LORA-BASED INTERNET OF THINGS (IOT) WIRELESS NETWORK SYSTEM TO MONITOR COVID-19 PATIENTS

by

MUHAMMAD IZZ ZHARFAN BIN AZHAR MUZAFAR

Thesis submitted in fulfilment of the requirements

for the Bachelor Degree of Aerospace Engineering (Honors)

July 2021

ENDORSEMENT

I, Muhammad Izz Zharfan bin Azhar Muzafar hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

(Signature of Student)

Date: 11/07/2021

(Signature of Supervisor)

Name: Dr 'Aiffah Mohd Ali
Date: 11/07/2021

(Signature of Examiner)

Name: Dr Norilmi Amilia Ismail
Date: 11/07/2021

DECLARATION

This thesis is the result of my investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date: 11/07/2021

ACKNOWLEDGEMENTS

All praises to Allah and His blessing for giving me the courage to have faith in myself for the completion of the thesis. I would like to express my heartfelt gratitude to Dr 'Aiffah Mohd Ali for her support and guidance in doing this project. She is willing to inspire me as well as sacrifice her time to guide any uncertainties and provide constructive feedback. It has been a great pleasure and honour to have her as my supervisor. I would like to thank Aizzat Iqbal, with his guidance I am able to wrap up this project successfully and accomplished it within the time limit even in the unprecedented times of COVID-19 pandemic.

My deepest gratitude goes to all my family members. I would like to thank my beloved mother Sasunawati who has always been my strongest and most loyal supporter, my father Azhar Muzafar who always give hope, motivates and teaches me the meaning of life, my brother Aqil Qayyum, my sister Qaseh Qamalia and my grandmother Zaharah. It would be impossible for me to write this thesis without the unconditional support from them.

I would like to express my gratitude to all my friends who have been so supportive. A special thanks to my bestfriend Nurin Syazwina who always lend me ears and motivates me, my fellow classmates Hafriz Najmi, Zulhilmi, Aqil, Nizam, Hafizuddin, Nazirul Syahmi, Fauzan, Syamil, Afiq, Alif and Haikal for making my life a little less stressful and more meaningful. I appreciate every single one of them.

ABSTRACT

The implementation of Internet of Things (IoT) in the medical field using Long Range (LoRa) technology is the key area of interest in this project. LoRa has the ability to transmit packets of data across great distances, has low power consumption, and high immunity to interference compared to other Low-Power Wide-Area (LPWA) technologies. The emergency situation for COVID-19 patients who have severe symptoms can be detected and diagnosed more efficiently by the medical staff because this LoRa LPWA technology provides an efficient, flexible, and cost-effective solution to real-world problems in urban, rural, and indoor use cases. The patients' blood oxygen saturation and pulse rate are measured via MH-ET Live MAX30102 sensor. This sensor has the advantage of being compatible with the Arduino board, specifically Arduino Uno which is based on ATmega328P. The sensor is then integrated with TTGO LoRa SX1276 modules of the Wireless Sensor Network. In this project, peer-to-peer LoRa communication is implemented, which covers the physical layer of the LoRa communication protocol where the transmitter and receiver communicates directly without the central server or gateway. After integrating the sensor to LoRa transmitter, the data are sent to the receiver, which the receiver is connected to Arduino IDE software to evaluate the sensor output. From the result, user must be in rested condition, place their fingertip onto the sensor properly for a few moments without any movement, and use body part of fingertip only in order to obtain an accurate readings. However, the measured pulse rate or oxygen saturation might be inaccurate of either numbers due to incompatible codes used or hardware defects with elevated value of heart rate 166 and 214 beats per minute recorded. Furthermore, this project evaluates the LoRa SX1276 transceiver module on outdoor environment at suburban area in Nibong Tebal with specific parameters that has been programmed. Line-of-sight (LOS) test shows that the maximum displacement between the modules are 1300 meters with limitation of received signal strength indicator (RSSI). The signal-to-noise ratio (SNR) and RSSI recorded at 1300

meters distance is -6.5dB and -118dBm respectively. Non-line-of-sight (NLOS) test shows that LoRa still able to communicate with each other after 8 blocks of houses with an approximate displacement of 240 meters apart between the modules, with each house has approximately 30 meters length. With the presence of other radio frequency devices that act as noise in the residential suburban area, LoRa modules are still able to communicate with RSSI and SNR value of -113dBm and -5.42dB respectively after being obstructed by 8 blocks of houses. Then, parameters of LoRa SX1276 module is calculated by using LoRa Modem Calculator Tool to analyse the theoretical performances and effectiveness of LoRa communications such as sensitivity, link budget, bit rate, time on air and symbol time by varying the spreading factor, bandwidth and coding rate. In the analysis, all these LoRa performance parameters shows various patterns of graphs because spreading factor, bandwidth and coding rate are the main input parameters that affects LoRa signal modulation and demodulation properties.

ABSTRAK

Pelaksanaan Internet Pelbagai Benda (IoT) dalam bidang perubatan menggunakan teknologi Long Range (LoRa) adalah bidang utama yang diminati dalam projek ini. LoRa memiliki kemampuan untuk menghantar paket data berjarak jauh, memiliki penggunaan kuasa yang rendah, dan kekebalan tinggi terhadap gangguan dibandingkan dengan teknologi Low-Power Wide-Area (LPWA) lain. Keadaan kecemasan bagi pesakit COVID-19 yang mempunyai simptom yang teruk dapat dikesan dan ditangani dengan lebih berkesan oleh kakitangan perubatan kerana teknologi LoRa LPWA ini menyediakan penyelesaian yang cekap, fleksibel, dan menjimatkan kos untuk masalah harian di bandar, luar bandar, dan kes penggunaan dalaman. Ketepuan dan kadar denyutan oksigen darah pesakit diukur melalui penderia MH-ET Live MAX30102. Penderia ini mempunyai kelebihan yang serasi dengan papan Arduino, khususnya Arduino Uno yang berdasarkan ATmega328P. Penderia kemudian disatukan dengan modul TTGO LoRa SX1276 dari Rangkaian Penderia Tanpa Wayar. Dalam projek ini, komunikasi LoRa titik-ke-titik dilaksanakan, yang meliputi lapisan fizikal protokol komunikasi LoRa di mana pemancar dan penerima berkomunikasi secara langsung tanpa pelayan pusat atau gerbang. Setelah mengintegrasikan penderia ke pemancar LoRa, data dikirim ke penerima, yang mana penerima disambungkan ke perisian Arduino IDE untuk menilai pengeluaran penderia. Dari hasil projek ini, pengguna mesti berada dalam keadaan rehat, meletakkan hujung jari mereka ke penderia dengan betul selama beberapa saat tanpa pergerakan, dan gunakan bahagian hujung jari badan sahaja untuk mendapatkan bacaan yang tepat. Walau bagaimanapun, kadar nadi atau ketepuan oksigen yang diukur mungkin tidak tepat sama ada nombor kerana kod yang tidak sesuai digunakan atau kecacatan perkakasan dengan peningkatan kadar denyutan jantung 166 dan 214 denyutan seminit dicatatkan. Selanjutnya, projek ini menilai modul transceiver LoRa SX1276 mengenai persekitaran luar di kawasan pinggir bandar di Nibong Tebal dengan parameter khusus yang telah diprogramkan. Ujian

pandangan lurus menunjukkan bahawa jarak maksimum antara modul adalah 1300 meter dengan had penunjuk kekuatan isyarat yang diterima. Nisbah isyarat-ke-bising dan penunjuk kekuatan isyarat yang direkodkan pada jarak 1300 meter adalah -6.5dB dan -118dBm. Ujian tanpa pandangan lurus menunjukkan bahawa LoRa masih dapat berkomunikasi antara satu sama lain setelah 8 blok rumah dengan jarak perpindahan sekitar 240 meter antara modul, dengan setiap rumah mempunyai panjang kira-kira 30 meter. Dengan adanya peranti frekuensi radio lain yang bertindak sebagai kebisingan di kawasan pinggir bandar kediaman, modul LoRa masih dapat berkomunikasi dengan nilai penunjuk kekuatan isyarat yang diterima dan nisbah isyarat-ke-bising masing-masing -113dBm dan -5.42dB setelah terhalang oleh 8 blok rumah. Kemudian, parameter modul LoRa SX1276 dikira dengan menggunakan LoRa Modem Calculator Tool untuk menganalisis prestasi teori dan keberkesanan komunikasi LoRa seperti kepekaan, anggaran pautan, kadar bit, masa di udara dan masa simbol dengan mengubah faktor penyebaran, lebar jalur dan pengekodan kadar. Dalam analisis ini, semua parameter prestasi LoRa ini menunjukkan pelbagai corak grafik kerana faktor penyebaran, lebar jalur dan kadar pengekodan adalah parameter input utama yang mempengaruhi sifat modulasi dan demodulasi isyarat LoRa.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
IoT	Internet of Things
LPWA	Low-Power Wide-Area
LPWAN	Low-Power Wide-Area Network
WSN	Wireless Sensor Network
NB-IoT	NarrowBand-Internet of Things
LTE-M	Long Term Evolution
M2M	Machine-to-Machine
NFC	Near Field Communication
IEEE	Institute of Electrical and Electronics Engineers
BLE	Bluetooth Low Energy
Wi-Fi	Wireless Fidelity
RFID	Radio Frequency Identification
WPAN	Wireless Personal Area Network
WBAN	Wireless Body Area Network
CDMA	Code Division Multiple Access
SC-FDMA	Single-Carrier Frequency-Division Multiple Access
OFDMA	Orthogonal Frequency-Division Multiple Access
QAM	Quadrature Amplitude Modulation
AES	Advanced Encryption Standard
UNB	Ultra Narrow Band
2G	Second Generation

3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
FDD	Frequency Division Duplex
TDD	Time Division Duplex
BCN	Beacon
PNG	Ping
CSS	Chirp Spread Spectrum
FHSS	Frequency-Hopping Spread Spectrum
BPSK	Binary Phase Shift Keying
DBPSK	Differential Binary Phase Shift Keying
GFSK	Gaussian Frequency Shift Keying
FSK	Frequency Shift Keying
MSK	Minimum-Shift Keying
OOK	On-Off Keying
GMSK	Gaussian Minimum Shift Keying
QPSK	Quadrature Phase Shift Keying
ISM	Industrial, Scientific, and Medical
IDE	Integrated Development Environment
OLED	Organic Light-Emitting Diode
COVID-19	Coronavirus Disease
SARSCoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
TX	Transmit
RX	Receive
HL7	Health Level Seven

UHF	Ultra-High-Frequency
UL	Uplink
DL	Downlink
P2P	Peer-to-Peer
ALOHA	Additive Links On-line Hawaii Area
IP	Internet Protocol
SiP	System-in-Package
TSMC	Taiwan Semiconductor Manufacturing Company
I2C	Inter-Integrated Circuit
PCB	Printed Circuit Board
RAM	Random Access Memory
LOS	Line of Sight
NLOS	Non-Line of Sight
SF	Spreading Factor
BW	Bandwidth
CR	Coding Rate
SNR	Signal-to-Noise Ratio
SNR_{limit}	Signal-to-Noise Ratio Limit
CRC	Cyclic Redundancy Check
NF	Noise Figure
PHY	Physical Layer
MAC	Medium Access Control
3GPP	Third Generation Partnership Project
RSSI	Receive Signal Strength Indicator
FEC	Forward Error Correction

LED	Light Emitting Diode
SPI	Serial Peripheral Interface

CHAPTER 1

INTRODUCTION

This chapter briefly explains the research general overview, problem statement, objectives of the research, and the layout of the thesis.

1.1 General Overview

In the past several years, LoRa technology has been develop rapidly due to its ability to transmit packets of data across great distances, low power consumption, and high immunity to interference. These criteria, which involve large-scale deployment, have made LoRa technology a potential solution in a wide variety of applications, including healthcare. As a result, there are numerous research on this LoRa technology, as well as other Low-Power Wide-Area (LPWA) technologies and various Wireless Sensor Networks (WSN), which are to be implemented under IoT applications.

In the near future, IoT for healthcare will provide a more stable solution for the healthcare system. The IoT has a wide range of applications, and because of its potentialities, IoT for healthcare is still at the top of research. Continuous and long-term healthcare systems are essential in the healthcare environment to make the process more effective and reliable, hence medical staff can provide continuous medical care towards patients by monitoring the individual on an ongoing basis.

1.2 Problem Statement

As of 18 October 2020, a total of 20498 confirmed cases of coronavirus disease (COVID-19) in Malaysia has been recorded and since then, the number of confirmed cases has increased dramatically, to the point that patients have outnumbered available medical staffs (WHO, 2020). Due to this rapidly grow number of positive cases, the capacity for patients in quarantine centre has increasingly being occupied, which eventually leads to crowded area. The healthcare systems become chaos with lack of human resources in handling this unprecedented situation. Moreover, there was worst-case scenario where several frontline healthcare workers tested positive COVID-19 due to exposure to the virus while nursing COVID-19 patients.

A systematic approach to monitor these patients is required to ease the frontline healthcare workers. With the presence of LoRa wireless network system a variety of challenges can be addressed more conveniently to establish a flexible IoT-based healthcare system. This includes a continuous involvement of the healthcare approach towards patients, where medical authorities can diagnose and isolate patients with severe symptoms more efficiently in emergencies.

The IoT-based healthcare system is now at its peak due to its potentialities among other IoT applications. The implementation of an IoT-based health monitoring system allows more structured treatment in certain circumstances. This will help the healthcare system be more organized in handling this pandemic in terms of monitoring COVID-19 patients and making the frontline healthcare workers more resilient towards the infectious virus due to less frequent close contacts with COVID-19 patients.

With the help of a pulse rate and oxygen saturation sensor, each COVID-19 patients are required to record their pulse rate and blood oxygen saturation every 8 hours via a pulse oximeter sensor to be monitored by medical authorities. COVID-19 patients with blood oxygen saturation less than 92% and elevated pulse rate are most probably at risk of severe symptoms requiring immediate medical attention, for example, further treatment in Intensive Care Unit (ICU). Integrating this sensor onto LoRa technology will make it easier for the medical staff to detect and isolate patients with severe symptoms across the wide area of the quarantine centre.

1.3 Objectives

This study aims to ease the healthcare system in handling COVID-19 patients by transmitting the data from the sensor to the receiver from time to time by implementing a wireless system with LoRa technology. The objectives of this project are:

- To develop a device for an IoT-based health monitoring system via LoRa
- To evaluate the performance and effectiveness of LoRa communication

1.4 Thesis Layout

This thesis will be divided into five chapters. Each chapter will be organized as follows:

- Chapter 1, Introduction : motivates the study initiative, points out the objectives of the study, explains the overview and the needs of the research done in this thesis
- Chapter 2, Literature Review : demonstrates the previous work of IoT, WSNs, LPWA technologies and the concept of LoRa related to the study.
- Chapter 3, Methodology : describes the actions taken to achieve the purpose of the study, which includes designing, developing and integrating hardwares. The test performed are explained in details with the required LoRa parameters shown in equations and formulas.
- Chapter 4, Results and Discussion : presents all the results and analysis obtained with the discussion
- Chapter 5, Conclusion and Recommendations : conclude the study and stating recommendations for future work of the thesis

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes the studies that is related to this research which includes the concept of LoRa, Internet of Things, Wireless Sensor Networks, Low-Power Wide-Area technologies, LoRa communication protocol, IoT in healthcare application and LoRa application for health monitoring.

2.1 Internet of Things (IoT)

Over the previous decades, the presence of the industrial revolution has caused humans to evolve dramatically. The fourth industrial revolution is the era in which a new generation of wireless communication allows machines and objects to be connected everywhere (Osseiran, 2016). The IoT is a term that refers to physical devices that are connected to the internet, to collect and share data. According to Elkhodr et al., 2016, IoT is a rapidly growing global network of interconnected devices that uses a standard communication protocol to support multiple input-output computers, sensors, and actuators.

Over the past few years, there has been increasing awareness regarding the concept of IoT, which includes connecting the Internet to various objects that we encounter in our daily lives (Großwindhager et al., 2017). Today, it has become impossible to construct a smart city without incorporating this concept. The IoT integrates various sensors, artefacts, and smart nodes that can communicate with one another without the need for human intervention. It can make objects operate independently in conjunction with other objects. Furthermore, the IoT nodes can deliver data, access and authorize cloud-based tools for data capture and retrieval, and make decisions based on the information gathered (Badii et al., 2019).

IoT act as a tool for people to save money, energy and time. Based on Boboc & Cebuc, 2020 and Saxena, 2016, there are many advantages of using IoT, which can give a significant impact on individuals, society and even businesses on a daily basis;

- it can positively influence various aspects such as health, safety, financial, and many daily activities.
- it may become useful for the companies with the presence of physical devices that can conveniently communicate with people, such as monitoring inventory, location, employees.
- it can track its individual consumer’s behavior and identify key customers and their preferences based on information provided by the devices.

In this era, many technologies are in the development phase due to the potentialities of the IoT, which numbers of IoT applications are being implemented or developed in the community. This development of the IoT applications will help to improve our daily lives (Nordin et al., 2018). There are many applications of IoT that has been implemented in variety of industries which includes healthcare (Jimenez & Torres, 2016), environmental engineering (Alam et al., 2019), transportation (Zantalis et al., 2019), security (Xiao et al., 2018), smart agriculture (Kodali et al., 2018), connected vehicles (Kim et al., 2017) and environmental monitoring (Velásquez et al., 2017). The smart city, which can be defined as a city with smart technology, smart people, and smart collaboration, is one of the most well-known IoT applications (Meijer & Bolívar, 2016). In some IoT applications, the technology available is limited by low-power consumption requirements, the device's hardware capabilities and overall cost. When connecting to the Internet, many IoT devices need to use low-cost and low-power wireless technology (Want et al., 2015).

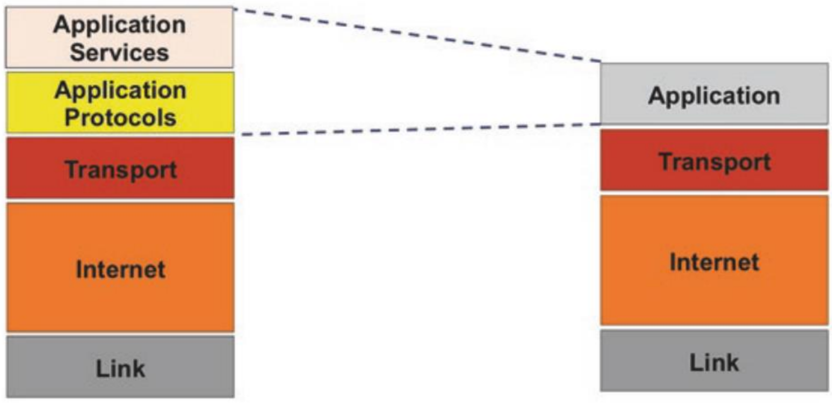

Figure 2.1 The IoT protocol stack (Rayes & Salam, 2019)

Current IoT technologies cover the entire protocol stack, from the physical layer to the application layer, as shown in Figure 2.1. The number of IoT devices is expected to be around 41.6 billion by 2025, generating 79.4 zettabytes, with an annual growth rate of 28.7% from 2018 to 2025 (MacGillivray, 2019). The exponential advancement of IoT technologies in recent years offers hope for a better and more convenient future, as every piece of technology currently in use will soon be connected to an always-on network of smart sensors and data feedback devices.

2.2 Concept of LoRa

2.2.1 LoRa Technology

LoRa, which stands for "Long Range" is a wireless technology that provides IoT applications with long-range, low power and secure data transmission. It is based on Chirp Spread Spectrum (CSS) radio modulation technique as a physical layer, which has low power characteristics such as Gaussian Frequency Shift Keying (GFSK) modulation but can be used for long-range communication (Gaitan, 2021). CSS is a technique that spreads out information by encoding it onto a chirped signal, where a linear frequency sweep is used to transmit messages. In addition, the CSS radio modulation technique makes it resilient and robust towards noise and interference signals such as multipath fading and doppler effects, which makes it difficult to be detected or jammed (Andreas et al., 2021; Gregorio et al., 2020;).

LoRa uses unlicensed Industrial, Scientific, and Medical (ISM) band frequencies under the order of sub-GHz, such as 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia (Hayati & Suryanegara, 2017; Mekki et al., 2019). It can connect sensors, gateways, computers, gadgets, livestock and many more wirelessly to the cloud. LoRa allows the usage of scalable bandwidths of 125kHz, 250kHz, and 500 kHz (Reynders et al., 2016). It utilizes star topology to broadcast signals between node and gateway. Each LoRa transmission is characterized by several customizable parameters such as the Spreading Factor (SF), the Code Rate (CR) and the Bandwidth (BW) (Leonardi et al., 2018).

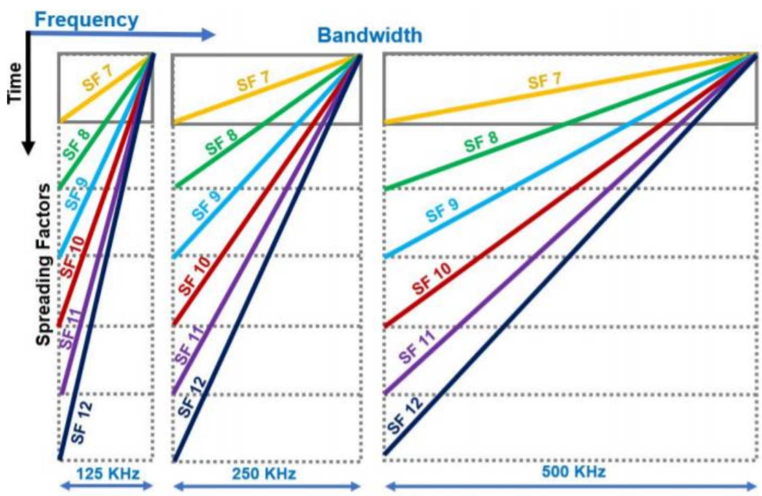

Figure 2.2 Different settings between SF and BW

LoRa communication can be divided into two; peer-to-peer (P2P) communication and network communication. For P2P communication, two LoRa devices communicate with each other using radio frequency signals without the help of central server or gateway. One LoRa device acts as a transmitter and the other as a receiver, or both LoRa devices act as transceivers.

For network communication, multiple LoRa node (end device) can be connected to multiple LoRa gateway, in which the data is sent to a network server via IP connection. Nowadays, more and more companies are using the IoT in markets such as agriculture, industries, or smart cities (Khan & Chen, 2019).

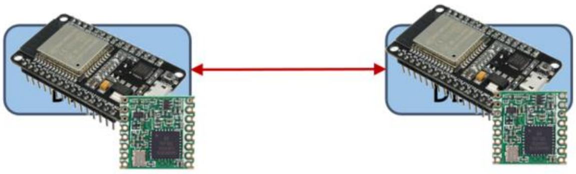

Figure 2.3 LoRa peer-to-peer communication

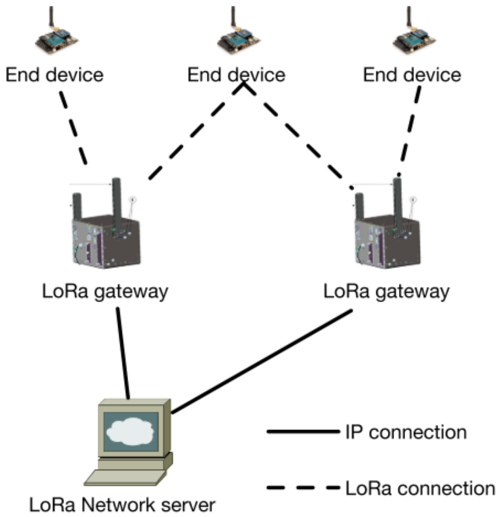

Figure 2.4 LoRa network architecture (Augustin et al., 2016)

LoRa is different compared to other short-range network sensor technologies. Comparing to short-range technologies such as Bluetooth, Wi-Fi, and Zigbee, LoRa is better suited for low-power IoT devices that transmit a small amount of data over a long distance. In addition, LoRa is more cost-effective due to its low hardware price and no need for subscription for service compared to cellular Machine-to-Machine (M2M) networks that are designed to cover a large area (Pan et al., 2012).

Figure 2.5 LoRa of IoT applications in different fields (Sharma, 2019)

Table 2.1 Comparison between LoRa and other communication protocol (Sheng et al., 2020)

Characteristics	Bluetooth	ZigBee	Wi-Fi	LoRa
Max. end-devices	255 (2 billion in BLE)	More than 64,000	Depends on number of IP address	More than 5000
Peak Current Consumption	30mA	30mA	100mA	17mA
Range	10m	10 to 100m	100m	More than 15km
Data Rate	1 Mbps	250kbps	11Mbps and 54 Mbps	290 bps to 50 kbps
Relative Cost	Low	Low	Medium	Low
Topology	Star	Star and Mesh	Star and point to point	Star
Transmission Technique	Frequency Hopping Spread Spectrum	Direct Spread Spectrum Sequence	Orthogonal Frequency Division Multiplexing	Chirp Spread Spectrum

Every LoRa communication consist of packet format. The LoRa packet is made up of three parts; the preamble, an optional header and the payload. The explicit header mode and the implicit header mode are the two types of LoRa packet format modes. The explicit header mode has a short header which consists of payload length, coding rate, and cyclic redundancy check (CRC). CRC is used to detect errors in digital data.

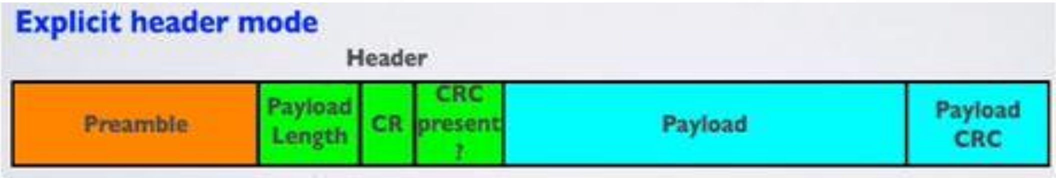

Figure 2.6 LoRa packet format explicit header mode (RF Wireless World, 2012)

The payload, coding rate, and CRC present are all fixed in the implicit header mode. Unlike explicit header mode, the header is removed from the packet in this mode, which reduces transmission time. Both sides of the LoRa transceiver must be manually configure for the payload length, coding rate, and present of payload CRC.

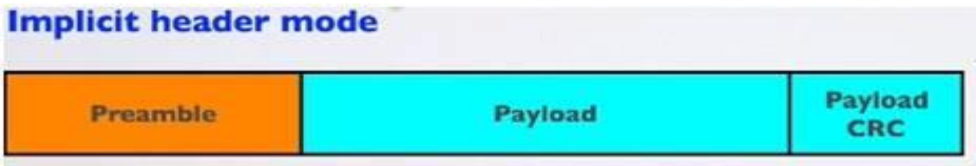

Figure 2.7 LoRa packet format implicit header mode (RF Wireless World, 2012)

2.2.2 WSNs Based on LoRaWAN

WSN is a set of wirelessly interconnected, spatially distributed computers that use sensors and actuators to analyses and interact with their surrounding environment (Tiete et al., 2017). WSNs are innovative networks made up of small, low-cost, low-energy sensors that sense, measure, observe, track, or monitor physical environmental phenomena such as temperature, pressure, wind, and humidity, and send the data wirelessly to a monitoring node for processing and analysis (Ala' Khalifeh et al., 2019). Figure 2.8 below shows the three characteristics of the WSN best performance triangle; range, data transmission rate, and power consumption of a WSN (Martinez et al., 2015).

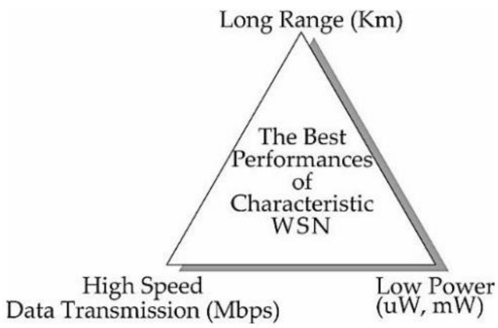

Figure 2.8 The best performances WSN characteristics (Prasetyo Adi & Kitagawa, 2020)

Sensor nodes are usually powered by batteries in most cases, so they will operate until the batteries are depleted, making the lifetime of a node very challenging due to its limited energy supply. According to (Darabkh et al., 2018; Ala Khalifeh et al., 2017), due to the limited power resources available to sensor nodes, energy consumption and interference reduction are two of the most challenging issues that long-life wireless sensor networks face. The nodes use a lot of energy during data transmission and during sensing, monitoring, and tracking applications (Goudos et al., 2017). Using efficient wireless technology is crucial for WSN deployment and operation. Thus, LPWAN technology provides great battery life for IoT-based sensor applications with only a small amount of data to send over a long distance (Kodali et al., 2018).

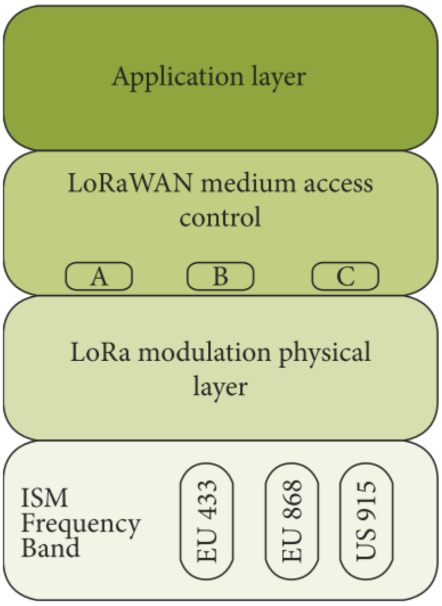

Figure 2.9 LoRaWAN communication protocol stack (Lavric, 2019).

From Figure 2.9, the ISM frequency bands and LoRa modulation is the LoRa physical layer, LoRaWAN medium access control is LoRa MAC layer followed by LoRa application layer. LoRaWAN is a low-power long-range wide area network wireless technology that is derived from LPWA. It is a wireless protocol that allows sensors to connect to the Internet while using the least amount of energy possible. The LoRaWAN architecture consists of sensors and gateway, which is meant to centralize and collect data received from various sensors. It can handle a high volume of messages per base station, allowing public network operators to serve their communities effectively (Lavric, 2019). Using LoRaWaN in urban environments, communication distance can reach in a range of 15 kilometers, and it can go longer in rural environments (Mikhaylov et al., 2017). The LoRa-Alliance has standardised LoRaWAN in 2015, and it is being implemented in more than 42 countries for its various mobile operators (LoRa Alliance, 2021).

LoRaWAN is the LoRa modulation's Medium Access Control (MAC) layer that can be divided into three types of communication classes; Class A, B, and C. Unless it is specifically configured to operate in Class B or C mode, a LoRa device is by default a Class A mode with power saving capabilities. The reception of packets is the major difference between the three class modes of operation. Each class have different latencies and can be used for different WSNs applications (Bankov et al., 2017; Cheong et al., 2017; Ala' Khalifeh et al., 2019)

- Class A (*bidirectional end-devices*): ALOHA-based protocol is the most basic type of LoRaWAN implemented in all LoRa chips and normally battery powered. End-nodes enable bidirectional communication by allowing two short windows for receiving downlink messages after each end-uplink device's transmission.
- Class B (*bidirectional end-devices with periodic receive slots*) : allows nodes to receive data signals from the Internet without sending requests, making it ideal for WSN monitoring and management. In response to the random receive windows of class A, the nodes open extra receive windows at specific intervals. For synchronisation between nodes in class B, the gateway sends beacon frames class B are normally battery powered.
- Class C (*bidirectional end-devices with maximal receive slots*) : this class of nodes has the shortest latency and consumes a lot of energy which makes it normally mains-powered. End-nodes keep receiving windows open all the time, closing them only when transmitting. This class is designed to send alerts and notifications in WSN applications.

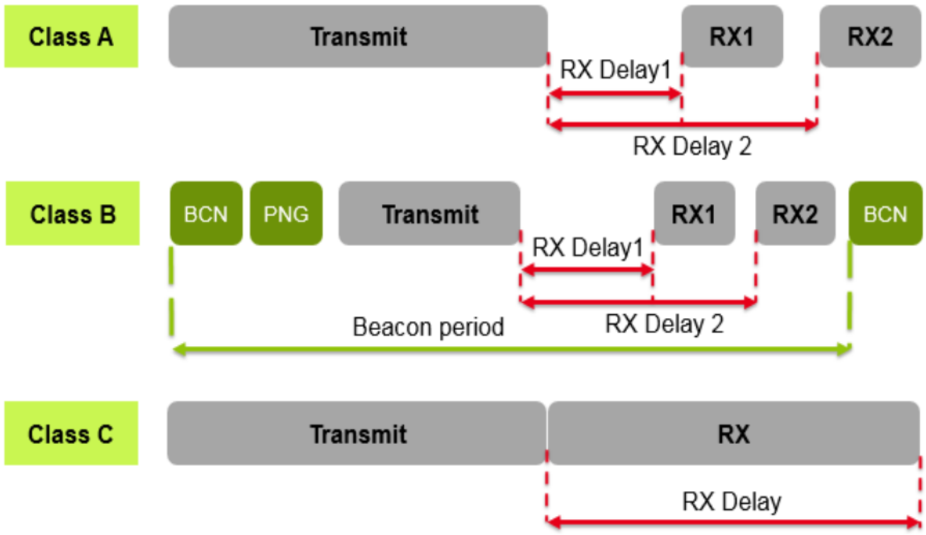

Figure 2.10 Different LoRaWAN classes (Bouguera et al., 2018)

LoRaWAN eliminates the need for repeaters between nodes due to its long-range communication capabilities, which will reduce node cost, increase the node battery life, and increase the network capacity, making it suitable for WSN applications (Mekki et al., 2018; Oratile et al., 2017). A complete LoRa network comprises of several components, including LoRa Node (end device), LoRa Gateway, LoRa Network Server and LoRa application server.

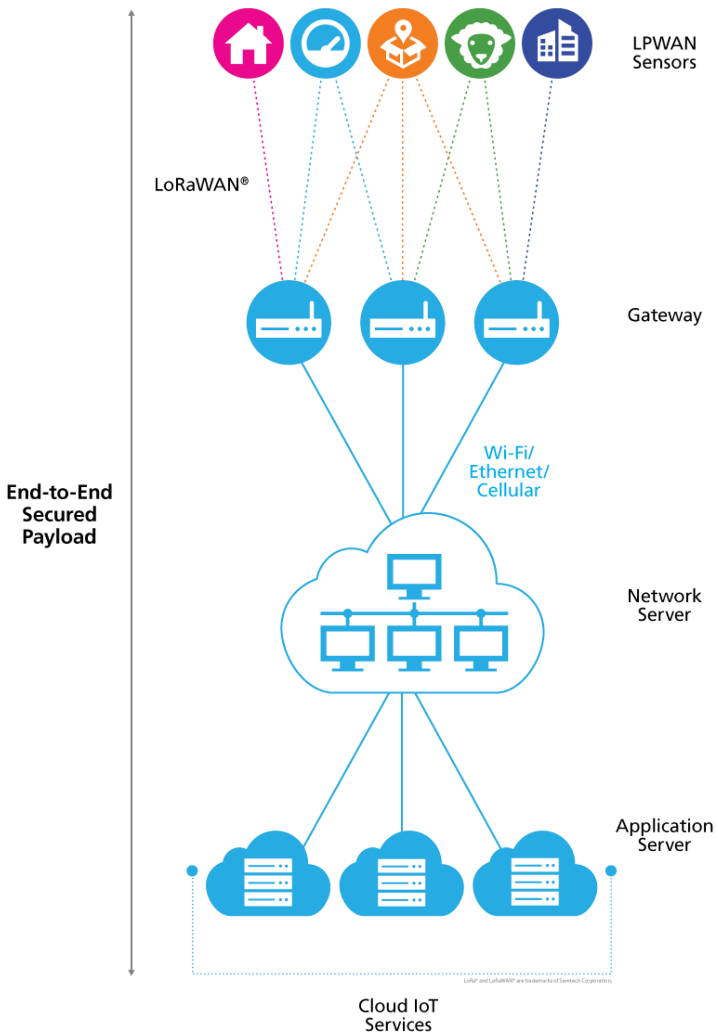

Figure 2.11 A complete LoRaWAN network architecture (LoRa Alliance, 2021)

2.2.3 Low-Power Wide-Area Network (LPWAN) Technologies

LoRa is a proprietary of Low-Power Wide-Area (LPWA) technology (Noreen et al., 2017). Low Power Wide Area Networks (LPWANs) is a term used to describe a group of wireless communication technologies that are used to support the deployment of Wireless Sensor Networks (WSNs) (Jebril et al., 2018). LPWAN is increasingly gaining popularity in industrial and research communities because of its low power, long-range, and low-cost communication characteristics. It provides long-range communication up to 10-40 km in rural zones and 1-5 km in urban zones (Pan et al., 2012). In addition, LPWAN is inexpensive (Raza et al., 2017) and highly energy efficient, with approximately more than ten years of battery lifetime (Patel & Won, 2017). These LPWAN technologies are not focused on enabling high data rates per device or minimising latency like 3G/4G or WiFi; rather the critical performance metrics are energy efficiency, scalability, and coverage (Song et al., 2017).

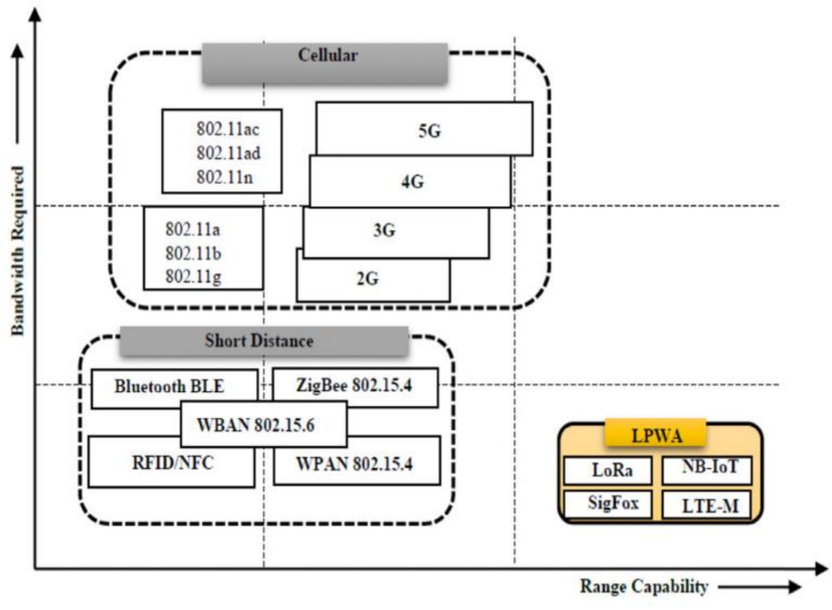

Figure 2.12 The required bandwidth vs. range capacity of short distance, cellular, and LPWA (Khan & Chen, 2019)

There are many types of WSNs, where the range and computational power are the key parameters, such as (Gaitan, 2021):

- High-range high-power include 2G, 3G, 4G, and 5G
- Low-range high-power include Ultra-wideband and WI-FI
- Low-range and low-power applications include Bluetooth, ZigBee, Near-Field Communication (NFC), and Bluetooth Low Energy (BLE)
- High-range low-power devices include LoRa, SigFox, LTE-M, and NB-IoT

Particularly, LPWA devices are expected to grow to 339 million by 2025 (Zhou et al., 2018). These LPWA technologies are targeting emerging applications and markets. It became one of the fastest growing areas in IoT as the IoT market grows rapidly. It has high range capabilities to transmit low-bandwidth data, as shown in Figure 2.12. LTE-M, SigFox, LoRa and narrow band (NB)-IoT are examples of LPWA technologies that have emerged in both licenced and unlicensed markets. Among these LPWA technologies, LoRa and NB-IoT are the two leading emergent technologies, which involve many technical differences (Lin et al., 2017). Table below shows the physical features between LoRa and NB-IoT.

Table 2.2 The physical features of LoRa and NB-IoT (Sinha et al., 2017)

Parameters	LoRa	NB-IoT
Spectrum	Unlicensed	Licensed LTE bandwidth
Modulation	CSS	QPSK
Bandwidth	125-500kHz	180kHz
Peak Data Rate	290 bps – 50 kbps (DL/UL)	DL: 234.7 kbps UL: 204.8kbps
Link Budget	154 dB	150 dB
Max. number of message/day	Unlimited	Unlimited
Duplex operation	-	Half duplex
Power Efficiency	Very High	Medium High
Mobility	Better than NB-IoT	No connected mobility (only idle mode selection)
Connection density	Utilized with NB-IoT	$1500 km^2$
Energy Efficiency	>10 years battery life of devices	>10 years battery life of devices
Spectrum Efficiency	Chirp SS CDMA better than FSK	Improved by standalone, in-band, guard band operation
Area Traffic Capacity	Depends on gateway type	40 devices household, ~55k devices per cell
Interference Immunity	Very High	Low
Peak current	32 mA	120-300mA
Sleep current	1μA	5μA
Standardization	De-facto Standard	3GPP Rel. 13 (planned)

NB-IoT networks require low latency and high data rate, while LoRa only require low latency and low data rate. The high data rate will require additional power, which makes the battery lifetime of the NB-IoT node is shorter than that in the LoRa node. Therefore, LoRa is more suitable for WSN applications that are insensitive to delay and do not need high data rates,while NB-IoT is more suited for WSN applications that require higher data rates transmission and low latency (Raza et al., 2017). Table 2.3 shows a comparison of technical specifications of LoRaWaN with other LPWA technologies.

Table 2.3 Technical specifications of LoRaWAN, Sigfox, NB-IoT and LTE-M technologies (Ala' Khalifeh et al., 2019)

	LoRaWAN	Sigfox	NB-IoT	LTE-M
Standard	LoRaWAN	Sigfox	3GPP	3GPP
Spectrum (MHz)	Unlicensed 868 in EU 915 in USA 433 in Asia	Unlicensed 868 in EU 915 in USA 433 in Asia	Licensed LTE frequency bands	Licensed LTE frequency bands
Tx Power (dBm)	13 in EU 20 in USA	14 in EU 21.5 in USA	23	23
Link Budget	154 dB	159 dB	151 dB	146 dB
Modulation	CSS	UL: DBPSK DL: GFSK	UL: GFSK DL: BPSK	UL: SC-FDMA, 16 QAM DL: OFDMA, 16 QAM
Channel Bandwidth (KHz)	125-500	0.6 in USA	180	1.4-20MHz
Max Payload (bytes)	243	Up: 12 Down: 8	1600	1000
Power Consumption	Very low	Low	Medium low	Medium
Battery Lifetime 2000mAH	105 months	150 months	90 months	18 months
Topology	Star of stars	Star	Star	Star
Security	AES CCM 128	Key generation, message encryption, sequence	NSA/AES 256	AES 256
Coverage (km)	~5 in urban ~20 in rural	~10 in urban ~40 in rural	~1 in urban ~10 in rural	~5
Max Data Rate	~50kbps in UL ~290bps in DL	~100bps in UL ~600bps in DL	~220kbps	Up to 1Mbps
Transmission Technique	FHSS(ALOHA)	UNB	FDD	FDD/TDD

2.3 IoT in Healthcare Application

Nowadays, healthcare is one of the biggest problems that every country faces. In developing countries, the healthcare sector is critical in reducing expenditures on chronic illnesses and disorders because health organizations are converting themselves into more effective, organised and user-centered programs (Misran et al., 2019). In the near future, IoT will become a more reliable healthcare system approach as an alternative. The IoT has various application domains in which IoT for healthcare is still at the top of the research because of its potentiality. According to Redondi et al., 2013, the major flaw in current patient monitoring, care, management, and supervision models is that the required operations are frequently performed manually by nursing staff, resulting in a de facto efficiency bottleneck.

According to Boboc & Cebuc, 2020, the primary goal of smart health programs is to reduce obstacles to monitor critical health parameters, improve the quality of life of individuals that require assistance, reduce health costs and provide adequate treatment at the right time. The uses of smart medical systems in the everyday life of people are; (1) to assist elderly that suffering from illnesses such as dementia, memory loss, Alzheimer's disease or to people with disabilities living alone by using sensors to monitor home activities or by sending reminders at which specific medications should be taken. (2) To remotely monitor patients with chronic diseases such as cardiovascular disease, diabetes to obtain reduced medical centre admissions. (Catarinucci et al., 2015) presented a smart hospital system that utilizes several IoT technologies to automatically monitor and track patients inside hospitals via Ultra-High-Frequency (UHF) Radio Frequency Identification (RFID) technology.

In order to overcome the health issues, the IoT provides a world of networked devices, cloud-based software and utilities, with numerous cooperation mechanisms based on the confluence of the proper standardization, reliable wireless protocols, upgraded sensors, low-power microprocessors, cheaper and wireless technologies (Fernandez & Pallis, 2014). The healthcare infrastructure based on the IoT is now at its peak due to its potentialities for all other IoT implementations. Supporting sensors integrated with IoT healthcare can effectively analyze and collect the physical health data of patients who have made healthcare based on IoT widely acceptable (Islam et al., 2019).

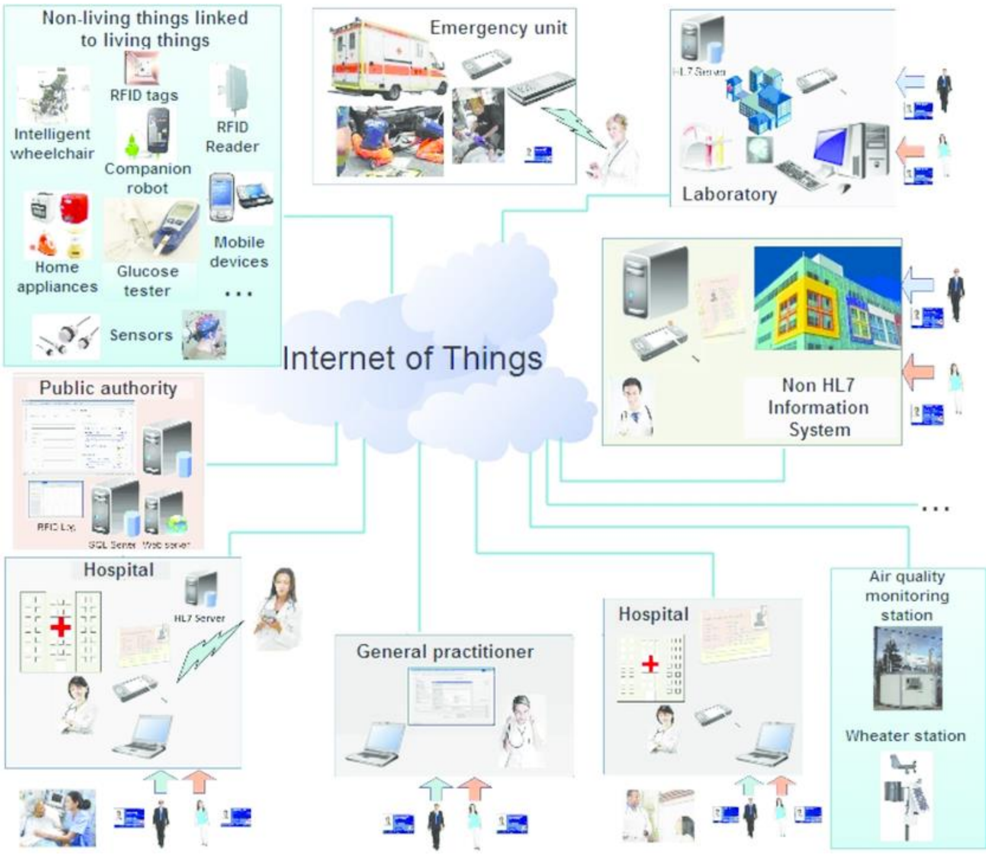

Figure 2.13 An IoT approach in healthcare (Turcu & Turcu, 2013)

In terms of smart healthcare, healthcare information and communication technologies will contribute to better treatment and disease surveillance for patients. However, the massive cost burden is a problem for the healthcare sector. Low cost and efficient LoRa network efficiency make it ideal for traditional smart healthcare applications. In addition, various biological information can be obtained by special sensors on the body and can be tested in real time (Zhou et al., 2018).

Diagnosing and monitoring patients by connecting to all available resources over the internet is the main idea to comply with an IoT-based healthcare system to perform all healthcare systems (Islam et al., 2019). Continuous and long-term healthcare services are now vital in the healthcare community to make the process involved more effective, reliable and to ensure patients' conditions by providing a complete medical care (Misran et al., 2019).

2.4 LoRa-based IoT to Monitor COVID-19 Patients

According to Lai et al., 2020, the spread of Coronavirus Disease (COVID-19) is due to Severe Acute Respiratory Syndrome Coronavirus 2 (SARSCoV-2) virus, which has caused dramatic changes in community lifestyles all over the world. Over twenty million positive cases had been reported by mid-August 2020, affecting over 180 countries and result in over 750,000 deaths worldwide (Jang et al., 2020). There are at least three ways SARS-CoV-2 may be transmitted to humans, first is via inhalation of liquid droplets produced by an infected person. Second is via close contact with the infected person, and the third is in contact with surfaces contaminated with SARS-CoV-2, while aerosol transmission of SARS-CoV-2 has been shown in confined spaces (Liu et al., 2020).

Since the SARS-CoV-2 is highly contagious as shown in Lotfi et al., 2020, the frontline healthcare workers are at extremely high risk of SARS-CoV-2 infection, with at least a fivefold increased risk of reporting a positive COVID-19 test and predicted COVID-19 infection when compared to the general community (Nguyen et al., 2020). A study from Mdhaffar et al., 2017 has proposed three steps to monitor patients with the use of LoRa in the medical field; gathering patient's physical metrics from the medical sensors, transmitting data through the LoRa sensors and gateway, and sending data to the cloud for further analysis of medical records.

According to Quaresima & Ferrari, 2020, fingertip pulse oximeters are one of the most commonly used and effective medical standard monitoring instruments for determining patients' oxygen status. A pulse oximeter is a non-invasive device that can be used by patients, doctors, and healthcare providers to determine arterial blood oxygen saturation in percentage. Furthermore, a study from Bergese et al., 2017 suggests that pulse oximeter is helpful to monitor pulse oximetry by providing continuous respiratory rate measurements. Thus, integrating the pulse oximeter sensor with the LoRa technology to implement in this healthcare field will be helpful in monitoring COVID-19 patients.