LORA BASED COMMUNICATION SYSTEM FOR RADIOSONDE APPLICATIONS

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Abstract

LoRa technology is a low-cost, low bitrate and low-power method of communication based on the chirp spread spectrum modulation technique. The long-range, wide-band characteristic makes the technology an effective method for internet of things network communication.

This thesis sets out to explore the possibility of utilizing LoRa for significantly longer range transmission, specifically for weather balloon air-to-ground communication. To achieve this, the analysis of previously published literature and several transmission tests, ranging from short to long-range, are to be conducted to establish the optimal configuration that results in the maximum transmission range that LoRa technology is capable of. The effects of compression and weather balloon tracking are also to be investigated. Finally, the relevance of utilizing LoRa technology for the specific application is concluded at the end of the thesis.

Acknowledgments

This thesis and project could not have been completed without the support and encouragement of several individuals. I wish to thank these people for their efforts and belief in myself throughout the duration of this project.

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Nomenclature

APRS Automatic Position Reporting System. 14

BW Bandwidth. vii–ix, 8, 9, 12, 17, 21, 27, 35–42, 44–46

CAD Computer-Aided Design. vii, 31

Chip A chip also known as a symbol is a small component of a frequency shifted signal, multiple chips form a chirp where the number depends on the spreading factor with larger spreading factors allowing more chips to produce a chirp pulse. 17, 20, 21, 45, 46

CR Coding Rate. vii, 8, 9, 21, 27, 35, 39, 40, 42, 44, 46

CRC Cyclic Redundancy Check. 18–20

CSS Chirp Spread Spectrum is a technique that utilizes wide-band linear frequency modulated chirps to encode information. 7, 17

dBm Decibels per Milliwatt. 21

Down-Chirp A Down-Chirp is a signal in the shape of a ramp in which the frequency decreases from the highest frequency to the lowest frequency in a particular bandwidth. 17, 19

Fresnel Zone Fresnel Zone, is an ellipsoidal region in space beginning at the transmitter and ending at the receiver. Obstacles with in the region have the greatest attenuating effect on signal propagation. 22, 29, 36, 38, 47

FSK Frequency Shift Keying (FSK), is a frequency modulation technique where digital information is transmitted by modifying the discrete frequency of a carrier signal. 2, 7

FSO Free Space Optics. 13

GFSK Gaussian Frequency Shift Keying (GFSK), is a variant of FSK modulation where a Gaussian filter is used to shape the signal pulses prior to modulation. 2

GPS Global Positioning System. 30–32, 43

Huffman Encoding Huffman Encoding is a lossless compression technique that reduces the overall size of data by identifying symbols that are used frequently. The symbol is then only referenced once in the data and the remaining symbol locations are recorded to allow for reconstruction upon decoding the message. 33

IoT Internet of Things. 8, 14, 18, 49

LoRa Long Range point to point communication. i, vii, 1–5, 7–21, 23–27, 29–36, 38, 39, 43–47, 49–51

LoRaWAN Short for Long Range Wide Area Network, is a media access control layer protocol, formulating the LoRa cloud creation infrastructure. 11, 15, 18

MAC Media Access Control. 20

MIC Message Integrity Code. 20

NOAA National Oceanic and Atmospheric Administration. 22, 27, 29, 42

PRR Packet Reception Rate. 9

PSK Phase Shift-Keying or PSK is a digital modulation process which represents data by modulating the phase of a constant frequency reference signal. 2

RSSI Received Signal Strength Indicator. ix, 10, 27–29, 33–38, 42, 43, 45, 47

SF Spreading Factor. vii, 8, 9, 20, 27, 38–44, 46

TP Transmission Power. 9, 46

Up-Chirp An Up-Chirp is a signal in the shape of a ramp in which the frequency increases from the lowest frequency to the highest frequency in a particular bandwidth. 17, 19

Chapter 1

Introduction

This thesis report details the investigation and the implementation for the communication of radiosonde data by means of the LoRa based spread spectrum technique. The focus was on the practicality and relevance of utilizing the LoRa technology for this particular application. The project involved the investigation of LoRa technology and the associated transmission parameters. Once an understanding of LoRa has been established, the implementation and optimisation of a point-to-point LoRa communication system is to be designed, to determine the possibility of real-world usage of the technology for weather balloon air-to-ground communication over long distances. This chapter outlines the thesis and delves deeper into the inspiration for this project.

1.1 Motivation

The measurement of atmospheric data requires that the telemetry device be deployed at high altitudes that can be done so by means of uncontrolled weather balloons or dropped from aerial vehicles at high altitudes. A consequence of both the deployment methods is that once measurements have been taken, the equipment falls back to the ground and usually lands in difficult to reach areas. Retrieval of the radiosonde modules are therefore usually written off after single use. This makes the atmospheric measurement task significantly more expensive given the high frequency that radiosonde modules are deployed across the globe. The radiosonde sensor module, being the telemetry device, and the power source are standardised and therefore cannot be altered. The only remaining component would be the communication hardware, that can be altered to reduce costs and weight. LoRa technology offers a cost effective, lightweight and low-power solution for the task if the technology can be implemented successfully. The goal of this thesis is to demonstrate if the LoRa technology can be used for radiosonde transmission applications.

1.2 Problem Statement

The current methods used in radiosonde applications for data communication, involves a proprietary Radio Frequency transmission method adaptation of either Frequency Shift-Keying (FSK), Gaussian Frequency Shift-Keying (GFSK) or Phase Shift-Keying (PSK) radio transmission techniques depending on the country that the telemetry device was purchased in. These methods of communication have to be optimized around the low-power, weight and cost constraints. These constraints mean that data resolution needs to be reduced to an extent and specialized equipment needs to be designed and manufactured for both the transmitter and receiver nodes. LoRa has an advantage over these methods by meeting all the requirements, with the current existence of cost-effective and commercially available modules developed by industry but have not yet been proved to successfully meet the required constraints at long distances.

1.3 Objectives

The broad objective of this project was to establish the extent to which LoRa technology can be used for long range radiosonde communication applications. This was to be achieved by implementing existing LoRa modules, testing the range capabilities and validating the transmitted data integrity at various distances. The main objective can be broken down into smaller objectives, with the first being the exploration and optimisation of the communication parameters that result in the best range. Then, to determine the effect of data compression and whether it is advantageous for the communication method. Finally, to determine the effect that balloon tracking, of the transmitter via the receiver, has on the range, height and the signal strength.

1.4 System Requirements

For the LoRa communication system to be deemed successful for usage of weather balloon communication, the system would need to achieve the following requirements as stated by the specification sheet for the project:

- Transmission bitrate of 1200 to 4800 bps
- Transmission Range of at least 100 km
- Transmission Altitude of at most 35 to 38 km
- Operation of system in environment temperatures greater than -90 °C

1.5 Scope and Limitations

The scope of this project was centred around utilizing existing LoRa modules, one for data transmission and a second for data received, to communicate actual atmospheric data across long distances. That involved an in-depth analysis of the LoRa protocol, specifically the parameters and the relationships dependant on signal transmission range. This was done using two commercially available LoRa modules being the ESP32 based LILYGO TTGO LoRa32 at 868 MHz [1] and the Dragino LoRa Shield at 433 MHz [2]. The modules transmission performance was then to be validated on the ground and air and under different weather conditions. The relevance of compression prior to transmission and the need for a transmitter tracking system were to be investigated.

During the investigation and execution, several limitations were experienced. The first limitation was that procuring a weather balloon was not possible due to current Covid pandemic circumstances and an actual flight was excluded from the scope. Tests had to be supplemented to simulate flight conditions of a weather balloon. A consequence of the first limitation was that a drone was utilized to mimic the flight of a weather balloon, the maximum height and range achievable by the drone were restricted to the physical limits of the drone as well as the wind conditions during testing that restricted altitude to prevent damage to the drone. The second limitation was the carrier frequency available for use that are restricted by law depending on the region. This project was limited to Cape Town South Africa, where the available unlicensed frequencies for LoRa are 433 MHz and 868 MHz. The third limitation were the weather conditions at the testing location, that were limited to the conditions experienced in Cape Town, South Africa.

The above limitations meant that not all system requirements were achievable specifically the height and range requirements. The requirements and scope were amended to a maximum transmission height of 500 [m] and a distance of 20 [km]. Secondly the utilization of existing LoRa modules meant that the temperature requirement was enforced and rated by the manufacturer and therefore testing of operating temperature was omitted from the project.

1.6 Thesis Outline

The remainder of this thesis is organized into various chapters beginning with Chapter 2. This chapter outlines the background and literature review surrounding the project. The next chapter, being Chapter 3, explores the LoRa standard and typical conditions, heights and travel trajectories experienced during weather balloons flights. Chapter 4 utilizes the findings of Chapter 3 and suggests the testing methodology for the project. Chapter 5 provides the experimental results and offers an analysis and trends observed from conducting the various tests. Finally, chapter 6 concludes the project and suggests potential future work to be completed at a later stage.

Chapter 2

Literature Review

2.1 Background

Atmospheric data consists of temperature, pressure, humidity, wind direction and speed. The data is vital for both short-term and long-term weather pattern prediction and the establishment of future pattern recognition. In some special cases, parameters such as radiation and gas emission concentrations are measured in the upper atmosphere to assess the effects of human activities, most prominently done in the Russia Federation as stated by Ivanov and Malygin [3]. The Russian Federation industrial sector produces immense amounts of greenhouse emission and knowing what the emission levels are, can be influential to reducing their overall environmental impact. The United State of America is another prominent user of weather balloons that releases 92 balloons twice a day across the country. To measure the data, a telemetry device known as a radiosonde consisting of various sensors that measure each variable are built into the device. The selection of sensors can vary with one such implementation designed and explained by three individuals from the Philippines named Raymart B. Balakit, Febus Reidj G. Cruz, May Anne C. Valencia [4]. Their telemetry device that was designed utilized a RFM96W radio frequency transmitter that utilizes the FSK modulation technique. However, many commercial radiosonde devices are available and used for atmospheric analysis. The device must then be deployed into the atmosphere by means of a latex or synthetic rubber weather balloon. The weather balloon allows for the device to reach the upper atmosphere in the most energy and cost-efficient manner. Measurements are taken periodically as the balloon rises that are transmitted by a radio transmitter to a ground station. This section is to establish the level of current understanding of LoRa, competing technologies and how LoRa fits in the available technology hierarchy and existing implementations of LoRa and LoRa networks that have been investigated and published by previous academics.

2.2 LoRa Origins

LoRa technology is based on the spread spectrum radio modulation method of transmission that utilizes the chirp spread spectrum (CSS) technique. The technique was developed in the city of Grenoble, in southern France, by a company named Cycleo in 2009 as published in this article written by Saucier later that year [5]. Cycleo is in the intellectual property and design solutions industry for wireless technology in existence even today. The company has been committed to developing long range, low power wireless technology which led to the development of the LoRa technique. The potential for the technology, was later noticed by Semtech Corporations that acquired the rights to Cycleo and the LoRa technology in 2012 again published by the French journalist Saucier [6].

Semtech has since improved upon the technology through its subsidiary Cycleo and produces commercially available LoRa modules known as the SX1270 series and having recently introduced a larger parameter configuration option for the technology into the market, as the SX1260 series. With the popularity of IoT devices around the globe, LoRa is becoming a easy option to satisfy one's communication needs.

2.3 LoRa Technology Theory Overview

2.3.1 LoRa Parameter Configuration

The behaviour of LoRa transmission has been shown to have a direct effect on the parameters set during module configuration. Umber Noreen, Ahcène Bounceur and Laurent Clavier from the University of Western Brittany, have explored and outlined the relationships between the fundamental parameters: Coding Rate (CR), Bandwidth (BW) and Spreading Factor (SF), and the effect on the data rate and transmission time that can be referred to here: [7]. These three scholars observed that any alteration to the parameters whereby there was an increase of either the CR or SF, resulted in an overall reduction in the data rate. On the other hand, an increase in the BW produced an increase in the data rate. The BW is however limited to the physics surrounding the technology where LoRa hardware has a physical limit of 500 KHz.

They then went on to develop the effects of transmission time resulting in the following relationship:

$$T_{packets} = T_{preamble} + T_{payload} \tag{2.1}$$

Where:

T_{packet} = Transmission time of a packet

$T_{preamble}$ = Time of initial standard chirp sequence

$T_{payload}$ = Time of dynamic data chirp sequence

In Equation 2.1, only the payload time term was shown to depend on all three parameters more so on the SF. They further determined that the higher the CR or SF, the longer the time on air, the opposite was observed for the BW.

With the establishment of LoRa transmission parameters, the question arises as to how to select the necessary parameters for a project's communication requirements, specifically concerning the transmission range, energy consumption and resilience to interference. This led to an interesting method derived by Martin Bor and Utz Roedig, that suggests an algorithm to use a fixed number of network nodes to select an optimum parameter configuration in a LoRa star network [8]. A short explanation of the algorithm requires a base configuration to be selected in the following format shown in Equation 2.2:

$$S_m = [SF_m, BW_m, CR_m, TP_m] \tag{2.2}$$

Then the selection of an ideal Packet Reception rate (PRR) threshold, that describes the ideal network characteristics as a numeric value, that is used as the metric for the algorithm. Whereby, any configuration setting below the PRR is deemed unusable for the network. The algorithm then increments the parameters in Equation 2.2 to form a new configuration shown in Equation 2.3:

$$S_t = [SF_t, BW_t, CR_t, TP_t] \tag{2.3}$$

The PRR of Equation 2.3 is determined, if higher than the required PRR, then:

$$S_t = S_m \tag{2.4}$$

If the PRR is not, then the next incrementation is considered. The Number of incrementations, N, selected to execute the algorithm, has a larger effect on the achievable result and depends on the network, that Martin Bor and Utz Roedig explores further in their paper [8].

2.3.2 LoRa Range

LoRa specifically means long range however the actual distance depends on various factors. Madoune R. Seye, Bassirou Ngom, Bamba Gueye and Moussa Diallo, located in Senegal, set out to determine the effective range in an urban city environment. The four individuals were successfully able to establish the maximum range of ground-to-ground transmission. Their data was measured in the city of Dakar. Their measurements were taken at 2 [km] intervals in the dense city area as shown by the coverage area in Figure 2.1. The achievable RSSI as a result of the city structure obstacles are shown in the map highlighted in the Figure that were transmitted from the Monument de la Renaissance Base Station.

Figure 2.1: Coverage range from Monument de la Renaissance Base Station taken from [7]

The packet loss (PL) ratio increases the further the distance from the base station, up to a maximum of 10 [km], whereby no packets were received. The loss in signal was observed to be from interference, due to the urban structures outlined in [9]. They further managed to derive a path loss model using their data as Equation 2.5, where PTx is the Isotropic Radiated Power and Grx is the Receiver Antenna Gain.

$$PL = |RSSI| + SNR + PTx + Grx \tag{2.5}$$

The model however does not take into account obstacles given the difficulties to derive a general mathematical expression to describe the shape of an obstacle.

2.3.3 Interference Susceptibility

Another major aspect that LoRa advertises is significant immunity against signal and noise interference. This claim has been shown to be true to a greater extent as Madoune R. Seye, Bassirou Ngom, Bamba Gueye and Moussa Diallo furth has shown in the validation of LoRa communication range in the previous LoRa Range sub-section. They observed that structures in proximity, as is found in most cities, results in signal attenuation, the further the receiver is from the transmitter. Therefore, LoRa is still able to achieve obstacle penetration but only up to a specific point depending on the type of obstacles located in the transmission region. The range determined by them of 10 km exceeds the claim made by Semtech that stated a max range of 330 m in concrete urban city environments stated here [10].

Apart from physical obstacle interference, Brody Dunlop, Ha H. Nguyen, R. Barton and J. Henry have observed the presence of cross LoRa interference between signals with similar parameter settings. They determined that cross signal interference causes significant errors as explained in [11]. The error further increases as the number of signals present is increased. Cross signal interference was observed to be most prevalent in LoRaWAN implementations. LoRaWAN networks consists of public network nodes that can receive multiple LoRa signals with different signal parameters simultaneously.

To handle the cross-signal interference, several methods have been explored. Nancy El Rachkidy, Alexandre Guitton and Megumi Kaneko have investigated two such methods explained in their thesis [12]. The first method enforced a small desynchronization between node transmission therefore minimizing any chance of signals being transmitted simultaneously. This would however require that every device on the network collaborates to maintain a time gap to enforce the desynchronization. The second method involved only decoding a single signal in the event of a cross interference. The team found that even if more than two signals interfered, isolating one and ignoring the remainder, allows for the full decomposition of the isolated signal. This however means that the remaining signals will be rendered void and would have to be re-transmitted at another time.

2.4 Competing Communication Technologies

There are several other existing technologies that can compete and exceed LoRa transmission performance. This section explores some of these and shows how LoRa fits amongst the technologies. A common characteristic shared by competing technologies is the low-power usage that were further investigated by Umber Noreen, Ahcène Bounceur and Laurent Clavier mentioned in the previous section [7]. Briefly summarised, they found these technologies to be similar:

– **Bluetooth:** Bluetooth technology is an IEEE standard 802.15.1, that uses a frequency of 2.4 GHz with a BW of up to 1 MHz and a data rate up to 1 Mb/s. The technology is based on the Frequency Hoping Spread Spectrum technique with the most recent variant being Bluetooth 4.0 that is even more energy efficient. The technology is utilized in master-slave point-to-point network applications that can process all types of data. A major downfall is the achievable range that is limited to only a few meters.

- **Zigbee:** Zigbee is an IEEE standard 802.15.4, based on the Direct Spread Spectrum Sequence modulation technique and can transmit at 250 kbps at an operating frequency of 2.4 GHz. This low-power technology is defined in the application network layer and is most often utilized in star and point-to-point topologies. Zigbee is similar to LoRa in also being low-cost and resistance to noise interference across short-ranges.
- **Wi-Fi:** is an IEEE standard 802.11, that offers significantly higher data rates used most commonly in Land Area Networks. The technology operates at several frequencies being 900 MHz, 2.4 GHz, 3.6 GHz, 5 GHz and 60 GHz with 2.4 GHz being the most commonly used. Wi-Fi can be used for network centered and data-centered networks that offers data rates of between 11 Mbps to 54 Mbps across a 100 m range.
- **Sigfox:** Sigfox is a more focused technology that operates in narrowbands and even ultra narrowbands that is used for radio transmission. The technology is used to receive and anaylse smaller spectrum signals with in larger transmission signals that may contain noise allowing for greater resolutions after data decoding. The technology is based on the Binary Phase Shift Key modulation method that utilizes unlicensed frequency bands. A shortfall of the technology is that a more expensive and complex base station is required to govern the network.

Another notable technology was tested and published in a collaborated paper being Radio Frequency Free Space Optics (FSO) communication cited at [13]. The numerous scholars tested the technology at the carrier frequency of 40 GHz under various severe weather conditions for air-to-ground communication at much higher data rates than even Wi-Fi. The technology is utilized by aerial unmanned drone vehicles where range and weather penetration is essential similar to the requirement of weather balloon transmission. The weather conditions that were tested are dense fog, severe rain and snow. Their tested determined that at the operating frequency, an average of 20 dB/km attenuation was experienced under the conditions at distances greater than 50 km. Their data showed significant promise to achieve extreme long-range communication even when line of sight is not present. A major downfall however was that to achieve optimal transmission ranges, significant power is required by the technology to achieve successful transmission both when in and not in severe weather.

2.5 Common LoRa Implementations

The smaller bitrate constraint of LoRa limits the usage of the technology for real world applications, however the low power nature makes the technology ideal for IoT communication. The most influential application has been implemented in the farming industry where lower bitrates are acceptable. Several students in Seoul South Korea have assessed the usage of LoRa for this application against competing technology specifically APRS outlined in a paper they published [14]. They were successful in implementing both technologies in a farm environment used to monitor crop growth. Upon comparison of the two technologies, LoRa proved to transmit further to a range of 4.2 km while APRS only transmitted to a range of 0.84 km with a receiver antenna gain of 6 dBi. The LoRa implementation also proved to be more feasible than the APRS implementation.

A second LoRa implementation was performed by May Anne C. Valencia , Febus

Reidj G. Cruz and Raymart B. Balakit from the University of Mapua in Manila, Philippines. They designed and implemented a LoRa transmission system for weather balloon applications described here [15] similar to this thesis. They utilized the RFM96W transceiver module at an operating frequency of 433 MHz to successfully transmit data using a weather balloon, to an altitude of 10 km and a distance of 10.1 km. Their system was further tested in temperatures of -40 °C to 30 °C and was optimized around weight and power usage. It should also be noted that a world record exists for the longest LoRa implementations being an astounding 832 km using only 25 mW [16]. The record was set by Thomas Telkamp, CTO and co-founder of Lacuna Space that was presented live in The Things Virtual Conference. The record was also set utilizing a weather balloon launched in the Netherlands, with a flight time of 4 hr and 25 minutes, and LoRaWAN receiver network nodes that received the data.

2.6 Literature Critique

The current literature that has been published on LoRa explores the technology adequately enough to validate the performance of the technology as shown in this chapter. Clear relationships of parameters and how they affect transmission has been established. There are also optimization methods derived on how to select and implement the best LoRa implementation for ones needs. A noteworthy downfall is that much of the research is isolated to short range applications and analysis. The only exceptions were the long-range weather balloon implementation done in the Philippines. This shows the potential for further research on the long-range applications of the technology in the future. There are also several low and high power methods of communication that can satisfy communication needs for weather balloon applications. LoRa however is closer to the more low-power and low-birate options such as Zigbee that have also not been tested over long ranges. The focus of LoRa literature also seems to be more focused on network communication rather than point-to-point communication further suggesting a future for potential future work from other academics.

Chapter 3

LoRa Standard and Weather Balloon Environment

3.1 LoRa Protocol

LoRa is a spread spectrum radio modulation technique based on the chirp spread spectrum (CSS) method that uses wide-band linear frequency modulated chirps, where a chirp is a signal that increases or decreases with time. The CSS technique is a method of transmission that generates frequency modulated chirp signals as either an Up-Chirp signal shown in Figure 3.1 as the positive gradient chirps or Down-Chirp signal shown in Figure 3.1 as the negative gradient chirps. Data is encoded as multiple Chip's that form a single chirp. This is done by varying the frequency of a signal while maintaining the phase as shown in Figure 3.1 if looked at from left-to-right where Up-Chirp's and Down-Chirp's are combined across the BW to encode the message. LoRa utilizes CSS across the entire available bandwidth which makes transmission signals more resistant to channel noise, fade and Doppler effects.

The main features of the modulation technique are the long-range and low-power

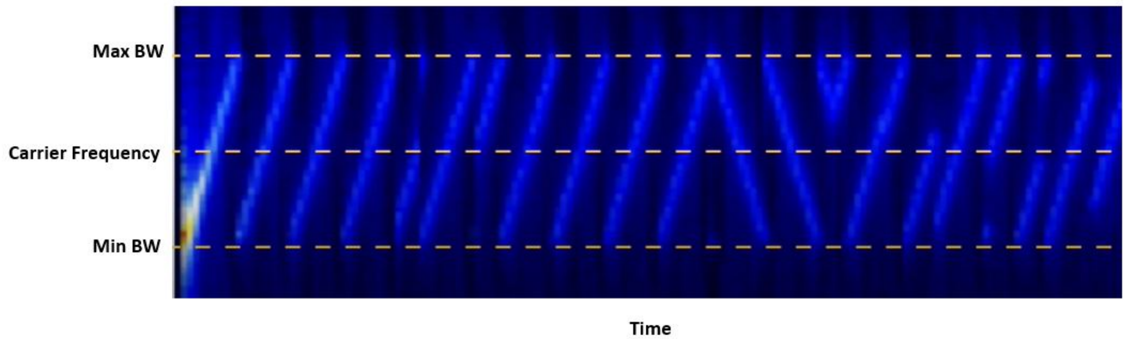


Figure 3.1: Example LoRa message seen at 433 MHz using an SDR

characteristics, that allows data to be transmitted at lower bitrates compared to other radio communication technologies. These key features have made LoRa communication popular for Internet of Things (IoT) applications. This has led to the development of LoRaWAN, which is a free public star network that is linked to the internet allowing for (IoT) devices to communicate directly with cloud networks. This thesis however only focuses on LoRa technology and excludes LoRaWAN. When utilizing LoRa with out a LoRaWAN receiver module, the transmission signal parameters need to be pre-configured at both the transmission and receiver nodes for successful transmission to occur. This chapter outlines the transmission parameters for the technique as well as conditions and the operating environment experienced during weather balloon flights.

3.2 LoRa Packet Structure

LoRa transmission requires that data be encoded in packets and allows a maximum packet size of 256-bytes. Every packet consists of at most four parts in order of the Preamble, Header, Payload and Cyclic Redundancy Check (CRC) as shown in Figure 3.2.

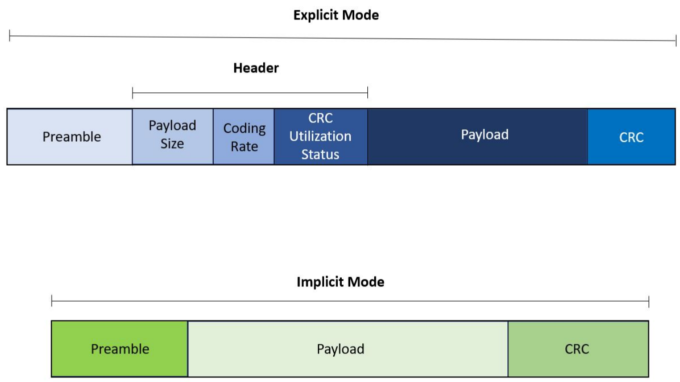


Figure 3.2: LoRa Packet structure for both Header modes

3.2.1 Packet Parameters

The packet contents are outlined below:

1. **Preamble:** the preamble is used to synchronize the receiver to match the data flow of the signal. The default preamble is a fixed pattern consisting of ten Up-Chirp's and two Down-Chirp's. The pattern length can be altered if configured at both the transmission and receiver end to allow for more bytes to be dedicated for the payload. The default pattern is shown in the first twelve chirps beginning from the left in Figure 3.1.

2. **Header:** The Header contains the parameter settings of the packet. The first parameter of the Header is the payload byte size, followed by the coding rate and ending with a single byte variable indicating if CRC is utilized. The Header is not essential and is only present if in Explicit mode. This mode allows for the optimization of LoRa and is used in this project. If set to the Implicit mode, then the parameters are fixed with the CRC parameter present. Adding the Header reduces the number of bytes available for the payload. The mode packet structure is further shown in Figure 3.2.

3. **Payload:** The payload contains the data intended to be transmitted. The

payload consists of a minimum of 2-bytes to a maximum of 255-bytes depending on the Header mode and the size of the data being sent. The Payload part is further broken down into the MAC header that contains specifics describing the data, the MAC payload that houses the actual data and finally the MIC that is a digital signature of the payload that prevents tampering or alteration of the data.

4. **Cyclic Redundancy Check:** CRC is a technique used for error checking where by a fixed number of bits known as a checksum are added to the end of the message. When the message is received, the bits are compared to the known pattern of bits to determine if any errors or losses occurred during transmission. This further reduces available bytes for payload if present in the packet.

3.3 LoRa Parameters

3.3.1 Spreading Factor

The Spreading Factor (SF) is a numeric variable between 7 and 12 inclusive, that dictates the number of Chip's or symbols, that is equivalent to 2^{SF}, that is used to formulate and encode data in a chirp pulse. Newer LoRa modules have a spreading factor beginning at 6. The higher the SF, the longer the time on air, the lower the bitrate and the greater the achievable transmission range.

3.3.2 Carrier Frequency

The carrier frequency is the specific frequency that is modulated to transmit a radio signal. LoRa technology makes use of unlicensed, free sub-Gigahertz frequency bands. That means that the carrier frequency would differ between regions depending on what unlicensed frequencies are available. The available frequencies are restricted by the law of the region. The carrier frequencies allocated for LoRa transmission are 915 [MHz], 868 [MHz] and 433 [MHz].

3.3.3 Bandwidth

The bandwidth (BW) is the difference between the upper and lower frequencies within a continuous frequency band, centered around the carrier frequency. The low-power design of LoRa limits the BW to a maximum of 500 [KHz], that directly affects the achievable bitrate. LoRa is different to most modulation techniques as the entire BW is used for transmission.

3.3.4 Transmission Power

The transmission power is the magnitude at the output of the transmitter power amplifier, that is connected to an antenna, generated by a radio hardware module. It is a representation of the rate of energy usage. The magnitude is measured in Decibels per Milliwatt (dBm) with higher power rates producing longer transmission ranges. The transmission power is limited by the hardware with most LoRa modules reaching a maximum of 20 dBm.

3.3.5 Coding Rate

The coding rate (CR) can be set to 4/5, 4/6, 4/7 or 4/8. The magnitude of the denominator is the number of transmission bits that encode every 4 bits of useful data. The addition of the extra bits effectively increases the size. The number of transmission bits increases the transmission time per Chip as a result of the additional bits which effectively increases the data accuracy. A downside is that increasing the CR decreases the bitrate of useful data.

3.4 Weather Balloon Environment

An average weather balloon flight involves a latex or rubber balloon filled with either hydrogen or helium that carries the payload containing the radiosonde and radio communication module that would measure atmospheric conditions at regular intervals during the flight. Flights occur frequently, up to twice a day, across the globe that measure temperature, pressure, humidity, wind speed and cosmic data at different altitudes. Helium and Hydrogen are both less dense than air and this difference in densities, propels the weather balloon vertically into the path of wind currents that propels the balloon horizontally. Heights of approximately 40 km can be reached, to a distance of 190 km over a span of approximately 2 hours before the densities between mediums equalize and the balloon fails beginning its decent to the surface. If the radiosonde happens to be retrieved at a later period after crashing, the device can be reused, however is not common practice. The driving forces that influence the balloons movement means that balloons can travel in any direction entirely dependant on the weather conditions at the time. Previous radiosonde data that was measured by NOAA in the United States of America, showed flights that were deployed on the same day, had travelled in opposite directions even though deployment occurred from the same site with the same wind currents.

Depending on the launch location, the conditions experienced during flight would differ. Cloud formation occurs at approximately 18 [km] depending on the region which is well within the maximum altitude of an average weather balloon. Therefore, weather balloons must endure any weather conditions that cloud formations produce or that wind propels into its path during flight. These conditions would also occur in the Fresnel Zone which is an elliptical region between transmitter and receiver where obstacles have the greatest attenuating impact on transmission. Communication would therefore have to penetrate any encountered weather conditions for successful transmission. Typical weather conditions that were experience in the test region (Cape Town, South Africa) for this project are listed below:

- Sunny
- Cloudy/Partly Cloudy
- Rain Clouds with short periods of rainfall
- Fog, Smog and Mist
- Regular wind that increases with altitude

The LoRa communication system would have to successfully transmit under these conditions however in other regions of the world more severe weather conditions occur such as electrical storms or snowfall. The trajectory of the weather balloon is entirely dependant on the wind. Therefore it is also likely that the scenario may arise where line-of-sight may not be possible for communication in mountainous or rocky areas that affect the wind direction. Communication methods would therefore have to be able to penetrate the terrain for successful transmission to occur. The radiosonde load hangs via a cable that is connected to the bottom of the weather balloon. The method of connection between the weather balloon and the radiosonde means that the radiosonde load is susceptible to swaying as a result of the weather and wind. The presence of swaying implies that the orientation of the antenna can change altering the propagation trajectory of the transmission antenna. This could result in the loss of measurements that are not received due to the temporary misalignment of antenna propagation vectors of the transmitter and receiver. The LoRa communication system would also have to investigate methods to circumvent this possibility.

Chapter 4

LoRa Implementation Design

This chapter begins with the LoRa hardware modules that were implemented for the project. The chapter then continues by showing how the modules are to to be used to validate the LoRa protocol in terms of transmission parameter optimization, system tracking and compression.

4.1 LoRa Modules

For this project, two boards being the LILYGO TTGO LoRa32, shown in Figure 4.1 on the left and the Dragino LoRa Shield with an Arduino Uno R3, shown in Figure 4.1 on the right. For both modules a 5V supply power bank is to be used to supply the transmitter module and the receiver is to be supplied from a laptop that stores the measured data. All software for both boards as well as the tracking system were implemented in C/C++. The code for both modules and the tracking system can be viewed on Github shown in Appendix A.

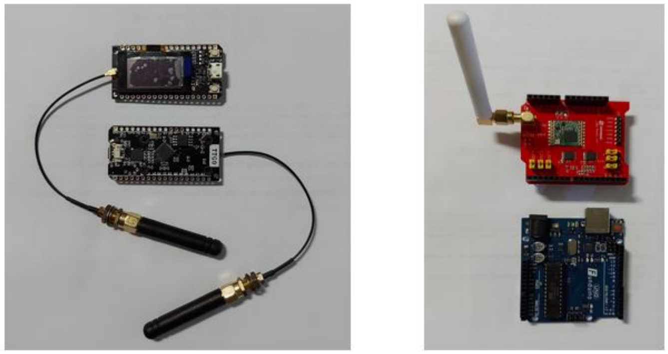


Figure 4.1: LILYGO TTGO LoRa32 at 868 MHz on the left and Dragino LoRa Shield at 433 MHz with an Adruino Uno R3 on the right

4.1.1 LILYGO TTGO LoRa32 OLED Board

The TTGO module is a development board with a ESP32 micro-controller, a built in LoRa chip based on Semtechs SX1276 and a 0.96 Inch OLED display. The board is thus fully operational requiring no additional hardware apart from a power source. The module has a monopole antenna connected to the board via a copper cable. The main board specifications are as followed:

– Frequency: 868 MHZ

– Sensitivity: min of -148 dBm

– Transmit Power: max of 19.5 dBm

– Operating Temperature: -40 °C to 90 °C

– Supply Power: 5V

– Cost per Module: $16.00

The board was selected as it was easily available during the project period, relatively easy to deploy and the OLED screen allows for rapid observation of errors and data being transmitted. The reader is urged towards [1] to gain a better understanding with examples utilizing the board. The LoRa library that was used was created by Sandeep Mistry where the library and the manual for the library can be found at [17] which is compatible for different Semtech LoRa modules.

4.1.2 Dragino LoRa SX1276 Shield

The Dragino LoRa module is an Arduino Shield that implements Semtech's SX1276 chip. The shield connects directly onto the Arduino Uno R3 IO pin configuration for easy implementation. The main board specifications are as followed:

- Frequency: 433 MHz
- Sensitivity: min of -148 dBm
- Transmit Power: max of 20 dBm
- Operating Temperature: -40 °C to 85 °C
- Supply Power: 3.3V or 5V
- Cost per Module: $21.50

The shield was selected due to the user friendly and well-developed Arduino platform utilized by the board. The monopole antenna on the shield is significantly better than the antenna on the TTGO module and screws directly onto the shield. The reader is directed to [2] to see the full specifications and examples. The library that was used for the shield is the RH_RF95 Library designed specifically for the shield. The manual for the library can be found at [18].

4.2 LoRa Validation Design

The implementation process for the LoRa modules involved the transmission of previously measured radiosonde data that was measured in Dodge City, Kansas, in the United States of America, measured in 1993. The data was acquired from [19] recorded and published by NOAA. Given that the project was limited to operate without a radiosonde module, the radiosonde behaviour was simulated such that the instantaneous, pre-recorded, data was packaged into a single packet and was transmitted at 3 seconds intervals. Therefore, this behaviour mimics the operation of an actual radiosonde while still allowing for sufficient time to validate the LoRa transmission signal data. Note the radiosonde data was acquired much later in the project and was therefore only used for Test 3: Long-Range Test. The validation tests that were to be implemented are explained below.

4.2.1 Test 1: Short-Range Ground-Ground Test

The first test involved the configuration of both LoRa modules to cycle between the various LoRa parameters. Then transmission occurred at 25 m intervals across a 200 m distance across an unobstructed field. The parameters that are to be cycled were the SF, BW and CR from the minimum to the maximum of each parameter. The carrier frequencies are fixed to the module being 433 MHz and 868 MHz and the transmission power is set to the maximum of 20 dB of the hardware to maximise range. The data that was transmitted consisted of an 88-byte character array consisting of alphanumeric symbols. The test was carrier out between two of the same modules in a point-to-point transmission manner. RSSI values, that describe the received strength of the signal was to be recorded for each configuration and distance.

4.2.2 Test 2: Medium-Range Air-Ground Test

The second test involved an air-to-ground test that simulated the weather balloon that would transmit from the air and would be received at a ground station. This is to be implemented with the better of the two modules from the previous Short-Range test. The signal parameter configuration is also to be the same as Test 1 to ensure that the results are at least equivalent if not better from air-to-ground as compared to the ground-to-ground test. To simulate the air component of the test a drone was used that carried the transmitter module across a 1 km distance and a constant height of 100 m. The distance and height will be limited to the drone range and wind conditions during the test period, in favour of minimal wind to maintain control of the drone. RSSI measurements were meant to be taken at 50 m intervals. The same 88-byte character message array was used. The drone that was used was the DJI Air 2S with the power bank and the transmitter fitted to the drone as shown in Figure 4.2.

Figure 4.2: TTGO LoRa32 module with a 5 V supply power bank taped to the DJI Air 2S drone

4.2.3 Test 3: Long-Range Mountain-Mountain Test

The third test involved a long-range test to be done from the peaks of Lions Head Mountain to Tygerberg Mountain Ranges, with an approximate fixed distance of 20.18 km shown in Figure 4.3. Both these mountains are in the Cape Town region where weather conditions are known to periodically change due to wind, the test would thus have to be conducted on a day when weather changes are present in the transmission region. The changes in weather simulate some of the conditions that would be present in an actual weather balloon flight mentioned in Chapter 3. The Fresnel Zone between the mountains better reflects the zone that would occur in an actual weather balloon test and is directly in the path of passing weather that is indicated in Figure 4.3 on the left. The elevation of the mountains also ensures that apart from the weather conditions, no other physical obstacles would be present in the transmission region. For this test, the NOAA radiosonde data was utilized for transmission. The data to be recorded would utilize the same LoRa parameter configuration transmitted during different weather conditions and the RSSI data was to be recorded.

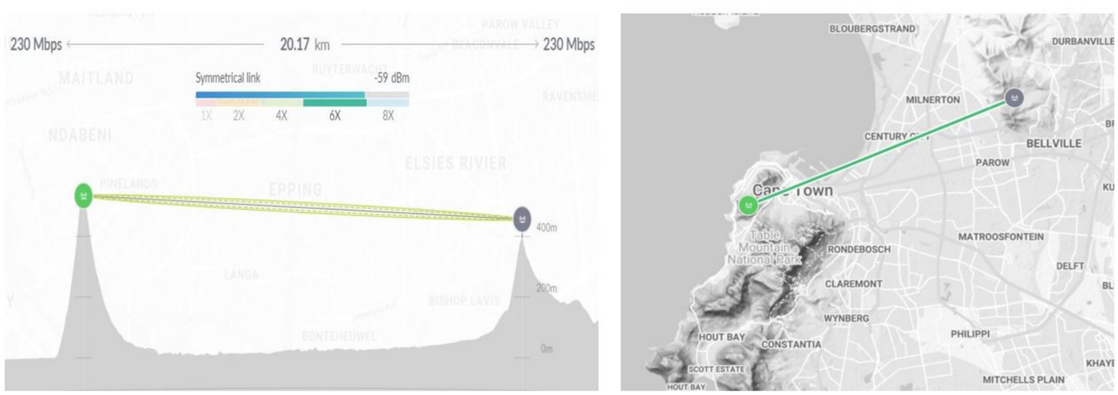


Figure 4.3: 20.18 km transmission region for Test 3: Long Range Mountain Test on the right with the expected Fresnel Zone on the left

4.3 Weather Balloon Tracking System Design

To test the effect of tracking the transmission module, the receiver module would need to be able to move freely to point towards the location and match the position of the transmitter module. To achieve this a tracking system is to be designed to allow for rotation along the vertical axis and elevation by means of rotation along the horizontal axis, of the receiver module. The system is then meant to be screwed onto a standard instrument tripod if unable to be placed on a flat surface.
The rotation actions are then to be automated. To achieve this a GPS module that determines location and height are to be implemented, deployed and synced with the transmission module. The instantaneous data is then to be periodically sent using the LoRa communication setup. The location and height can then be used to derive the rotation actions required to be implemented by the tracking system.

The hardware design of the stand would involve 6 components being:

1. Receiver Module Mount, that would house and stabilize the module as rotation and elevation occurs. The mount would fit onto the shaft of the stepper motor.

2. 2x 5 V JK42HS40-1704 Stepper Motors with individual mb20b DRV8824/25 driver modules, the first for rotation and the second for elevation. The stepper motors are cubical in shape.

3. Base Plate, the broad base would allow for the stand to be screwed on to a tripod or placed onto a flat surface. The base would also house one of the motors that implements vertical rotation.

4. Stand, the stand fits onto the base stepper motor shaft and is high enough to give enough clearance for the receiver module mount to clear the ground without making contact. The stand would also house the second stepper motor

that implements horizontal rotation that fits onto the mount.

5. 1x bread board that connects the driver modules with male-to-male end cables.

6. GPS module, being the Waveshare GSM/GPRS/GNSS Hat, described here [20], that is to be deployed and operated by the transmitter LoRa module.

The Mount, Base Plate and Stand are to be designed and rendered in Fusion360 CAD software and 3D printed using the Prusa Mini 3D printer. Figure 4.4 shows the placement of the components that form the system.

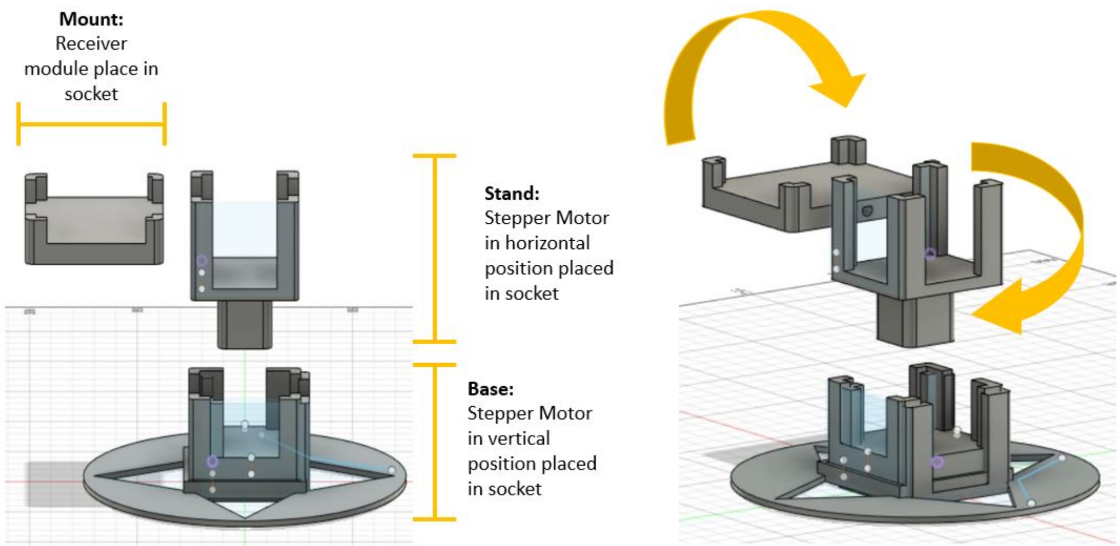


Figure 4.4: Tracking System CAD Design Rendered using Fusion360

The control actions are to be powered and executed by the Arduino Uno R3 or the ESP32 micro controllers depending on which board proves to be more successful. The controller is to be a proportional difference controller that runs alongside the LoRa code. The controller would work by determining the angular difference between the current orientation of the tracking system and the location and elevation of the transmitter. The controller would then implement the angular equivalent stepper voltage to position the stand correctly. The actions would be implemented as the location data from the GPS module has been received. The driver, motor controller (being the Arduino is this case) and power supply setup for the implementation of the tracking system is shown below as Figure 4.5 and was replicated for both stepper motors.

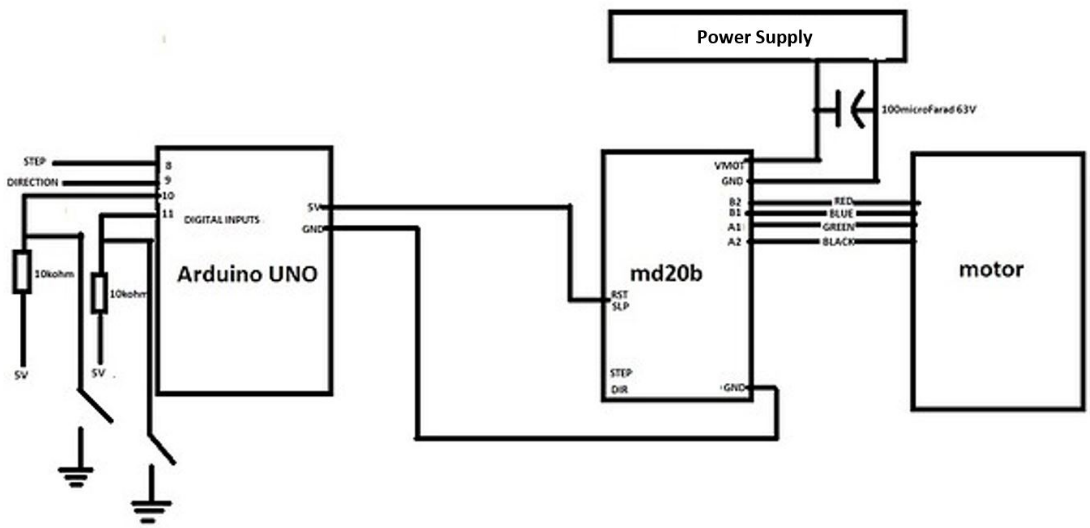


Figure 4.5: Tracking System circuit configuration

4.4 Test 4: Tracking System Test

Then the system is to be deployed to investigate the effect that tracking has on antenna positioning and propagation of the LoRa module. Test 2: Medium Range Air-Ground Test, is to be altered to incorporate the stand housing the receiver and the GPS module that interfaces with the transmitter. The code would be adapted to govern the stepper motors and GPS module, to interface with either the ESP32 micro-controller for the TTGO LoRa32 modules or for the Arduino Uno R3 for the Dragino LoRa Shield depending on which board proves to be better in the Short-Range Ground-Ground Test. This would address any antenna misalignment induced by windy weather conditions. The same parameter configurations that were tested in Test 2 are to be tested for this test.

4.5 Test 5: Compression Validation

Data compression reduces the size of the payload of a packet as well as the number of packets required for a set amount of data. This would result in fewer transmissions needing to occur reducing the required power and time needed by the transmitter. To test the effect that compression has on LoRa transmission, instead of transmitting the instantaneous measurements being temperature, pressure, humidity, time, altitude and coordinate location as a single 88-Byte payload, each measurement would be transmitted individually. The separation would reduce the overall payload per transmission packet to a 3-Byte payload, simulating the effect of a compression algorithm. This method was selected over using a lossless particular compression technique such as Huffman Encoding (which initially proved to be promising) as this would only validate the particular algorithm instead of compression overall. The test is then to be carried out in a similar manner to Test 2 Medium-Range Air-Ground test. The only exception would be that the signal parameter configuration used for transmission would be the optimal configuration derived by Test 1, 2 and 3. The smaller payload would then be compared to the larger payload RSSI measurements to determine if there is any notable difference. The results would then be used to determine if compression should be beneficial for this application.

4.6 Validation Method

The process to be used to analyse the results would begin with the comparison of the short-range ground, medium-range air and long-range test results. The short-range ground results of Test 1 are to be used as the metric that is used to determine the optimal parameter settings for LoRa in terms of signal strength, range and weather conditions when compared to the other two test results. The optimal parameter configuration is to be supported with reasons as to how and why the outcome were determined. To validate the results of tracking and compression, the measured data is to be individually compared to the medium-range air to ground data of Test 2 to be used as the metric at the optimal configuration, as the data is to be measured in the same manner. Conclusions derived for both tracking and compression are to be supported with possible reasons as to why results were achieved. The transmission data of Test 2 and 3 is to be used to determine a theoretical distance and altitude achievable given the observed loss in RSSI signal quality seen in the previous tests. Finally, an overall conclusion based on all 5 tests are to be used to conclude the potential usage of LoRa transmission for Radiosonde applications.

Chapter 5

LoRa Implementation Validation

This chapter outlines the results that were measured for each of the five tests. The chapter then continues with the analysis of the results and offers insight on the ramifications that the results would have on LoRa technology for weather balloon communication. The validation method that was described at the end of the previous chapter was then utilized to determine the optimal LoRa configuration as well as the estimated range and altitude that can be achieved based on the results.

5.1 Test 1: Short Range Ground-Ground Test

The short-term ground to ground test yielded the following results shown in Table 5.1 for the TTGO LoRa32 module and in Table 5.2 for the Dragino LoRa Shield. The data reflected in the tables outlines the RSSI measurements at the lowest BW of 125 KHz with the minimum CR of magnitude 4/5. From the results the Dragino module had a much lower RSSI at every distance point compared to the TTGO module and was the case for the other BW's and therefore proves to be the better module. The main difference between the modules was the carrier frequency, with the lower carrier frequency of 433 MHz producing the better results. A problem that arose with the ground test was the effect of the Fresnel Zone. The remaining result would thus be heavily influences by the ground obstacle that is shown in Figure 5.1 where the bottom of the Fresnel Zone radius intersects with the ground. Due to that fact, apart from determining which is the better board, the remaining data would offer less knowledge into the usage of LoRa for the specific application apart from being a benchmark.

Table 5.1: RSSI dBm values recorded using the TTGO LoRa32 Board at 868 MHz at a BW of 125 KHz

Distance [m]	**Spreading Factor**						
		7	**8**	**9**	**10**	**11**	**12**
0		-67	-76	-65	-76	-86	-84
25		-89	-93	-95	-96	-102	-103
50		-100	-104	-105	-103	-108	-110
75		-104	-109	-109	-111	-116	-111
100		-109	-110	-109	-111	-111	-112
125		-108	-111	-113	-112	-113	-115
150		-111	-114	-115	-112	-116	-118
175		-112	-114	-114	-115	-117	-119
200		-113	-114	-115	-113	-119	-118

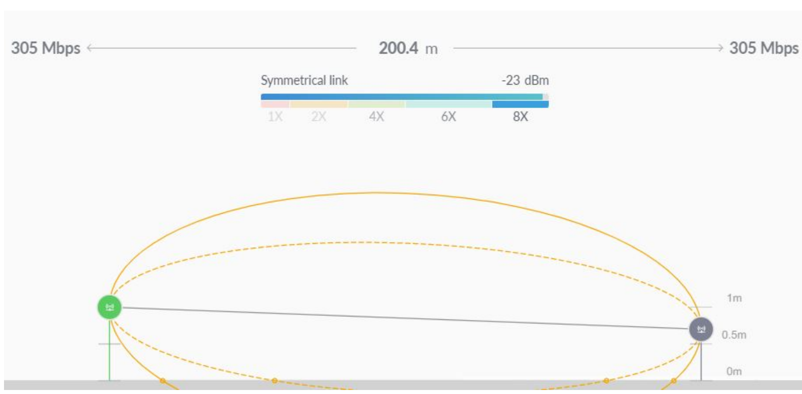


Figure 5.1: Fresnel Zone across a field implemented for Test 1

Table 5.2: RSSI [dBm] values recorded using the Dragino LoRa Shield at 433 MHz at a BW of 125 KHz

Distance [m]	**Spreading Factor**						
		7	**8**	**9**	**10**	**11**	**12**
0		-24	-26	-25	-22	-19	-20
25		-71	-64	-64	-66	-66	-72
50		-75	-74	-74	-74	-73	-76
75		-83	-84	-83	-83	-82	-82
100		-87	-86	-84	-86	-86	-87
125		-89	-88	-88	-90	-88	-88
150		-91	-91	-90	-92	-87	-91
175		-94	-93	-94	-95	-94	-96
200		-95	-93	-94	-93	-100	-99

5.2 Test 2: Medium Range Air-Ground Test

The air-to-ground test was conducted on a rugby field in an open area along a straight-line distance as shown in Figure 5.2 on the right. When conducting the test, the amount of time taken to accurately acquire the data at each distance resulted in the drone battery to drain. The open area also meant that windy conditions at a height of 52 m, limited the operational area of the drone. The battery and windy conditions thus prevented the measurement of data at greater distances limiting the test to 500 m. Test 1 concluded that the Dragino LoRa Shield at a frequency of 433 MHz was superior producing better receive signal strengths to the TTGO LoRa32 modules and was thus used for the remainder of the tests. It should also be noted that the Dragino Shield proved to be more user friendly to code, implement and the, Arduino IO pins available made the task of adding additional components specifically for the tracking system significantly easier.

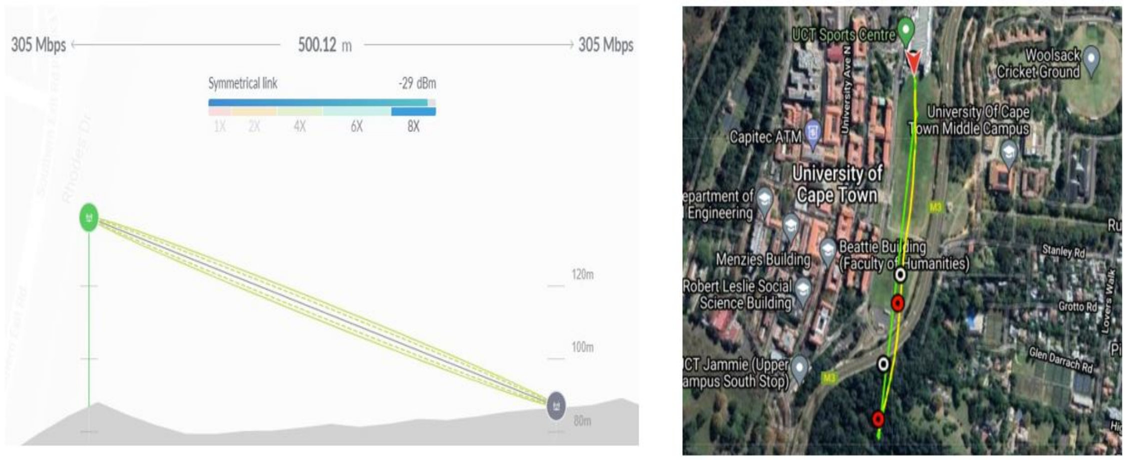


Figure 5.2: Fresnel Zone for Test 2 shown on the left and the drone flight path shown on the right

The parameter configurations yielded the following results at all SF at the available BW of 125, 250 and 500 KHz that are equivalent to the bitrates being 1200, 3000, 3800 bps that is shown in Figure 5.3. Increasing the BW any further surpasses the limits of LoRa technology. The results clearly show that a lower BW with a lower bitrate, produces a better receive signal increasing the range. This is shown by the red plots in Figure 5.3 across all the SF configurations. Overall, the RSSI measurements are significantly greater than the previous ground-to-ground test due to no physical obstacles located in the Fresnel Zone, as would be present in a weather balloon flight, shown in Figure 5.2 on the left.

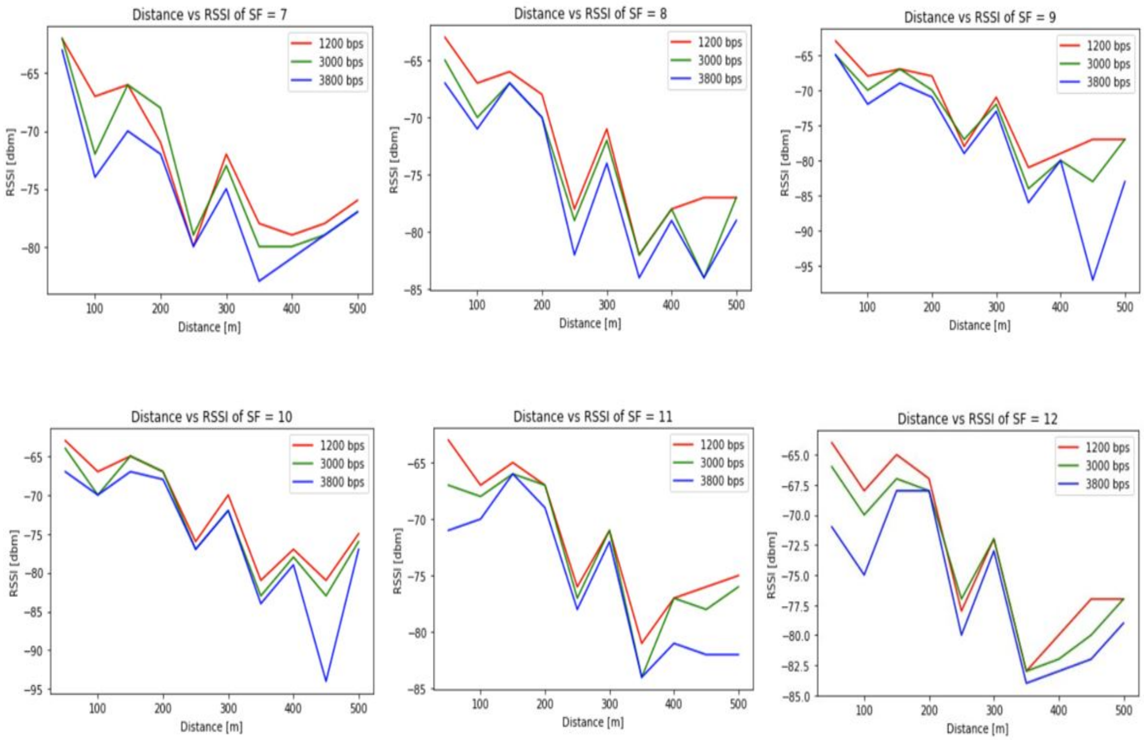


Figure 5.3: Individual LoRa parameter configurations signal strengths while varying SF, BW and CR

In order to determine which SF yielded the better results, the minimum BW plots, shown in red from Figure 5.3, for each SF was plotted in Figure 5.4. LoRa technology dictates that a higher SF should have improved signal performance at greater distances. The test however showed that a SF = 11 proves to be the better parameter setting at the maximum test distance, closely followed by SF = 10 and 7 as shown in Figure 5.4.

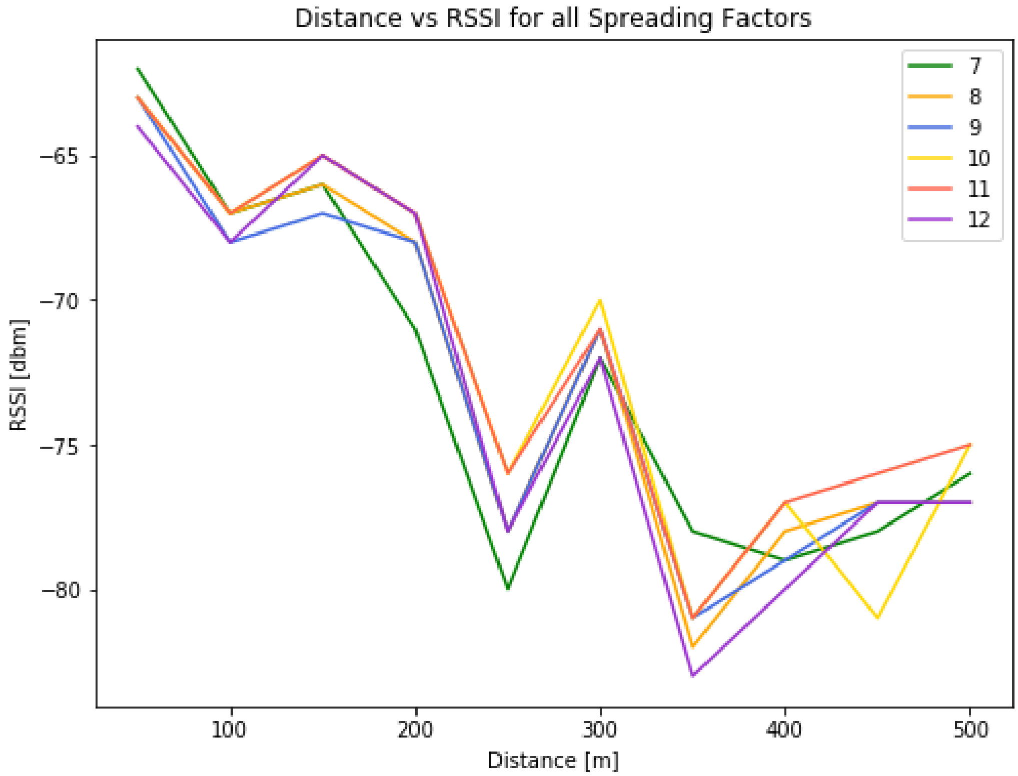


Figure 5.4: RSSI dBm measured from air-to-ground at a BW of 125 KHz

The second observation is that the individual SF plots are of similar trajectories. This does not support the current known relationships of the SF parameter. The short distance of 500 [m] however may have diminished the effect of the parameter that would not be the case in weather balloon applications that occur at significantly longer distances. For every packet that was received the, the data integrity was maintained at all CR settings. The CR, being the third parameter to be optimised, therefore had no significant effect at the test distance suggesting that the CR can be reduced to the minimum to allow for more bits to be allocated for the payload.

5.3 Test 3: Long Range Mountain-Mountain Test

The mountain-to-mountain test was conducted on the 9 October 2021, during the hours of 12:00 to 13:30. The weather conditions that occurred in the transmission region between the mountains consisted of scattered clouds and rain with wind speeds of approximately 13 - 19 km/h that continuously altered the instantaneous weather conditions [21]. The location of the receiver and transmitter were frequented with passing fog and clouds that obstructed the view at regular intervals. The conditions experienced are highlighted below in Figure 5.5 showing the rapid difference in conditions.

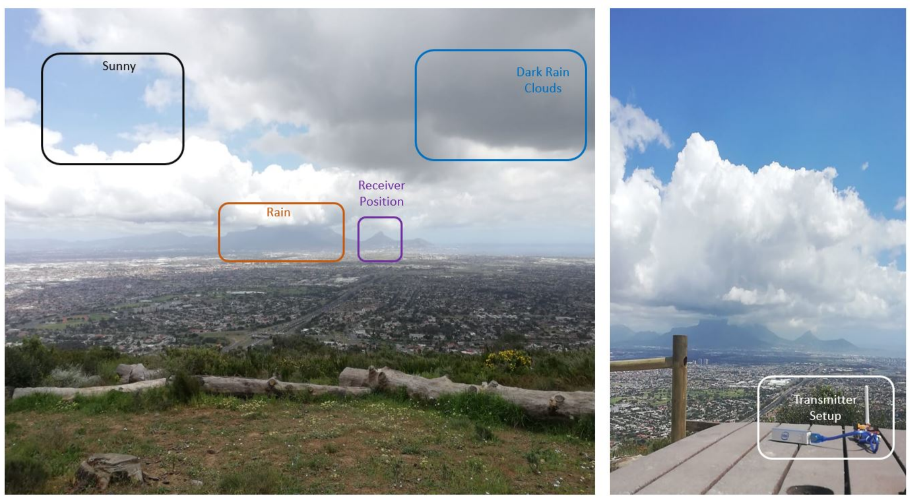


Figure 5.5: Typical weather conditions shown on the left and the position of the receiver on the right, taken 20 minutes apart from Tygerberg Mountain Range

The dynamic weather conditions meant that measuring large amounts of data for specific weather within the certain period was not possible. Smaller amounts of signal strength data that allowed for every SF and BW to be tested, was possible with the Dragino Shield. The measured data and the instantaneous weather conditions are shown in Figure 5.6.

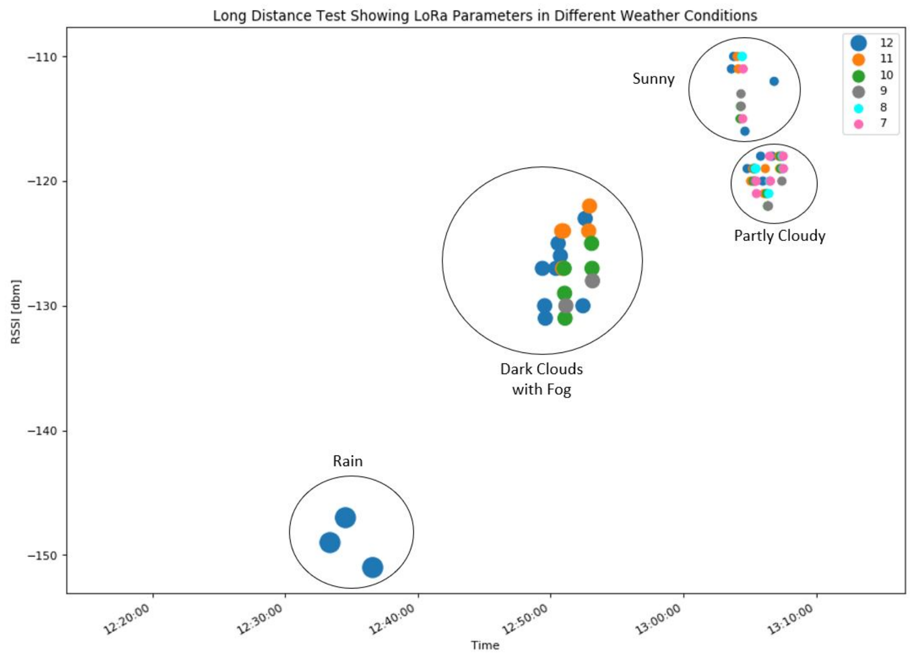


Figure 5.6: RSSI dBm values measured from Lions Head to Tygerberg Mountains during different weather conditions

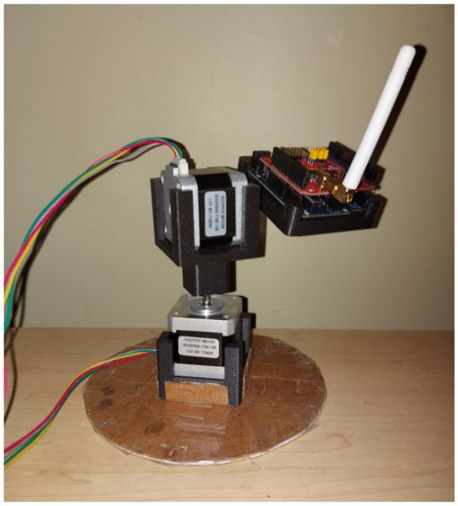
Note for all packets that were received, data integrity was maintain with the instantaneous NOAA data fitting into a single packet. This fact further supports the need for a reduced CR = 4/5 that was used in the test due to the lack of errors in the received data. The first weather condition experienced in the transmission region was rainfall. During that period, at time 12:30 - 12:40, only a total of three packets were received at a minimum BW = 125 KHz of = 12 with very low RSSI values smaller than -140 dBm. Rainfall therefore had a significant destructive effect on transmission which may limit usage for weather balloon applications.

The second weather condition was dark rain clouds with fog blanketing the transmission region. During this period, at time 12:45 - 12:58, all BW's at SF's of only 12 - 9 inclusive, packets were received, with RSSI values ranging between -135 to -120 dBm. This observation shows that dark cloud penetration only affects transmission configured at lower SF's of 7 and 8 however the signal strength of the received packets were lower compared to the air-to-ground test at the much greater testing distance showing weaker signal strengths.

The remaining weather conditions were completely sunny, that occurred between 13:00 - 13:04 and partly cloudy that occurred between 13:04 - 13:10. Under both these weather conditions all transmitted packets for all parameter configurations were received. The RSSI values ranged between -125 to -108 but were much closer to the results yielded in the air-to-ground test. The data shows that sunny and partly cloudy conditions are preferable for LoRa transmission and proves that LoRa communication can be used for weather balloon communications under these weather conditions with the exception of rain. The observation of higher SF's penetrating the poorer conditions is as a result to higher SF having longer transmission times. This allows for a greater periods for the signal to endure the interference before being completely attenuated.

5.4 Test 4: Tracking Test

The development of the tracking system was successful, however during the 3D printing process, regular power outages occurred disrupting the printing task. The design was therefore amended to limit printing only for the stepper motor and LoRa receiver sockets. The remaining components were assembled using cardboard and glued together. The complete system is shown in Figure 5.7. The rotation and elevation actions of the system were successfully able to track fixed coordinate and altitude positions given that the tracking systems reference location was calibrated prior to deployment. The Waveshare GPS module that was utilized for the test was only able to calculate the coordinate location and not the altitude and therefore the LoRa range transmission test was not conducted with the tracking system. The effect of tracking was therefore not determined in this thesis.



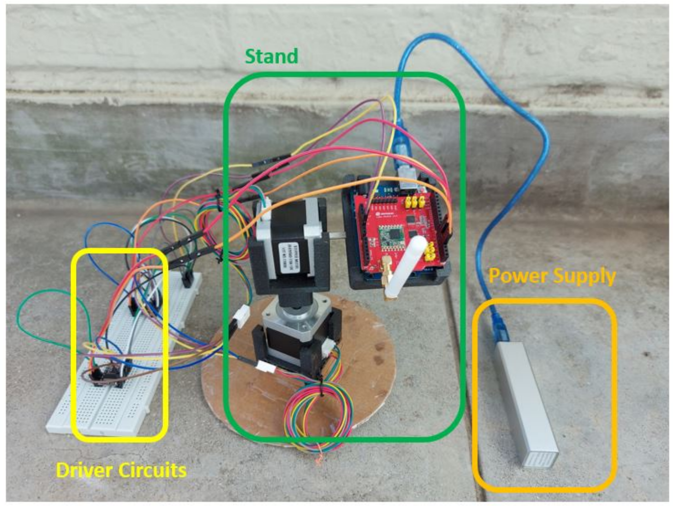


Figure 5.7: Tracking System housing the Dragino LoRa Shield receiver module that is unconnected on the left and is connected to the driver modules on the right

From Figure 5.7, the image on the left showing the connected and deployed tracking system could be altered to minimise cables hanging in the rotation path that hindered rotation even though the system could successfully rotate. Thus would be a suggestion for future implementations as cables getting wrapped around the stand were observed when the system would perform more than one complete rotation in either axis.

5.5 Test 5: Compression Test

The compression test was executed with the Dragino LoRa Shield and given that the lower BW and CR produced the stronger signal, the parameters were configured as such. A 3-byte payload size was then transmitted at every SF that was compared to the equivalent parameter configurations of Test 2 that transmitted the initial 88-byte payload.

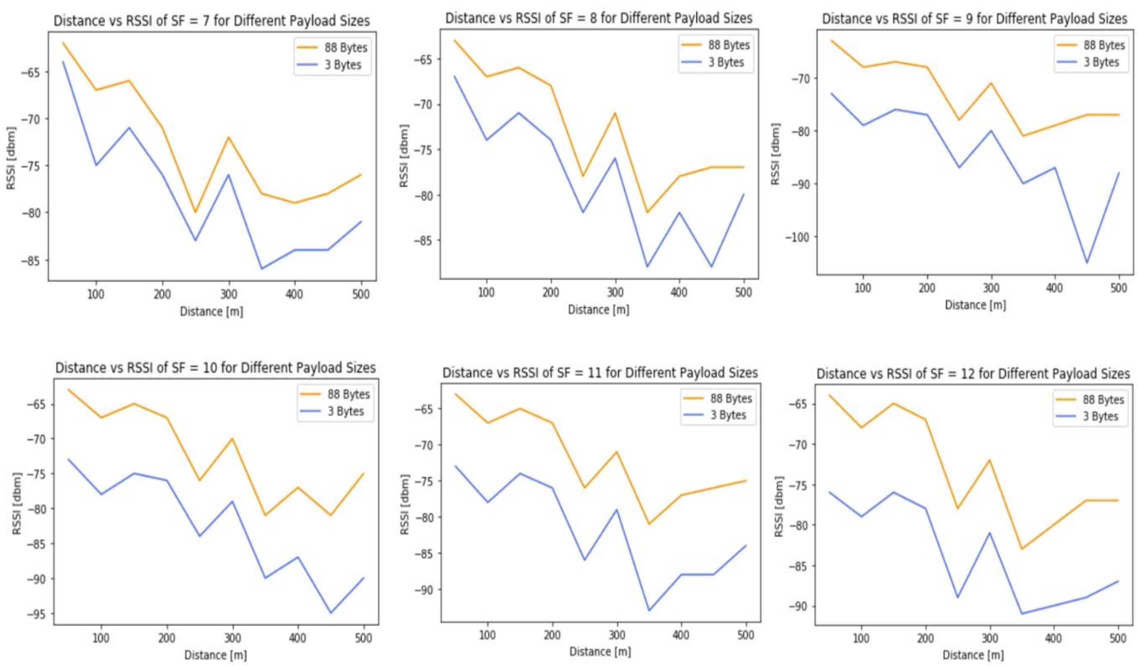


Figure 5.8: Effect of compression with 88-Byte vs 3-Byte character type payloads at a minimum BW = 125 KHz

The RSSI measurements for both tests are shown in Figure 5.8. There is a clear distinction between the 88-byte and 3-byte payload with the larger payloads producing a better result across all configurations. This was unexpected as compression algorithms that are implemented in competing frequency modulation transmission methods had shown significant performance improvements when implemented. LoRa technology spreads the payload across the entire BW therefore a smaller payload would result in an inefficient Chip spread across a chirp pulse which is believed to be the cause of the diminished signal strength. It should be noted that the instantaneous measurements taken by a radiosonde module fits within a single transmission packet shown in Test 3 without the need for compression. Thus if a compression algorithm was applied to the data prior to transmission, the chances of the last packet payload not being complete utilized is likely to occur. The reduced payload packet would this produce a lower signal strength during transmission that could result in packet not being received by the receiver due to the ineffcient Chip spread. This would likely produce gaps in measurements. The lower signal strength at smaller payload sizes along with the fact that compression is not required for packet size efficiency signifies that compression seems to have a more negative affect for Radiosonde transmission.

5.6 Validation

From the first three test that were focused on determining the optimal LoRa configuration, several parameters proved to produce significantly better signal transmission. These where the minimum BW, minimum CR, lower carrier frequency and maximum TP that would all maximise the transmission distance. The SF however did not have a clear configuration for range with conflicting results across the tests. Test 3 however, which tested the performance of LoRa transmission in different weather conditions, exhibited that a SF = 12, with the largest spread and greater transmission times, proved optimal under all conditions only partially failing to be received during rainy conditions. Given that weather balloons are likely to experience severe weather conditions during flight the maximum SF would produce the best results for the application. The optimal LoRa parameter configuration using the Dragino LoRa module is therefore:

- Bandwidth: 125 KHz
- Bitrate: 1200 bps
- Coding Rate: 4/5
- Carrier Frequency: 433 MHz

- Transmit Power: 20 dBm or greater if hardware allows
- Spreading Factor: 12

The lack of success in implementing Test 4 covering the effect of tracking, meant that the achievable signal height is limited to a hypothetical theoretical validation. If the test was successful, the receiver could by oriented to match the position of the transmitter replicating the positions of the modules in the mountain Test 3. The Fresnel Zone would not differ if in a vertical execution replicating the transmission region between the mountains. The horizontal range performance could thus be applied to the vertical distance to show a theoretical transmission altitude of 20.18 km achieved in Test 3. However, given that theoretical height that the transmitter module could achieve, there is a less likely chance of obstacles occurring in the zone and thus the hypothetical altitude of 20.18 km is very likely that signals could still be received.

Figure 5.6 from Test 3 shows that, at the maximum recorded horizontal range of 20.18 km, the difference between the possible receivable RSSI = -160 dBm limited by the LoRa module and the measured RSSI = -122 dBm, allows for an average of 48 dBm possible further transmission to be received. This estimation is assuming that ideal sunny conditions are experienced. The estimation would be significantly reduced under more severe weather conditions. Then comparing Figure 5.4 and 5.6 at distances of 0 - 20 km suggests that there is an exponentially decay relationship between distance and the receivable signal strength or RSSI. Simple stated, the RSSI measured reduced at a lower rate, the further that receiver was from the transmitter. Due to insufficient amounts of data measured across the region, due to the drone range limitations and lack of access to a weather balloon, a usable model could therefore not be derived as the current data could not converge to accurately produce a usable exponential model. The current data does suggest that the signal would be receivable at ranges greater than the required 100 [km] given the additional remaining 48 dBm is available and that signals would be reflected both from the ground and the atmosphere when line-of-sight is not possible due to the curvature of the earth.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

The motivation of the project was to assess the potential for using LoRa technology as a communication method specifically for weather balloon communication. LoRa is a low-power and cost-effective technology that is growing in popularity for IoT applications and showed significant promise for long range communication that was evaluated in this thesis.

The thesis began with the analysis of current literature available on LoRa to establish the origins and context surrounding the technology. The review of current literature reflected that LoRa is a relatively new compared to competing technologies. There was still significant research done on the topic that showed the effects of LoRa parameters on range and interference rejection. The results mentioned in the papers, supported the claims made by the current suppliers of LoRa hardware being Semtech Corporations. Several existing implementations have even exceeded the range claims setting a world record. The evaluation of LoRa was considered in the design and analysis chapters following the literature review that was implemented

using commercially available LoRa modules. The evaluation was broken down into 5 tests that considered LoRa across the ground, air and long-range transmission to determine the optimal LoRa configuration that produced the maximum transmission distance. The development process and tests found that the Dragino LoRa Shield proved to be a better board than the LILYGO TTGO LoRa32 module both in usability and performance as a result of the difference in operating frequencies and monopole antenna configuration. The effects of tracking by means of development of a tracking system and compression were also considered. Unfortunately, circumstances prohibited the complete evaluation of the tracking system.
Overall, the results yielded an optimal LoRa configuration of:

- Bandwidth: 125 KHz
- Bitrate: 1200 bps
- Coding Rate: 4/5
- Carrier Frequency: 433 MHz
- Transmit Power: 20 dBm or greater if hardware allows
- Spreading Factor: 12

This configuration produced a successful transmission with data integrity maintained, to a distance of 20.18 km at a altitude of 452 m achieved in the mountain-to-mountain test. Secondly, the tracking system was successful in directing the receiver module towards fixed altitudes and coordinate locations but was not tested with live location tracking. Thirdly, the effect of compression had a negative impact with compressed packet payloads producing lower signal strength than uncompressed packet payloads. Lastly the effect of weather such as rain and heavy clouds had a significant deterioration effect on transmission range completely attenuating the signal under severe conditions.

To conclude the bitrate and temperature, as rated by the hardware, system requirements were successfully met. The distance and altitude requirements were not due to project limitations prohibiting the measurement of sufficient data across a larger enough distance to determine an actual or a theoretical approximation. The data however did suggest that under sunny/partly cloudy conditions, both the height and distance requirements have the potential to be met. LoRa has shown significant potential for Weather Balloon communication but requires further analysis and testing to realise the full capabilities for utilization in weather balloon applications.

6.2 Future Work

The limitations experienced in this project offers potential for further investigation and analysis. This is briefly summarized below:

1. The implementation of the LoRa modules deployed in an actual weather balloon flight test. This would establish a more detailed evaluation of the transmission strength and range when utilizing LoRa as a transmission method. This would also allow for a better model between distance and signal strength to be established

2. A notable observation was the significant effect of weather. The weather conditions tested in the thesis were limited to the testing location. Given that the usage application is focused on weather and atmospheric measurement, the ability to transmit in more severe weather conditions is an essential requirement. Conditions such as snowfall, electrical storms and dust storms should be tested.

3. The effect of weather can be further combated with the utilization of more powerful and sensitive antennas. The results of this are to be further examined

as well as the weight and feasibility constraints if to be deployed on a weather balloon.

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Appendix A

Github Code Repository

Throughout the duration of the project, all resources and code were stored in a Github repository. To view the contents, the reader is urged to click on the link shown in Appendix A.1, which is the README file, that outlines the contents of the repository.

A.1 EEE4022S_Final_Year_Project README.md

LoRa Based Communication System for Radiosonde Applications

URL for Repository: https://github.com/yashivfakir/EEE4022S_Final_Year_Project.git

The files found in this repository are for the LoRa based communication device for weather balloon comunication. The object of the project was to explore the possibility of using LoRa technology for long range weather balloon communication.

The LoRa modules that were utilized for the project are the:

- **LILYGO TTGO LoRa32 module @ 838 MHz**
- **Dragino LoRa Shield @ 433 MHz**

Several progress summaries were written up during the project that outline the findings:

- **[SP21-06S] LoRa Based Communication System for Radiosonde Applications.pdf (Project Specification document)**
- **LORA - Summary.pptx**
- **LoRa Project Update.pptx**

Repository Structure

- **Literature** - Contains published papers on LoRa and is indexed in the word document
- **Possible Boards** - This lists some of the other possible LoRa modules that could have been used
- **Report Graphics** - Contains the graphics that were used in the final thesis
- **Report Graphs** - Contains the graphs summarizing the measured RSSI data
- **Resources** - Contains some useful links and insight to introduce the topic
- **Rubric** - Contains the rubric used to assess the final thesis
- **SDR** - Contains the SDR code that was used to control the SDR monitor to observe the LoRa signals and changes

- **Test Data** - This is the Raw data that was measured when conducting experiments
- **Tracking System** - Contains the the CAD rendered in fusion360 that were converted to be 3D printed using a PrusaMini
- **NOAA Radiosonde Data.zip** - Contains the Radiosonde data that was measured in USA in Kentucky that was utilized in the project

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Code

The code is stored in several zip folders:

- **Arduino Dragino LoRa Shield Code.zip** - Contains the code that governed the Dragino LoRa shield
- **TTGO LoRa32 Module Code.zip** - Contains the code that governed the LILYGO TTGO LoRa module
- **WaveShare GPS Module Code.zip** - Contains the code that governed the GPS module

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Appendix B

Ethics Form

Assessment for Ethics Regarding Research Projects for the investigation LoRa for this thesis is shown here:

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

ETHICS APPLICATION FORM

Please Note:

Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Yashiv Fakir
Department		EBE Electrical Engineering Department
Preferred email address of applicant:		fkryas002@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	Beng Mechatroincs
	Credit Value of Research: e.g., 60/120/180/360 etc.	40
	Name of Supervisor (if supervised):	Dr Stephen Paine and Dr Robyn Verrinder
If this is a researchcontract, indicate the source of funding/sponsorship		n\a
Project Title		LoRa Based Com - System for Radiosonde Applications

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Yashiv Fakir		15/08/2021
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	Stephen Paine		16/08/2021