JARDIN - Baptiste
NGUYEN - Justin
BERNERD - Clara

PROJECT REPORT: Indoor Geolocation with LoRa 2.4 GHz

I- Introduction :

Current context: There are many well-known geolocation tools currently available (notably GPS, which is a satellite-based geo-positioning system usable by anyone) but these are generally very expensive in terms of energy and material resources and sometimes not very accurate over short distances. With this project, we are exploring new possibilities that would allow us to obtain similar or even better results but with fewer resources required.

Our project therefore focuses on the measurement of distances between a transmitter and a receiver in Lora 2.4GHz. The specific aim is to experimentally evaluate the accuracy of this measurement.

In this report, we will explain the angles of attack we have chosen, the technologies we have used, the existing solutions to our problem, our modifications of pre-existing code and finally a conclusion summarizing what we have learned and what remains to be done to complete this project.

We decided to separate our project into several independent phases. Firstly, we sought to understand the project issues and the technologies and hardware used. For this first phase, we took the time to do a lot of tests and trials, to see what could and could not be done with the equipment available. In a second phase, we defined our measurement protocol by taking into account the existing solutions. We made sure that our measurement protocol was as accurate as possible (taking into account various constraints). We then studied our results and finally tried to draw the relevant conclusions based on our data and assumptions.

II- Technologies, hardware and software used:

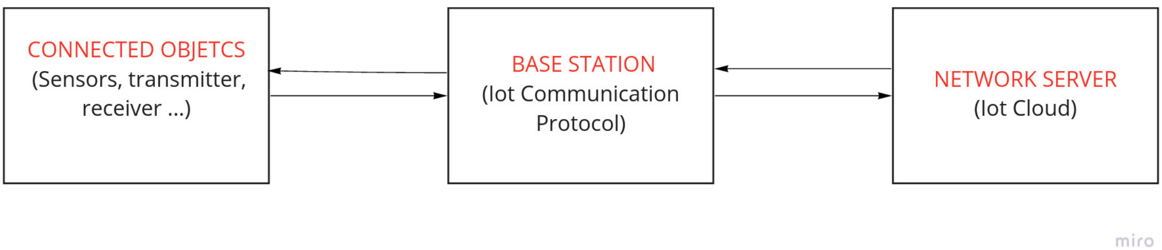
- LoRa 2.4GHz :

The most important technology used in our project is probably the Lora 2.4GHz protocol.

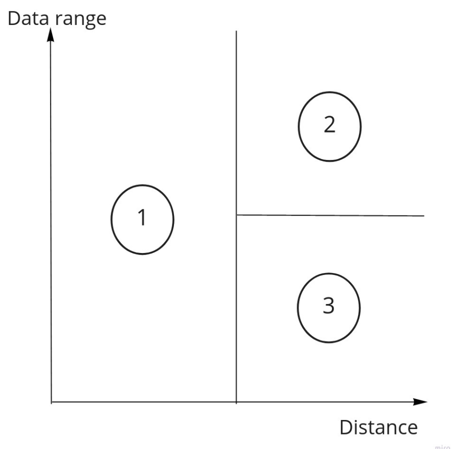
According to the definition given by the official Semtech website:

"LoRa (Long Range) is the de facto wireless platform of Internet of Things (IoT). Semtech's LoRa chipsets connect sensors to the Cloud and enable real-time communication of data and analytics that can be utilized to enhance efficiency and productivity. LoRa devices enable smart IoT applications that solve some of the biggest challenges facing our planet: energy management, natural resource reduction, pollution control, and infrastructure efficiency.

This technology is part of the Internet of Things (interconnection between the Internet and physical objects, places or environments). In short, the IoT is the way to make terminals communicate as receivers and transmitters using the Cloud). This principle is represented in the following diagram:



The LoraWAN protocol (above LoRa) goes from the "Connected Objects" part to the "NetWork Server" part. This protocol makes it possible to send small amounts of information over very large distances. We compare this protocol to others in the following graph:



(1) corresponds to contactless card payment technologies, Bluetooth and Wi-Fi. In this part of the graph, a lot of data is exchanged but over a short distance.

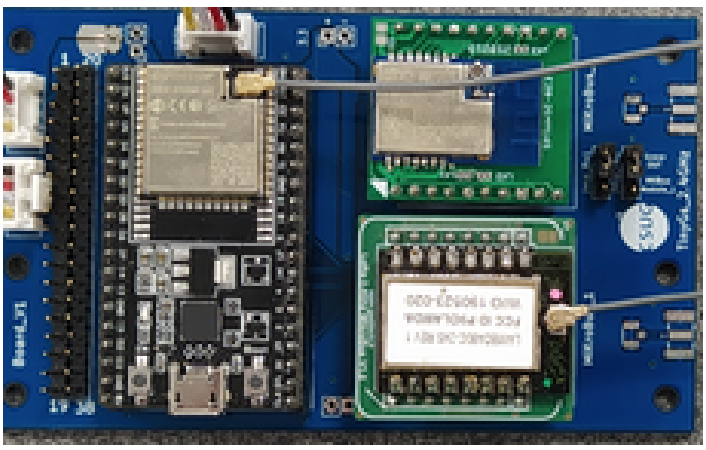
(2) corresponds to 2G, 3G, 4G, 5G: this is a communication that carries a long way but consumes a lot of energy (and therefore rapidly depletes the modules' battery)

(3) This is where LoRa is located. It is a communication that carries far but sends little information and therefore consumes little energy.

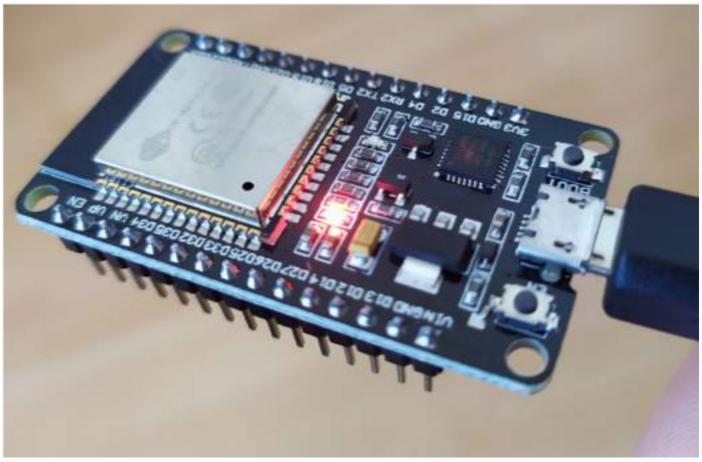
We now have a clearer idea of what the LoRa 2.4 GHz protocol is and how it is used. Let's see now with which hardware we have implemented it.

- TinyGS, ESP-32 and antennas.

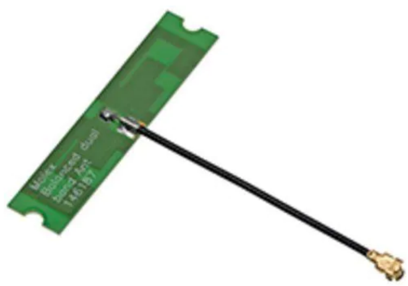
We got some equipment from the FabLab in order to realize our project.First of all a TinyGs card which is a ground station card that will receive (or send) messages on the 2.4GHz band.



On this board there is a module called ESP32. The ESP_32 is a small electronic board which is a microcontroller. This module is very similar to the Arduino board. Microcontroller boards are circuits with programmable inputs and outputs. They are used to acquire data from sensors, to send data signals or to control a circuit. On this module we have a port to connect our card directly to our computer via the USB port. It is this microcontroller board that we are going to program with the Arduino software that we will talk about next.

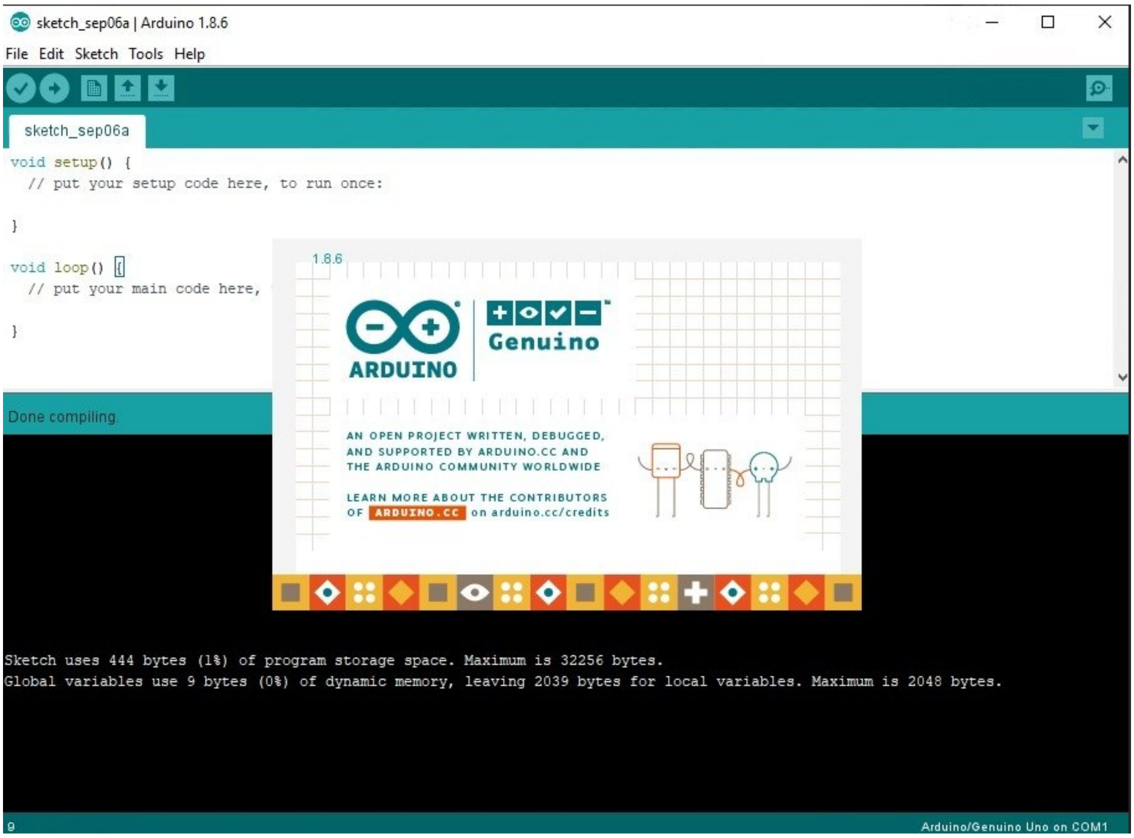


Finally, a second module on the TinyGS board allows us to attach our antennas to send and receive messages.



- Arduino :

The Arduino software allowed us to realize/ revisit the code necessary for our project. This software is used to program the ESP32 microcontroller board. The interface is called Arduino IDE (Java application) and provides a code editor and compiler. The programming language used for Arduino is C++. Arduino also provides a library manager. It is a very easy to use software. The code of our project could also have been realized through the RIOT OS operating system.



III- One solution : Ranging

The principle of ranging is based on Round Trip Time-of Flight (RTToF) distance measurements. Let's illustrate the process of ranging on the diagram below. The ranging Master is M, and the ranging Slave is S.

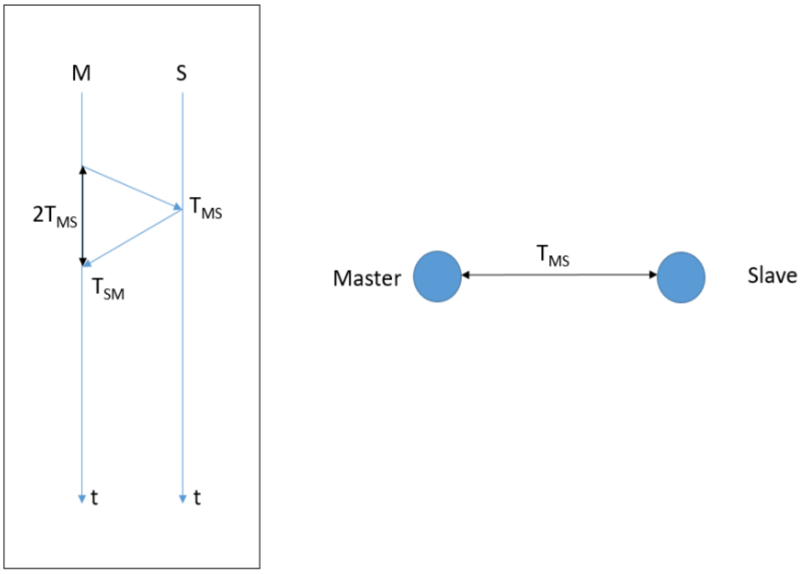


Figure 3: RTToF Distance Measurement

First of all, a ranging request is sent by the ranging Master to the ranging Slave. At the moment the Master transmits its request, an inner timer is started. The signal is an electromagnetic wave, which means its speed is known and equal to the speed of light. Then, the request finally arrives to the Slave after a time T_{MS}. After that, the Slave sends back a synchronized version of the ranging request. This request takes time $T_{SM} = T_{MS}$ to reach the Master. Indeed, the speed of the request is the same, and both the Master and the Slave did not move, which means the amount of time required is the same.

Ultimately, it took twice the amount of time needed for one trip. We can then calculate the distance by using the formula Distance = Speed * Time, because we can consider the speed as a constant.

One problem is that it takes time for the Slave to treat the request and send back a request to the Master. Thanks to calibration, this amount of time can be estimated and cut off the time measured.

IV- Protocol, measurement methods and measurement results

We established a protocol beforehand in order to carry out our measurements:

- Choose two points on a map that can be easily located and that respects certain constraints such as taking into account the Fresnel zone
- Send a distance message using one of the two devices
- Calculate this distance ourselves (taking into account the uncertainties) to determine the accuracy of the message
- Make as many measurements as possible under various conditions to get an overview of the capabilities of our equipment.

But depending on the distance estimation methods, some steps are not necessary.

Code modifications to calculate RTT (Round-Trip Time)

The code base we have been provided with allows us to send messages between a sender and a receiver, but we have to decide beforehand which of the two roles the device will play, as the codes are separate.

To calculate the RTT, a first node must send a packet, then a second node must receive this packet and immediately send a packet to the first node. The times at which the packets are sent and received give the transmission time of the waves, and knowing the speed of these waves we can calculate the distance between the two cards with distance=speed x time.

We first combined the two codes into one to carry out the role of a transmitter (sending and receiving packets) to be able to calculate an RTT but also so that it can be executed on any of the devices.

We have also added the functionality of sending a message with the push of a button to control when to start the measurement.

However, this method requires an atomic time to have as little uncertainty as possible and the processing time of the chips to be known, neither of which we have achieved with this code.

Measurement with the Ranging code

The Ranging method allows us to have direct distance measurements without additional calculations. We thus carried out multiple measurements by varying different parameters.

Rue de la Chimie (607 m on Google Maps)

Spreading factor/ Bandwidth (Hz)	SF5	SF6	SF7	SF8	SF9	SF10
400	0.0 (not valid)	609.2	654.0	567.5	632.1	594.1
800	0.0(not valid)	0.0(not valid)	0.0(not valid)	0.0(not valid)	606.8	606.8
1600	0.0(not valid)	0.0(not valid)	0.0(not valid)	0.0(not valid)	0.0(not valid)	0.0(not valid)

Distance between the Oxford tram stop and Marie Louise Paris - CEA (492 m on Google Maps)

Spreading factor/ Bandwidth (Hz)	SF8	SF10
400	529.8	omitted
800	491.4	494.3

Rue de la Chimie between Aiova and the Department of Molecular Pharmacochemistry (DPM) (100 m on Google Maps)

Spreading factor/ Bandwidth (Hz)	SF5	SF10
400	104.7	86.3
800	93.8	133.8
1600	176.1	148.6

Distance between the 6th floor of the Flandrin residence and Rue Jacques Thibaud (Height test) (38m Google Maps + Pythagoras)

Spreading factor/ Bandwidth (Hz)	SF5	SF10
400	omitted	0.0(not valid)
800	53.4	35.9
1600	omitted	84.1

Close range test (3 m between both cards inside a classroom)

SF8/ Bandwidth (Hz)					
800	0.0(not valid)	56.3	35.2	2.6	89.4

Receiver sensitivities (in dB)

Spreading Factor/ Bandwidth	SF5	SF6	SF7	SF8	SF9	SF10
400	-103	-115	-120	-120	-120	-120

Background and interpretation of results

We chose reference distances that are easy to gauge on a map (here from Google Maps) even if they are not exact distances, they are all based on the same source.
The values in the tables are in meters (to the accuracy of 0.1 meters) and are the averages of several measurements if applicable.
Some measurements were omitted after our first round as redundant/non-essential.

We notice that multiple values are 0.0 (not valid), which means that the Master and Slave nodes have not managed to establish a stable link despite numerous messages hence the not valid error message which is common with low Spreading Factors combined with higher bandwidth. This means that the bitrate (which depends on the Spreading Factor and the bandwidth) influences the communication distance between the devices.

The sensitivity of the receiver is higher as the Spreading Factor increases (the maximum is set to -120 dB in the modulation configuration files).

Regarding the accuracy of the measured distances, it can be deduced that the most accurate distances are those measured with the best communication between the two cards in general. Furthermore, some measurements are surprisingly accurate and others are very inaccurate, suggesting measurement errors due to poor communication between the boards.
Measurements taken in closed places and at very short distances cannot be valid.

It should be noted that:

- The higher the Spreading Factor, the further apart the cards can be.
- The lower the bandwidth, the further the cards can communicate.

V- Conclusion :

Distance measuring using LoRaWAN seems to be an interesting alternative to existing solutions such as GPS (Global Positioning System).

Observed measures on medium distance (about 500 meters) are very satisfactory with a relative gap lower than 5%. The LoRa network also consumes less energy than its competitor. Although, it could be interesting to measure to what extent this difference is significant.

However, measures on very short distances, below a dozen of meters, aren't always reliable. Some spreading factors and bandwidth should also be avoided in order to ensure transmission of data.

Moreover, if there are obstacles between the transmitter and the receptor, the communication may be cut off. That's why we chose open areas while measuring. One solution to reduce the impact of obstacles may be to put the transmitter and receptor at a certain altitude, in order to reduce the Fresnel zone. We started interpreting the impact of height but it could be interesting to take measures with someone at the Bastille, as well as measures on distance above 1 kilometer.

For further research, LoRa Ranging can be used for localization. Indeed, by using three ranging Master at a fixed position each, we can trilaterate the position of the moving ranging Slave as shown on the diagram below.

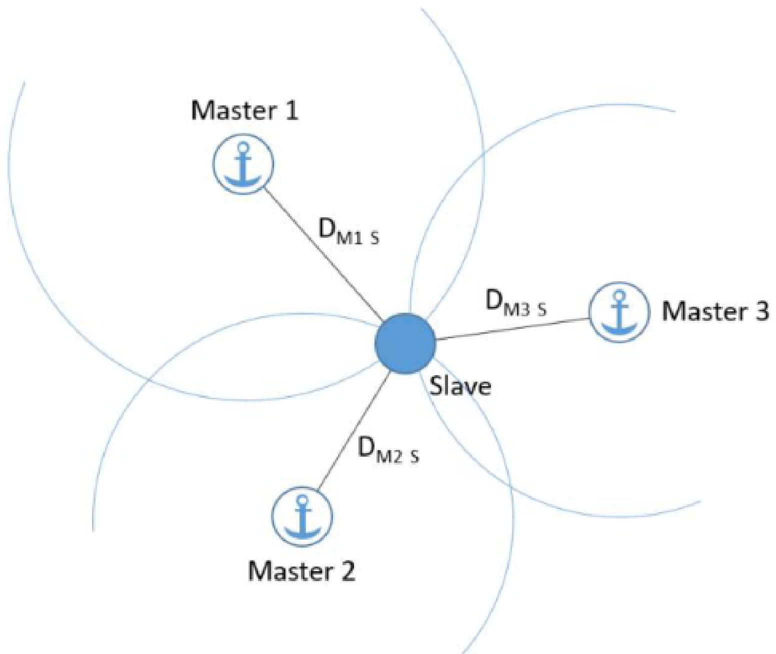


Figure 4: Distance Measurement Trilateration

Using only one Master can give us a line on which the ranging Slave is. Using two Master gives us two intersections where the ranging Slave can be. But by using three ranging Master, you can determine the exact point where the ranging Slave is, with as unique incertitude the precision of the respective measures of each ranging Master.

Finally, in the current geopolitical context, the LoRa network allows a certain independence regarding American satellites, which is wished by Europe who is by the way currently implementing its own GNSS (Global Navigation Satellite System) using satellites with the Galileo project.