreover, we made use of a Cloud computing platform (Firebase) and developed a cross-platform application for managing our system using the MIT App Inventor.

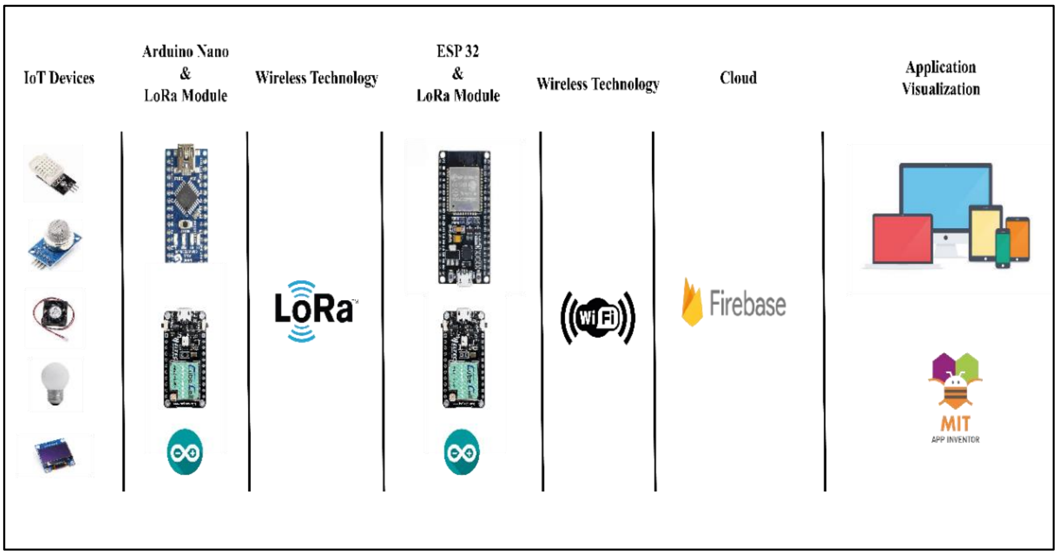


Figure 2.13 : Presentation of our iHENs system

### 2.6.1 Prototype

In this part, we will outline the structure of the End-Node prototype and the Gateway prototype, along with the smart poultry prototype.

#### 2.6.1.1 Sender Device (End-Node prototype)

The End-Node board is built with an Arduino Nano module and a LoRa Heltec HTCC AB01 V2 (Sx1261) module for data transfer. It features a temperature and humidity sensor (DHT22) and an air quality sensor (MQ135) specifically calibrated for toxic ammonia gas (NH3).

Additionally, the board includes a relay to automatically control fan operation when the temperature, humidity, or air quality exceeds a set limit, as well as a button to activate the light. There is also an OLED SSD1306 display and four buttons for setting the maximum and minimum values for temperature and humidity.

The End-Node diagram with Flowchart is illustrated in Figure 2.14.

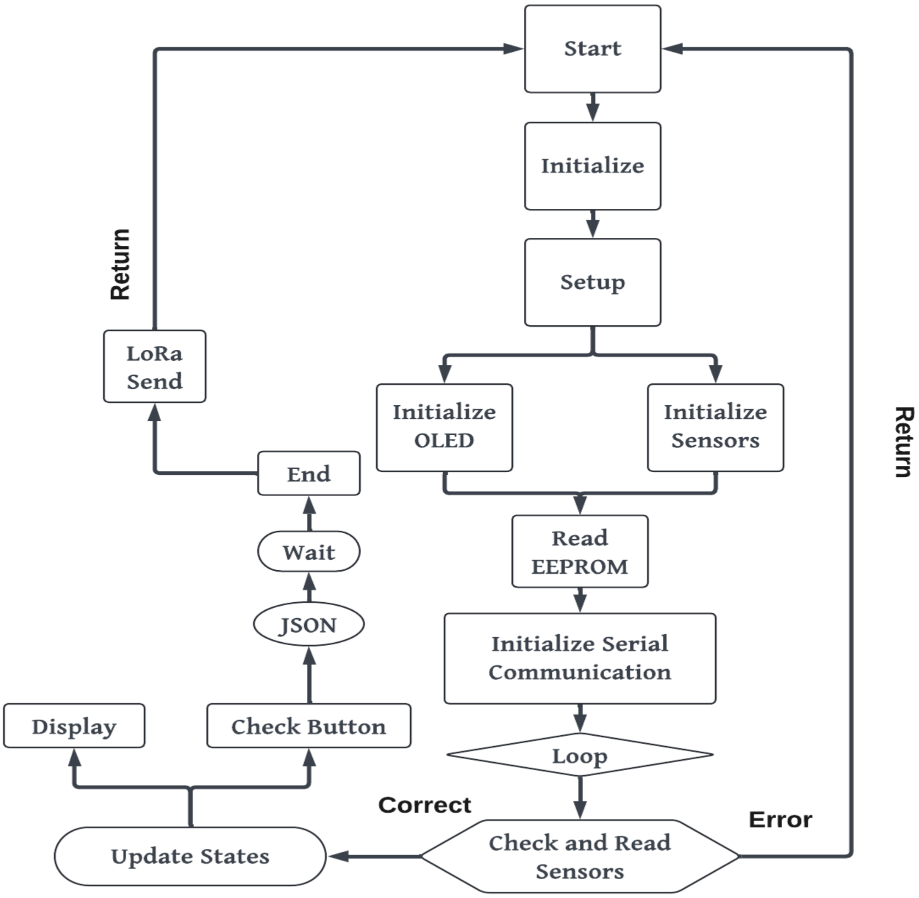
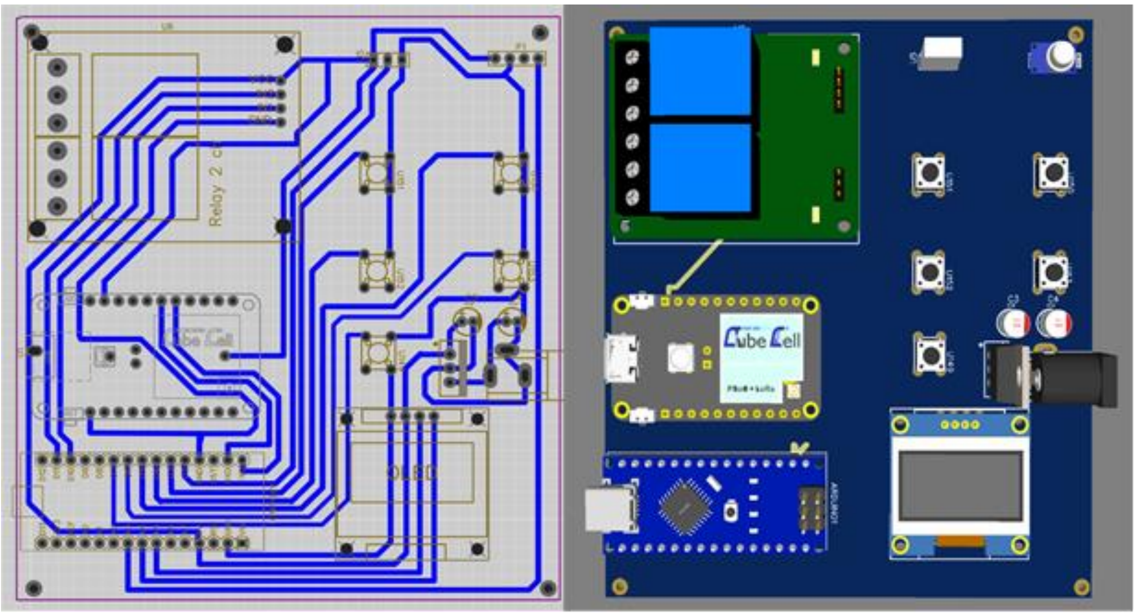


Figure 2.14 : End-Node Flowchart

Furthermore, for the design of this board, we used the open-source EasyEDA software to design and print the circuit of our End-Node prototype. Figure 2.15 displays the PCB simulation and the 3D visualization for the End-Node circuit.



**(a)** **(b)**

Figure 2.15 : (a) End-Node PCB (b) End-Node 3D Model (Top view)

After the PCB implementation with EasyEDA, we fabricate the End-Node prototype. Where the PCB fabrication process involves several steps, including Epoxy preparation, application of photoresist, exposure and development, etching, drilling, plating, testing and final inspection.

Finally, Figure 2.16 shows the prototype of the End-Node.

Figure 2.16 : End-Node Prototype

#### 2.6.1.2 Receiver Device (Gateway prototype)

The gateway board utilizes the LoRa Heltec HTCC-AB01V2 module to receive data from End-Nodes and transmit it to the ESP32 WROOM-32 for analysis. This data is then transferred to the "iHENs" iOS and Android application and displayed on OLED SSD1306. The Gateway diagram with Flowchart is illustrated in Figure 2.17.

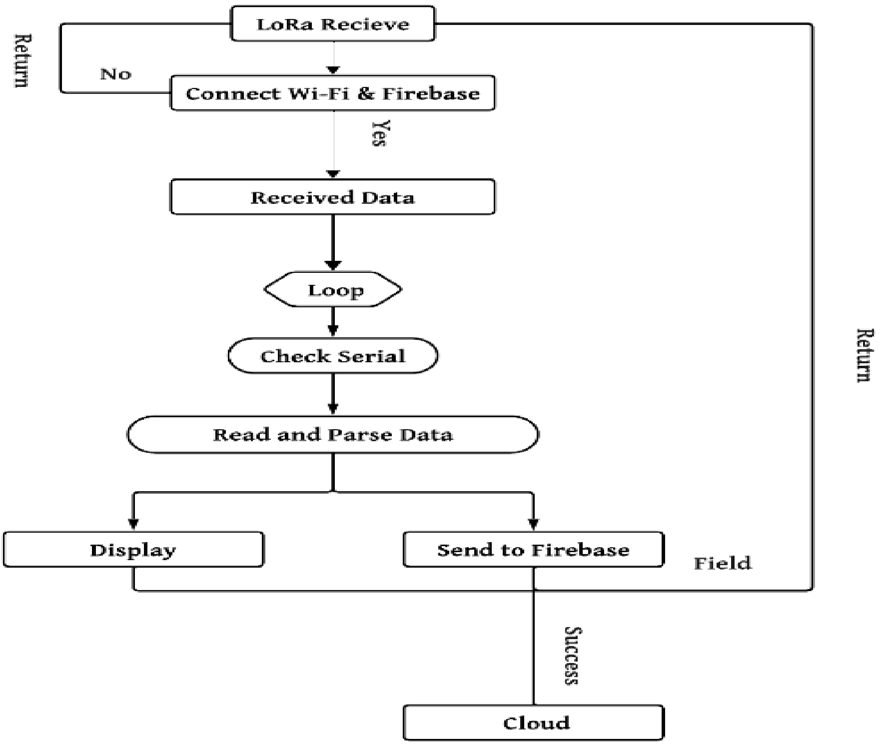
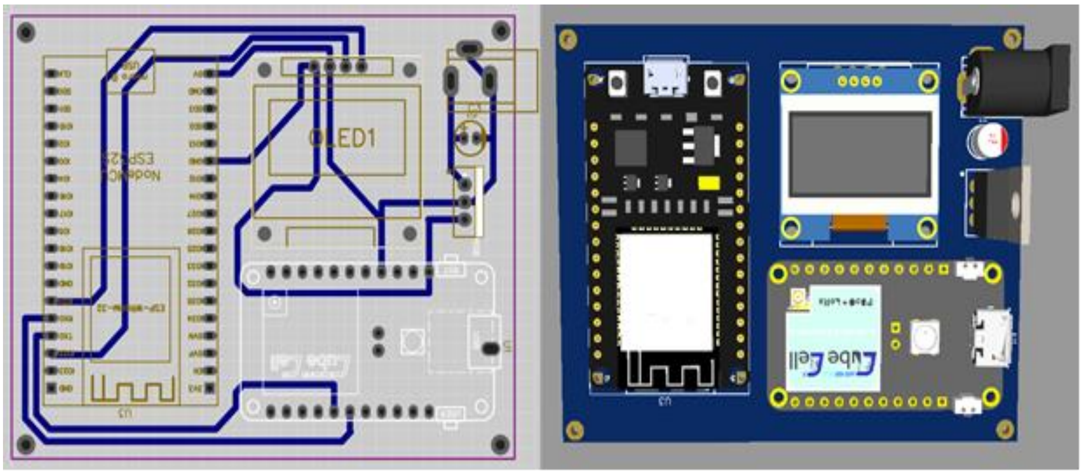


Figure 2.17 : Gateway Flowchart

Furthermore, Figure 2.18 shows the PCB simulation and the 3D visualization for the Gateway circuit.



(a) (b)

Figure 2.18 : (a) Gateway PCB (b) Gateway 3D Model (Top view)

Finally, Figure 2.19 shows the prototype of the Gateway Device.

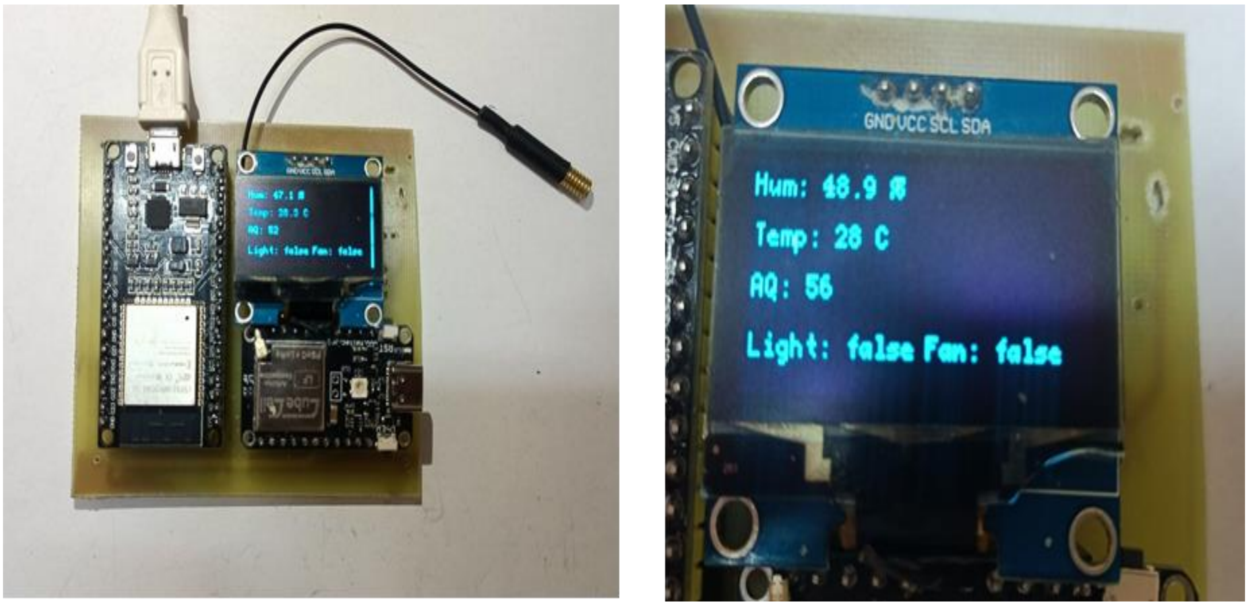


Figure 2.19 : Gateway Prototype

#### 2.6.1.3 Smart Poultry

We have developed a prototype for our smart poultry system, which includes a fan, a light, and the End-Node device we discussed previously.

This system is designed to monitor the biosphere inside the poultry house. The prototype of the smart poultry is illustrated in the following Figure 2.20.

Figure 2.20 : Prototype Smart Poultry

### 2.6.2 System operation

We have developed an iHENs monitoring app that enables the user to remotely monitor their poultry biosphere reliably and automatically. The app is cross-platform, allowing access on both Android and iOS. Figure 2.21 displays the app's logo.

Figure 2.21 : "iHENs" System Logo

#### 2.6.2.1 Authentication and System Access

The system user logs in using the username and password that are stored in Firebase. Not everyone is able to register as a new user for additional security. The iHENs system administrator handles this task. The authentication interface is depicted in Figure 2.22.

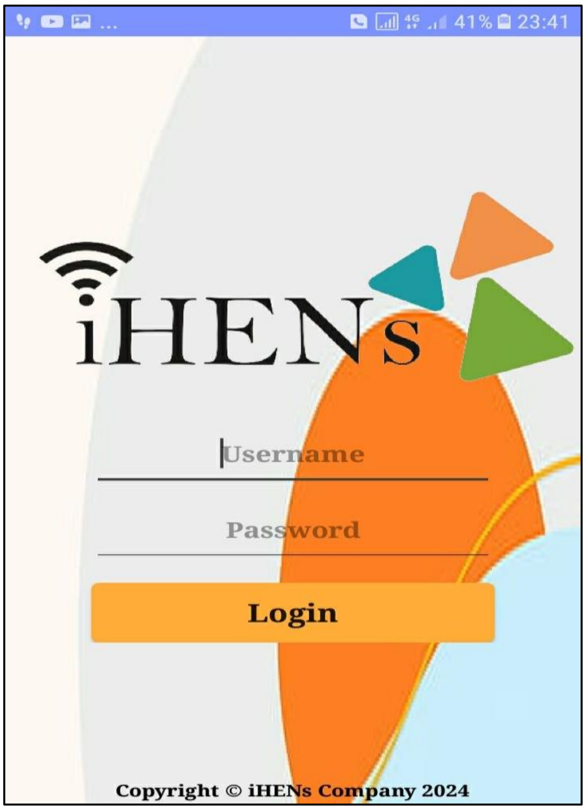
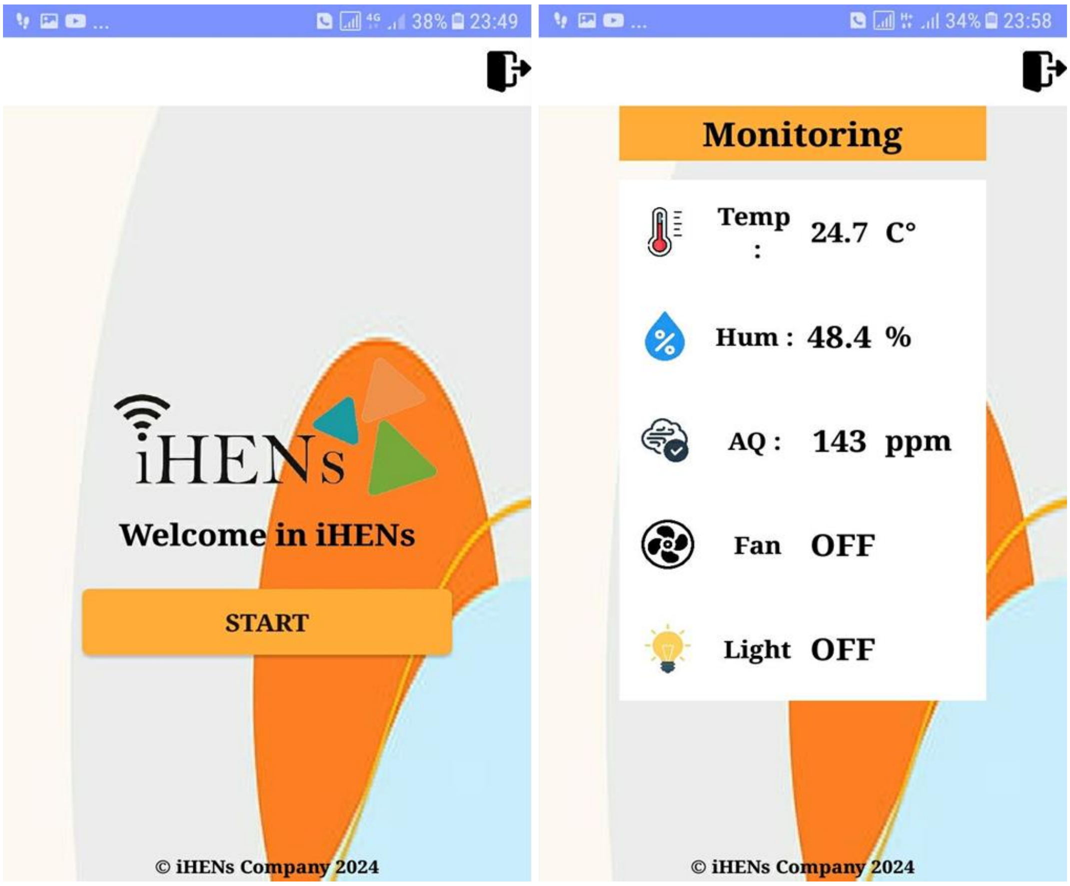


Figure 2.22 : Authentication interface

#### 2.6.2.2 Poultry Management

After successful authentication, the welcome page will be displayed, featuring two buttons: "Start" and "Exit." Pressing the "Start" button will directly lead you to the home page, where you can monitor the temperature, humidity, air quality, and fan status. The fan is programmed to activate when the temperature or humidity rises, or if the air quality deteriorates. Additionally, the system monitors the lighting status in the event that someone switches on the lights within the poultry house. The Home interface is depicted in Figure 2.23.



Temp : 24.7 C°

Hum : 48.4 %

AQ : 143 ppm

Fan OFF

Light OFF

Figure 2.23 : Home interface

## 2.7 Results and Discussions

To check if LoRa can effectively send data from areas we first tested the LoRa Sx1262 module by sending data packets from the End-Node to the gateway. After that we looked at RSSI, SNR and PER. Lastly, we measured how far it can reach by examining the RSSI and SNR values and compared the results with a reference [6].

### 2.7.1 End-Node-To-Gateway Test

The indoor testing took place at seven different locations within BBA University, as detailed in Table 2.7.

Table 2.7 : Indoor Testing Location in BBA-University

| Test No | LoRa Transmitter | LoRa Receiver |
|---|---|---|
| 1 | 28 meters away from Receiver | Laboratory of Materiel and Electronic Systems-BBA University |
| 2 | 32 meters away from Receiver | |
| 3 | 36 meters away from Receiver | |
| 4 | 40 meters away from Receiver | |
| 5 | 47 meters away from Receiver | |
| 6 | 50 meters away from Receiver | |
| 7 | 57 meters away from Receiver | |

During the testing period, the LoRa gateway was situated in the LMSE lab, while the final LoRa device was moved between locations for each test. The distance between the LoRa transmitter and receiver was measured using the Google Map app. Only one LoRa device and one LoRa gateway were utilized for testing at this stage. Six different modes were employed to assess the internal performance of the LoRa network, with each mode representing a unique combination of SF and BW while CR and TP remained constant (as shown in tables 2.8).

Table 2.8 : Deference Parameter LoRa

| Mode No | SF | BW (KHz) | CR |
|---|---|---|---|
| Mode 1 | 7 | 125 | 4/5 |
| Mode 2 | 7 | 250 | |
| Mode 3 | 9 | 125 | |
| Mode 4 | 9 | 250 | |
| Mode 5 | 12 | 125 | |
| Mode 6 | 12 | 250 | |

Subsequently, each site was tested using these six different modes. The test results are summarized in Tables 2.9, 2.10, and 2.11.

Table 2.9 : Result of The Indoor Test at 7 Location with Mode 1 and Mode 2

| Test No | Mode 1 | | | Mode 2 | | |
|---|---|---|---|---|---|---|
| | RSSI (dBm) | SNR (dB) | PER (%) | RSSI (dBm) | SNR (dB) | PER (%) |
| 1 | -88 | 12 | 0.00 | -80 | 12 | 0.00 |
| 2 | -100 | 5 | 0.00 | -99 | 2 | 0.00 |
| 3 | -86 | 12 | 0.00 | -99 | 6 | 0.00 |
| 4 | -111 | -9 | 0.00 | -105 | -1 | 0.00 |
| 5 | -106 | 3 | 0.00 | 102 | -9 | 0.00 |
| 6 | -109 | -6 | 0.00 | -106 | -5 | 0.00 |
| 7 | -108 | 0 | 0.00 | -106 | -8 | 0.00 |

Table 2.10 : Result of The Indoor Test at 7 Location with Mode 3 and Mode 4

| Test No | Mode 3 | | | Mode 4 | | |
|---|---|---|---|---|---|---|
| | RSSI (dBm) | SNR (dB) | PER (%) | RSSI (dBm) | SNR (dB) | PER (%) |
| 1 | -83 | 11 | 0.00 | -84 | 10 | 0.00 |
| 2 | -101 | 5 | 0.00 | -98 | 3 | 0.00 |
| 3 | -89 | 10 | 0.00 | -95 | 6 | 0.00 |
| 4 | -103 | 6 | 0.00 | -107 | -11 | 0.00 |
| 5 | -111 | -5 | 0.00 | -101 | -6 | 0.00 |
| 6 | -108 | -4 | 0.00 | -104 | -14 | 0.00 |
| 7 | -111 | -8 | 0.00 | -108 | -15 | 0.00 |

Table 2.11 : Result of The Indoor Test at 7 Location with Mode 5 and Mode 6

| Test No | Mode 5 | | | Mode 6 | | |
|---|---|---|---|---|---|---|
| | RSSI (dBm) | SNR (dB) | PER (%) | RSSI (dBm) | SNR (dB) | PER (%) |
| 1 | -82 | 6 | 0.00 | -80 | 4 | 0.00 |
| 2 | -94 | 5 | 0.00 | -99 | 2 | 0.00 |
| 3 | -92 | 3 | 0.00 | -98 | 2 | 0.00 |
| 4 | -110 | -5 | 0.00 | -108 | -11 | 0.00 |
| 5 | -109 | -5 | 0.00 | -109 | -15 | 0.00 |
| 6 | -108 | -7 | 0.00 | -108 | -5 | 0.00 |
| 7 | -108 | -1 | 0.00 | -107 | -3 | 0.00 |

While Figures 2.24 and 2.25 offer a visual representation of the Test results.

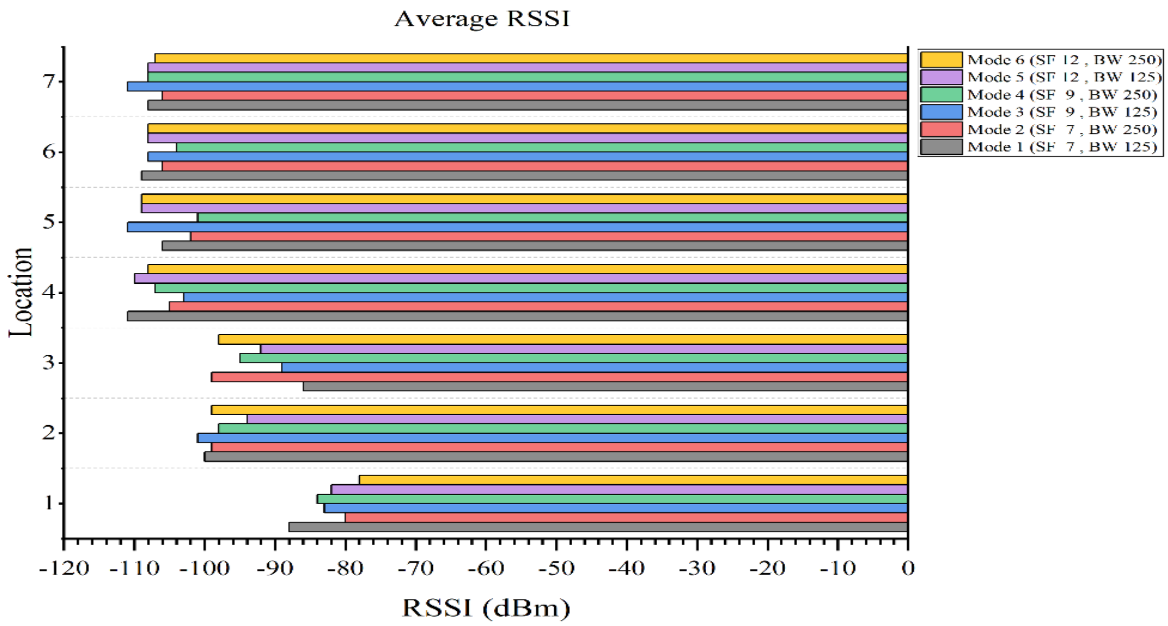


Figure 2.24 : Average RSSI of LoRa Sx1262 at each test location for different mode

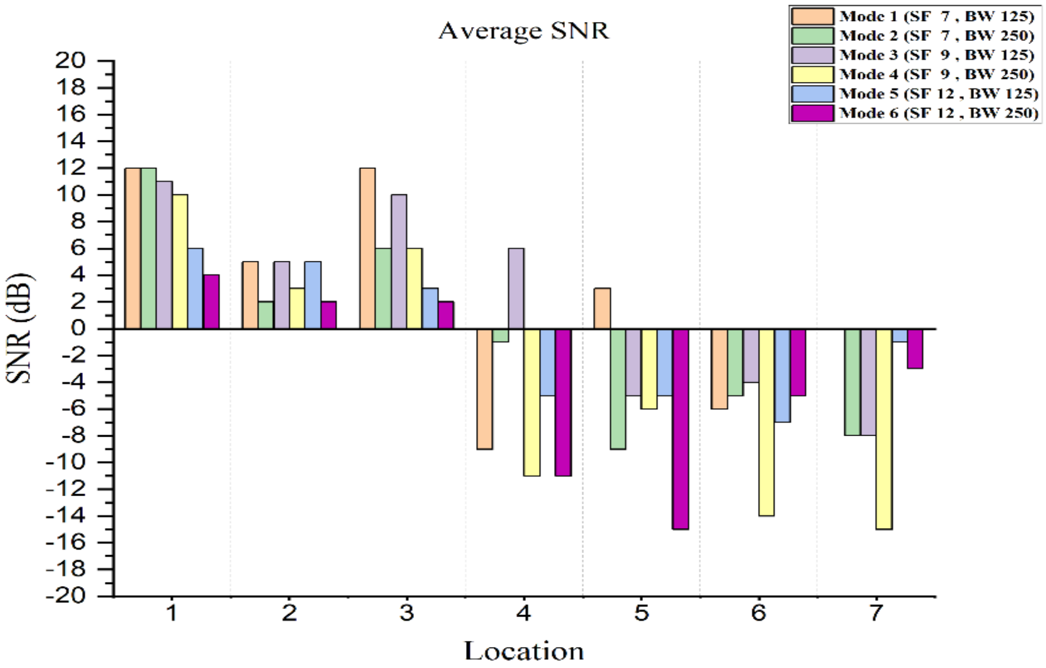


Figure 2.25 : Average SNR of LoRa Sx1262 at each test location for different mode

The received signal strength index (RSSI), signal-to-noise ratio (SNR), and packet loss rate for different modes at each test site (test number) are tabulated in Tables 2.9, 2.10, and 2.11. The results have been converted into graphs (Figure 2.24 and Figure 2.25) for better visualization.

The average RSSI of the entire test result ranges from -80 dB to -120 dB. Location 2 shows the lowest average RSSI value, while locations 4 and 7 show the highest average RSSI value in each mode. Additionally, the average RSSI value decreases when the spacing factor increases in the same bandwidth (Mode 1, Mode 3, and Mode 5 for the 125 kHz band and Mode 2, Mode 4, and Mode 6 for the 250 kHz band).

The average noise rate collected at each test site shows that sites 1, 4, and 7 have higher noise interference compared to sites 2, 3, 5, and 6. Among all locations, location 2 shows the highest average noise rate in all modes, while location 7 shows the lowest average noise rate in all modes. Furthermore, increasing the bandwidth from 125 kHz to 250 kHz with the same spreading factor reduces the SNR reading, except for spreading factor 7 (mode 1 and 2).

Increasing the spreading factor with the same bandwidth increases the SNR of the signal. The test site closest to a location in the transmission path shows a different result than the other sites when the spreading factor is increased. A significant decrease in the signal distortion rate is seen at location 2 and 3 when the spreading factor is increased from 9 to 12.

Based on the findings from Tables 2.9, 2.10, and 2.11, our main focus was on examining transmission efficiency at various distances without encountering any significant obstacles. During the tests, we did not encounter major obstacles such as trees or cars, which allowed the data packets to be transmitted without any interference.

Surprisingly, the distance between the LoRa End-Node and the LoRa Gateway did not have a noticeable impact on the quality of communication. For instance, in reference [6], a 45 percent obstacle ratio resulted in a 45 percent loss, but in our tests, the effect on transmission was minimal.

Furthermore, as we conducted NLOS test, we observed that the distance between the LoRa End-Node and the LoRa Gateway did not have a significant impact on the communication quality. This may be attributed to the structural elements or trees in the university environment, which only had a slight effect on the signal loss levels.

Additionally, we found that increasing the distance from the LoRa Gateway did not lead to a decrease in packet quality in terms of Radio Frequency Interference RSSI and SNR.

In conclusion, our results indicate that the LoRa Heltec HTCC AB01 V2 (Sx1262) is more effective than the two devices used in [6]. This difference in effectiveness is clearly reflected in the results we obtained.

### 2.7.2 LoRa Long-Range Test

Table 2.13 provides the results of the outdoor coverage test (Performance of LoRa as shown in table 2.12), specifically detailing the LoRa (433MHz) parameter settings. During this test, a propagation factor of 10 and a bandwidth of 250 kHz were utilized to optimize coverage distance and communication sensitivity. To prevent interference with other networks, the transmission power was maintained at 20 dBm. The LoRa Gateway was situated within the first-floor communications lab, while the LoRa End-Node was positioned away from the Gateway for data collection purposes.

Table 2.12 : LoRa Performance Testing in Outdoor BBA University

| SF | BW (KHz) | CR | TP (dBm) |
|---|---|---|---|
| 12 | 250 | 4/5 | 20 |

Throughout the test duration, the LoRa Node transmitted a message to the gateway every 10 seconds, and the gateway reciprocated with a confirmation message, denoted by a flashing LED on the LoRa Node, indicating a successful connection.

Table 2.13 : Result of The Outdoor Test

| Range (m) | RSSI (dBm) | SNR (dB) |
|---|---|---|
| 0 | -81 | 10 |
| 10 | -84 | 6 |
| 20 | -99 | 3 |
| 30 | -98 | 3 |
| 50 | -107 | -14 |
| 100 | -111 | -17 |
| 300 | -110 | -18 |
| 500 | -111 | -15 |
| 700 | -111 | -20 |
| 1000 | -111 | -20 |

The outdoor LoRa Gateway in this area has a maximum connectivity coverage of 1 km, which is better than the distance obtained in [6]. However, for our purposes, the distance obtained falls short of our desired range of 2 km to 5 km. This limited coverage is primarily due to high levels of interference and path loss, both indoors and outdoors on campus.

When a LoRa End-Node sends a message to a LoRa Gateway, the signal strength diminishes with distance. This is because the omnidirectional nature of the antenna scatters signal energy in all directions, leading to energy loss and reduced reception. Additionally, obstructions in the transmission path reduce signal strength.

To improve LoRa coverage, it is recommended to utilize line-of-sight scenarios, such as placing the LoRa Gateway near a window instead of indoors, and using a different type of antenna to enhance transmission and reception capabilities.

## 2.8 Conclusion

In this chapter, a successful iHENs system has been developed for intelligent poultry monitoring and management, utilizing LoRa technology within IoT. The system encompasses a range of features including temperature, humidity, and air quality monitoring, as well as lighting and automatic fan control. Extensive testing has demonstrated the system's capacity to efficiently transmit data across various environments, with the capability for long-range communication. This marks the conclusion of the design, development, and implementation phase, affirming its effectiveness in advancing smart and efficient poultry management.

# General Conclusion

# General Conclusion

This thesis represented the first study of the LoRa device Heltec HTCC AB01 (Sx1262) in Algeria, presenting a new approach to designing a LoRa communication system using the latest version of the technology for a smart poultry biosphere monitoring project. Different system functionalities were presented and compared to the system functionalities indicated in [6].

The thesis proposed the design and implementation of a prototype LoRa-based IoT system for analyzing and monitoring sensor and port data. The system aims to extend LoRa technology from isolated areas to those with Internet networks to minimize installation costs and energy consumption levels, especially for low-power IoT applications. In addition, a data storage model is proposed for our iHENs.

Both the hardware and software of the system were simplified, with MIT app inventor and Firebase being used as the solution for data storage and security. The system was tested through two experiments, where the first experiment showed the efficiency of the LoRa Sx 1262 device when connecting the End-Node to the Gateway, compared to the two devices used in [6].

In the second experiment, the maximum reachable distance was tested and compared with the distance obtained in [6], confirming the advantage of our device used in our system “iHENs” over reference [6].

Potential design improvements were identified, including studying End-Node and Gateway localization, exploring different antennas for LoRa devices, and enhancing the transmission protocol by developing a full duplex system and adding encryption to secure the data.

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