

LoRaWan on Genova

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Abstract

This thesis aims to:

- Mesure performance LoRaWan communication standard on packed cities and with moving end nodes
- Many different scenarios were tested and analized
- The conclusions reached prove that the assumptions made were sound

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Introduction

0.1 Motivations

In recent years, Internet Of Things technologies (IoT) have grown in importance and are expected to have an exponential increase in their use in the coming years. For this reason, there is a need for communication protocols with two key features, which are: - Long range communications - Low power consumption. To cover these needs LPWANs (Low Power Wide Area Networks) were created and offer big advantages when compared to high bitrate and shorter range technologies such as Wi-Fi or Bluetooth, and cellular ones like GSM or 4G that have a much higher power consumption.

The study of these technologies on the environment of tightly packed cities is highly important in order to advance to achieve smart cities.

0.2 Context of the Study

The study is performed on the city of Genova, tightly packed with buildings, for the most part made with concrete and brick. Other cities with different architecture could perform different as the distribution of the buildings is important in the reach of the signal. One example of this is the problems with GPS localization when near skyscrapers.

0.3 Tools used in the thesis

For the storage and analysis of these messages The Things Network is being used, which is a free to use LoRa network that offers not only gateways but also data storage and various functionalities for a particular network, being able to make it private or public.

0.4 Overview of the Thesis

In this thesis we are going to take a look at LoRaWAN (Long Range Wide Area Network), a communication protocol with a low bit rate and power consumption that can reach distances of up to several kilometres, we will study the characteristics of the communication and recreate various real life scenarios to study different characteristics such as packet loss, power transmitted and the best configuration for the end- devices. With these measurements we can obtain valuable information about how to optimize the network for its different use cases, as there are big differences depending on the topology and placements of the nodes and gateways.

Chapter 1

Previous required knowledge

1.1 LPWAN

LoRa and LoRaWAN protocols are based on the LPWAN technology. LPWAN stands for “Low Power Wide Area Network” and it allows radio- equipped devices to communicate more efficiently and over longer distances. This emergent technology had the goal of finding a better data transmission protocol than other technologies such as Bluetooth, Wi-Fi or 3G/4G. The low-power consumption and the long range transmission that this technology offers, positions it as a cost-effective solution when compared with the other big technologies. As LPWAN is not concerned with transmitting big quantities of data, it offers aspects that simply others can't complete such as the coverage of long distances as it can be appreciated in the figure below.

This is why LPWAN has become one of the fastest growing spaces in the Internet of Things (IoT) ecosystem. One of the biggest and most interesting applications of this data transmission technology is on the Smart Cities field. This protocols are a perfect solution for the Smart City data networks, which requires low data rate but constant data streams and the coverage of long distances with

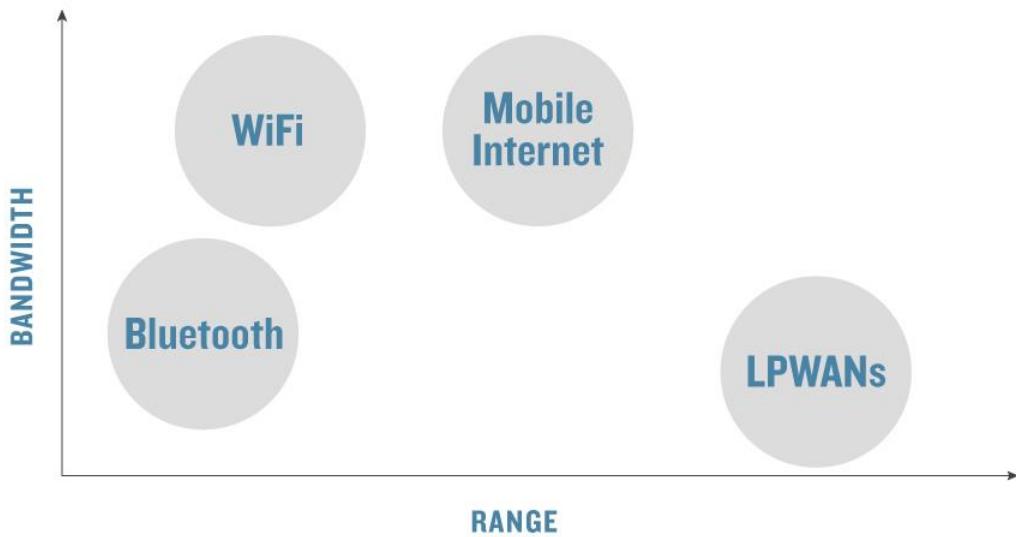


Figure 1.1: Graph comparison of range and bandwidth for different data transmission technologies.

the benefit of using significantly less power than other data network platforms. Shanghai is a perfect example of a Smart City where LPWAN is used in order to connect thousands of sensors to measure the air quality and human movement, more info [here](#). The future of this technology is bright as IoT devices are growing a 12% annually according to a [IHS Markit report](#). and LPWAN is one of the greatest spaces in the IoT ecosystem. LoRa and LoRaWAN are realizations of the Low Power WAN concept, and with such high demand for the technology both are having great impulse in their development.

1.2 LoRa

LoRa is the protocol which defines the physical (radio) layer of the communications in TTN. This protocol fixes the frequency band and defines the modulation that is used to transmit data which enables the long-range communication link.

1.2 LoRa

The frequency band depends on the region in which you are, for example, in the US they use a band from 902.3 to 914.9 MHz, here in Europe the band goes from 863 to 870 MHz as it's illustrated on the next table:

Frequency band depending on the region	
Region	Frequency (Mhz)
Asia	433
Europe	863-870
US	902-928
Australia	915-918
Canada	779-787
China	470-510

Table 1.1: frequency band of different regions

The LoRa modulation is based on the Spread Spectrum technique and it's crucial for the long distance communication. This technique spreads the signal all over the frequency band and it allows LoRa to be very robust to interferences and noise, allowing the signal to reach longer distances. More precisely it's called chirp modulation and it transmits symbols encoding them into multiple signals of increasing (upchirp) or decreasing (downchirp) radio frequencies. A LoRa transmission always starts with 8 upchirps and 2 downchirps as we can see in the figure number 1.2. In LoRa communications we are able to reduce our data rate in order to gain range by changing the Spreading Factor. The Spreading Factor means the number of raw bits that can be encoded in a symbol. ("Modelling

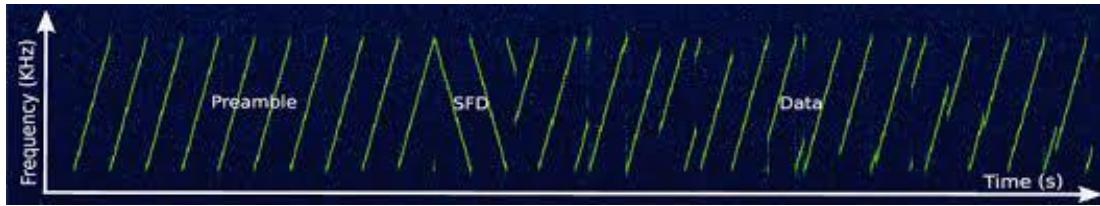


Figure 1.2: Snapshot of a LoRa transmission

and Performance Evaluation of LoRa Network Based on Capture ...") The SF value goes from 7 to 12 and as we increase this value the number of raw bits in a symbol increase and this leads to a gain of range but also to a reduction of data rate, to an incrementation of the time on air and to more battery consumption. The SF value can vary from 7 to 12 both included, trading data rate with range. The increase or decrease in data rate is proportional to the time on air, greater meaning not only more battery consumed but also greater chance of collision. The increase in range is due to the higher sensitivity of the receiver at greater values of SF. In short, increasing a level the SF means stretching the signal twofold, with its corresponding higher power consumption but better range.

LoRa has to deal with the specific regulations and norms of each region. Here in Europe we must comply the following rules:

- For uplink, the maximum transmitted power is limited to 25 mW (14dBm)
- For downlink, the maximum transmission power is limited to 0.5W (27dBm)
- There is between an 0.1% and 1% duty cycle per day. This means that the time on air of the transmission must not exceed a proportion of the total time.
- Maximum allowed antenna gain +2.15 dBi

1.3 TTN and LoRaWAN

LoRaWAN defines the communication protocol and the system architecture, it acts like a MAC layer for LoRa packets. The Things Network is a LoRaWAN network operator that use this protocol and its network topology to give free LoRaWAN connectivity.

The LoRaWAN network topology, as it's represented in figure 1.3, consist of 4 layers: end-nodes, gateway, network server and application server. Gateways are

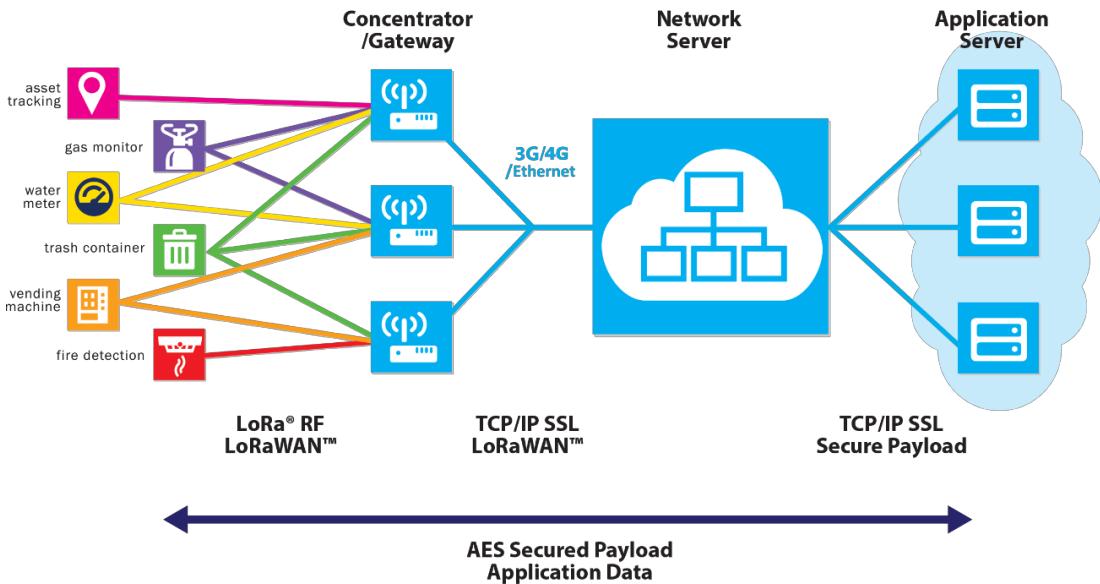


Figure 1.3: LoRaWAN network topology

able to listen from hundreds of end nodes at the same time, even if those nodes are transmitting at different frequencies or SF. The data transmitted through the gateways arrives to the network server via TCP/IP. Then the network server (NS) sends those packets to the application server (AS) and if it is needed, a different server called join server (JS), enters in the process. This server stores the sensitive parts of LoRaWAN applications such as the root keys and generates the session keys when a join procedure takes place.

In LoRaWAN communications we distinguish two types of transmissions depending on the sense of communication. An uplink message is sent from an end-node to a network server and in the case of a downlink message the message is sent from a network server to a specific device.

- **Uplink message:** this message uses the LoRa radio packet explicit mode, which consists of a physical header (PHDR) and a cyclic redundancy check (CRC) header (PHDR-CRC). Another CRC is required to protect the integrity of the payload; all of them are together inserted by the radio transceiver in the following way:

Preamble	PHDR	PHDR-CRC	PHYPayload	CRC
----------	------	----------	------------	-----

Table 1.2: Uplink message format.

- **Downlink message:** The structure is very similar to the uplink message, the only difference is that in a downlink message there is no existence of CRC:

Preamble	PHDR	PHDR-CRC	PHYPayload
----------	------	----------	------------

Table 1.3: Downlink message format.

This PHYPayload that both, the uplink and the downlink messages contains, starts with a single-octet MAC header (MHDR), followed by a MAC payload (MACPayload) and finishing with a 4-octet message integrity code (MIC):

MHDR	MACPayload	MIC
------	------------	-----

Table 1.4: PHYPayload

The MHDR defines the type of the message that is sent. Those types are join request, join accept, unconfirmed data up/down and confirmed data up/down,

1.3 TTN and LoRaWAN

where confirmed means that it has to be acknowledged by the receiver, while unconfirmed does not require that.

The MACPayload contains a frame header (FHDR), which is the device address of an end-device (DevAddr), followed by an optional port field (FPort) and an optional frame payload field (FRMPayload):

FHDR (DevAdd)	FPort	FRMPayload
---------------	-------	------------

Table 1.5: MACPayload

Three device classes are defined in LoRaWAN:

- Class A: in this class after the uplink transmission two reception windows are set in order to receive downlink messages. A stands for All, since all devices must implement this functionality.
- Class B: in addition to class A devices, this class open extra receive windows at scheduled times. Time synchronized beacons are sent from the gateway to fix those scheduled times in the end node.
- Class C: this type of devices have almost all time open receive windows and are only closed when transmitting.

Class A is the most common class as it is the most energy efficient.

The frequency band defined by LoRa is divided into 8 channels. In the case of downlink messages there are 8 channels used by the first reception window and another one used by the second window. Due to the regulations in Europe each channel must be of 125 KHz of bandwidth. During a data transmission the channel is constantly changing in order to make the communication more robust to interferences.

An important mechanism that is used to control the uplink connection between

the end node and the gateway is the Adaptative Data Rate (ADR). This protocol is able to modify automatically parameters like the Spreading Factor or the transmission power according to the signal power that the gateway is receiving. As it's explained before, the SF also affects the power used by the node so this mechanism is able to find the optimal point in which the node is only using the necessary power. The Things Network allows to disable or enable it depending on your purpose. If the device is stationary, TTN recommends to leave the ADR active, but if the end node is supposed to move, the SF and power should be in charge of the programmer.

The ADR algorithm is simple, but has important ramifications on the performance if the device is not stationary. The reason for this is that the ADR algorithm was designed in order to provide the best bandwidth utilization and the best battery life to devices with a stable radio communication. From this falls that a moving end node is not the optimal target for the algorithm. Nevertheless, the effects of it are easy enough to analyze. Currently The Things Stack takes the 20 most recent uplinks, starting at the moment the ADR bit is set.

For any LPWAN technology it's crucial to incorporate security. LoRaWAN uses two layers of security: one for the network layer and another one for the application layer. The network security layer ensure the authentication and all the transmission is encrypted by the application layer with the AES method. Private session keys are needed and there are two main different methods to obtain them:

- **Over the air activation (OTAA):** in this method the device needs to be equipped with a DevEUI that identifies the device, with a AppEUI to identify the application and with a AppKey that is used to sign an initial join request. Once the initial request is validated, the join server generates the two session keys, and they are sent to the end node. Those keys are

1.3 TTN and LoRaWAN

the NwSKey and the AppSKey and are used to identify the network server and to encrypt the payload.

- **Activation by personalization (ABP):** with this method you can access the network without a join request because the device is already equipped with the AppSKey and the NwSKey.

Usually the OTAA method is preferred, this is because it can generate new session keys for each session and it allows re-key. ABP is not as flexible as OTAA as the session keys are fixed in the device.

Chapter 2

Related Work

Summary

There have been studies conducted previously that aim to analyze parameters of lora communications in various environments, in this section we will see how they relate to our work and measurement results.

In the paper [1] the performance of ADR in a scenario in which the end nodes aren't fixed is analyzed. The ED were following three different routes inside a truck with different speed. The authors found that as the mobility increase, the performance of the ADR starts to decrease leaving space for further improvements in the LoRaWan adaptative data rate.

The idea of paper [2] is to improve the ADR system used in LoRaWan and TTN for mobile ED. The E-ADR (enhanced ADR) they propose is based on transmit messages with the shortest possible time interval between them and to assume the trajectory of the mobile end-node. The results are impressive as they achieve to reduce the ToA and the energy consumption of the ED in the scenarios

that are proposed. As a consequence, the packet loss is also reduced or eliminated because the achieved ToA minimizes the use of the allowed time limited by the duty cycle.

The authors in [3] develop a system of geolocation apart of gps or gsm based on the distance between the ED and the different gateways that is connected. They have reached an accuracy of 100m proving two different algorithms but it's only a first approach as this method can't be applied in real scenarios.

Chapter 3

System architecture and hardware/software used

Summary

In this chapter the design of our system is explained to give an idea of how the idea of this project is applied to the TTN architecture. In the other section we describe the devices and software used in order to achieve the objective.

3.1 Proposed system model

The next figure describes the proposed system in a graphical way to make it clear:

This LoRaWan system that is implemented starts with the laptop running the Arduino program on the adafruit board. The LoRaWan communication module of the board is capable of transmitting LoRaWan packets to the gateway. This communication is the one in which the measurements will be taken, so is the one that will be analized in this thesis. The gateway is connected to the Internet

3.2 Devices used and their implementation

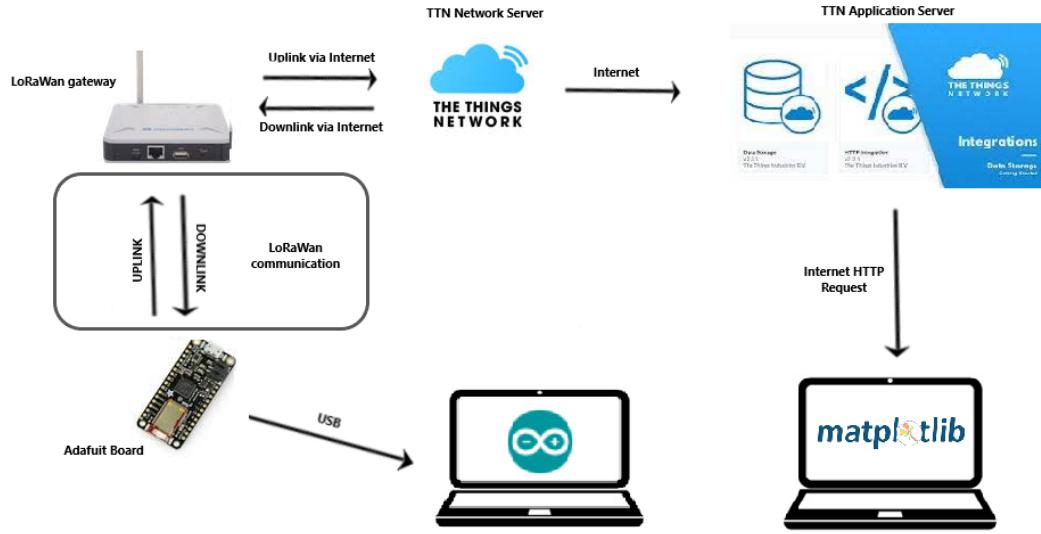


Figure 3.1: Proposed system

via the operator network and the data sent by the gateway will arrive first to the network server of TTN and then to our respective application server. The laptop is also making HTTP requests in order to analyze the data from the database of the application server using python, specifically the library matplotlib. This architecture allows to analyze the LoRaWan communication, which is the goal of this project.

3.2 Devices used and their implementation

3.2.1 The gateway

The model of gateway used for this is the indoor Dragino lps-8. This device is forwarding LoRaWan packets via internet. This gateway acts like a bridge connecting the LoRaWan wireless network with the Internet. The indoor model was selected because in this case the gateway is fixed inside a building. The

3.2 Devices used and their implementation

gateway is on the 5th floor, connected to wall power through a USB-C port near a window in order to have the best possible . The access to the internet is provided through WiFi connection to the house router/modem. The configuration of the router was done as it is illustrated in the figure 3.2:



Figure 3.2: Configuration of the gateway via WiFi

On google maps, with a scale of 20 meters as shown in the image at figure 3.3
The gateway was located in the pinpoint shown in figure 3.3



Figure 3.3: Location of the gateway on the map

3.3 The microcontroller

The microcontroller used as a node in the network is the Adafruit Feather M0 RFM95 LoRa Radio. The device is equipped with a transceptor module LoRa, with built in USB and battery charging. The processor is a ATSAMD21G18 ARM Cortex M0 at 48MHz and 3.3v (the same as the Arduino Zero) and a quarter of a megabyte of FLASH, with 32k of RAM. Thanks to the USB port, and a bootloader, the device can be programmed and debugged through the USB port, no need for an external programmer, which would have been yet another thin layer of complexity.

More info of the board and the pinout can be found [here](#) The I2S connectors were used to connect the sensors which communicated through the protocol, and DIO1 was manually wired to GPIO6 so that the radio would work. For each individual sensor a different connection may be needed, so in general, we connected the I2S to the same pins SCI and SDA and the simple voltage for temperature sensor was connected directly to the GPIO A0, setting it to an input on software to read from it.

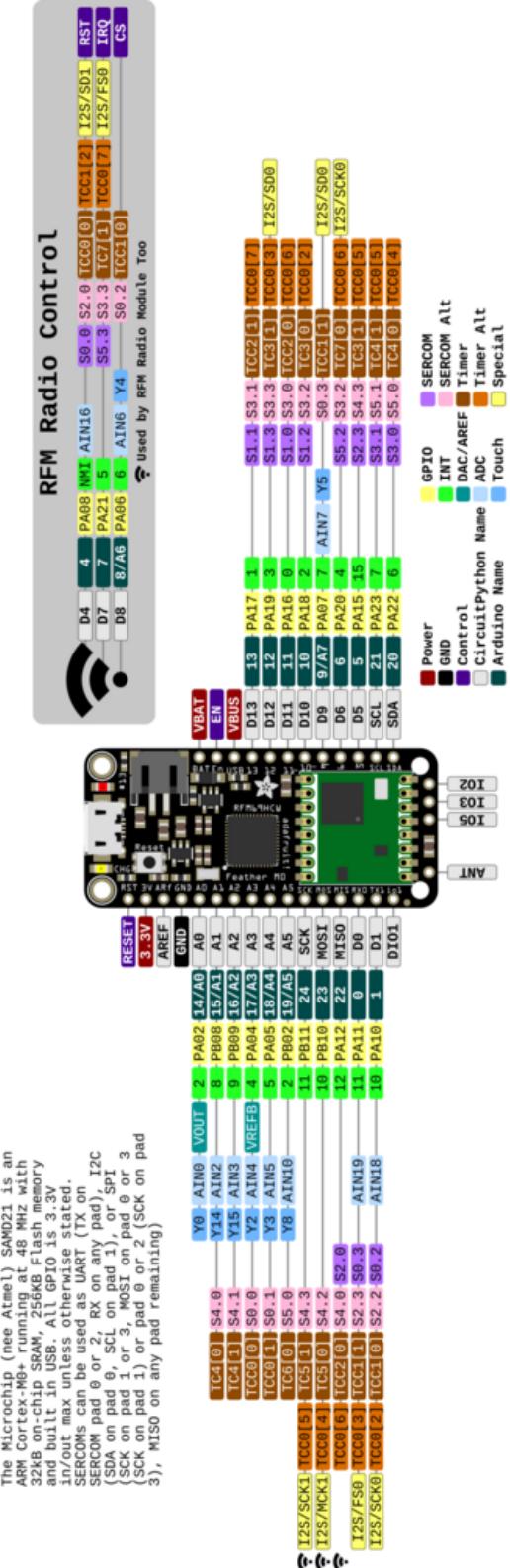
3.3.1 Sensors

The first sensors mentioned were used to introduce us to the Arduino and IoT enviroment and the last one (the gps module) is the one we finally used in order to measure the distance between the node and the gateway:

- Temperature and humidity sensors:
 - The [hdc1080 sensor](#) is a digital humidity sensor with integrated temperature sensor that provide respective measurements using low power consumption.

3.3 The microcontroller

Adafruit Feather M0 RFM69
<https://www.adafruit.com/products/3176>



3.3 The microcontroller

- Another sensor with similar purpose is the [bme280 sensor](#). in addition to the other one this sensor is capable of measuring pressure apart of temperature and humidity.

Two of this sensors were used and the respective models are hdc1080 bme280

- Air quality sensor: sensor of the brand **SPEC SENSORS** specifically the model [ULPSM-IAQ](#). It measures the indoor air quality with very low power consumption and the output signal in this case is analog.

This sensors are designed for the IoT enviroment as all of them use low power consumption. This characteristic is optimal for the purpose of LoRaWan networks using the less power consumption as possible.

3.3.2 GPS module and antenna

The module [u-block LEA-6S-0-001](#) is able to obtain the specific coordinates in which the module is placed with a precission of 2.5m and it's also designed for low power consumption.

This module is designed for the use of passive and active antenna. The antenna selected for this gps module is an active one, which means that the received signal is amplified. The available frequency bands are the following ones:

In our case we will work with 1575 MHz as it is the band that detects our antenna.

3.4 Software used

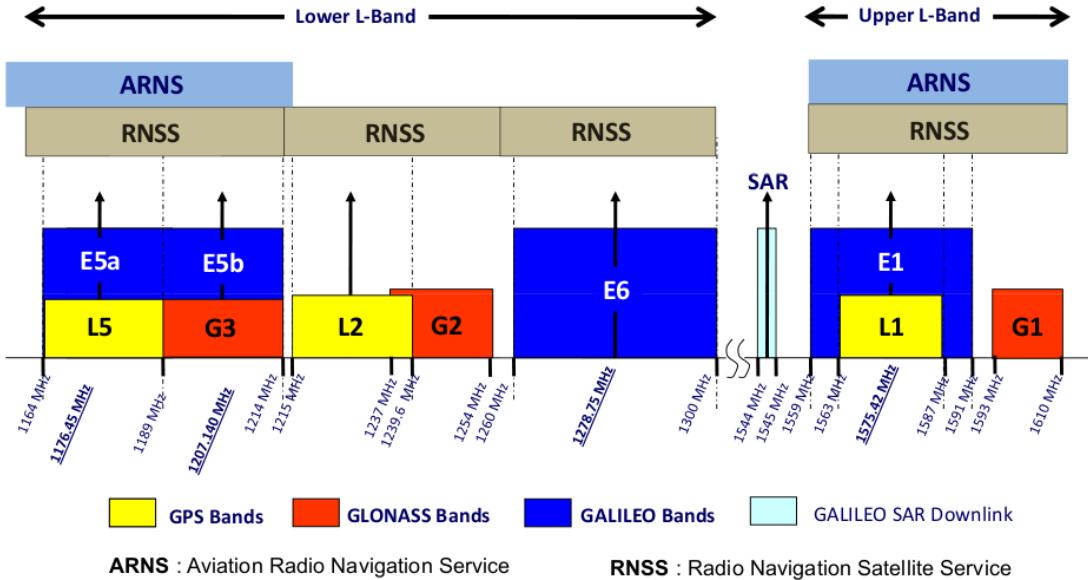


Figure 3.5: Center frequency and BW for the three different GPS bands

3.4 Software used

3.4.1 MCCI LMIC Arduino library

The MCCI_LoRaWAN_LMIC library was the most complete library for our purpose. The recommended library by Adafruit has the flaw of not being compliant with the TTN standard anymore as it cannot receive downlink messages, and the RadioHead library is a LoRa library, requiring us to implement the whole LoRaWAN engine for ourselves. MCCI_LoRaWAN_LMIC library is already done so there was no need to waste our efforts. For more information about the library, the documentation, code and repository are [here](#). The library is a pretty big and complex piece of C code, so a brief explanation will be given. Using the 4.1.0 version, so it will be the model explained: (GPS Click - Breakout Board for u-blox LEA-6s, 2022)

In figure 3.6 is pictured the whole finite state machine. The only part a user should be concerned about is the frame data set up, the actions to be taken

3.4 Software used

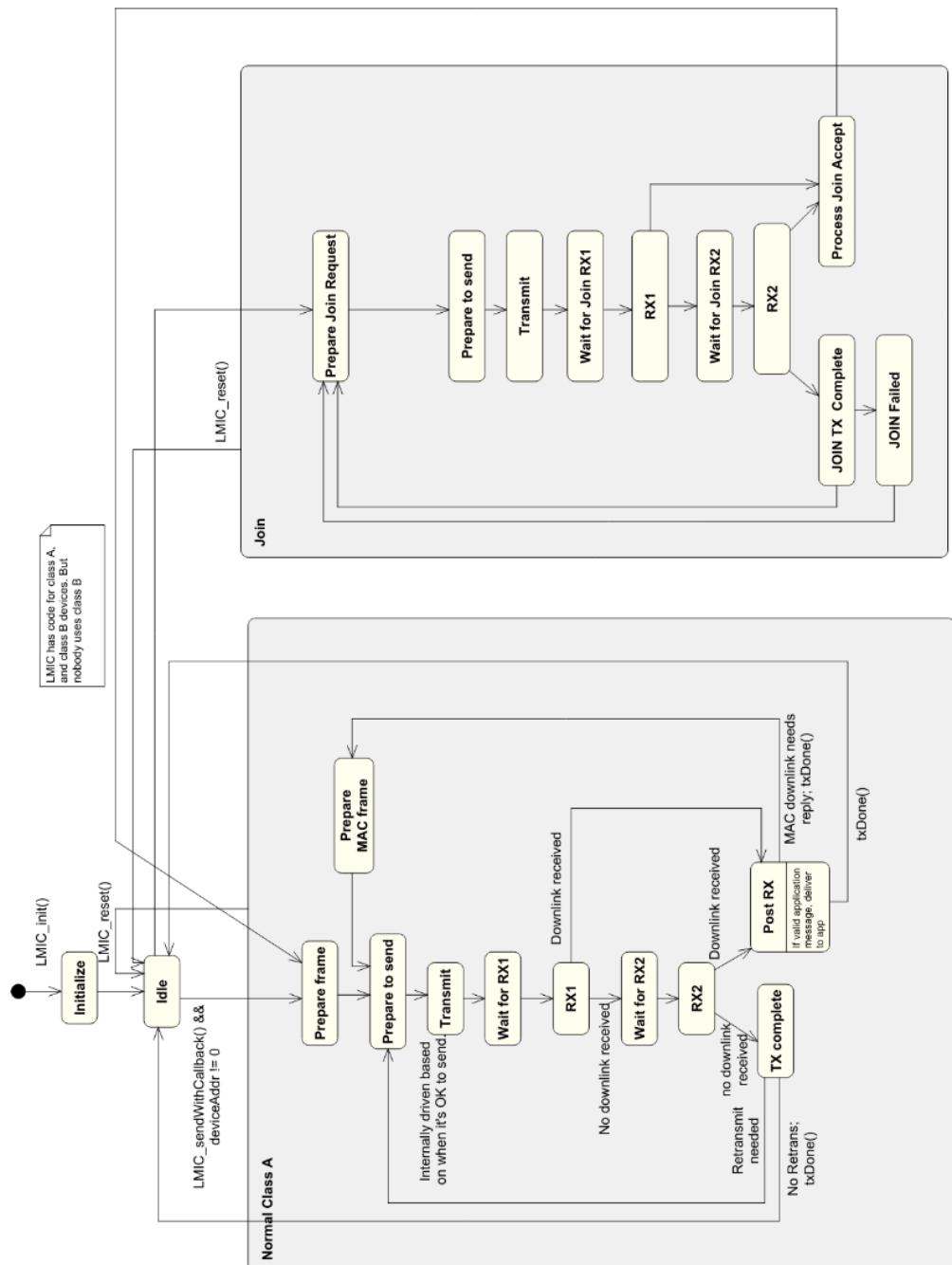


Figure 3.6: Finite state machine of LMIC library

for every event desired to react to with the `onEvent()` call-back function or `LMIC_registerEventCb()` API function. Both are currently supported, and although the `onEvent()` application call-back is currently deprecated, it still works on version 4 and it is simple to implement and debug. The other option is the recommended one, but is harder to comprehend. We ended with a function that, when the package is sent, a timed call-back is issued thanks to the convenience function `os_setTimedCallback()` to schedule a job in the next `TX_INTERVAL`, that job in charge of queuing up another packet of data to be sent, which will be collected by the engine and, when sent, the cycle starts once again:

first job → sent → wait TX → job → sent → wait TX → job ...

This is “interrupted” by the compliance engine, that ensures that the law is not broken by keeping track of the air time so that the device can’t send more than the percentage set by the region configuration in the library (currently on EU 868). The I2C library was used to communicate with the sensors, as a dependency of the particular libraries for each one of them. `ClosedCube_HDC1080` library was used for the more straightforward and the `Adafruit_BME280` was used for the other sensor.

3.4.2 TinyGPSPlus

This library is designed to parse all type of NMEA data that the GPS module provides. In our case this library is used in order to extract the exact latitude and longitude of the ED. More info about this library can be found in the [github repository](#)

3.4.3 U-center

The software developed by the company u-block is a monitoring system for the gps module mentioned before. U-center provides info about the signal that gps is

3.4 Software used

detecting from the gps-satellites. Once the gps is calibrated the u-center software provides all data the gps is collecting including the longitude and latitude.

3.4.4 Arduino

3.4.5 Python

Chapter 4

Experimental measurements and methodology

Summary

In this chapter the methodology followed in experiments and the different measurements that are observed during the data transmission are explained in detail.

4.1 Measurements

The following indicators describe the quality of our wireless LoRaWan communication in the mentioned experiments:

4.1.1 RSSI

RSSI (Received Signal Strength Indicator) is one indicator that provides the information about how strong the received signal is. It is measured in dBm and its value is always below zero, this means that the closer to zero the RSSI value, the stronger the received signal is.

4.1 Measurements

This indicator is calculated by the sum of different parameters like the path loss, the transmission power of the antenna, the cable losses and the antenna gain.

4.1.2 SNR

This indicator of quality of signal received takes into account the noise floor signal power in the communication. When we transmit in wireless communication, the presence of the noise can surpass the power of signal received and not being able to get any information from the signal. The SNR is also measured in dBm and it's the subtraction between the power received and the power of the noise floor during the communication.

However, LoRa due to its demodulation explained in chapter 2, is able to demodulate and extract information from the signal for negative SNR values. The limit of the minimum value of SNR for the receiver depends on the SF as the figure below shows:

SF	chips / symbol	SNR limit
SF7	128	-7.5 dB
SF8	256	-10 dB
SF9	512	-12.5 dB
SF10	1024	-15 dB
SF11	2048	-17.5 dB
SF12	4084	-20 dB

Table 4.1: Limit SNR and chips per symbol for different SF

4.1.3 Packet Loss

The Packet Loss is simply the ratio between the packets that the gateway is receiving and the packets the end node is sending. This measure is observed thanks to the frame counter that the LoRa packets implement. The frame counter contains the number of packets that the end node is sending.

In order to calculate this ratio the frame counter and the number of packets that appear in our TTN server are considered.

4.2 Metodology

4.2.1 First Experiment

The ADR as it's introduced in 1.3 can modify parameters of communication such as the SF, the transmission power or the BW to get a better SNR or to reduce the excessive power consumption of the end node.

The so-called "Margin" is calculated after a number of transmissions (uplink). The maximum SNR of those transmissions minus the required SNR to demodulate a message given the data rate are considered. This margin is used to determine how much we can increase the data rate or decrease the transmit power.

In the things stack for modifying the SF to increase the SNR and get a better communication, 64 packets without a downlink message of the ADR are needed. In that case the node will increase the SF or the transmission power in order to start receiving downlink packets again.

In the case that the margin is high enough, which means that the node is

4.2 Metodology

consuming excessive power, the ADR after 20 packets of uplink sends a dowlink message to the node in order to adapt the parameters of communication and consume less power.

As it can be supposed from the last information about the ADR, its performance is useful when the end node is fixed. But if the end node is moving with the ADR activated, what happens to the communication? Is better for the data transmission to fix one SF and the transmission power in the end node?

Those questions were formulated in order to perform our first experiment. In this first experiment two types of configuration between the end node and the TTN servers are selected. In one, the ADR is activated from both sides of the communication as it follows:

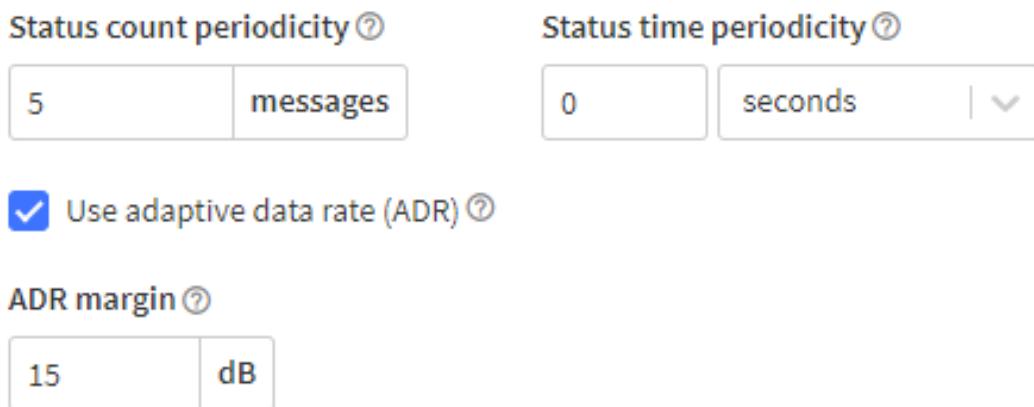


Figure 4.1: ADR configuration in TTN console

For the other one a medium SF is selected, SF10, and the transmission power is fixed to the default one (14 dBm).

The idea of this experiment is to follow the same route in a urban area for both configurations and analize which is performing better by measuring the packet

4.2 Metodology

loss, RSSI and SNR in both cases. The route planned for this experiment is inside the city of Genova, in the Porto Antico area as it is illustrated in 4.2

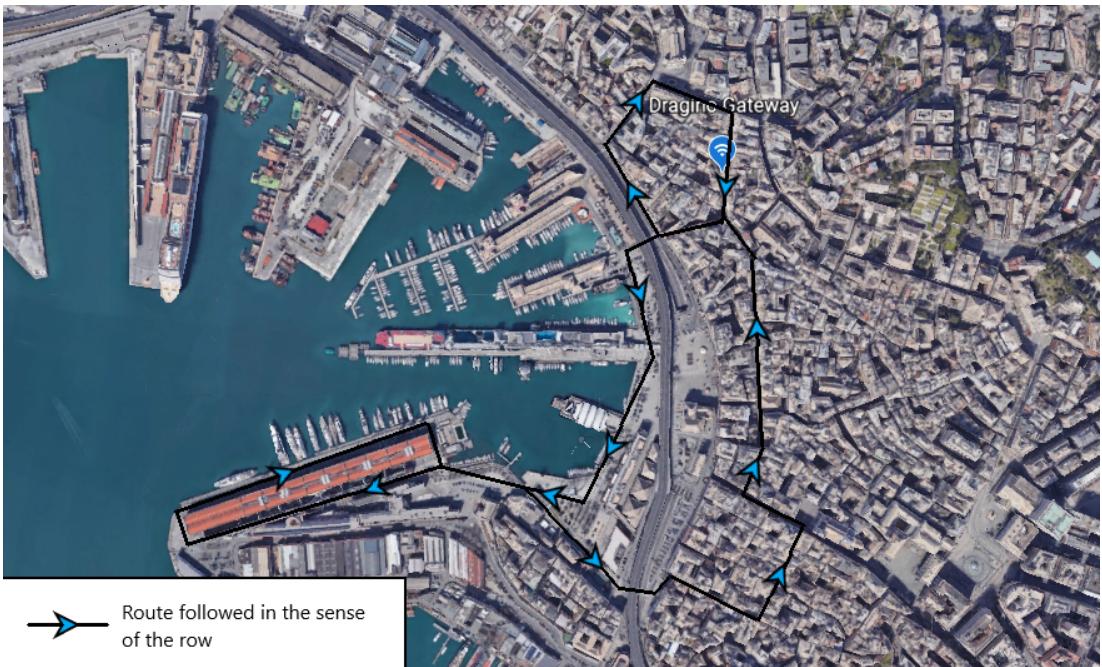


Figure 4.2: Area of Genova where the experiment is performed

Thanks to a battery connected to the adafruit board the mobile end node is builded. This battery was attached to the bottom of the board and packed inside a tupper as it is ilustrated in 4.3 allowing us to move confortably following the planned route.

4.2.2 Second experiment

The ADR shows how important is to choose the correct Tx power and SF in a LoRaWan data transmission. The margin calculated by the network server depends basically on how far from the gateway the ED is located and on the area/landscape the network is placed. We know that different scenarios can cause a huge difference in terms of interference for our comunnication, e.g, in

4.2 Metodology

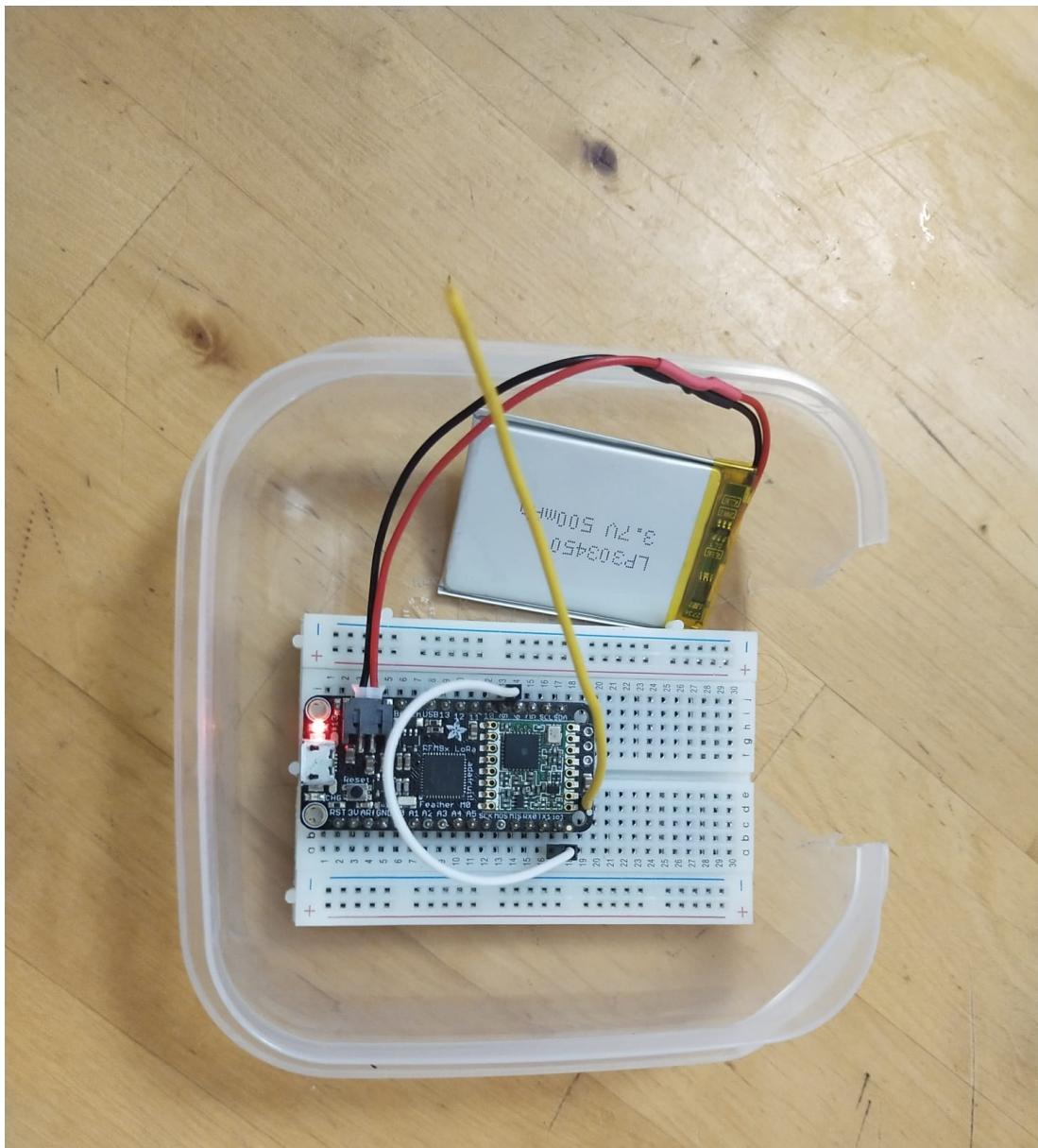


Figure 4.3: LoRaWan mobile end-node used

4.2 Metodology

an open space LoRaWan protocol is able to perform much better than in urban areas where buildings and other causes of interference are present. This idea is corroborated by the thesis ([link](#)).

We wanted to know how different transmission parameters can affect a LoRaWan communication without the use of ADR and to see the influence of different landscapes inside a urban area for the indicators cited in 4.1.

The idea for this second experiment the objective is to further expand and analyze the results obtained previously designing a program that will be running in the adafruit board that is constantly changing the values of SF and Tx power.

[Insertar foto]

Once the device is set up we modified our test code to send the coordinates of its current position which will allow us to calculate the distance from our Gateway to the end node and it also allows us to trace the path and determine in which part of the city we are sending our packages. With this information we can analyze how different parameters behave in different environments.

The area of testing will be the same as in the last experiment with the exception that in this experiment we won't follow a fixed route.

Chapter 5

Simulation and data analysis

5.1 Results for the first experiment

ED configuration	Packets sent	Packets received	Packet loss
ADR activated	263	156	40.68%
SF10 and 14 dBm	112	70	37.5%

Table 5.1: Table comparing the packet loss of the two cases

ED configuration	Medium SNR (dB)	Medium RSSI (dBm)
ADR activated	2.07	-103.68
SF10 and 14 dBm	-2.11	-111.85

Table 5.2: Table comparing the medium RSSI and SNR in both cases

5.1 Results for the first experiment

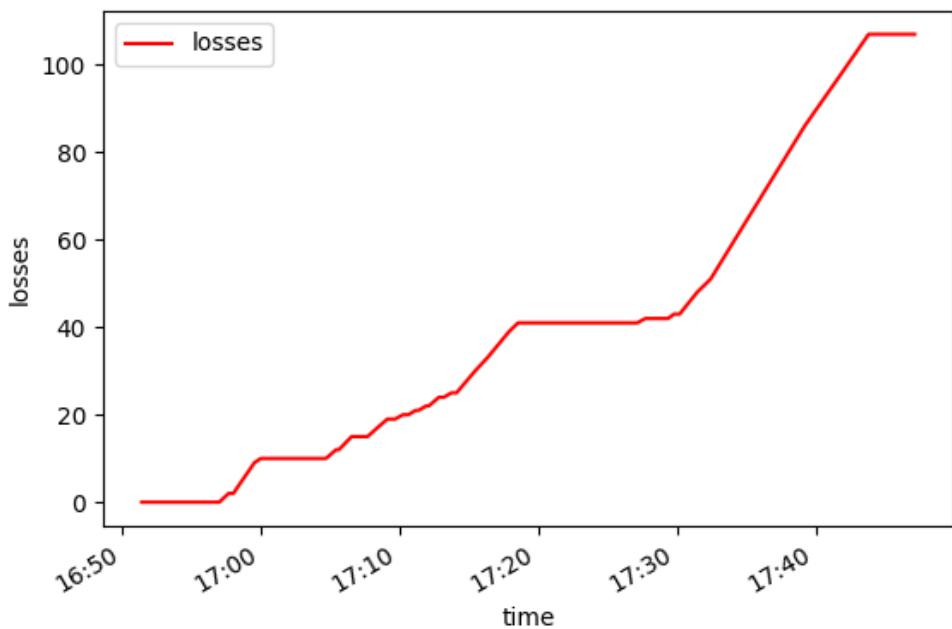


Figure 5.1: Acummulative packet loss with ADR depending on the time the packets arrived

5.1 Results for the first experiment

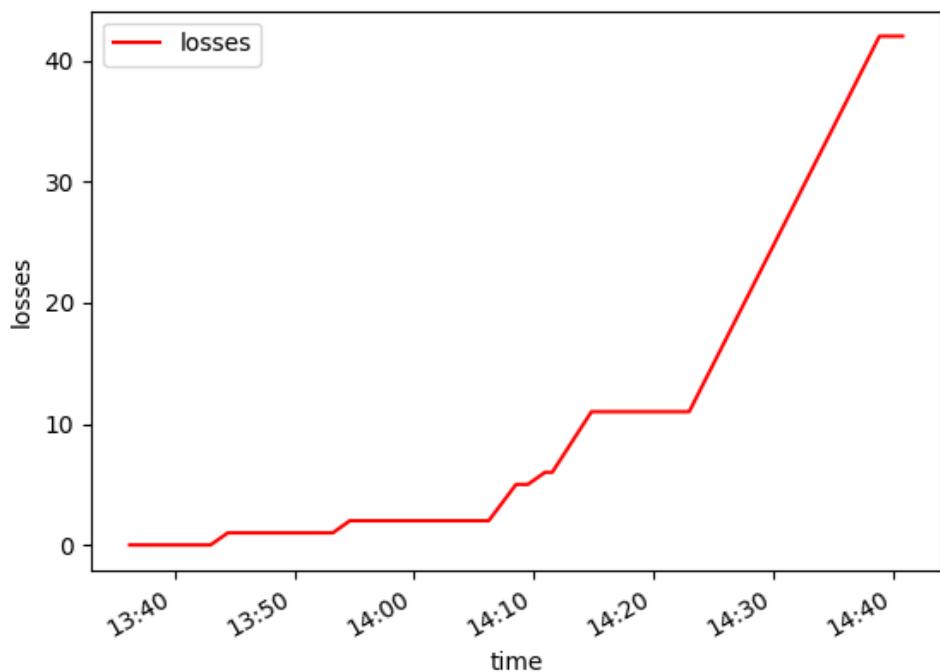


Figure 5.2: Acummulative packet loss without ADR depending on the time the packets arrived

5.1 Results for the first experiment

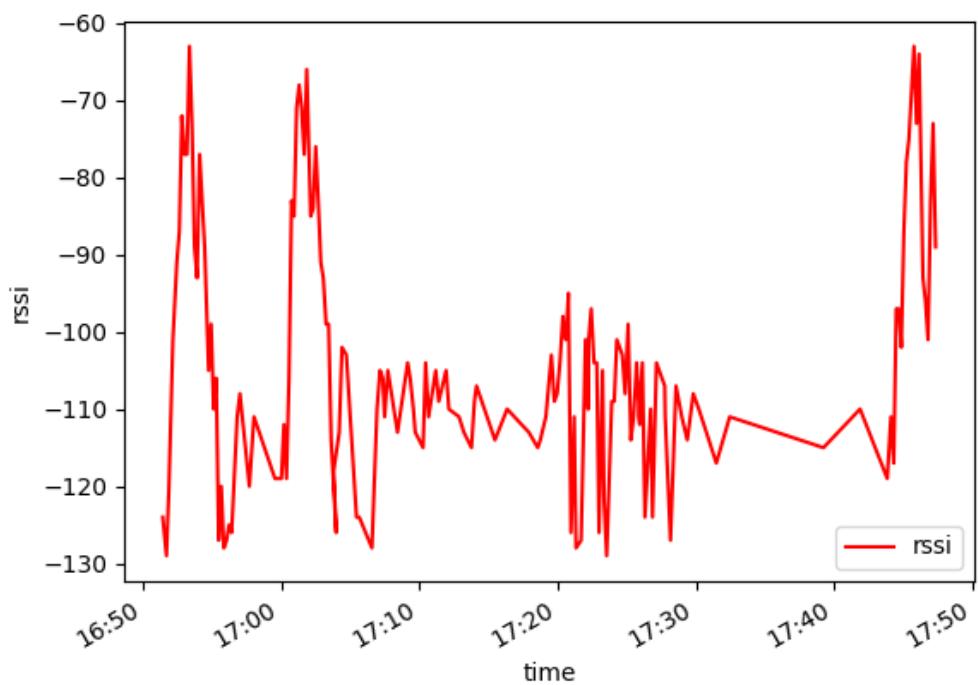


Figure 5.3: RSSI with ADR config. depending on the time

5.1 Results for the first experiment

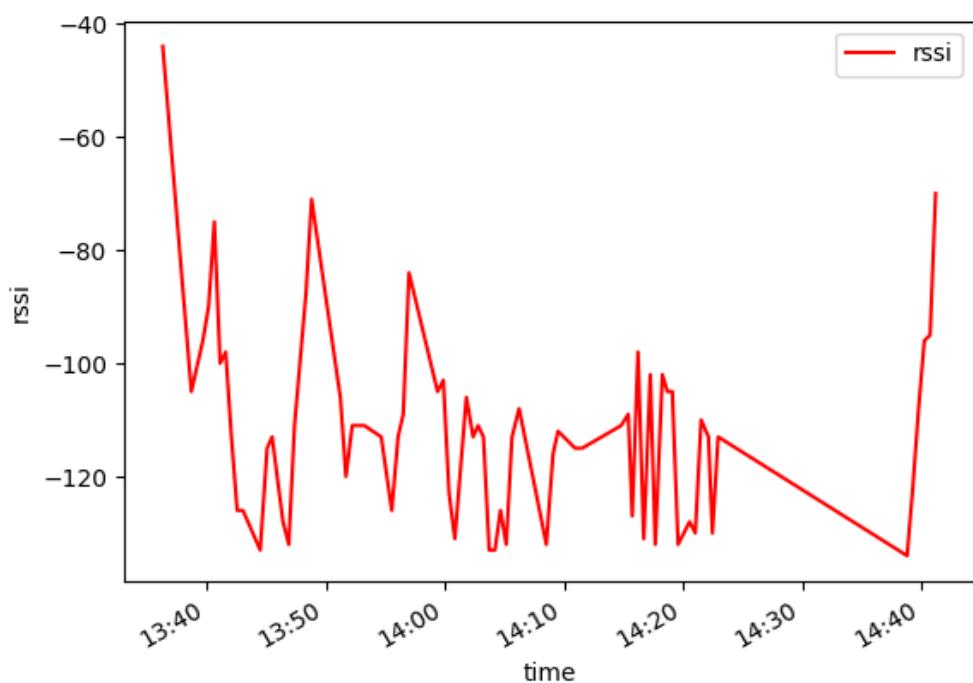


Figure 5.4: RSSI without ADR config. depending on the time

5.1 Results for the first experiment

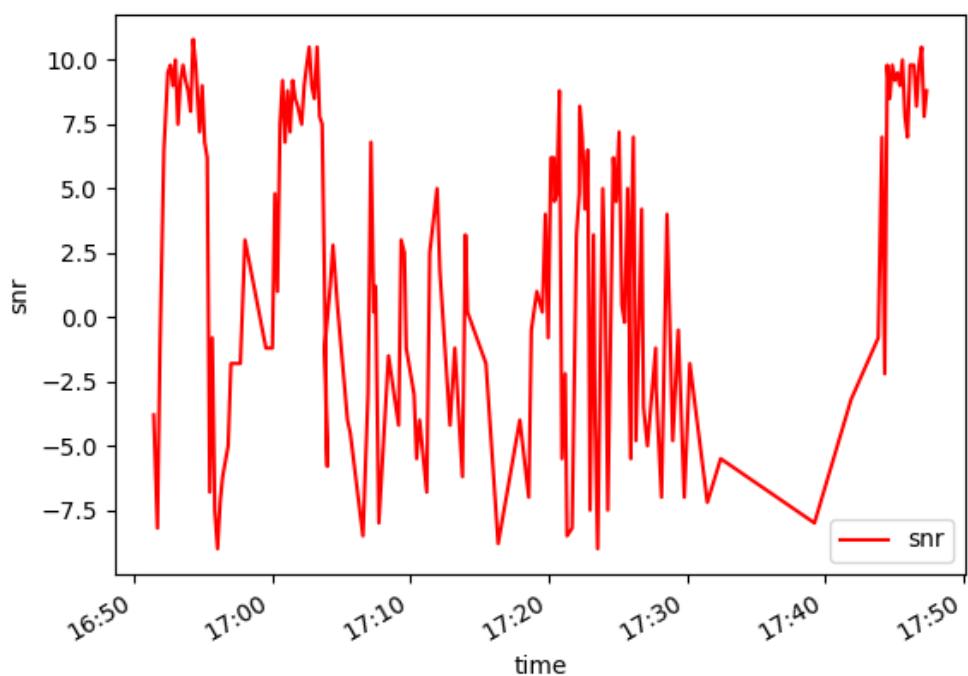


Figure 5.5: SNR with ADR config. depending on the time

5.1 Results for the first experiment

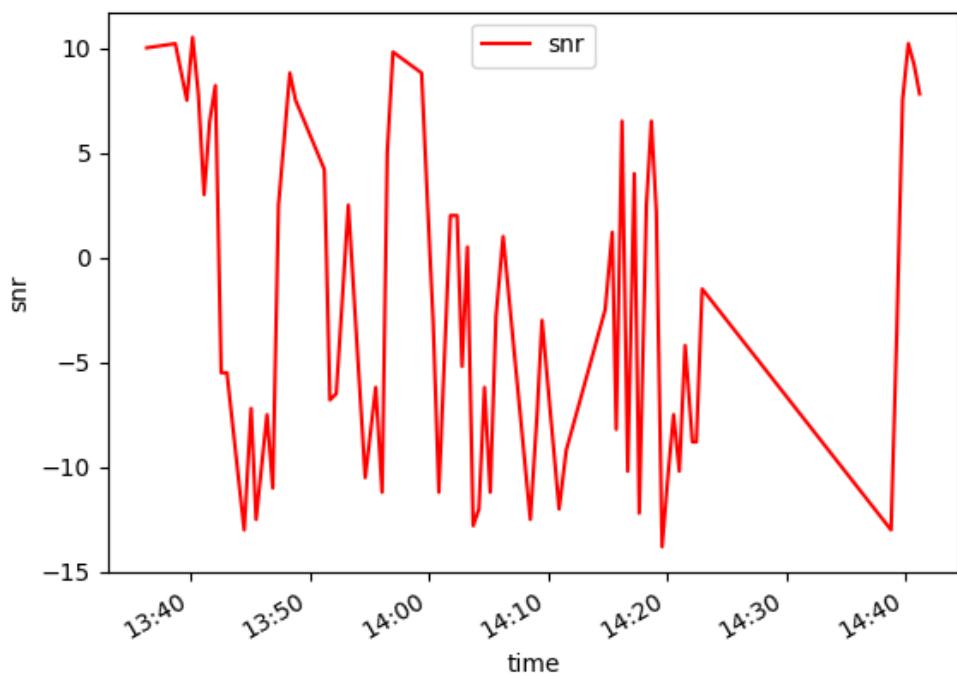


Figure 5.6: SNR without ADR config. depending on the time

Chapter 6

Conclusions and future work

6.1 First experiment conclusion

In the configuration with ADR the ED did not change from SF7. This is probably because we were moving and we didn't get 20 uplinks a low maximum SNR to increase the SF. We didn't get either 64 uplinks without a confirmation as our maximum packet loss between two uplinks is 35. (All this is explained in 4.2.1). In this case the ADR configuration was pointless as the end node wasn't able to change the parameters like the SF or the power to obtain the optimal data transmission. As we got always an spreading factor of 7, the performance during the experiment with this configuration is worse compared with the one we selected with SF10 and a fixed Tx power of 14dBm as you can see in 5.1. The reason why in ?? the values of SNR and RSSI are lower in the case of ADR is because the other configuration is able of detecting signal in worse situations as we can see in Thanks to the performance of this experiment we were able to extract valuable information related with the signal received depending on the landscape of the city. We distinguish two zones, the area of 'vicoli' and the port area: 'Vicoli' is an italian word used in the city of Genova for narrow streets. The historic center of Genova is plenty of them making the data transmission almost impossible unless the ED is close to the gateway (around 100m but it depends if you have direct

6.2 Second experiment conclusion

vision). Next to this zone is the area of ‘porto-antico’ which is a much more open-space area where the communications reach much longer distances. The results and graphics shows that the port area showed in the figure (link) is much more suitable for a LoRa communication rather than the area of the ‘vicolis’.

6.2 Second experiment conclusion

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