Département de Génie Electrique & Informatique

RAPPORT DE PROJET DE RECHERCHE TUTORE

4$^{\text{ème}}$ année Informatique et Réseaux

Smart Communicating Material

Fig.1 Bluetooth Low Energy Module

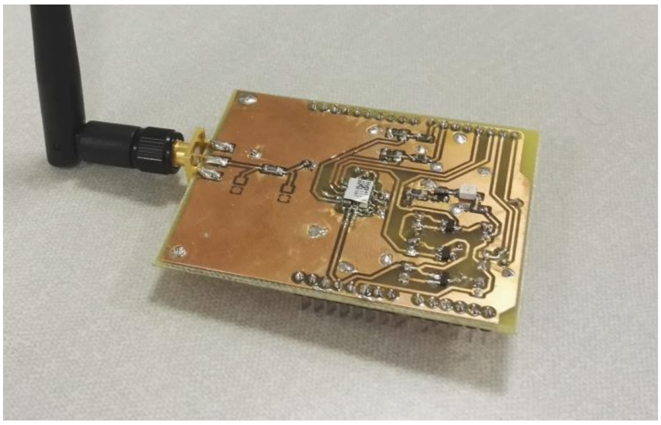

Fig.2 LoRa Module

Axelle ALOISI **Damien NICOLAS**

Lucie HELCMANOCKI **Juan YU**

Juin 2018

Tuteurs : **Daniela DRAGOMIRESCU**

Alexandru TAKACS

Gaël LOUBET

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I. INTRODUCTION

The Internet of Things (IoT) will change the way we build. It allows us to connect different electronic objects together for them to exchange data. It enables us to monitor the environment and predict events to simplify people's lives.
The different breakthroughs in the IoT field are an inspiration, especially in civil engineering with the concept of Building Information Modelisation (BIM). The main idea is to monitor all buildings with a wireless system to create an exploitable modelisation of .the structures.

The system we studied is composed of different levels of nodes. The first level nodes are buried inside the reinforced concrete part of the structure. They can collect and send data to other nodes. The second level nodes are on the surface of the structure. They are meant to be used as gateways to transmit the collected data to either a server that will process it or to a user who wants to access it on location (within the building).

The sensors are buried in reinforced concrete slabs and not accessible for maintenance. So they should be embedded, wireless, low-energy and have the same lifespan as the structure. We decided to search for technological solutions fitting our requirements: wave propagation which is not impacted by the concrete slab and energy autonomy for the sensor. Our system must be capable of storing data and communicating with the surrounding environment.

The study presented in this paper focuses mainly on the first level nodes, and especially the wireless link between two of those nodes.

Different technologies exist and we explored them in the state of the art previously done. We now focus our experiments on two technologies :

- LoRa, an open source technology that combines long range, low power consumption and secure data transmission. It emits at approximately 868 Mhz in Europe. This technology is the base of the LoRaWAN network. [1]
- BLE, or Bluetooth Low Energy is designed for very low power transmission and emits at 2.4Ghz. [2]

Our objective is to find the best suited wireless technology for the communication link.

II. PROJECT MANAGEMENT

We are a group of 4 students at INSA Toulouse and our speciality is Network and Telecommunication. This part presents our organization all along the project. We define our goals and our choices in terms of time management and resources.

We made a Gantt chart with different separated tasks to accomplish during our research. The chart evolved a lot during the semester as we faced disastrous setbacks due to faulty materials.

After the state of the art which was an exhaustive presentation of wireless technologies, this experimental study was narrowed down to 3 technologies. We were to focus on LoRa, the Bluetooth Low Energy (BLE) and the Ultra Wide Band (UWB). [3]

First, we read technical documents on these technologies, to learn how to use them. With the help of an Arduino module, the Arduino Software (IDE), the LoRa modules used in previous projects and coding libraries we were able to start programming LoRa modules to get familiar with them and the Arduino Software.

Once we had acquired the skills to use the materials for basic LoRa communication, we started thinking about the different tests we could do with all three technologies. We wanted them to be tested in the same conditions. The UWB and the BLE are tested in a point to point communication. So we tried to establish a point to point communication through LoRaWAN.

Along with the test protocols that we wrote for the point to point communication, we tried to check the performance of our communication. We wanted not only to test the quality of the communication, but also the power consumption. The test protocols include measuring the range of the transmission, estimating the power consumption of the device and the influence of the data rate on said power consumption.

At this point, we were only missing the LoRa, BLE, and UWB modules. However, our project was highly dependent on another team. This team was in charge of making the modules. As it was their first time doing it, they had some issues. The first LoRa module we got was not working properly, we were not able to communicate with it. Our tutor helped us figuring out the issue and the other team tried to correct it in the next two LoRa modules they made. As it turned out, the mistake we thought had previously been made was not a mistake. The two new modules were not working either. In the end, we had to reroute the LoRa modules by hand with small wires. We had functioning LoRa modules on the 14th of May, so just two weeks and a half before the deadline of the project. As for the BLE module, they were lacking materials to make it so we received it on the 14th as well. And they did not have time to make the UWB module.

After the tests, we had planned to make a table to compare the performances of these three technologies. This table would have been our result for this project. Instead, we had to write new test protocols that could be performed during the little time we had left to compare the BLE and LoRa technologies.

Each time, we began the session by recapitulating what we did previously, to clarify where we are and what is left to do. Afterwards, we divided up the tasks. Each group of two had several tasks to perform before the next session. At the end of each session, we talked about the results, the problems that we had met during our research and the possibility of improvement.

As we did not have the materials to proceed to the tests, we started writing our research paper together. We first distributed the writing in different parts with different titles: introduction, project management, material and methods, results and conclusion. Then, we worked on the paper again once we had some test results and every part was written, to improve the structure and the grammar.

We also settled several meetings with our tutor Gaël Loubet all along the project to make sure that the direction of our research was as he expected. If we were heading in the right direction, we would keep moving forward. If it was not the case, we would talk to our tutor, ask him for advices and adjust our strategy. And with the unexpected delay in the modules' delivery, we tried to find ways to adapt the project.

Gantt Chart - Communicating material for Building Information Modeling Project

TASKS	Start date	Planned Finish date	% Completed	Real Finish date
1.Technical skills				
Reading technical documents	26/02/ 2018	26/03 /2018	-	-
Learning how to use the LoRa module with Arduino	26/02/ 2018	12/02/ 2018	-	26/03/ 2018
Learning how to use the UWB and BLE modules with arduino	Reading the libraries 28/02 /2018	-	-	-
Learning how to establish a P2P communication with LoRa	9/03/ 2018	15/03 /2018	-	-
Seeing how to establish a communication to the Gateway with the LoRa module	28/02 /2018	9/03/ 2018	100%	9/03/ 2018
Seeing how to establish a P2P communication in UWB	09/03/ 2018	15/03 /2018	-	-
Seeing how to establishing a P2P communication in BLE	09/03/ 2018	15/03/ 2018	-	-
2.Methodology				
Making a Gantt chart	28/02/ 2018	30/05 /2018	100%	29/05 /2018
Establishing a test protocol to check the propagation range	21/03/ 2018	30/03/ 2018	100%	30/03/2018
Establishing a test protocol to check the current consumption in transmission	21/03/ 2018	4/04/ 2018	100%	23/05 /2018
Establishing a test protocol to check the current consumption in deep sleep mode	21/03/ 2018	04/04/ 2018	100%	23/05/2018
Establishing a test protocol to measure the current when the module wakes up	21/03/ 2018	04/04/ 2018	100%	23/05/ 2018

TASKS	Start date	Planned Finish date	% Completed	Real Finish date	
3.Testing					
Measuring the adequation of the range of the LoRa module with our application inside/outside reinforced concrete	23/05/ 2018	25/05/ 2018	100%	25/05/2018	
Measuring the current consumption of the LoRa module	23/05/ 2018	24/05/ 2018	90%	24/05/2018	
Measuring the propagation range of regular Bluetooth	26/05/ 2018	26/05 /2018	-	26/05/ 2018	
Measuring the propagation range of the BLE and UWB in adequation with our application	-	-	-	-	
Measuring the current consumption of the UWB and BLE modules	-	-	-	-	
4.Writing					
Abstracts	12/03/ 2018	13/05/ 2018	100%	13/05/2018	
Introduction/ Project Management	12/03/ 2018	26/03/ 2018	100%	13/05/2018	
Material and Methods	28/02/ 2018	2/05/ 2018	100%	19/05/ 2018	
Conclusion	29/05 /2018	29/05 /2018	100%	29/05/ 2018	
Results	27/05/ 2018	29/05/ 2018	100%	29/05/ 2018	
5.Managment	Dates				
Meeting with our tutor	26/02/2018	06/03/ 2018	04/04/2018	18/04/2018	23/05/2018

Fig.3 Gantt Chart

III. MATERIAL AND METHODS

1. Material

In this part we will go over the materials we used to conduct our experiments starting with the Arduino board.

Fig. 4 shows the one module we used in all of our experiments: the Arduino Leonardo. This module is able to send instructions to the microcontroller. It has a lot of functionalities but we will only describe what is important to the experiment. The Arduino Leonardo has a micro USB connection. It needs to be connected to a computer to be powered up through a USB cable. We also use the cable to upload programs. We used the Leonardo to communicate with the modules on which we implemented the different technologies. The microcontroller provides Universal Asynchronous Receiver Transmitter (UART) serial communication available on the pin 0 for reception and the pin 1 for transmission. This UART enables the communication between a computer and a serial port. We used Arduino Software (IDE) to write our test codes. [4]

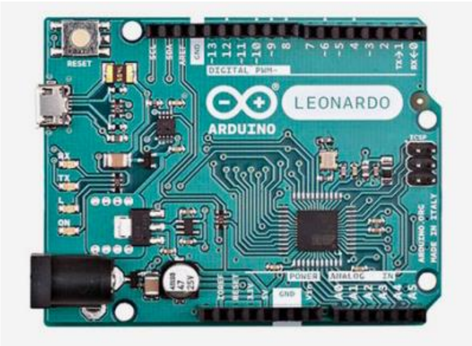

Fig.4 Arduino Leonardo board

The Modules

1.1. LoRa

We used different materials to experiment on the LoRa technology, so that we could obtain its energy consumption and ability to propagate through reinforced concrete. The LoRa module (shown in Fig. 5) we used is a Microchip RN2483 which can be programmed through the UART interface. It provides a LoRa transceiver module that operates in the 433 MHz and 868 MHz frequency bands. The pins that interests us are the power and communication related ones. The UART_RX and the UART_TX respectively, the reception and transmission need to be connected to the corresponding Arduino's pins. The data sheet of the microchip describes it as a Low Power Long Range transceiver module with a typical single operating voltage of 3.3 V. It is supposed to have a 15km range in suburban areas and a 5km range in urban areas. [5]

The Microchip RN2483 works over the Things Network via the gateway belonging to Insa on the roof of the Electrical and IT department, as shown in Fig.6 It enables us to instantiate a radio frequency communication between the module and the gateway. The Things Network is a member of the LoRa Alliance which builds a network for the Internet of Things by creating data connectivity using LoRaWAN. [5]

The LoRa module was supposed to be used as a shield for the Arduino Leonardo.

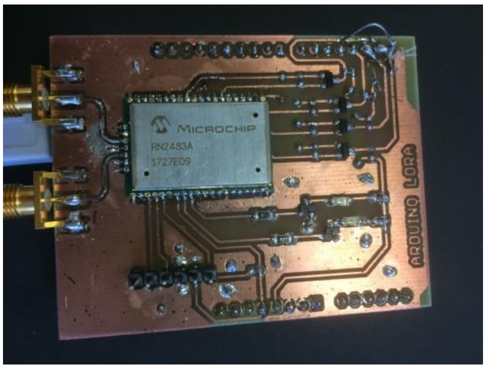

Fig.5 Module with Microchip RN2483

Fig.6 LoRa gateway at INSA

1.2. Ultra-Wide Band (UWB)

The Ultra-Wide Band module is an IR-UWB module called Decawave DWM1000. It is a low-power, single chip CMOS RF transceiver IC compliant with the IEEE 802.15.4-2011 UWB standard. It enables a data rate up to 6.8Mbps. It contains both a receiver and a transmitter enabled through a TX/RX switch that connects the receiver or the transmitter to the antenna. [6]

The receiver amplifies the signal received and converts it into a baseband signal. The chip supports 4 radio frequency bands from 3.5GHz to 6.5GHz. According to its data sheet, it has a low power consumption and a very good communication range up to 300m. [6]

With the Always-On (AON) memory of this module, DWM1000 can keep its configuration data during its lowest power operational states. This can help keep the low power consumption. [6]

Unfortunately, we never had this module, so the information we have about its range and power consumption come from the data sheet only. We did not get the chance to compare them with experimental data. [6]

1.3. Bluetooth Low Energy (BLE)

The BLE module is the RN4870/71 Bluetooth Low Energy Module. It provides Bluetooth 4.2 connectivity. The RN4870/71 module is based on Microchip's IS1870 Bluetooth Low Energy. As the other two previous module, the commands are sent over UART from the command interface. The ASCII command interface provides us an easy way to use the modules. [7]

Bluetooth Low Energy uses the Industrial, Scientific and Medical (ISM) 2.4 Ghz radio frequency band. With a simpler modulation system than Classic Bluetooth, BLE can keep low power consumption. When two Bluetooth Low Energy devices are connected, they must have one device in a central role and the other in a peripheral role. The central device can scan service advertisements advertised by the peripheral device and initiate a connection to the peripheral device. The advertisements sent by the peripheral device can show its connection status. [7]

As with the first LoRa module, the BLE module we receive does not seem to be functioning properly, so the information we have on the BLE come from the data sheet as well. However, we led some experiments with Bluetooth speakers and mobile phones to intuit the regular Bluetooth range.

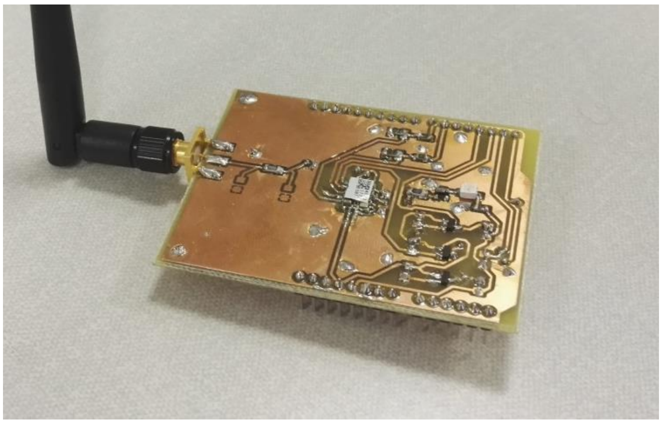

Fig.7 Module with RN4870/71

1.4. Manufacture of a reinforced concrete box

While doing our research for the state of the art, we did not find any study about wave propagation measurements in reinforced concrete. To emulate the real layout of the modules in a Structural Health Modelling (SHM) approach we made a reinforced concrete box. It has 2.5-to-3 cm-thick walls with metallic structure inside all 6 sides. This prototype is less than the average minimal width of a reinforced concrete wall so the box stays light enough to be moved. It is able to accommodate one module and its Arduino board at a time and provides a small exit for the USB cable. [8]

Fig.8 Our reinforced concrete box

1.5. Measurement tools

To measure power consumption and propagation range we used measurement tools. We used a benchtop multimeter, a handheld one, a phone geolocation system as well as a spectral analyser and the information provided by the things network website. We used the multimeters while measuring the power consumption of the LoRa module. We acquired new skills while using the spectral analyser that we had never handled before. We used it to visualize the strength of our signal and if it the module was emitting in continuous mode, in discontinuous mode or not emitting at all. Finally, to estimate the propagation range of the modules, we used a phone geolocation system to give us our coordinates and thus deduce the distance between the receiver and the transceiver. For the LoRa module, we found the data about the quality of our communication on The Things Network website (TTN).

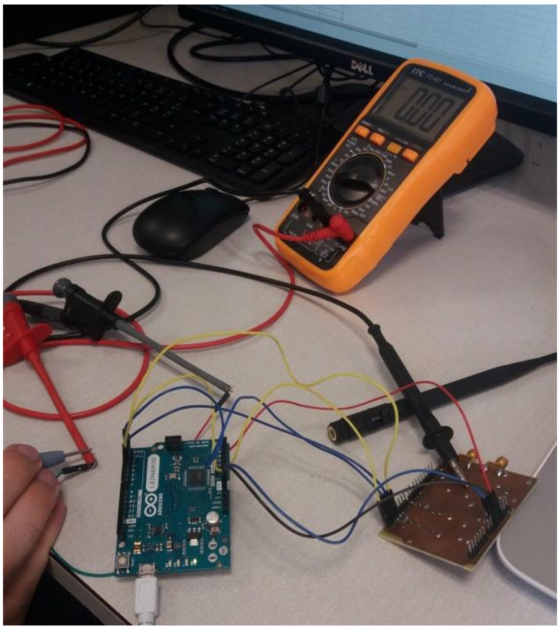

Fig. 9 Current consumption measurement

2. Methods

In this part, we introduce the test protocols we considered to make a comparison between the different technologies. To select the technology we deem more appropriate for Structural Health Monitoring, we have to test the three technologies in the same way.

2.1. Protocols for the LoRa technology

We have two parameters to test: the propagation range and the power consumption. First, we tried to implement a point to point communication between the LoRa modules, but we failed. In the following protocol, we test the communication link between the gateway and the device when the device is emitting.

1. Testing the range

For the range to be coherent with our application, we need the technology to have a range that goes up to 200 meters. We do not know how the embedded modules and gateways are distributed in the reinforced concrete yet so we want a range that complies with a quite long building.

We need a Lora shield with an Arduino Leonardo, a computer with the Arduino software and a basic program to send data. We also use the computer to check the Signal to Noise Ratio (SNR) of the received message on the gateway through the TTN website. The program is simple and consists of sending a word in repeat at a certain output power. Once we have the SNR for a set of data, we proceed to change the output power and reiterate the experiment.

What we need to take into account while testing the range is that our transceiver and the gateway will be separated by a reinforced concrete wall

In order to make a comparison between a propagation through reinforced concrete and a free-space propagation, we need to collect data on the later. The protocol is to start testing the free-space propagation from within the GEI department on the first floor. It is very close to the LoRa gateway but at the same time in an office environment and not in clear line of sight. We start with an output power of 15dBm and work our way down to -3dBm. We send discontinuous messages in a loop. We write down the SNR and see if the message sent has been received and deciphered. As long as the messages reach the gateway, we get the emitting module further away from it.

Once the free-space propagation is characterized, we do the previous experiment in the same conditions except that the module is now inside the reinforced concrete box. Hopefully, when all the data is collected we can establish the influence of two parameters on the propagation: the radio output power and the reinforced concrete.

2. Testing the energy consumption

We have different parameters to test regarding the energy consumption. We need to know the energy consumption when the module is in sleep mode, when the module is waking up and when the module is awake and transmitting.

We use a Lora module with the Arduino Leonardo and a computer with the Arduino software. We proceed to the experiment on the first floor of the GEI department as the location has no incidence on the power consumption. We need two multimeters to measure current consumption. We use a hand-multimeter to assert that there is no fluctuation in the powering of the card. The bench multimeter is used as an ampere meter connected in series between the 3.3V pin of the Arduino and the module. Regarding what we want to evaluate we follow one of the recommendation below.

a. Module in Deep Sleep Mode

We measure the energy consumption of the module while it is in deep sleep mode (DSM). The module is put in DSM by using the system command *sleep* in the program we upload to the module. The sleep command has a duration parameter which enables us to put the module to sleep long enough to measure the energy consumption.

b. Module Waking up

We measure the power consumption when the module wakes up. It will indicate if it is worth it to put it in DSM when it is not emitting. If the energy consumption to wake it up is greater than the energy saved by putting it in DSM, it is better to never put it in DSM.

c. Module in Transmission

In order to measure the consumption in transmission we need the module to emit in continuous or we will not have a stable result on the ampere meter. To put the module in continuous transmission, we can use a radio command of the module that enable the continuous wave mode. We verify that the module is indeed in the continuous transmission mode thanks to the spectral analyser. While we scan the channels used by LoRa we notice a continuous light pattern corresponding to a continuous emission whereas in a discontinuous emission we see several discontinued light patterns.

As with the range, we do a test with each radio output power from -3dBm to 15dBm. In the data sheet, there is a table expressing the expected supply current at 3.3V that we will be able to compare with our results.

2.2. Protocols for the UWB technology

The protocols for the UWB technology aim to check the same parameters as for the LoRa technology. The protocols are the same as the one used with the LoRa technology except that the connection is point to point and there is no TTN website. In consequence, we need to use a new type of measurement tool to characterize the link. According to previous publications we need a network analyser to do so. [9] [10].

However, as we have written before, we did not have the UWB module to try and implement these protocols.

2.3. Protocols for the Bluetooth Low Energy (BLE)

With this last technology, we check once again the range and energy consumption parameters. To test those parameters, the initial protocol was to use a BLE module as a transceiver and a mobile phone in Bluetooth mode as a receiver. The test protocols in this case are practically the same as with the other two technologies. The main difference is that a mobile phone is used as the receiving end of the communication and not a second module. However, we received the BLE module very late in the semester and it was just, as the first LoRa module, not working. As a last resort we had use Bluetooth speakers and phones to intuit the range of the Bluetooth technology.

We put a Bluetooth speaker in a free-space environment and connected it to the phone at close range. Then we moved the phone away from the speaker and considered the quality of the link acceptable as long as they stayed connected. We ran the same test with the second type of speaker. We then ran the test with the devices inside the reinforced concrete box.

This set of tests for this technology is not a precise way of testing the range of a wireless technology but rather to make a rough estimate of it.

IV. RESULTS

In this part, we compare our results for the propagation and the power consumption with what can be found in the data sheets and the literature.

1. Power consumption for the LoRa technology

The following table contains the current measurements we made and their comparison with what is announced in the module's data sheet.

Radio Power (dBm)	U(V)	I (mA)	P(mW)	Typical Supply Current (data sheet) (mA)	Variation : I-Typical Supply Current
15	3,26	43,5	141,81	38,9	4,6
12	3,26	42,5	138,55	35,1	7,4
9	3,26	37,8	123,228	31,2	6,6
6	3,27	32	104,64	27,5	4,5
3	3,27	26,8	87,636	23,5	3,3
0	3,27	22,8	74,556	20,2	2,6
-3	3,27	18,58	60,7566	17,3	1,28

Fig.10 Table of the current consumption in terms of the radio power

As we can see our results are very close to the typical supply current expected according to the data sheet. The idle mode current consumption is 3.35mA which is rather close from the expected idle current of 2.8mA. [5]

We have a discrepancy with the data sheet in our sleep mode current consumption. We measure 0.65mA whereas the constructor advertises a typical current in sleep mode of 0.0016mA. However, we believe the origin of this is that we did not put the Arduino Leonardo in deep sleep mode as well, only the LoRa module. [5]

Our amperemeter did not allow us to see the current consumption corresponding to the waking up of the module. It was either because the amperemeter was not precise enough or because the module woke up too quickly for us to notice anything. In the literature, experiments have been made with an oscilloscope where the current consumption to wake up the module is visible.

The literature claims that the current consumption from the data sheet provides a lifespan of more than 10 years for a battery. Considering we have similar results with our experiment, the LoRa technology is indeed low power and qualifies for Structural Health Modelling related uses. [5]

2. *Power consumption for the UWB and BLE technologies*

Since we did not have functioning BLE and UWB module, we will make a current consumption comparison with the following tables that can be found in the literature. The first table shows the current consumption of the UWB module we were supposed to use. Similarly, the second table shows the current consumption for the BLE module. [6][7].

Parameter	Min.	Typ.	Max.	Units	Condition/Note
Supply current DEEP SLEEP mode		200		nA	Total current drawn from all supplies.
Supply current SLEEP mode		550		nA	
Supply current IDLE mode		13.4		mA	
Supply current INIT mode		3.5		mA	
TX : 3.3 V supplies (VDDAON, VDD)			140	mA	Channel 5:TX Power: 9.3 dBm/500 MHz

Fig.11 Table of the current consumption for the UWB module

For the UWB module, there is a distinction between a sleep mode and a deep sleep mode for which the current consumption is even lower. The UWB technology also aims for low power consumption.

In terms of sleep modes, both the DSM and regular sleep mode of the UWB module have a lower power consumption than the LoRa module (0.0002mA & 0.00055mA<0.0016mA). However, when it comes to the idle mode, the current consumption is more important for the UWB. In fact, the UWB current consumption in idle mode is 4 times the current consumption for LoRa. The last criterium of the emitting current consumption is harder to compare as we do not really have the same type of information for UWB and LoRa. It seems that the emitting current consumption for UWB is way higher than for the LoRa module at the same voltage supply of 3.3V, but we only know the maximal current consumption for one channel at a specific radio output of 9.3dBm. [6]

Parameter	Min.	Typ.	Max.	Units
Supply Current				
TX mode Peak Current at V_{DD} = 3V, TX = 0 dBm, Buck mode	—	10 at +25°C	13 at +75°C/+85°C	mA
RX mode Peak Current at V_{DD} = 3V, Buck mode	—	10 at +25°C	13 at +75°C/+85°C	mA
Low-Power Mode Current[(2)]	—	60 at +25°C	—	µA
Shutdown Low-Power Mode	1	—	2.9	µA

Fig.12 Table of the current consumption for the BLE module

Just like for the UWB module, the BLE module we should have used makes a distinction between a Low-Power Mode corresponding to the sleep mode where the BLE connection can still be maintained and a shutdown Low-Power-Mode corresponding to the DSM. The LE in BLE stands for Low Energy and we can see from the table above that it does indeed have a low current consumption. The DSM and the sleep mode of the BLE have both a greater current consumption than the LoRa and UWB modules. On the other hand, the typical current in emission is lower than both other modules. We did not have the resources necessary to check the current consumption advertised by the manufacturer of the BLE module. [7]

3. *Propagation range for the LoRa module*

The following table contains the measurement of the signal to noise ratio found on TheThingsNetwork regarding our measures. We used the SNR as a measure of the ability of a receiver to correctly extract and decode a signal from the ambient noise. We did three sets of measurement, one at the first floor of the building of the department of electronics and computer sciences, one at 100 meters of the gateway and the last one at 200 meters of the gateway, which is on the roof of the building. For each set we measured the SNR inside and outside the reinforced concrete box for different output power.

		Signal-to-Noise Ratio SNR (dBm)					
		Inside		100 meters		200 meters	
TX Power Setting	Output Power (dBm)	Free-space	Box	Free-space	Box	Free-space	Box
15	14.1	-2.5	-2.75	-6.1	-15	-7	-12.2
12	11.6	-7	-5.8	-5.8	-12	-12	-7.7
9	8.1	-2.4	-4.7	-9.5	-15.8	-12	-7.3
6	4.7	-4.5	-4.33	-9.6	-12.13	-7.5	-6.9
3	1.4	-11	-5.7	-9.6	-13	-6.2	-5.4

0	-1.7	-10.6	- 4.58	-14	-11.6	-13.6	-6
-3	-4	-4.6	- 6.15	-12.1	- 12.33	-9.2	-8.1

Fig. 13 Table of the Signal-to-Noise ratio in terms of the radio output power

As shown in the table and as we expected, the SNR is usually lower inside the reinforced concrete box. But unlike what we thought, the impact of the distance is not significant. It is maybe due to the different obstacles between our location of measure and the gateway.

The variation of the output power also has an effect on the SNR as it decreases with it.

Following our results, LoRa seems to be an adequate technology for our application. However a problematic issue was that one out of two messages sent by the module was not received by the gateway, especially in the lower radio output power settings. This must be linked to the inconsistency of the propagation channel even if due to a lack of time we did not look into it further. We think that that loss of messages could be explained by the interferences in the path as the SNR is lower after each lost communication. The advertised propagation range of the LoRa technology is up to 15 kilometres and we were far from it, so we cannot have reach the maximum range.

But if it is not solvable a lot of data will be lost, and if they need to be sent again the power consumption might go up, as the module will have to be in transmission longer. [5]

4. Propagation range for the BLE and UWB technologies

The regular Bluetooth propagation range we measured is 30 meters. The weather conditions were good, with no rain and a clear sky. The influence of the reinforced concrete box was not noticeable. This is far from the 400m expected for the propagation range of the BLE module. [7]

The UWB module has a 290 meters propagation range according to its datasheet, making it the shortest propagation range of the three. It is still an acceptable range considering a building of average size. [6]

5. Problems

During our study, we met some problems while configuring our modules.

When the first and then second sets of LoRa modules did not work, we did not know at first whether the issue was the code or the module’s conception. In order to eliminate the possibility of error in the code, we ran our code on the old module we had. There was no problem, all worked out as we expected. But when it came to the test on the new LoRa modules, we couldn’t obtain the result we wanted.

Our tutor helped us to debug the program and the module. He presented us a method to check our set-up.

To check if the Arduino card was not the cause of the malfunction, we checked if it was working by connecting two cards by the UART interfaces. Indeed the LoRa modules are connected to the Arduino by the UART interfaces. We sent a stream of data to the other card by the UART and checked if it was received on the other Arduino. If the reception is good, the problem does not come from the Arduino card but if it is not the problem comes from the Arduino.

The first time we did it, we discovered a misuse of the library as the Arduino module we used initially was not the same as the one compatible with the LoRa module. We did a quick change in the test code and the UART test was working perfectly. We then transposed our fixes in the LoRa code and it was still not responding. The problem was the module.

In order to find out what the problem was, we connected the essential pins of the module to the Arduino card, to bypass any possible error of routing. Then, as it was still not working, we tried different solutions such as switching the RX and TX pins. In the end, the module did have a routing problem but as of today neither us nor the other group have been able to find out what it is.

6. Possible improvements

The results of the study showed above are not sufficient to make a decision regarding the best wireless technology for structural health modeling (SHM). We did not have enough time to reach all of our goals and some new ideas sparked along the way. In this part of our paper, we are proposing new parameters to include in the decision making process to elect the most adequate technology for SHM.

Among the improvement that can be made to our protocols is to implement a point to point communication in LoRa. We worked on this while we were still waiting for the LoRa module but it did not work out. From the literature, we found no concrete evidence that it was possible with our material. However, in the last days of the project we came upon an idea. One module should be used as a gateway, but then it would only be able to listen on one frequency channel as being a gateway is not its primary purpose. The other module would then have to transmit data on this particular channel. We did not have the time to try and implement this solution, so we cannot be sure it would work. In the case that it does work it would allow for a much more precise estimate of the propagation range.

Secondly, we regret not having been able to put the Arduino Leonardo in Deep Sleep mode, which would have given us a more accurate idea of the current consumption of the LoRa module. Furthermore, we would have been able to use our own value to compare the three technologies.

To make an informed decision regarding the most appropriate technology, extensive test campaigns need to be led on the BLE and UWB as well as other technologies and modulations (using the FSK modulation instead of the LoRa modulation with the LoRa modules, extend the test to the Wifi…). Besides, the data we collected with the Lora module was not sufficient and conclusive enough to draw real conclusion regarding the influence of the reinforced concrete on the propagation. Consequently, to be closer to the reality of our application, it would be best to directly include the module's antennas inside the reinforced concrete.

Finally, a major factor we did not take into account is the influence of the data rate and the length of the messages on the energy consumption. If we had more time this is definitely a parameter we would have included in our test protocols.

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CONCLUSION

In a more personal point of view, we are going to talk about the things that we have learned and achieved during this project.

Since we worked in group, we had to learn how to work together and how to divide the work among us. We also learned to define the objectives, to be organized, and to move forward together. We found that the most efficient way to develop our study was to start by clarifying what to do at the beginning of each session, and to end each session with a recap of the obtained results, as well as the problems met. It was also important to arrange meetings with our tutor, so that, we could confirm the direction of the research and adjust it if necessary. It is the longest-running project that we have ever done so far during our study at INSA.

Our project was muti-field oriented which led us to work with a team of students in AE (Automatic and Electric). As we explained it in the first part of this paper, they were in charge of making the modules we used for the test. It was not an easy task as our entire project relied on them. When the second set of LoRa module did not work and we could not reach our tutor, they really came through and help us to fix them. It was very rewarding working with them to make the modules function and have a little more hands-on experience on the modules troubleshooting.

The project was really multidisciplinary. It was a mix of various fields such as computing, electronic and civil engineering. For instance, since we wanted to test and measure the module propagation range through reinforced concrete, we had to conceive and make it ourselves.

On a technical level, we discovered and understood the different technologies used in this project: LoRa, Ultra-Wide Band and Bluetooth Low Energy. We had never used these technologies before and it was very interesting to learn and apply them in a real use case by ourselves. Despite the late delivery of the modules, we managed to run several tests with the LoRa ones. We did not have all the modules therefore we had to make do with the information from the data sheet for the BLE and UWB modules. Still, it enabled us to work on our ability to read and comprehend technical documents.

There are some other goals that we had set earlier in our project but didn't reached. For example, we didn't create a point to point connection between Lora modules.

It was our first experience with a long experimental project that applies to concrete use case. We have been confronted with tasks specific to the world of research, searching information in the literature, in the datasheet, working in almost complete autonomy, setting ourselves objectives and showing initiative. This has not been easy, especially with the material difficulties we faced but it was stimulating, and we learned a lot.

Finally, writing the report in English was a very challenging but also very rewarding work. We improved our writing skills and learned the structure of a research paper which could prove helpful in the future. We learned how to present our project under different forms, such as an abstract, a poster and a scientific paper.

To conclude, it was a great team experience and a good insight of the research world. Although we do not have as much results as we would have wanted, we learned a lot about the research process. We only wish we would have had more time to experiment.

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Table of Figures

Département de Génie Electrique & Informatique

Smart Communicating Material

Resume :

L'emergence de l'Internet des Objets (IoT) nous conduit a des villes plus intelligentes, capables d'interagir avec leur environnement. C'est dans cette mouvance que s'inscrit notre projet. En collaboration avec le BIM (Building Information Modelisation) nous souhaitons trouver la technologie permettant de faire communiquer un batiment avec des serveurs externes afin de transmettre des informations sur l'etat de la structure.

Les principaux enjeux applicatifs sont la surveillance de l'evolution de la structure dans le temps et la detection des deteriorations anormales et possiblement dangereuses. Les enjeux sont donc tant economiques pour la maintenance, qu'humains en cas d'accident.

L'objectif de notre projet est de comparer des technologies sans fils et a faible consommation d'energie permettant un « beton communicant » pour des structures en beton arme. L'application finale est la creation d'un reseau de capteurs sans-fils, enfouis dans les plaques de beton arme, capables de collecter des donnees et de les communiquer. Les capteurs etant situes dans la plaque nous avons des contraintes lies a la propagation du signal dans le beton arme ainsi que sur la consommation energetique. Le capteur doit etre autonome sur la duree de vie de la structure.

Nous avons choisi d'etudier trois technologies sans-fils : LoRa, Bluetooth Low Energy et l'Ultra Wide Band. Dans le cas de notre projet nous avons pu mesurer les deux parametres de performances : la portee et la consommation energetique

Mots-cles : *reseau de capteurs, communication sans-fils, LoRa, BLE, UWB, energie, debit, portee, beton arme, BIM*

INSTITUT NATIONAL DES SCIENCES APPLIQUÉES TOULOUSE

Université de Toulouse

Département de Génie Electrique & Informatique

SMART COMMUNICATING MATERIAL

ABSTRACT:

THE DEVELOPMENT OF THE INTERNET OF THINGS (IOT) BRINGS LIFE TO DIFFERENT INNOVATIVE PROJECTS SUCH AS THE SMART CITY OR THE CONNECTED HOUSE. ADAPTED TO THE CIVIL ENGINEERING FIELD, THE IDEA IS TO MONITOR THE BUILDING STRUCTURE AND TO TRANSMIT RELEVANT INFORMATION TO A SERVER.

THE MAIN OBJECTIVE OF OUR PROJECT IS TO FIND THE MOST ADAPTED WIRELESS TECHNOLOGY TO ESTABLISH THE LINK FROM THE REINFORCED CONCRETE TO A GATEWAY.

BECAUSE THE SENSORS ARE NOT ACCESSIBLE, THEY SHOULD BE WIRELESS, LOW-ENERGY AND THEY MUST HAVE THE SAME LIFESPAN AS THE STRUCTURE. THIS STUDY FOCUSES ON THREE TECHNOLOGIES: LORA, THE ULTRA-WIDE BAND AND BLUETOOTH LOW ENERGY.

IN ORDER TO COMPARE THE DIFFERENT SOLUTIONS, WE TEST THE ADEQUACY OF THE LORA TECHNOLOGY WITH OUR APPLICATION AND COMPARE IT WITH THE BLE AND UWB. WE MEASURE TWO RELEVANT PARAMETERS: THE PROPAGATION RANGE AND THE POWER CONSUMPTION, BOTH INSIDE AND OUTSIDE A REINFORCED CONCRETE BOX.

IN THE FUTURE OUR RESULTS COULD HELP TO ELECT THE MOST ADAPTED WIRELESS COMMUNICATION FOR STRUCTURAL HEALTH MODELLING.

KEYWORDS: *IoT, wireless technology, sensors, LoRa, Bluetooth Low Energy, UWB, power consumption, monitoring, transmission, BIM*