Study of performance variability of LoRa/LoRaWAN telecommunication systems

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***Abstract*— This report was written by a student in the frame of the MAB1 project of ”Multimedia and Telecommunications” at the FPMS (Faculté Polytechnique de Mons) of UMons in Belgium. This paper presents a study of the variability of reception of a LoRa/LoRaWAN wireless communication system in an urban environment, in the city of Mons. To perform the study, 8 LoRa emitters have been placed in the area and 2 receiving gateways. The emitters were sending every 10 minutes temperature, relative humidity and pressure measurements from their location. This study shows that the obstacles of urban environment and the distance between the emitter and the receiver affect greatly the quality of the transmission. There is also a link between the RSSI and the SNR, which appears to be exponential and positive, and the limiting factor of a LoRa transmission seems to be the SNR, not the RSSI. In addition, the temperature, coupled with humidity, influences negatively the transmission. The pressure, however, doesn't seem to impact the communication.**

I. Introduction

The Internet of Things is the the connection of physical devices to the Internet and between themselves [1]. Such devices are usually embedded electronics or sensors that send a smaller amount of data than classical Internet applications on smartphones, tablets or computers. Also, the battery lifetime is an important factor to consider. Specific protocols to the IoT world exist (CoAP, Sigfox, ZigBee, AMQP, ...[3][17]) and one of them is LoRaWAN (MAC layer protocol in the OSI model). This protocol allows low-speed communications, using radio frequencies and for devices with limited access to power, both electrical and computational [4]. The physical implementation is called LoRa. It uses Chirp Spread Spectrum (CSS) modulation in order to send data up to 15 km (in a rural environment) [5][19]. Data sent by the emitters is received by gateways that will send the information on the Internet. The slope of the instantaneous frequency of the chirp depends on a spreading factor SF. Two symbols sent with different SF are quasi-orthogonal and do not interfere with each other. The higher the SF, the greater is the transmission distance but the slower is the communication (smaller bit rate) [5].

This project aims to implement a LoRa telecommunication system by placing emitters in and near the city of Mons. It analysis the performance variability of the transmissions (from the different emitters to the receivers). The goal is to determine which are the most influencing factors on the communication (distance, temperature, relative humidity, ...) and to establish the possible existence of a correlation between the transmission and these factors.

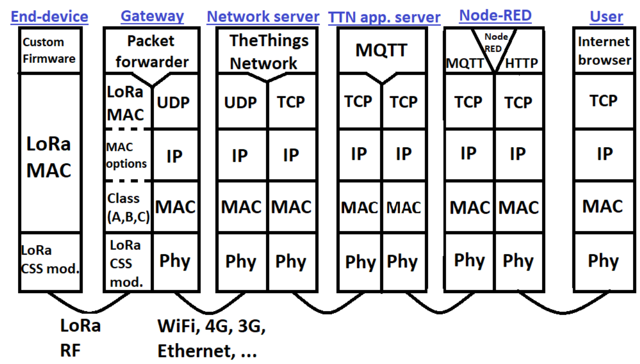

Fig. 1. Complete transmission chain for data collection

II. Methodology

The practical implementation for collecting the data is shown in figure 1. The end-device, before accessing the IoT network of ”TheThingsNetwork”, is activated through the OTAA (Over-the-Air Activation) process. The device and the network server exchange keys and unique identifiers that are used later by the device for transmitting its data to our own application server [6]. This process is mandatory to identify the device and allow it accessing the network.

After this activation process, the device can broadcast its data (encrypted and with a checksum to verify its integrity at the reception) to any compatible LoRa receiver . These receivers are called gateways and they forward the packets to the network server of TTN (if the device is identified on this network). Then, the packets are verified (integrity check) and decrypted by the TTN application server before being sent to the user's application server (here, Node-RED). Finally, the user can see the data in Node-RED from his browser and can also export the data to a text file.

A. Emitters

The static devices that have been used for this project comprise a *lopy MicroPython* development board using LoRa for radio transmission and a *Pysense* board on which the *lopy* is connected and that senses temperature, relative humidity and pressure inside the case. The whole system runs on a lithium battery (AA size). The case of the static devices is 3D-printed and conceived in such a way that water droplets and humidity should not enter inside the area containing the electronic components. The emission antenna is standard and is not calibrated. The payload (5 bytes) sent by each device is composed of the temperature (10 bits), relative humidity (8 bits) and barometric pressure (12 bits) sensed by the *Pysense* module. The battery level (10 bits) was also sent in the payload (only to monitor the variation of the battery level). The nodes 6_02 and 6_03 were placed on the 4^{th} of April 2019 and the nodes 7_01, 7_02 and 8_01 were placed on the 5^{th} of April 2019. The devices 6_01, 8_03 and 8_04 have been placed 2 weeks before the end of data collection (respectively 25.04, 26.04 and 28.04), which has been concluded on the 6^{th} of May 2019.

The choice of the spreading factor for emitting the packets is important, as higher spreading factors imply a longer time on air and the duty cycle limitation of 1% must not be exceeded [13]. To avoid this situation, the lower spreading factors were chosen more often than the higher ones. The emitters were programmed in such a way that for 63 packets sent, 32 will be sent with a SF7, 16 with a SF8, 8 with a SF9, 4 with a SF10, 2 with a SF11 and 1 with SF12. It is not a probabilistic drawing but a way to send packets with different SF, without spending excessive time in the air [2]. The distribution is shown in the figure 2, for the whole data.

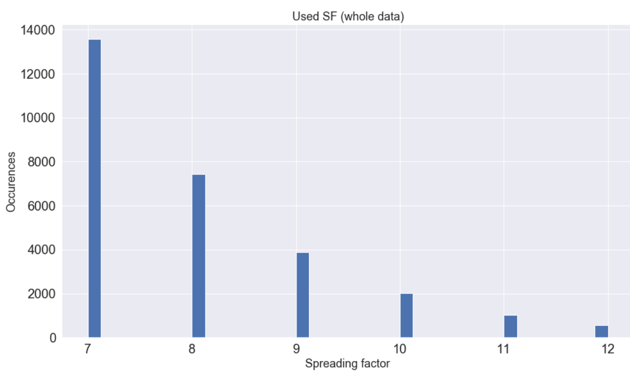

Fig. 2. SF used to send packets

B. Gateways

There were two receivers with different hardware at two different locations. The first one is on the roof of the UMons building "La cité Houzeau". The model is a *Kerlink Wirnet Station* with a specified reception sensitivity level as low as -141 dBm [7]. Its identifier is "eui-0000024b08030186". The second receiver is inside a building, at the street of "Joncquois", ground level. This model is a *RAK831* using a *Semtech* chip that allows reception sensitivity levels of -124 dBm for a spreading factor 7 (fast transmissions) and -137 dBm for a spreading factor 12 (slow transmissions but more resistant to noise) [8]. Its identifier is "iotlab-rpi-03".

C. Emitter and receiver positions

The experiment has been conducted in the vicinity of the city of Mons (see map on figure 3). Except for the device 8_04, the emitters and the receivers were placed in urban environment. The emitters 6_01 and 7_02 were the only emitters to be placed indoor. The rest of the emitters were placed outdoor. The white circles represent the approximate distance from the receivers (in fact the middle between the two gateways is represented by the red square).

Fig. 3. Geographical location of emitters (blue) and receivers (yellow) (Image taken using Google Earth Pro)

D. Data analysis tools

Data analysis has been performed using Python 3 with Spyder and Jupyter.

III. Results and discussion

This section presents the data collected from the experiment and some general trends that have been seen in the transmissions. The first will presents the difference in data reception per device and per gateway. The second point focuses on the distance between the emitters and the receivers, the topology of the area and the presence of obstacles. The next points focus on technical (RSSI and SNR) and environmental parameters (temperature, relative humidity and pressure) and establish their impact on the transmission.

The database provided the following information : timestamp (up to the ns), device ID (the name of the emitter), device eui (unique identifier on TTN), gateway ID (the name of the gateway that received the packet), counter (number that increments by one unit each time a new packet is sent by the emitter), frequency (in MHz), data rate (SF and bandwidth), coding rate, RSSI, SNR, battery level, humidity, pressure and temperature

A. Data reception and dispersion

Tabe II in the appendix shows the number of packets that were received by the two gateways. It is clear that the gateway eui-0000024b08030186 at the top of the building "Cité Houzeau" received most of the packets from the emitters. Almost 75% of the successful packets were received by this gateway. This is explained by the height and the fact that the gateway was placed outside (not inside a building).

Figure 4 shows the dispersion of the RSSI (Received Signal Strength Indication) and SNR (Signal to Noise Ratio) for each device at the gateway eui-0000024b08030186. It appears that the behaviour of each device is different and data dispersion is also not identical for each emitter. The device 8_04 is a particular case, because it has only successfully sent 3 packets and therefore, has no dispersion in the data. It will be explained later in this article ("*C. Distance between emitters and receivers*").

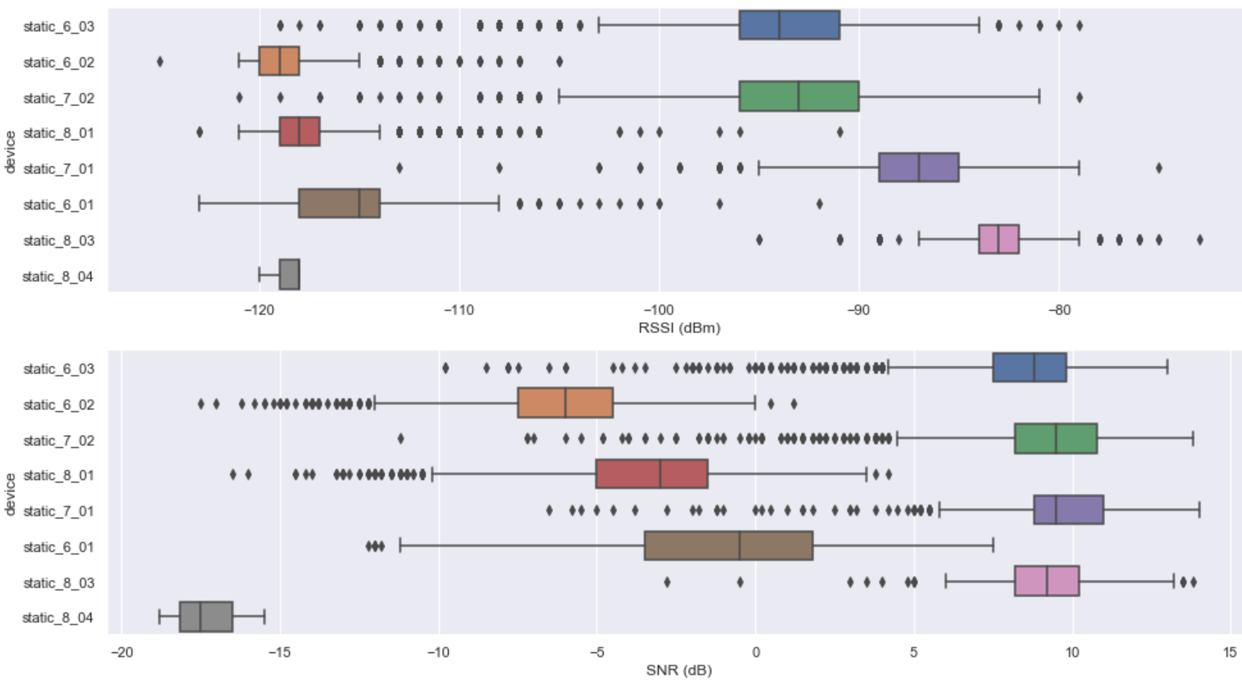

Fig. 4. RSSI (top) and SNR (bottom) dispersion at the gateway eui-0000024b08030186 [2]

B. FER (Frame Error Rate)

The FER can be computed by looking at the ”counter” value of the received packet at the gateway. Each time a packet is sent by the device, its counter increments by one unit, which means that in an ideal case the values of the counter always follows an arithmetic progression of common difference equal to 1. In practice, every packet that is sent is not necessarily received. The table I shows the percentage of the FER on each link. Where there is 100% it means that no packet has been transmitted on this link.

dev\gtw	eui- 0000024b08030186	iotlab-rpi-03
static_6_01	22.319%	100%
static_6_02	49.1085%	100%
static_6_03	3.5887%	33.9718%
static_7_01	2.2207%	20.2839%
static_7_02	3.0909%	98.1789%
static_8_01	24.5774%	100%
static_8_03	3.396%	36.5607%
static_8_04	99.6774%	100%

TABLE I
FER OF EACH LINK

A quick analysis of this table reveals that the receiver at Joncquois (iotlab-rpi-03) performs poorly at receiving packets from the emitters (contrary to the other gateway). When looking at devices that sent to both receivers (like 6_03 or 7_01), it clearly appears that the FER is higher at the Joncquois receiver (the one inside the building), meaning that something is deteriorating the quality of the transmission to this gateway. This is discussed in the following point.

C. Distance between emitters and receivers

Figure 3 at the first page shows the location of the two receivers and the eight emitters. This figure also presents white circles that indicate the approximate distance from the receivers. By comparing the table II in the appendix, the figure 4 and the map, it is clear that the emitters closer to the receivers have higher RSSI and SNR values and have successfully sent a higher number of packets (6_03, 7_02, 7_01 and 8_03). Those who were further away from the receivers have a lower RSSI and SNR and are less successfull at transmitting packets correctly. It should be reminded that devices 6_01, 8_03 and 8_04 have been placed 2 weeks before the end of data collection and it is normal that they have sent less packets than the other nodes. In practice, measurements show that under 800 m and in urban environment, RSSI and SNR remain in the higher range of values.

An important parameter to consider is the height at which the receivers are placed. The one at the top of the building Houzeau (eui-0000024b08030186) has received almost 75% of the total number of received packets, and the indoor receiver (iotlab-rpi-03) at the ground level has had much more trouble in receiving data, even though the two were not so far from each other (approximately 200 m). The higher receiver had less obstacles (trees, buildings, houses, ...) between it and the emitters. On the other hand, the Joncquois's receiver was inside a building at ground level, which meant that any signal arriving at this receiver was attenuated by the obstacles it had encountered (including the walls and the windows of the building)[16]. For instance, the number of packets sent by the node 6_03 and received by the Houzeau's receiver was about 46 % higher than at the Joncquois's receiver. The same observation can be seen at the node 7_01, although the difference in reception is smaller (about 22%). The hypothesis can be confirmed even more by the device 7_02, which was emitting from inside a building, near a window. The table II clearly demonstrates that the Joncquois's receiver (inside a building at ground level) could not receive as much packets as the Houzeau's receiver (on the top of the roof). In fact, this is mostly due to the position of this device inside the city. The signal needed to go through the window, then travel the distance separating the emitter from the Joncquois's receiver and before it could reach the receiver, it was heavily attenuated by the obstacles on its path and the building where the receiver was located. The emitter 8_01 has not been able to send a single packet to the Joncquois's receiver for the same reasons (position of the emitter relative to the receiver and obstacles in the path).

Not only the placement of the receivers is important, but so is the placement of the emitters. The device 6_02 is roughly under 800 m of distance from the receivers, but table II and figure 4 indicate that it had some difficulties in sending its data properly. This is due to the fact that this particular emitter was placed in an area surrounded by a lot of buildings, which have considerably attenuated the signal. The farthest device (8_04) that was placed near the end of the experiment only managed to send three packets properly ... The reason is that the emitter is hidden behind a hill, when looking from the receivers's perspective. Here, it is the topology of the landscape that had a major influence on the transmission.

These observations confirm a previous study made by a Swiss team in the Antarctic using mobile LoRa emitters, where the "*varying terrain elevation is shown to be the dominating factor influencing the propagation[...]*" [14]. This team could achieve up to 30 km of range between the base and the mobile emitters (using directional antennas) with a Line-of-Sight communication.

Another study has also highlighted the link quality degradation of indoor transmissions between buildings and confirms that indoor nodes closer to a door/window were able to send a stronger signal to the gateway [12].

D. Link between RSSI and SNR

The RSSI and the SNR are two different values used to characterize the quality of the transmission. It is interesting to establish the existence of some kind of correlation between these two parameters.

The RSSI (Received Signal Strength Indicator) is a measurement of the power of the received signal from an antenna, usually expressed in dBm [9] [10]. The SNR (Signal-to-Noise Ratio) is a ratio that compares the power of the useful signal to the power of the background noise and interferers, usually expressed in dB. Above 0 dB, the useful signal has more power than the noise [11]. The RSSI will indicate the power of the received signal, but the SNR will tell the power of the useful signal.

The scatter plot of the RSSI as a function of the SNR on the whole data is shown on figure 5. The best devices, with the highest number of successfully received packets and higher RSSI values tend to have a higher SNR. On the contrary, the weaker devices with a lower RSSI tend to have a lower SNR. The computation of the Pearson's linear correlation coefficient gives 0,874 (positively linear correlation).

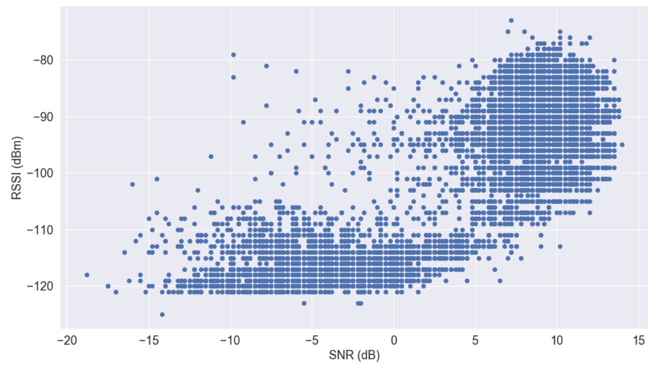

Fig. 5. RSSI vs SNR at the Houzeau gateway (all devices)

E. The limiting factor of the transmission

The fact that some packets were not properly received by the gateways means that some parameter(s) limit the reception of packets. In the scope of this project, it appeared that the SNR is the limiting factor.

The gateway Joncquois only received 68 packets from the emitter 7_02, with the highest spreading factors only (10, 11 and 12 - see figure 11 in appendix). The sensitivity of this receiver is -137 dBm for SF12, but the lowest RSSI level was recorded at -108 dBm (29 dB above the sensitivty threshold). This means that the RSSI reception level didn't limit the reception of the packets, but it was the SNR. The lowest SNR value was recorded at -19.5 dB (with a RSSI level of -103 dBm) (see figure 12 in the appendix).

For the device 8_04, the lowest SNR value was -18.8 dB with a RSSI level of -118 dBm, at the Houzeau receiver.

Observations on other communications that present poor performances confirm that the RSSI sensitivity level of the receiver was never reached and that SNR values were always lower than -10 dB. Such low values of SNR are easily explained by the obstacles in the environment that attenuate the power of the signal (as explained previously).

F. Frequency bands of a LoRa transmission

The frequency of a LoRa transmission is at 868 MHz in Europe. In this experiment, 8 frequency bands, ranging from 867,1 MHz to 868,5 MHz, were available and almost equally used by the emitters under normal conditions (appendix - figure 13). However, some transmissions had an issue at a specific moment in time. For instance, the node 6_02 had a sudden packet delivery drop between the 12^{th} and the 17^{th} of April 2019 (appendix - figure 14). The analysis of the environmental parameters (temperature, relative humidity and pressure) showed no sudden change that could cause this issue. However, the analysis of the frequency band usage (figure 6) revealed that 3 frequency bands were much less used (867,5 MHz, 868,3 MHz and 868,5 MHz). This is confirmed by figure 15 in the appendix where those 3 frequencies were less used during this period (especially 867,5 MHz). A plausible hypothesis is that electromagnetic noise interfered with the LoRa transmission at this time (possibly other LoRa or Sigfox emitters). This phenomenon has also been observed on the node 7_02 between the 8^{th} and 10^{th} of April at the Joncquois's gateway. This only remains a hypothesis, as no means of measuring the electromagnetic noise have been deployed in this project.

No similar problem has been observed during the rest of the experiment.

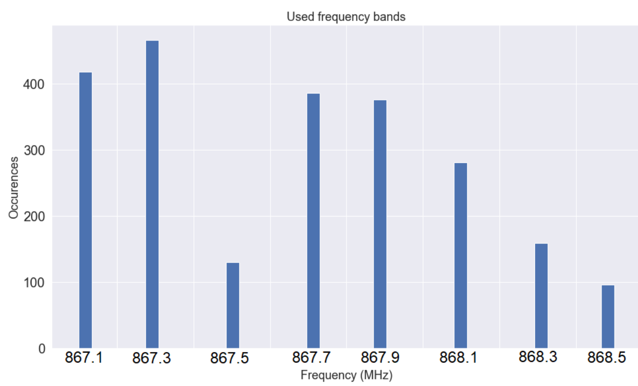

Fig. 6. Histogram of the frequency bands used by 6_02 during the experiment

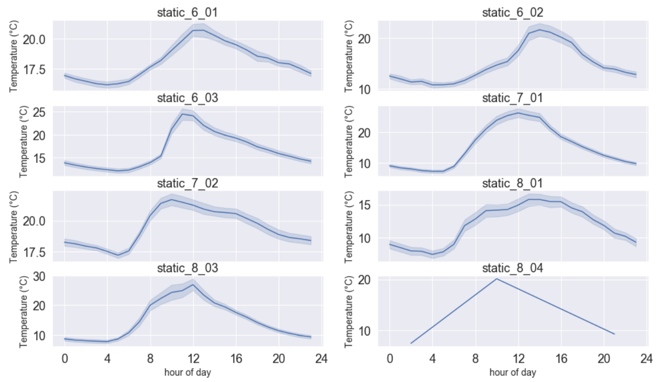

Fig. 7. Temperature profile on each device (averaged values on 24 hours)

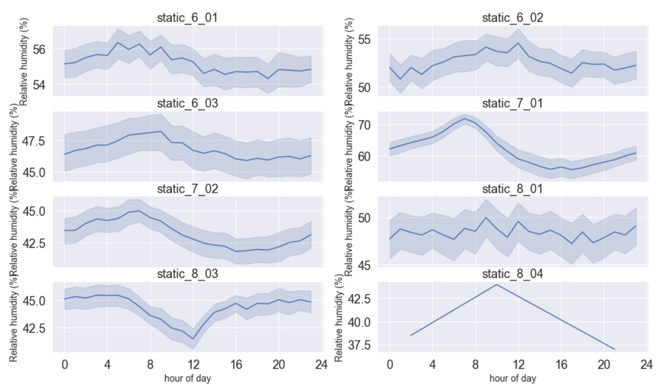

Fig. 8. RH profile on each device (averaged values on 24 hours)

G. *Impact of the temperature and relative humidity on the communication*

This subsection analyses the impact of the temperature and the relative humidity on the LoRa transmission. The analysis show global and daily variations (averaged over 24 hours).

The temperature evolution throughout the experiment was almost identical on every device (appendix - figure 16). The device 7_02 had the smallest variations (less than 10°C), because it was inside a building. The device 7_01 had undergone the largest variations in terms of temperature. The device 8_03 had also large variations of temperature. During 24 hours, the temperature increases steeply from 5 to 13 o'clock and decreases smoothly afterwards. This can be observed on every device, every day (figure 7).

Evolution of the relative humidity was identical on emitters 6_02, 6_03 and 7_02, with the last one having smaller variations. The largest changes of RH were observed on the node 7_01 and, on average, values were the highest too. The device 8_01 had a constant increase of humidity, from 25% at the beginning of the experiment up to 75% at the end of it. Other devices had no significant changes of RH (appendix - figure 17).

The average evolution of the SNR doesn't seem to be affected much by the environmental variations, but the average evolution of the RSSI is much more relevant (figure 9). During a full day (24 hours), the RSSI of emitters 6_03 and 7_01 fell by approximately 2 dB between 8 o'clock and 18 o'clock. For both devices, the temperatures were higher (over 25°C) between these two moments of the day. The relative humidity, however, was different on both devices (figure 8), where 7_01 has measured 60% to 70% of RH at this time. The other device measured 46% to 48% of RH. This demonstrates that the temperature is actually more influencing than the relative humidity, but coupled effects (high temperature and high humitidy) seem to produce a significant impact. According to Mrs Véronique Moeyaert, when an electronic equipment is put inside a box and this box is subject to high levels of relative humidity (inside humidity is above 50%-60%, without having necessarily condensation), if the sun rays hit directly the box then the temperature inside the housing will rise and can reach values up to 50°C. This means that if the LoRa emitters have been exposed to humidity and directly to the sun, the transmission's RSSI has been affected. The fact that a LoRa transmission is affected by the temperature has been proved by a previous study, led by Austrian researchers who showed that a rising temperature from 10°C to 40°C lowered the RSSI by 3 dB [15].

The emitter 7_02 had minor variations in both parameters because it was protected inside the building from the external variations and its RSSI remained relatively constant. This indoor device proves that a controlled environment stabilises the quality of the transmission.

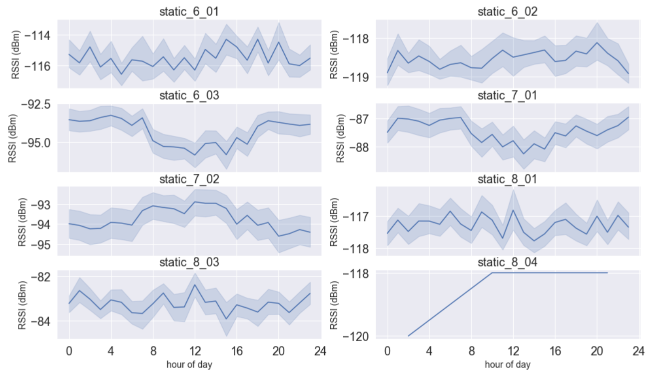

Fig. 9. RSSI of packets received at Houzeau gateway (24 hours)

Fig. 10. Evolution of the atmospheric pressure during the experiment (31 days)

H. Impact of the pressure on the communication

The evolution of the atmospheric pressure was extremely similar on every device, as shown on figure 10. This is perfectly normal, as the atmospheric pressure is generally constant over areas of many square kilometers. This experiment has not highlighted any impact of the atmospheric pressure on the performance of the LoRa transmission.

IV. Conclusions and Future Work

The present study shows that the top influencing factor of a LoRa communication is the environment where the emitters are placed. In a city, there are a lot of obstacles that absorb or reflect electromagnetic radio waves (glass, concrete, metal, people, ...) [16]. In rural environment, there is less obstacles to propagation and it could be expected that the communication would be better there. Indirectly, the positioning of the emitters and the receivers, and in particular the height, has to be considered in this context.

The second most influencing factor is the distance between the emitter and the receiver. It is directly linked to the first one. It has been shown that the presence of obstacles in the communication path coupled with a high separating distance give a transmission of a poor quality.

The temperature also has an influence on the RSSI of the communication. This has been shown in this paper but also in previous studies [12][14][15].

In order to establish more correlations with the environment, other parameters have to be considered (wind speed, wind direction, rain, airborne particulate matter from combustion engines, ...). Instead of measuring them directly at the emitters, it could be interesting to measure them from a ”super-node” that would be placed in the measurement area.

Also, this experiment only focused on static devices. A future work recommendation could be to implement a few mobile nodes with a GPS chip that would reproduce exactly the same data collection as here, but while moving.

Finally, the possibility of deploying many more nodes in different environments (urban and rural) will provide more data, make the observations more reliable and perhaps highlight new correlations that could not be observed here.

Acknowledgments

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APPENDIX

dev\gtw	eui- 0000024b08030186	iotlab-rpi-03
static_6_01	1159	0
static_6_02	2312	0
static_6_03	4379	2999
static_7_01	4271	3482
static_7_02	4264	68
static_8_01	3302	0
static_8_03	1337	878
static_8_04	3	0
Sum	21027	7427

TABLE II

NUMBER OF RECEIVED PACKETS BY EACH GATEWAY (04.04.19 TO 06.05.19 - 31 DAYS)

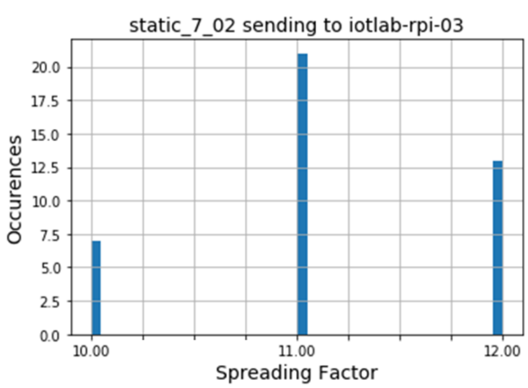

Fig. 11. SF of the packets received by the Joncquois gateway

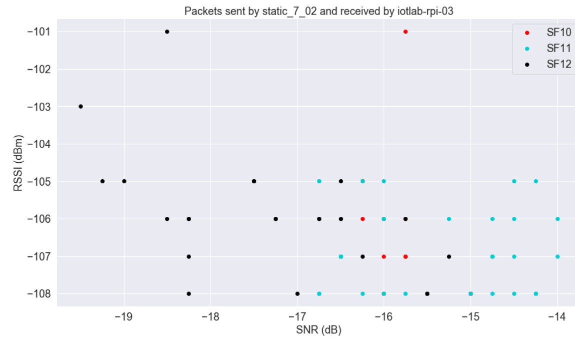

Fig. 12. SNR values of a mediocre transmission

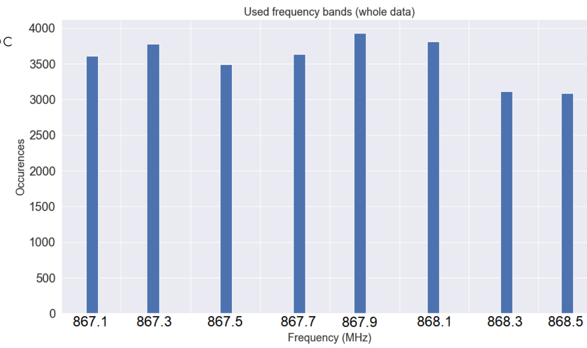

Fig. 13. Frequency bands used during the experiment

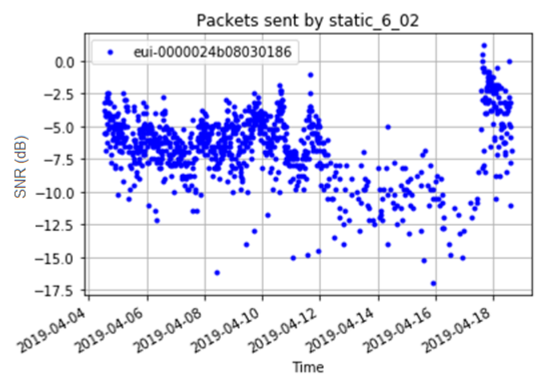

Fig. 14. Packet delivery drop between the 12.04 and 17.04 (device 6_02)

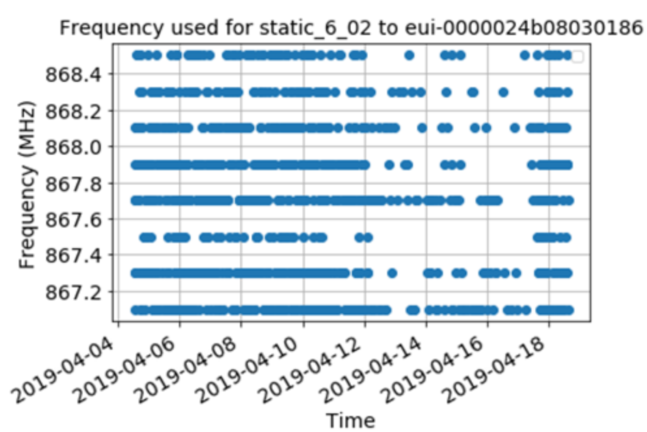

Fig. 15. Frequency band used by the device 6_02 between the 04.04.2019 and 18.04.2019 (Houzeau gateway)

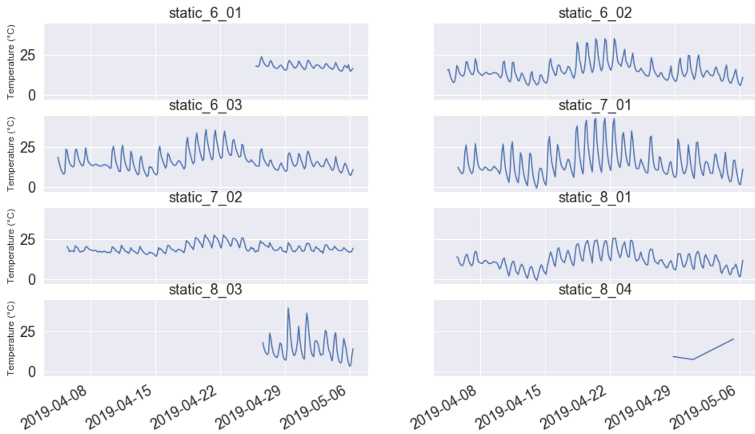

Fig. 16. Temperature profile on each device (31 days)

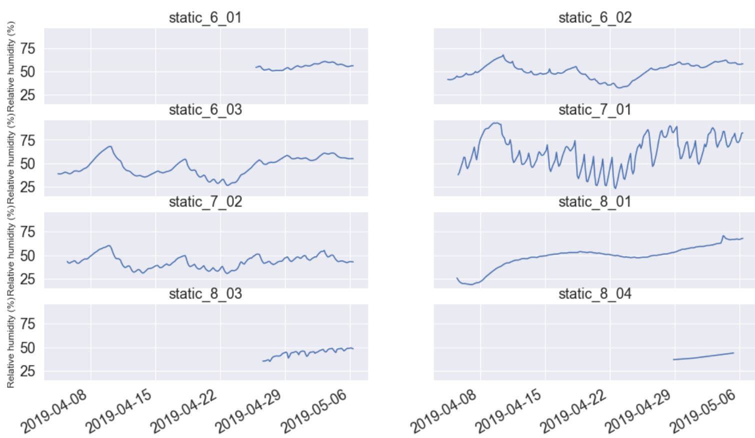

Fig. 17. RH profile on each device (31 days)