Measurement of Node Mobility for the LoRa Protocol

Marius Lucian Andrei, Liviu Alexandru Rădoi, Dan Ștefan Tudose
Computer Science Department
University Politehnica Bucharest,
Bucharest, Romania
mariuslucianandrei@gmail.com, liviu.r2@gmail.com, dan.tudose@cs.pub.ro

Abstract **- The existing communication technologies for IOT have become either saturated or do not meet actual needs, regarding long distances or low power consumption. We propose a study about mobility for the LoRa protocol, a new Low Power Wide Area Network technology. The paper draws upon a short overview of LoRa physical layer protocol, as well as on our testing design, some distances achieved and signal results gathered in Bucharest, Romania and its surroundings.**

Keywords— lpwan, lora protocol, lorawan, sensors mobility, IOT communication

I. Introduction

Internet of things is an area that nowadays has become increasingly popular. Even if we talk about sensors, industrial or home devices, they all connect to Internet. IOT allows these systems to access data and to be controlled remotely.

According to LoRa Device Developer Guide[1], it is predicted there will be over 25 billion of IOT connections by 2025, and about 5 of them will be performed using Low Power Wide Area Networks (LPWAN), while others will be still using Fixed & short range connections.

When the power consumption and the battery life do not represent an issue, the current technologies can be used for IoT like WiFi, Bluetooth, ZigBee or LTE, and these technologies cover both fixed, short and long range connections.

As an addition to the cellular networks, there are LPWAN technologies that can send data over longer distances with a very low power consumption. These devices can operate even for years without replacing their batteries. But, despite these advantages, there is a trade-off: those devices are designed to deliver data at a very low rate. LPWAN will solve a lot of problems for cities, such as lighting, parking, metering, energy or problems for agriculture, like soil moisture or air parameters measurement.

For supporting the new LPWAN approach, there are already a couple of competing standards and vendors like UBN (ultra Narrow Band), LTE-MTC (LTE Advanced for Machine Type Communications), Senet, Sigfox, Weightless and LoRa, NB-IoT.

But, since all these technologies are at their beginning, there are just few examples of applications. On Semtech official web page [2] one can find a couple of applications, among which we mention animal tracking, waste management, smart lighting, etc.

We are facing an intense absence of papers or studies about these protocols. For LoRa, there are just specifications, datasheets, but just a few of them are really tested like distance, for example.

The paper proposes a study of distance and some antenna tests for the LoRa protocol. In Section 2 we will discuss a similar study that we found while we were testing our nodes. In Section 3 we will present the differences between LoRa and LoRaWAN protocol. In Section 4 we will present a study regarding the selection of the proper antenna. The next chapter presents our LoRa nodes architecture. Section 6 comes with our testing and some achieved distances, while in the last section we will present our conclusions and the future work.

II. Related Work

During our protocol distance testing, we found an interesting article posted by HAL[3], presenting a similar approach to ours, about testing LoRa in Rennes, France. They did a great work by having three gateways, called LoRa IOT stations, and measuring how these stations received packets from a mobile Lora node. As gateway, they used a Kerlink Wirnet Station 868MHz[4], a powerful LoRa to 3G and Ethernet translator. As LoRa node, they mounted on an Arduino board a FroggyFactory LoRa Shield [5], which comes with a STM32 ARM controller and a SX1272 LoRa module, manufactured by Semtech. Studying the schematic[5], we discovered that the ARM controller was used to exchange data with the SX1272 chip, but also with the Arduino main board. Basically the ARM chip had two SPI connections running (one for SX and one for Arduino).

The protocol used was a proprietary protocol, called LoRa-Fabian, based on a JSON payload, so they used the gateway just as translator for a HTTP request. They used PCB embedded antenna and also an external antenna mounted on some modules.

Thus, in the proposed paper, the distance achieved is about 3 - 6 km. Also, the LoRa efficiency depends on the surroundings (elevation and buildings).

The difference between our approach and their testing hardware architecture is that we used a STM evaluation board with a compatible SX1272 LoRa module. The shield was manufactured by us, so no Arduino was involved, but more details about our approach can be found in the next section.

Regarding the transmission settings, we decided to use:

- Carrier frequency: 868.3 MHz
- Bandwidth: 125 KHz
- Coding Rate: 4/8
- Spreading factor 7

In comparison with their settings:

- Carrier frequency: 868.0 MHz
- Bandwidth: 125 KHz
- Coding Rate: 4/7
- Spreading factor: 9

According to the article "Understanding the limits of LoRaWAN"[6], the time on air that a packet spends must be as low as possible, because the nodes access the medium using ALOHA method. If there are N nodes over n channels, it is obvious that there will be no collisions. But if we talk about N nodes over one single channel, there will be collisions if the nodes use the same SF. The Spreading factor impacts two important things: time on air (this implying also the data rate) and the distance. So, the higher the value chosen for the Spreading factor a longer range (and also a longer time on air) is obtained in the detriment of data rate. Due to the fact that codes used in the various settings of the Spreading factor are orthogonal, multiple packets of data can be exchanged at the same time if each packet sent has a different spreading value. So it's important to choose the Spreading factor according with your needs.

III. LoRa And LoRaWan

LoRa protocol was developed by a French company called Cycelo, acquired by Semtech in 2012[7]. If we refer to the OSI stack, LoRa represents the physical layer, while LoRaWAN is the MAC layer "which was added to standardize and extend the LoRa physical communication"[1]. LoRaWAN protocol also provides security features like end-to-end encryption, adaptive data rate optimization or quality of service.

There is a difference between LoRa and LoRaWAN. LoRa represents the physical layer, while LoRaWAN is the MAC layer above LoRa. It comes to connect and arbitrate the nodes together in a star topology.

LoRa operates over ISM frequency bands under 1 GHz. For Europe it is designed to be used over 433/868 MHz band, while in USA it can be used over 915 MHz band, according to "IoT.augmented with STM32 MCUs & LoRa" [8].

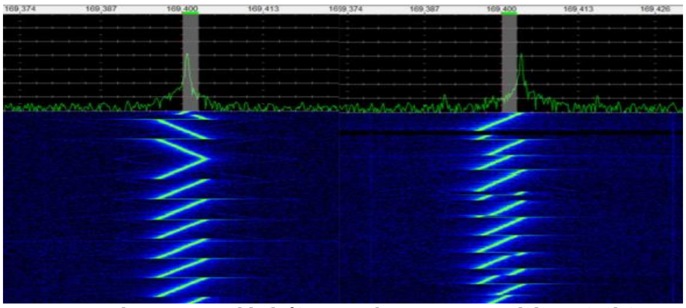

Fig 1. Semtech Lora Preamble(left)/Semtech Lora Data Modulation(right). Img source: https://www.link-labs.com/what-is-lora/

LoRa is a Semtech proprietary protocol, so how it actually does the data modulation is private. If you want to use this protocol, you must purchase a module from Semtech that does all the job for you in hardware. However, according to "What is LoRa?"[9], for sending symbols it uses “frequency modulated (FM) chirps”, initially developed for radar applications(1940's). A typical message consists of a preamble and data. In Fig. 1 there are represented two LoRa message segments. The left side of the image contains a preamble sequence ended with a "reversed chirp", while the other side of the image contains a segment of the transmitted data modulated over chirps.

One of the LoRa radio settings is called "Spreading Factor" and represents LoRa chirp rates. The elements which define a LoRa network are: Frequency, Bandwidth, Spreading factor, Coding rate and Transmit power.

In the "LoRa Modulation Basics"[10], Semtech defines the modulation bit rate (Rb) as an equation between Spreading factor (SF [7..12]), the modulation bandwidth (BW [Hz]) and coding rate (CR [1..4]).

$$R_b = \frac{SF * \frac{4}{4+CR}}{\left[\frac{2^{SF}}{BW}\right]} bit/sec$$

LoRaWAN is a protocol designed for low power nodes organized as a star of stars topology. Every star group is connected around a gateway, a device that listens every time on air after LoRa traffic. Data rates can vary from 0.3kpbs up to 50kbps, depending of spreading factor coding rate and so on. The messages are AES encrypted, so the provided security is good.

LoRaWAN divides the nodes in three bidirectional classes:

1. Class A - all end devices - consists of those devices that are battery powered and the communication must be kept as low as possible in order to extend battery life. Every device must be personalized and activated before sending data to the server. In order to do that, there are two possibilities: Over-The-Air Activation (OTAA) and Activation by Personalization (ABP).
2. Class B - Beacon - devices consists of those devices battery power that must open and request messages at fixed time intervals, in order to let gateway to initialize a downlink for the end-node device. By default, all devices in B class start as an A class and then they try to switch to class B. In this class

there is a beacon message scheduled at a certain time that synchronizes all the B node devices and opens an extra reception window called "ping slot". A class B end-device must periodically inform the server about its location in order to update the downlink route. If no beacon is received for a given period of time, the synchronization is lost and the device becomes class A again. The device has the option to switch to class B periodically.

3. Class C - Continuously listening end-device - If the device has enough energy to stay always on, the reception window will not be limited. After a Class C transmits a packet, it waits to receive a message until the next transmission.

IV. LoRa Nodes

We tested LoRa using a compatible SX1272 module which can be connected with a microcontroller over SPI protocol. We tried an architecture with an Arduino and one of these modules and we used an open source library. The design with Arduino and LoRa can be suitable for sending some messages between two nodes, but not to sustain a communication with a real LoRa Gateway, because the board has only 2kB of SRAM, which is not enough to implement the LoRaWAN MAC layer.

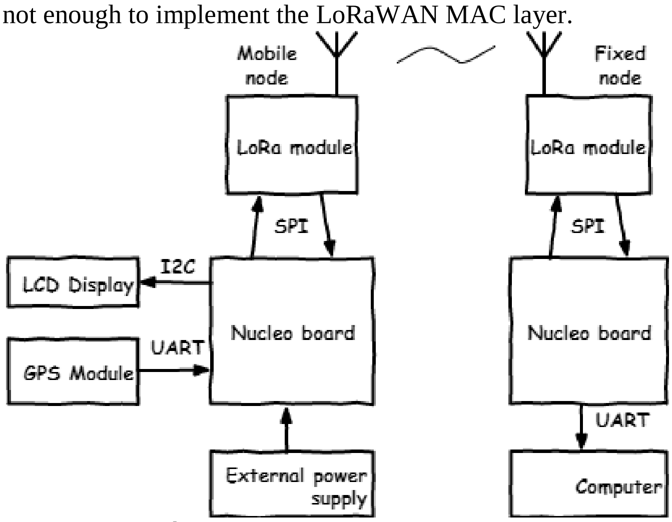

Fig.2 Lora nodes Diagram

In order to do the tests we used a Nucleo Board manufactured by STMicroelectronics. Nucleo comes with a Cortex-M4 ARM controller, more powerful and more suitable for implementing the LoRaWAN MAC layer than an Arduino board. For interfacing this evaluation board with the LoRa module we developed our own libraries.

We decided to measure the maximal distance that can be achieved in Bucharest and Comana Natural Park with LoRa protocol between two nodes, using the same basic architecture: Nucleo and LoRa module (Fig 2).

For the setup in Bucharest we used a fixed node which was positioned at the eleventh floor of a building and a mobile one which was carried around by a person. Due to the fact that gateways are usually placed in high spots, we decided to position our receiver node in the highest point on which we had access to. For the setup in Comana Natural Park, we mounted the antenna on a pole at 6m above the ground level.

Regarding the mobile node, we had two iterations. In the first one we used a GPS module (PMB-688) to determine the position from where we exchanged the packets, and some LEDs to notify the person who carried the node about the communication state. In the second iteration we changed the GPS module with a more accurate and reliable one (Maestro GPS) and we replaced the LEDs with an LCD for extra info due to the fact that we wanted to use a car to be able to cover as much area as we could.

Fig.3 Antenna mounted on the car roof

Fig.4 Node placed in the car

For sending and receiving data, we firstly used a simple a quarter wave antenna (8.6 cm) and a custom ground plane antenna (Fig 3), manufactured by 5 identical 1/4 λ wires: the one that transmits is fixed in a vertical position, while the other four wires are cross disposed, at an angle of 135º about the vertical wire and 90º between them. Those 4 wires are called the reflector elements and they create a powerful artificial ground.

V. Testing Setup and Results

The mobile node acts as follows: after booting, it waits to receive a fixed GPS packet. Depending on the area this takes about half a minute. After that it sets the packets number to zero it starts transmitting the last &GPGGA packet every 10 seconds. When it is not transmitting, the node waits for a message from the fixed node position like a Class C end-node. After Nucleo analyses the message, it updates the LCD display.

During our testing in Bucharest, we walked with the mobile node to achieve a better resolution. The person who carried the node had a visual feedback regarding the state of the current packet: send, receive, validity. The receiver node was placed at the eleventh floor (approx. elevation 30m).

As we mentioned before, we were very interested in the communication distances that can be achieved using LoRa in an urban area. We chose Bucharest for testing our nodes because we live here and, also, we found no information about some tests or an already existing LoRa architecture here.

After we established a valid communication between node M and F, we mounted F in Crângași neighbourhood, Bucharest at the eleventh floor of a residence. In Figure 5 the top left point represents the fixed node.

In the first measuring session, represented by the darker points in Figure 5, there are a couple of these locations condensed around a point that represents the starting point for our measurements. While the dots go to Eroilor area, the points the points become more rare. An interesting factor, that we observed during our tests, was that moving the node while transmitting affects the quality of the received packet. Here you have two packets: 240 and 241.

RXPN: 0240, RSSI: -95, LEN: 064, PLD:
*$GPGGA,231905.000,4426.7341,N,02603.3731,E,1,04,3.3,81.9,M,36.0,M,,0000*65*
RXPN: 0241, RSSI: -90, LEN: 064, PLD:
*$GPOG`$631913.00549"6.g#41,I,0260:.3730,E,,04'4/5,h1.9,D*08.8M,,0000*6@*

Two packets received from "Eroilor Bridge"

The packet 240 was received with no errors, the RSSI was -95 and the payload is in the GPGGA format that represents a valid GPS location. The next packet has the same length 64, but the GPGGA payload is invalid. This packet is so badly received that the location cannot be reconstructed.

After the mobile node got on "Eroilor Bridge", receiving packets from the node M, while in motion it was not possible to receive even a bad packet. So we fixed the node on the bridge railing. On the map, there are three good packets received from that bridge. The last packet for which we received a valid response was the one next to the Bucharest National Opera. There, the straight distance between M and F is 3.55km (measured on Google maps). The last point from which we tried sending data was on the "Izvor Bridge". Here, we got only one packet sent by the M note to F and no response, the distance is 3.97km. The next point from which we tried to communicate was next to the Politehnica underground underground station and we got the same results, i.e. from that spot we were able to send just one way packet:

RXPN: 0377, RSSI: -93, LEN: 064, PLD:
*$GPGGA,210900.00,4426.0536,N,02603,1510,E,1,08,1.2,86.7,M,36.0,M,,0000*60*

The packet received next to Politehnica underground with a simple wire antenna

For the next tests we built the custom ground plane antenna and went back to "Izvor Bridge" to check both way communication. We noticed a significant improvement, resulting a two even way messaging from that bridge, but the best results were achieved inside the "Izvor Park", very close to the House of Parliament. The maximal distance achieved is 4.3km.

RXPN: 0255, RSSI: -99, LEN: 064, PLD:
*$GPGGA,211323.000,4425.7367,N,02605.4768,E,1,05,2.2,90.3,M,36.0,M,,0000*68*

The last packet received when the M node was next to the House of Parliament

After measuring the area next to the House of Parliament, we went to "Unirii Square", but from there, we only received two bad packets and we are unable to reconstruct the GPGGA payload.

RXPN: 0313, RSSI: -100, LEN: 064, PLD:
$GPGGA%2!2858.001,4425.5943,N,02605-c"hS!t$){55|l70.0,MlsVP,~-0000*v60P*
RXPN: 0314, RSSI: -100, LEN: 064, PLD:
$GPW+,tw/vF[Jjt402u(c>iHv{r606@0397,M;<0BoG"~0Z|4tqi5 %5L0]XX^J/O

Two bad packets received from "Unirii square"

On the same map, there are 6 points next to "Grozăvești Bridge". Those points are recorded, while the M node was inside a moving car, and the RSSI for them was about -96.

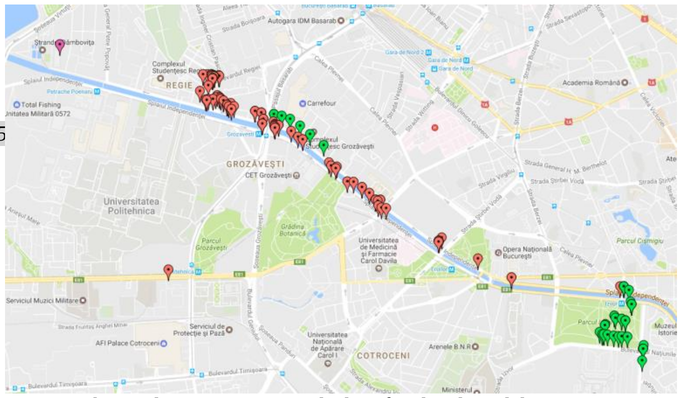

Fig. 5 Bucharest distances map: Purple dot - fixed node, red dots - quarter wave antenna mobile node, green dots - ground plane antenna mobile node

We should also mention that the distance measuring tests were done at night, because here, people seem to be very uncomfortable when they met a total stranger walking on the streets with a box full of wires, antennas and glowing LEDs. The outside temperature was below -5ºC.

For testing the communication outside the city, we went to Comana Natural Park, at 35km South of Bucharest. The first important update to the mobile node was to replace the GPS module. The one used at the last session was not as accurate as we wanted, because we were surprised to see that we were sending a location not even 50 meters away from our real position. We used a Maestro GPS with an on board antenna which proved to be very accurate. To connect the GPS to Nucleo board we used the UART protocol at 4800 8N1 settings, as the datasheet mentioned.

Fig. 6 LCD display information

Another important change to the mobile node was mounting an LCD display. This addition proved to be the best change we made, because for the carrier of the module it is very important to know the state of the node. We split the LCD display cells as follows:

- Addr[0x01:0x07] shows the LoRa state:
  - TX:… – if the node is transmitting
  - RX:… – if the node is receiving a packet
- RX:.OK(NOK) – OK if the node received a good packet or NOK if the packet was damaged
- Addr[0x08:0x0B] – received packet RSSI value
- Addr[0x0C:0x0F] – number of total received packets

- Addr[0x41] – last $GPGGA payload signal if is fixed or not
- Addr[0x42] – blinks when Nucleo receives a position update from the GPS module
- Addr[0x43:0x44] – satellites number of the last position packet
- Addr[0x45:0x46] – how many seconds until the node sends the next LoRa packet
- Addr[0x47] – “S” from sent packet number
- Addr[0x48:0x4C] – the number of total sent packets
- Addr[0x4D:0x4E] – the percentage of the total packets received correctly.

Also, some software changes were made in order to have some feedback from the stationary node. If it didn't receive any packet from the mobile node in the last 60 seconds, the stationary node sent a blank packet full of zeros.

The settings for the LoRa communication were preserved. The frequency used was 868.3 MHz, the bandwidth was kept at 125kHz, SF7 and the coding rate was 4/8. For very long distances a spreading factor of 12 would be the best choice, but the air time of the packet is around 2 seconds. Taking into consideration the fact that the node was moving, we decided to keep the SF7 because the air time of the packet was under 0.3 seconds.

We mounted the fixed node in Comana village at a current altitude of 56 meters, the one indicated by the GPS. For this test we will take into consideration only the altitude indicated by the GPS.

At a distance about 850m, at an altitude of 46m, we obtained a RSSI of -97. For 6.13km, the height of the mobile node was 69m and the RSSI was -104. The furthermost point was reached at about 9.67 with a RSSI of -104 m and the height was 83, so, actually, the mobile node was higher than the fixed node.

We started driving outside Comana village on DJ411 road. We went to Budeni village and from there the communication was very good. The thing that pleasantly surprised us was the fact that although we traveled with 90 km/h (the legal speed limit outside the city), we were still able to send and receive correct packets. But near Budeni Monastery the connection was lost, so we had to turn back and we changed direction to Gradistea village. On the map there one can notice the absence of the points (representing the success TX/RX points), probably because of the trees and plants around the road. But when we left DN5A road, we got the link back and measured 9.87km between points.

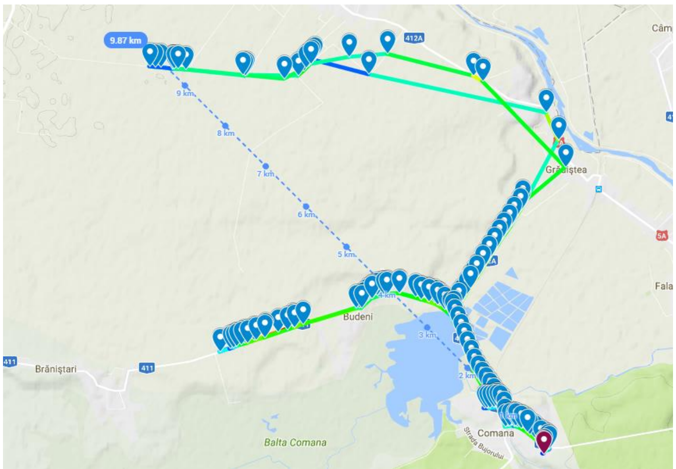

Fig. 7 Comana Natural Park measured results

Later on, we tried to replicate the results in Bucharest, at the exact same place like we did in the last study. We placed the antenna on the 11th floor and tried to measure from the car with the antenna on the roof. But for some reason the link was up just on the right graph in Fig 8, but afterwards we were not able to set up the link again until Carrefour. We used a different antenna for the fixed node, but no results. So we put the mobile node in the trunk and we let it transmit. After getting home we were pleased to see that somehow the link went up and we measured the left graph in the same image. The RSSI average was -80.

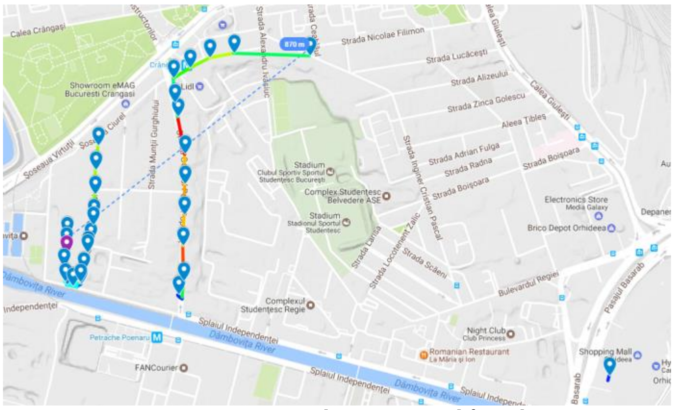

Fig.8 Distances in Bucharest measured from the car

In figure Fig.9 the distance (diamond) is plotted versus RSSI (circle) signal strength. As we expected, the signal strength is conversely proportional with the distance. On the left side of the plot, on vertical axis there is represented the distance in meters, the maximal one has reaches almost 10000 meters. On the right side on the vertical axis is represented the RSSI. On the right corner the value is zero, because the RSSI is negative (higher the better). On the horizontal axis there is represented the packet number. Once can clearly recognize the moment when we turned the car and went on the same road and then went to Gradistea village.

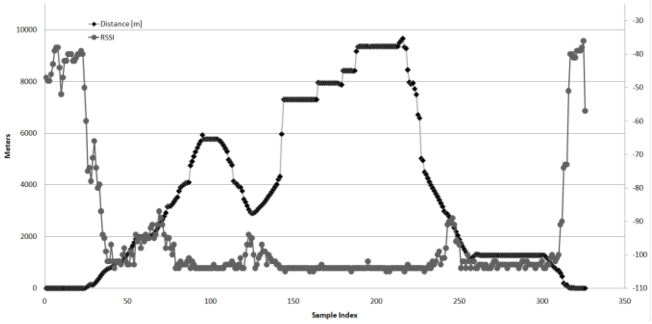

Fig. 9 A plot representing Distance(diamond) versus RSSI(circle) at the Comana Natural Park measurements

VI. Conclusions and Future work

During our tests we managed to achieve important distances in communication between two LoRa nodes. We measured 4.3km in urban area and 9.7km over an open field outside the town, so there are no doubts regarding the LoRa protocol distance capabilities.

We have developed our own LoRa communication nodes and we have successfully changed packets between them at a more than appropriate geographical distance. We still need to test some different LoRa module configuration, like varying the spreading factor or the bandwidth.

Providing such distances at low power, makes LoRa and LoRaWAN a great communication medium for applications that do not need real time or high resolution data. For example, LoRa can be used to monitor the soil humidity in agriculture. Mounting a gateway provides probably as we measured for this paper, a radius of sensors of 9.7km.

Next, we will focus on testing and developing LoRaWAN nodes and gateways designed for this small applications. We started with STM32Nucleo and we will continue designing nodes using this platform. We will probably integrate some other modules like RN2483 produced by Microchip.

LoRa protocol promises a great way for devices interconnection and we strongly believe that it will have an important role in building the future of Internet of Things.

References

[1] Lora Device Developer Guide Orange, https://partner.orange.com/wp-content/uploads/2016/04/LoRa-Device-Developer-Guide-Orange.pdf

[2] LoRa Technology Is Connecting Our Smart Planet http://www.semtech.com/wireless-rf/internet-of-things/lora-applications/briefs. Last accessed on 27 January 2017

[3] Tara Petri´c, Mathieu Goessens, Loutfi Nuaymi, Alexander Pelov, Laurent Toutain. Measurements, Performance and Analysis of LoRa FABIAN, a real-world implementation of LPWAN. 2016.

[4] Kerlink 868MHz Gateway LoRa to Ethernet and 3G modem http://www.kerlink.fr/en/products/lora-iot-station-2/lora-iot-station-868-mhz Last accessed on 24 January 2017

[5] FroggyFactory LoRa Shield http://froggyfactory.com/index.php Last accessed on 24 January 2017

[6] Ferra Adelantado,Xavier Vilajosana,Pere Tuset-Peiro,Borja Martinez,and Joan Melia, "Understanding the limits of lorawan", arXiv:1607.08011,2016

[7] Introducing LoRa http://www.instructables.com/id/Introducing-LoRa-/ Last accessed on 24 January 2017

[8] IoT.augmented with STM32 MCUs & LoRa http://www.st.com/content/ccc/resource/sales_and_marketing/presentation/product_presentation/group0/b5/72/c6/ec/c8/e3/4a/8c/IoTaugmented_stm32-lrwan/files/IoTaugmented_stm32-lrwan.pdf/jcr:content/translations/en.IoTaugmented_stm32-lrwan.pdf Last accessed on 24 January 2017

[9] What is LoRa? https://www.link-labs.com/what-is-lora/ Last accessed on 24 January 2017

[10] *AN1200.22 LoRa™ Modulation Basics*, Semtech Corporation, Revision 2, May 2015

[11] Very simple homemade outdoor 868Mhz antenna (groundplane)https://www.thethingsnetwork.org/forum/t/very-simple-homemade-outdoor-868mhz-antenna-groundplane/3160 Last accessed on 10 July 2017

[12] Aloÿs Augustin1 , Jiazi Yi 1,*, Thomas Clausen 1 and William Mark Townsley, A Study of LoRa: Long Range & Low Power Networks for the Internet of Things, Published: 9 September 2016