Factors Influencing LoRa Communication in IoT Deployment: Overview and Experience Analysis

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Abstract: LoRa communication offers wireless sensor networks deployment for system or environmental monitoring over long distances and with low energy consumption. However, this radio communication technology is subject to environmental disturbances. In this paper, we propose an overview of the studies carried out on LoRa signal disturbances, taking the RSSI as a comparison parameter. Secondly, we extract the main influences to compare them with the data collected on the experimental platform of the Smart Village of Cozzano (Mediterranean area, Southern of Corsica island), a scientific program aiming to develop digital tools for the monitoring and the preservation of the environment. We use one of the most popular techniques in multivariate statistics, especially when analyzing large datasets, the principal component analysis (PCA). The results show the impact of some environmental parameters on communication quality.

1 INTRODUCTION

Environmental monitoring is a crucial issue in the scientific field. The smart village, a scientific project, proposes to develop a set of technologies for the environment observation and preservation and its inhabitants in a rural, mountainous and isolated area. (Antoine-Santoni et al., 2019b),(Antoine-Santoni et al., 2019a). In this context, it is essential to think about a correct deployment of the devices to ensure the transmissions quality from the deployed sensors.

With a view to sustainable development, the scientific program has set up an information system based on a wireless sensor network using LoRa communication technology with a LoRaWAN protocol. This technological choice aligns with a desire for energy efficiency to limit the impact of technologies on the environment and human maintenance over time. Indeed, we can find many works using LoRa technology for telemetry purposes (Haxhibeqiri et al., 2018): smart cities, industry, transport, agriculture, etc. We see many results presenting the various applications of LoRa, but in (Shanmuga Sundaram et al., 2020), the authors specify the axes of reflection around the

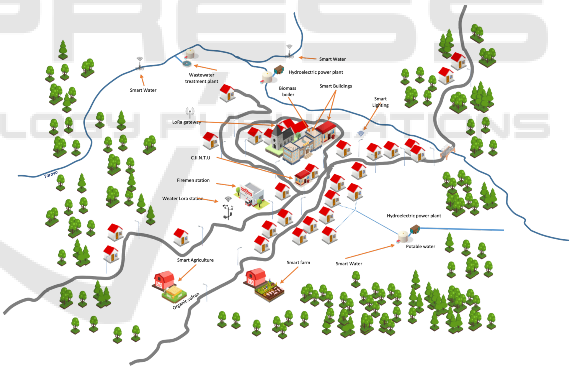

Figure 1: Smart Village of Cozzano (South of Corsica) - Deployment of Lora devices.

scientific challenges around LoRa/LoraWAN. Within the Smart Village, illustrated by Figure 1, in the various applications deployed, we can find weather stations on different points of the village and in altitude and GPS trackers to locate animals raised in the wild. However, despite the relative system stability, we have noticed variations in the signal quality performance, impacting the data transmission quality of the information feedback. These failures create gaps in the database. In this paper, we propose to make a statistical analysis of the collected environmental data to evaluate the impact of the environment on the signal and determine the environmental factors influ-

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encing long-range communication. In a first step, we will make a literature review on the studies conducted around the influence of the environment on the LoRa signal, taking the RSSI as a parameter. We confront them with a statistical analysis on the devices deployed in the Smart Village since 2018. We will then conclude on the areas of improvement of these different parameters and improve communications and network coverage.

2 STATE OF ART

LoRa, for "Long Range", is a long-range wireless communications system promoted by the LoRa Alliance (Alliance, 2015). This system aims at being usable in long-lived battery-powered devices, where the energy consumption is of paramount importance (Augustin et al., 2016). Lora distinguishes two main layers: a physical layer using the Chirp Spread Spectrum (CSS) radio modulation technique and a MAC layer protocol (LoRaWAN). LoRa is a technology that operates in the ISM, Industrial, Scientific and Medical (ISM) frequencies bands, 868 and 433 MHz in Europe and 915 MHz in the USA. These different frequencies can, however, have a performance impact on the network as studied in (Alset et al., 2020) where the authors determined with simulations that the lifespan of the batteries can be affected by the carrier frequency in use. With long-range and low power capacities, LoRa belongs to the LPWAN category. Semtech, an owner of the technology, claims an effective range of thirty miles (sem,), or approximately forty-eight kilometres, in urban areas. However, with the adequate material, it is possible with LoRa, to transmit over a hundred kilometres (Jovalekic et al., 2018). Thanks to the low consumption of LoRa devices, a connected device can run for several years on a battery. LoRa technology is at the heart of many academic and industrial works, and many scientific questions are still open, as revealed by (Shanmuga Sundaram et al., 2020). The principal value in use when studying a LoRaWAN, and generally signals, is probably the Received Signal Strength Indication (RSSI). The RSSI is a measure of the power at the reception of a signal. It formulates in decibel-milliwatts (dBm). In general, the RSSI usually spans between -60 and -130 dBm; the closer value is to 0, the better the RSSI and, on the contrary, a signal relative to -130 dBm means a weak reception. The network architecture of LoRaWAN uses a star topology where the data from all the devices gather to a gateway. LoRaWAN is a data link layer protocol to provide a low power connectivity system to battery-powered devices. The current LoRaWAN specification is 1.1 (the most used specification is 1.0.3). The gateway can then transmit these data to a server. Through the Adaptive Data Rate, a LoRaWAN gateway can change the data rate by changing its spreading factor (SF). The CSS modulation uses a Spreading Factor (SF) to spread the information over the frequency (from 7 to 12), determining the number of bits necessary to transmit the same amount of data. A higher number of bits per symbol increases the capability of the receiver to demodulate the message. Higher SF means that more bits are necessary to send the same information. By increasing the SF, the range can be increased at the cost of data throughput (Zhu et al., 2019), throughput varying from 0.3 kilobits per second to 50 kilobits per second. As with every means of communication, LoRa can suffer from external factors that would diminish the signal quality, starting with the urban environment where IoT networks can use the LPWANs. This kind of impact has been studied in (Villarim et al., 2019; Dambal et al., 2019; Inagaki et al., 2019; Villarim et al., 2019; Yousuf et al., 2018). In (Dambal et al., 2019) the authors study the impact of a rural environment over a LoRa message. Thus, in an urban situation, positioning the antennas is extremely important. By increasing the antenna height, the coverage will increase too, as the height of the buildings can be an obstacle for the signal. As buildings occupy the Fresnel zone, the signal can be heavily impacted. In a village like Cozzano, the buildings tend to have fewer floors, thus less height, potentially reducing the mentioned interference. However, in (Villarim et al., 2019), the authors estimate that vegetation might be even more of an obstacle to the propagation of Lora signal than buildings. It is important to consider that Cozzano is located in the mountains with much Mediterranean vegetation. This vegetation needs to be taken into account when measuring the values of the RSSI, according to (Iova et al., 2017). By comparing the measures made in an airport and a forest, the authors observed that while 95% of the received data in an open field, only 80% are received when vegetation obscures the path.

Furthermore, it appears from their experimentations that vegetation could reduce the range at which a message can be transmitted: from 500 meters in an open field, the signal reached about 90 meters in a forest, this kind of impact needs to be taken into account as it could severely damage the reception of the data. These results are comforted by other works such as (Wiyadi et al., 2020; Ali et al., 2019; Ansah et al., 2020; Hidayat et al., 2019; Elijah et al., 2019) where we can observe an impact of the vegetation on signal propagation. In (Ali et al., 2019) the authors men-

Table 1: Comparison of works surrounding LoRa.

Publication	Impacted parameters	Distance	Temperature	Snow	Vegetation	Mobility	Buildings
(Souza Bezerra et al., 2019)	RSSI		-	-			-
(Dambal et al., 2019)	RSSI	-					-
(Boano et al., 2021)	RSSI, PDR		-				
(Petäjäjärvi et al., 2017)	RSSI, PDR	-				-	
(Iova et al., 2017)	RSSI	-			-		
(Ali et al., 2019)	RSSI, SNR, PDR				-		
(Alset et al., 2020)	RSSI, PDR	-					
(Ansah et al., 2020)	RSSI, SNR, PDR				-		
(Avila-Campos et al., 2019)	RSSI, SNR	-					
(Qaraqe et al., 2020)	RSSI	-				x	
(Inagaki et al., 2019)	RSSI	-					-
(Hidayat et al., 2019)	RSSI, PDR	-			-		-
(Wiyadi et al., 2020)	RSSI, PDR	-			-		
(Elijah et al., 2019)	RSSI, PDR	-			-		-
(Villarim et al., 2019)	RSSI, PDR	-			-		-
(Doroshkin et al., 2019)	RSSI, SNR	-				x	
(Yousuf et al., 2018)	RSSI, PDR	-				x	-

tion the vegetation occupying the Fresnel zone and that this is the reason why the vegetation impact the signal. Thanks to the equations surrounding the Fresnel zone, it is possible to estimate more precisely the impact vegetation could have on a LoRaWAN. SF is an adjustable parameter to increase the range of the LoRa signal at the cost of throughput, representing a solution inside dense vegetation. A signal emitted with a higher SF tends to be more robust than one cast with a lower SF, further increasing the signal capacity to pass through vegetation.

Mobility is already been studied in (Petäjäjärvi et al., 2017; Doroshkin et al., 2019; Qaraqe et al., 2020). According to these studies, speed is a parameter that can negatively impact the RSSI. For example, with an SF 12, an approximate speed of 40 km/h is enough to impact the RSSI value negatively(Petäjäjärvi et al., 2017). However, according to (Doroshkin et al., 2019), the impact of the speed already observed in (Petäjäjärvi et al., 2017) cannot be applied in Line of Sight (LOS) scenarios as the multipath phenomenon can amplify the impact of the Doppler effect.

Furthermore some works studied the impact of temperature on a LoRa signal, such as (Souza Bezerra et al., 2019) or (Boano et al., 2021). In (Souza Bezerra et al., 2019) the authors studied the impact of temperature on a LoRaWAN device in a Swedish town, while in (Boano et al., 2021) the authors studied the impact of temperature on a heated bed. From the results, relatively high temperature can hurt the quality of a LoRa network as it could decrease the RSSI. Even if heat has a negative impact, too cold weather associated with snow seems equally harmful. Indeed in (Souza Bezerra et al., 2019), the authors precise that snow hinders signal propagation.

The references analysing the impacts on the signal have been summarised in Table 1 where the significant effects mentioned have been noted as unfavourable (-) or neutral (x). The LoRa parameters that are studied are generally a combination of the RSSI, the Signal to Noise Ratio (SNR) and the percentage of packet lost or received. To make the analysis more understandable, we consider that studying the data portion of received packets (PDR) versus transmitted packets is identical to the packet loss rate (PL) because they are opposite.

3 COZZANO'S RSSI MAPPING

The data pass through an information system developed specifically for the Smart Village to collect the information, as illustrated in Figure 2.

The central communication technology of the Smart Village being LoRa, we felt a need for a better understanding of how the signal spread around the village of Cozzano. For this purpose, we developed LoRa devices allowing us to transmit a location through a message to the LoRaWAN gateway on the church bell tower. The used LoRa gateway is a kerlink device (Kerlink, 2022). All the used devices on

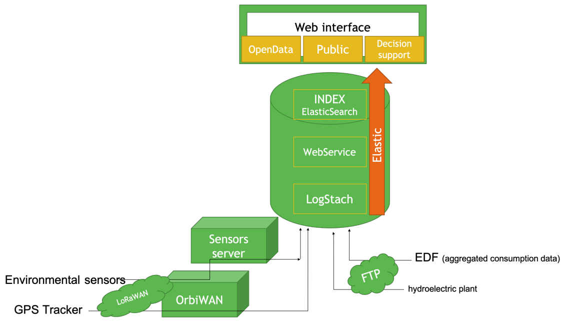

Figure 2: Information system architecture.

the Smart Village are Class C of Lora.

We walked around the village with the devices and regularly sent our position to the gateway to take these measures. The transmissions used a spreading factor of 7 and a bandwidth of 125 kHz. Using the data collected in the Smart Village, we were able to produce the map presented in Figure 3. We can see coloured circles representing the RSSI on a location. In Figure 3, the gradient from green to red represents an increase in the quality of the RSSI. However, these circles are numerous and difficult to observe separately. The rings regroup 30 square meters wide. By calculating the circle's mean value, we attributed a colour to each one, following the already used colour scale. Furthermore, we can see there is more than one square

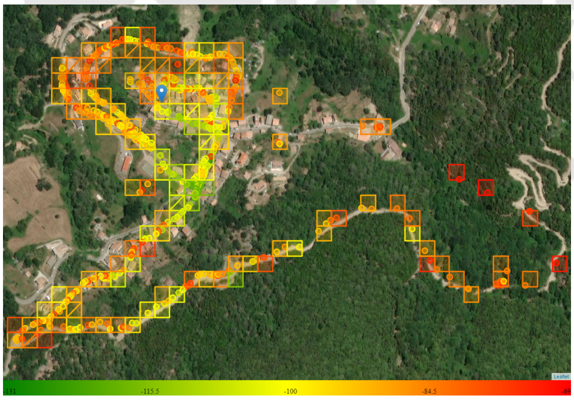

Figure 3: Map of RSSI distribution in Cozzano.

type. The standard squares are measured from our results, while the barred ones are estimated from the neighbouring measured squares. For simplicity, we assumed that the propagation of the signal would be regular on really short distances such as 30 meters and estimated the value of the barred squares as the mean of the surrounding squares (in the case where there are at least five neighbours). We attributed a colour to these estimated squares according to the previous colours gradient. As presented on 3, there is a substantial evolution of the RSSI within the village. Thus, RSSI varies from strong values (around -80 dBm) to fragile ones (down to -131 dBm). The village's topography can explain this range of values; granite stone buildings strongly impact a signal and cause rebound through the alleys, deteriorating the signal. Thus, the more open fielded areas can transmit a message with high RSSI. While taking our measures, we could also retrieve the RSSI on a trail above the village. It cannot be seen, but the trail altitude gives a clear viewpoint gateway's position on the bell tower. Without any obstacles, the message can be transmitted to the gateway in the best condition; thus, the high values of the RSSI we can find on this trail despite the gateway distance. From these results, we can see that buildings significantly impact message transmitting. The presence of buildings can lead to RSSI lower than -100 dBm for a distance approximating 150 meters, while in an open field situation, messages are received with higher RSSI for greater distances.

4 STATISTICAL ANALYSIS

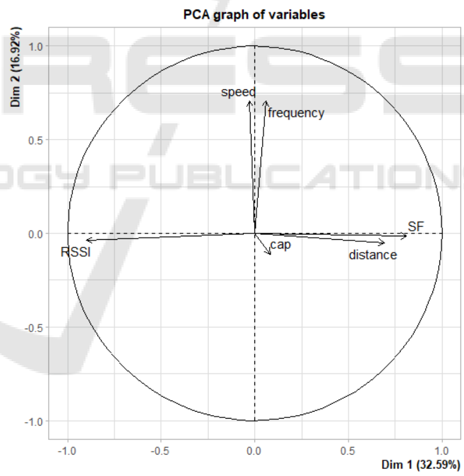

Figure 4: PCA of the trackers datas.

From the analysis of the RSSI values, the question is to know which parameters influence the LoRa signal strength. We, therefore, relied on the popular statistical method, Principal components analysis (PCA) (Jolliffe, 2013). The principal component analysis allows extraction and visualising information from a multivariate data table. PCA synthesises this information into just a few new variables called principal components. These new variables are a linear combination of the original variables. The number of principal components is less than or equal to the number of original variables. The information

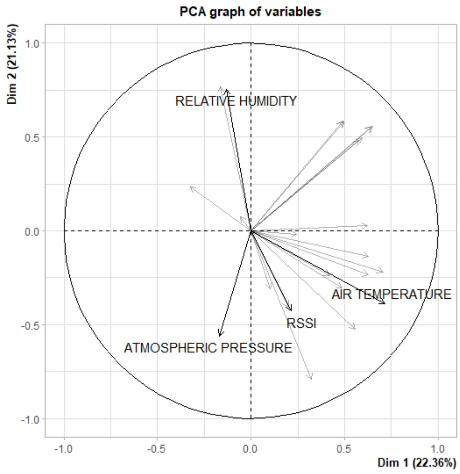

Figure 5: PCA of the datas from the firefighters station.

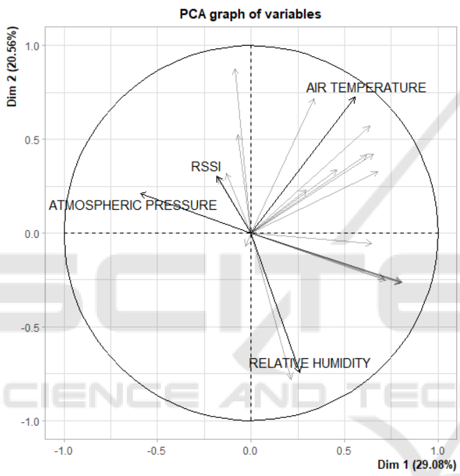

Figure 6: PCA of the datas from the saffron field.

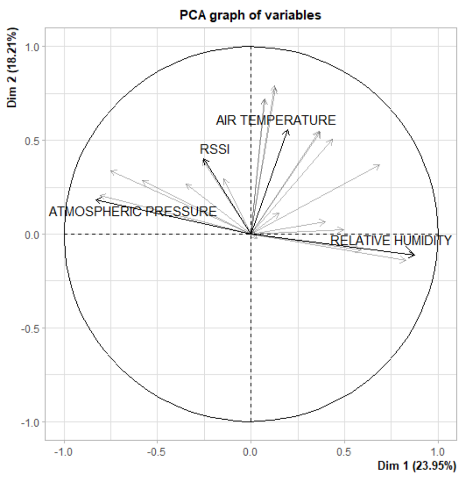

Figure 7: PCA of the datas from the Casteddu.

contained in a dataset is the total variance or inertia. The objective of PCA is to identify the directions (i.e., principal axes or principal components) along which the variation in the data is maximum. We tried to define the parameters above by running the PCA through multiple emitters. The first emitters chosen for this analysis were GPS trackers (Rf-track, 2022) on the animals. We can retrieve a certain amount of data through these trackers, such as position, RSSI, spreading factor, frequency, movement speed, and direction. We can calculate the distance between the emitter and the gateway at each transmission with a known location. We used this distance instead of the location in the PCA. For the experiment, tracker devices were placed on different herd animals. These animals move freely on a vast mountainous territory. We retrieved around fourteen thousand transmissions and the PCA results presented in Figure 4. Many models such as Free Space Path Loss or Okumura-Hata already consider distance when estimating RSSI values. Thus, it seems coherent to see distance negatively correlated to the RSSI. According to this PCA, the SF appears also negatively correlated to the RSSI. The SF could have changed to assure the transmission of the message in harsh conditions. It could explain the aforementioned negative impact. Furthermore, the animals usually travel at low speed, which, according to literature, isn't enough to impact LoRa signal propagation. This observation can explain the lack of correlation between the speed and the RSSI represented in Figure 4. The minor variations in frequency operated in LoRaWAN don't seem to impact the RSSI either as the RSSI and frequency vectors are at an angle close to 90°. Thus it is unlikely that the differences in frequency provoked by the channels in use by LoRaWAN are detrimental to the signals.

Another exciting piece of information is the impact of atmospheric pressure, as the weather could affect signal propagation. It seems that with higher pressure, we obtain a better RSSI.

5 WAY TO ENHANCE LoRa DEVICES DEPLOYMENT

We evoke the axis in which we will contribute to improving the deployment of wireless sensor networks. We imagine coupling a Machine Learning algorithm to predict positions and optimize these positions. Our idea base itself on the coupling of two algorithms for placement optimization:

- The k-nearest neighbours algorithm (KNN), which allows an accurate estimation of the signals on the deployment area from localized measurements

- Hitchcock bird-inspired algorithm (HBIA) optimizes the devices' positioning according to different parameters: environmental parameters and signal quality according to the defined areas of interest.

In the example in Figure 8, we can see different signal qualities collected by field measurements. It can see that the signal from the antenna is worse to the northeast of the antenna than to the southeast, probably due to obstacles (vegetation, buildings) or environmental conditions. If we want to place the antenna in an optimal way (RSSI, gateway link) in an area of interest, we use an optimisation process; the yellow diamond represents the result in the Figure 8. This process can reproduce in different regions of the map.

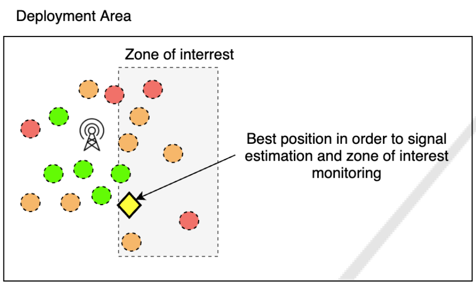

Figure 8: Example of best position found by signal estimation.

6 CONCLUSION AND PERSPECTIVES

This paper first presents a literature review on the factors influencing LoRa signals. In a second step, we have analysed the RSSI results in a village in Corsica with its own LoRA network. We see that environmental factors, as well as granite buildings strongly, influence the signal quality. These exploratory works lead us to think about optimisation of the deployment of the devices by using machine learning and optimisation algorithms.

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