LoRa in a haystack: a study of the LoRa signal behavior

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Inria, France
{ibrahim.amadou, brandon.foubert, nathalie.mitton}@inria.fr

***Abstract*—Over the years, LoRa has been raising a lot of interest, both from the academia and the industry. LoRa is indeed a promising technology that enables long range and low power communications to connect IoT devices to the Internet. LoRa is often envisioned for several applications such as regular reporting but it is also aimed to be exploited for other applications, such as geolocation for instance. However, current implementations of LoRa geolocation system or other alternative applications suffer from severe inaccuracy. The purpose of this paper is to investigate where the inaccuracy comes from but also to determine LoRa technology based geolocation best uses-cases. The paper characterizes the LoRa radio signal properties, through a real validation campaign, over different contexts and different LoRa physical layer settings. Our results show that the signal properties, such as RSSI or SNR, are more stable in a peri-urban area than in a high density urban area. In the latter scenario, we also observe an asymmetric reception.**

***Index Terms*—LoRa, LoRaWAN, Physical Layer Properties, RSSI, Geolocation, IoT**

I. Introduction

Low Power Wide Area Networks (LPWANs) offer long communication range at a low energy cost. Those networks rely on recent technologies, such as Long Range (LoRa) [1]. LoRa is a proprietary radio modulation technology owned by Semtech. It is based on a variation of Chirp Spread Spectrum (CSS), which is said to be robust against interference, multipath and Doppler effect. LoRa operates on the unlicensed Industrial, Scientific, and Medical radio (ISM) bands [2]. The main upper layer, known as LoRaWAN, is based on a simple ALOHA-like MAC protocol and leverages a star-of-stars topology that reduces the infrastructure complexity and costs. LoRa recently attracted a lot of interest and became one of the key communication technologies for the Internet of Things (IoT) [3]. Thanks to its long range and low power characteristics, it is useful for a wide range of applications (e.g. civil, military, healthcare...). LoRa incorporates four parameters that partially determine its abilities: channel, bandwidth, spreading factor and transmission power. Those parameters drastically change the range, delay and data rate achieved by LoRa (e.g. higher spreading factor requires lower signal-to-noise ratio (SNR) for demodulation). Among numerous applications, LoRa is foreseen as an alternative geolocation system. Geolocation is the identification of the geographic location of an object. It is used to keep track of electronic devices, animal, people, etc.

LoRa has been widely studied by the academic community for different uses and from different perspectives. Several studies [3]–[6] look at the characteristics of the LoRa signal in different settings. Some of those study LoRa under mobility [3]–[5], [7]. The general conclusion is that LoRa communication is robust to mobility, as long as the devices are moving at a moderate speed. LoRa for geolocation is studied in [8], [9]. Results are generally very inaccurate. Accuracy can be improved with computing techniques, but it takes a heavy toll on battery longevity [10].

To the best of our knowledge, there is no study that provides a precise profile of LoRa radio signal characteristics in relation to the environment as we aim to show in this paper. As the accuracy of the LoRa geolocation relies on the signal quality, we want to observe the signal characteristics in relation with the environment. We ran in-field experiments using different LoRa settings under various environmental conditions and extract interesting properties that explain why and whether an alternative use of LoRA could be interesting. In this article, we share the results we achieved during those experiments.

The rest of this paper is organized as follows. Section II presents the experiments settings and scenarios. Then Section III details and discuss the results we have obtained. Finally, Section IV summarizes our contribution and introduce future works.

II. Experimental testbed

This section briefly describes the LoRa radio transceiver, which was used, along with the different experimental environments. As our goal is to investigate the feasibility of using LoRA technology for accurate positioning, we wanted to assess the stability of the signal within different environments.

A. System setup

A typical LoRa-based communication network, as defined in the LoRaWAN standard [1] by the LoRa-Alliance, is based on a star-of-stars topology in which gateways relay messages between end-devices and the core network. In this work, we chose to use device-to-device communications, because the network infrastructure has no influence on the device's wireless link characteristics. Thus, we use two devices: a receiver and a transceiver, and measure the Received Signal Strength Indication (RSSI) of their link over time and in different settings to evaluate its stability.

We used two B-L072Z-LRWAN1 LoRa®/Sigfox™ discovery kit devices for our experiments. Those devices contained an onboard Semtech SX1276 transceiver chip. We adapted an existing open source firmware, called *SX1276 Generic PingPong*, to send a customized *beacon*. The initiator device of the *PingPong* (*Ping* sender) is referred as transmitter. The device that replies with *Pong messages* to the initiator is referred as receiver.

We used the 868 MHz frequency band and compared different spreading factors. Table I summarizes all of the parameters we experimented with. These settings are chosen according to the European LoRaWAN specification [1], [11].

Parameter	**Values**
Spreading factor	[7, 8, 9, 10, 11, 12]
Bandwidth	[125, 250] kHz
Coding rate	4/5
Transmission power	+14 dBm
Carrier frequency	868.1 MHz
Payload size	32 bytes

TABLE I: Experimental settings

B. Considered scenarios

To characterize the LoRa radio properties regarding to our objectives, we conducted experiments in three kinds of environments. Note that all these scenarios are carried out without line of sight between the two devices.

1) *Peri-urban areas between lab buildings A & B*: as shown in Fig. 1a, the transmitter is deployed on the second floor of building A (orange marker on the map). The receiver device is placed in front of building B (white marker on the map). In this scenario, the maximum communication range is approximately $122.5m$. This is because the initial device setup that uses a spreading factor of 7 limits the range. This restriction is mainly due to the building metallic structure, that limits the possibility to deploy the receiver device within the building.
2) *Peri-urban area with mobile transmitter*: this scenario takes places in both a peri-urban zone and a rural zone with a mobile device moving at a speed of approximately $90km/h$. It is illustrated in Fig. 1b and Fig. 1c. First, on Fig.1b we can see the initial setup of the experiment, where the transmitter (white marker on the map) is onboard a vehicle while the receiver is static and on the second floor of building A (orange marker on the map). Note that the receiver is outside of the building. Then on Fig. 1c we can see the trajectory along which the experimental measurements are registered for the mobile device. The vehicle initially starts from the white marker to the light green marker. It then moves along the path to the red marker, then from the red marker to the dark green marker. From the dark green marker, it returns toward the light green marker from same path it came. Finally, the last stretch of trajectory followed by the vehicle goes from the light green marker to the blue marker and then back to its initial position (white marker). The environment between the two green markers is mainly rural, while the rest of it is peri-urban. Notably, the rural environment is kind of a 'bowl' surrounded by embankment. In this scenario, the maximum communication range with correct signal reception at both the receiver and transmitter devices is around $1.12km$, while the maximum reached distance is $2.069km$.
3) *High density urban area*: this experiment was conducted in an environment surrounded by several buildings and with several human activities. We can see the map of this scenario in Fig. 1d. Like the first scenario, the transmitter is placed within a room located on the second floor of a building (orange marker on the map), while the receiver is moved around outside the building to assess the maximum communication distance for each spreading factor we could achieve. These distances are shown on the map as white markers and reported in Table II.

On the one hand, the scenarios 1) and 3) are carried out by varying the settings of both the spreading factor and bandwidth as introduced in Table I. The evaluations of these two scenarios last for half an hour. On the other hand, the mobility scenario is carried out with a fixed spreading factor of value 12, a fixed bandwidth $B = 125KHz$, and an experimentation duration equal to the time needed to the drive through the circuit depicted in Fig. 1c.

SF	7	8	9	10	11	12
Range (m)	104.22	122.91	164.98	184.49	208.30	208.96

TABLE II: Maximum range per spreading factor

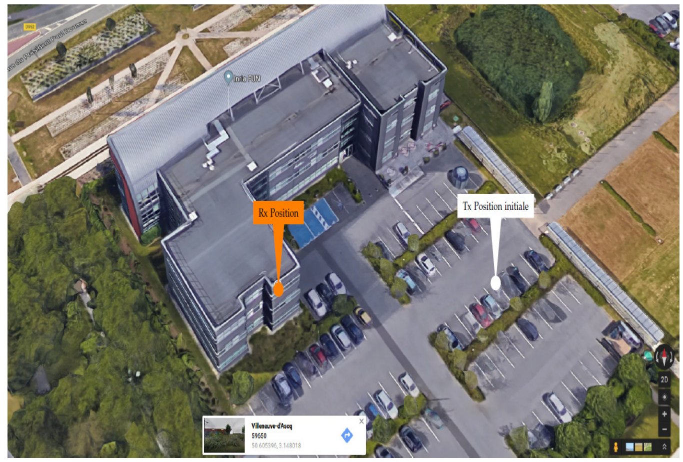
III. OBSERVED RESULTS

In this section, we introduce the results we obtained from our experiments. We present one result per scenario and focus our analysis on the most important aspect of our study, the signal strength variation over time for both devices. The full results for all experiments can be found in [12]. Fig. 2a, Fig. 2b and Fig. 2c respectively present the results of these three scenarios: (1) *Peri-urban areas between lab building A & B*), (2) *Peri-urban area with mobile transmitter* and (3) *high density urban area*.

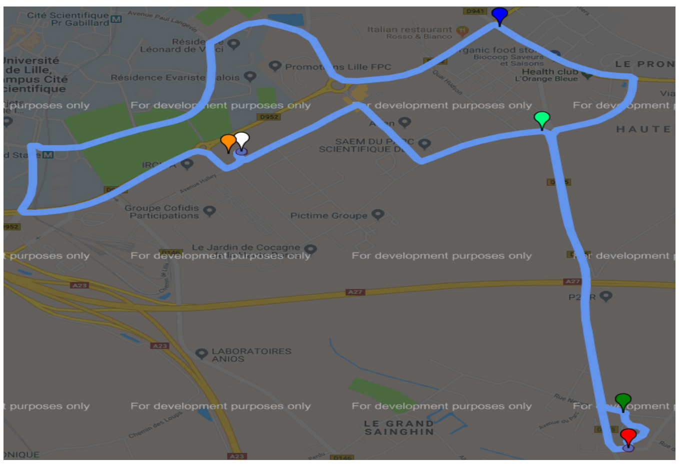
In Fig. 2a we can see the results of scenario (1) for a spreading factor of value 12 and a bandwidth of value $125Khz$. In this scenario, independently of the spreading factor and bandwidth, the RSSI exhibits similar behavior with a similar average value for both devices. This shows that the RSSI was rather stable for both devices. Moreover, it presents a small variance (see [12] for more details), which could lead one to believe that in these conditions, LoRa might be a good candidate for geolocation.

Fig. 2b shows the results obtained from experiments in scenario (2). We can see that as the distance increases (respectively decreases), the RSSI value decreases (respectively increases). Both devices exhibit an almost similar behavior with their closest average value when they are able to receive each other beacon. According to these results, we can observe three phases. The first phase corresponds to the moment

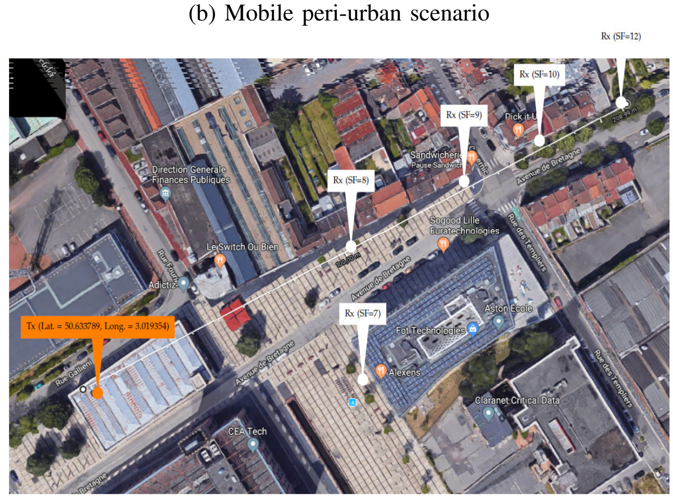
(a) Static peri-urban scenario



(b) Mobile peri-urban scenario



(c) Mobile peri-urban scenario: path trajectory

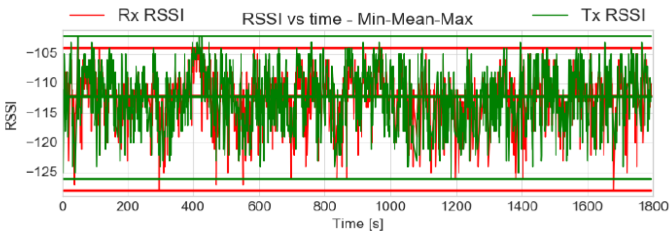


(d) Static urban scenario

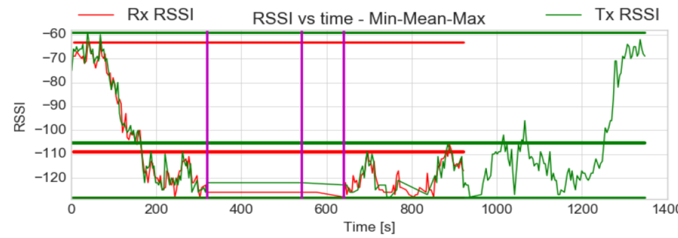
Fig. 1: Experiment scenarios

where there is a quasi-symmetric communication between the receiver and transmitter. During this moment, both signals are quite similar and it corresponds to the first $1.12Km$ as explained in Section II-B. It last from the white marker visible on Fig. 1c) to the light green marker. The second phase corresponds to the rural environment shaped like a bowl and it last from the light green marker to the dark green marker while passing through the red marker. During the vehicle traveling time, there is almost no communication between the transmitter and the receiver in both directions. The exception was at the place marked with the green marker, where few receptions were recorded, most likely because that place was higher in altitude than the rest of the surroundings. The third step corresponds to the moment where the vehicle is the closest to the light green marker. During this step, we observe a symmetrical communication between the two devices. Results also show that as the transceiver becomes closer to the receiver, the RSSI value increases. At almost $1000s$ on Fig. 2b we see that the computer logging data from the receiver suffered from a system failure, but it did not affect the receiver operations.

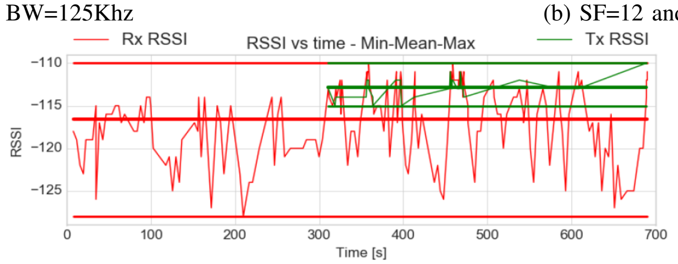
Fig. 2c depicts the results measured in a dense urban environment for a spreading factor of value 8 and a bandwidth of value $125KHz$. Unlike the results from the previous scenarios, here we can see that the signal characteristics from both devices are very asymmetric. This behavior can also be observed for different spreading factor and bandwidth values in [12]. The greater the bandwidth, the more asymmetric the signals are. This is due to the fact that a bigger bandwidth allows lower sensitivity and makes the signal less robust to interference and environmental disturbance. This effect is even stronger on the transmitter as the metallic structure of the building greatly impacts the signal propagation.



(a) SF=12 and BW=125Khz



(b) SF=12 and BW=125Khz



(c) SF=8 and BW=125Khz

Fig. 2: RSSI value over time

IV. Conclusion

From the previous results, we deduce the following: first, that using two LoRa devices in a device-to-device fashion instead of the classical device-to-base-station greatly reduces the communication range. The maximum reached communication range is very shorter than the previously cited studies that followed a standard device-to-gateway communication model. Secondly, in compliance with [5], LoRa devices configured with a spreading factor of 12 and moving at a moderate speed ($\simeq$ 40km/h) do not disrupt LoRa communications. While traveling at a high-speed, around $\simeq$ 90km/h, greatly increases link breaking probability. And thirdly, LoRa signal stability is greatly depended on the environment. In a rural environment, the signal appears to be more stable than in an urban zone. This is mainly due to the presence of less obstacles in the area, which, on the other hand, means less signal reflection. Furthermore, a urban zone is more unstable area with high density and dynamic obstacles.

In this article, we present the results we have obtained from in-field experiments to assess LoRa signal characteristics in relation to the environment. Our aim is to understand how it can be used for alternative applications such as geolocation. According to these results and analysis, we can conclude that LoRa signal stability greatly depends on the environment and it is more stable in peri-urban areas than in high density urban areas. As future work, we wish to further study the impact of the environment, in terms of atmospheric conditions (air humidity, pressure, etc.), on the LoRa performance.

Acknowledgments

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