LoRa™ Radio Testbed

Ibrahim Amadou & Brandon Foubert & Nathalie Mitton
Inria Lille – Nord Europe
firstname.lastname@inria.fr

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1 Experimental TESTBED

A typical LoRa-based network communication, which is defined in the LoRaWAN standard [?] by LoRa-Alliance, is based on a star-of-stars topology in which gateways relay messages between end-devices and the network core. In this work, we only focus on the device-to-device communication because the network infrastructure, such as gateway, has no influence on the device's wireless link characteristics. Two B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery kit devices are used during the experiment. This device contained an onboard based on Semtech SX1276 transceiver chip. We adapt an existing open source software module, called *SX1276 Generic PingPong*, to send a customized *Beacon*. The devices are respectively defined as transmitter (e.g., noted as **TX**), for the initiator of PingPong process also known as the *Ping* transmitter, and receiver (e.g., noted as **RX**) for the device that sends the response (i.e., *Pong message*) to the initiator *beacon*. Table 3 summarizes our experimental Setup. These Parameters are chosen regarding to a LoRaWAN specification for Europe [?, ?].

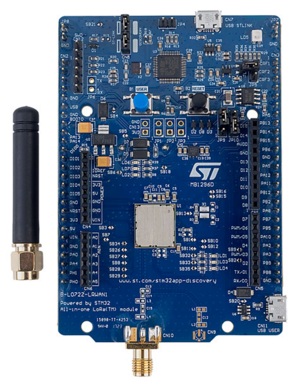


FIGURE 1 – LoRa transceiver B-L072Z-LRWAN1

Parameters	**Values**
Spreading Factor	[6, 7, 8, 9, 10, 11, 12]
Transmission power	+14dBm (+17/+20dBm)
Set of Frequencies (mHz) / Channel	(868.0, 0), (868.1, 1), (868.3, 3), (868.5, 5)
Bandwidth (kHz)	125 - 250 - 500
Coding Rate	[(1 : 4/5), (2 : 4/6), (3 : 4/7), (4 : 4/8)]

TABLE 1 – LoRa Radio Parameters for Europe

LoRaWAN Data Rates

The Table 2 summarizes the combinaison of the above parameters.

Data Rate	Modulation	SF	BW	Physique bit rate (bit/s)
0	LoRa	12	125	250
1	LoRa	11	125	440
2	LoRa	10	125	980
3	LoRa	9	125	1760
4	LoRa	8	125	3125
5	LoRa	7	125	5470
6	LoRa	7	250	11000
7	FSK 50 kbps			50000

TABLE 2 – Data rate

Modulation	SF	Bandwidth (BW)	Coding Rate	Transmission Power	Frequency
LoRa	7 - 12	125kHz & 250kHz	4/5	+14dBm	868.1 Mhz

TABLE 3 – The Experiment parameters

2 Scenarios

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 the LoRA technology for accurate positioning, we wanted to assess the stability of the signal within different environments.

2.1 Peri-urbain areas between Building A & B

Peri-urban areas between lab buildings A & B : as shown in Fig. 2, 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 which 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.

FIGURE 2 – Peri-urbain areas between Building A & B

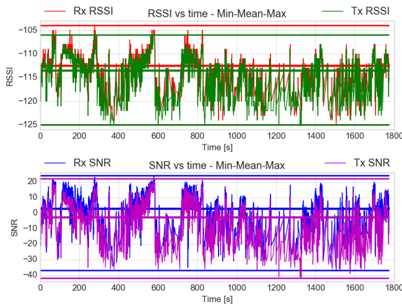
2.1.1 Results Analysis

RSSI & SNR

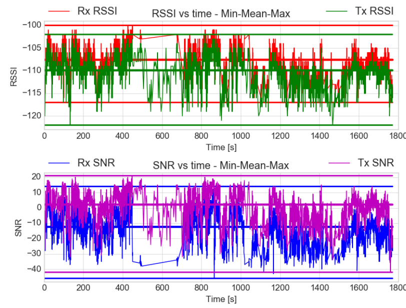
In Fig. 3 we can see the results of scenario (1) for a spreading factor of value 12 and a bandwidth of value 125*Khz*. In this scenario, independently of the spreading factor and bandwidth, the RSSI exhibits similar behavior with a similar average value for both devices. This shows that the RSSI was rather stable for both devices. Moreover, it presents a small variance (see 4 for more details), which could lead one to believe that in these conditions, LoRa might be a good candidate for geolocalization.

Delivery Ratio

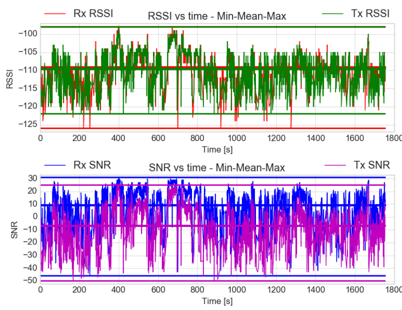
Fig. 4 shows respectively the packet delivery ratio, the packet loss rate, and the packet eror rate.



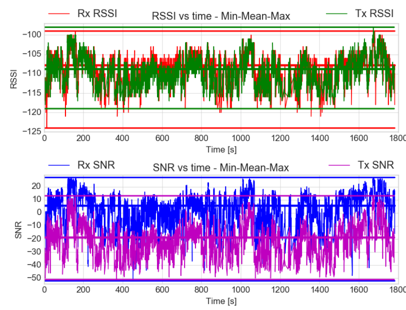
(a) RSSI & SNR (SF=7 BW=125)



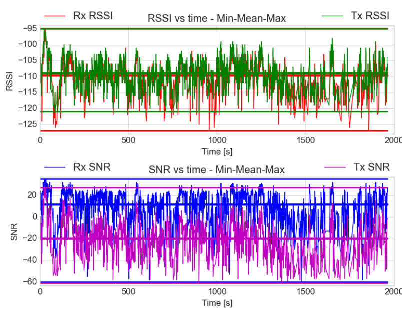
(b) RSSI & SNR (SF=7 BW=250)



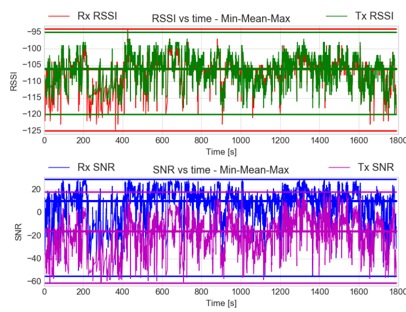
(c) RSSI & SNR (SF=8 BW=125)



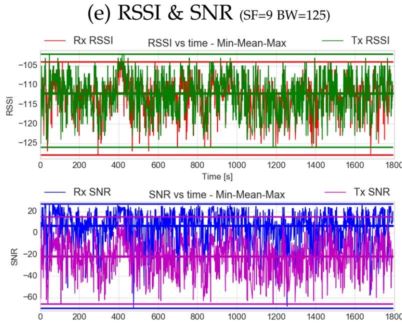
(d) RSSI & SNR (SF=8 BW=250)



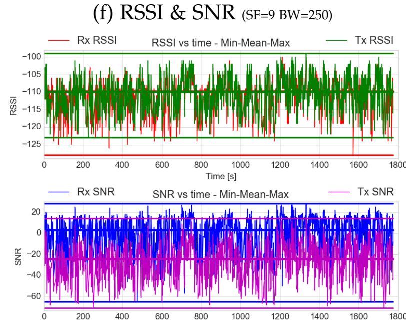
(e) RSSI & SNR (SF=9 BW=125)



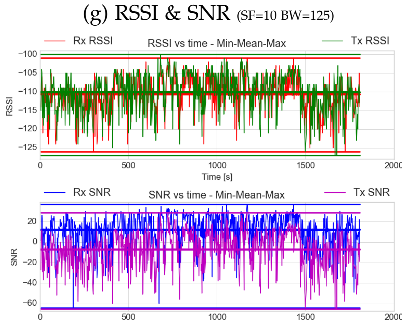
(f) RSSI & SNR (SF=9 BW=250)



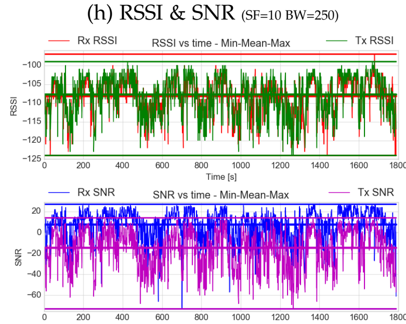
(g) RSSI & SNR (SF=10 BW=125)



(h) RSSI & SNR (SF=10 BW=250)



(i) RSSI & SNR (SF=11 BW=125)



(j) RSSI & SNR (SF=11 BW=250)

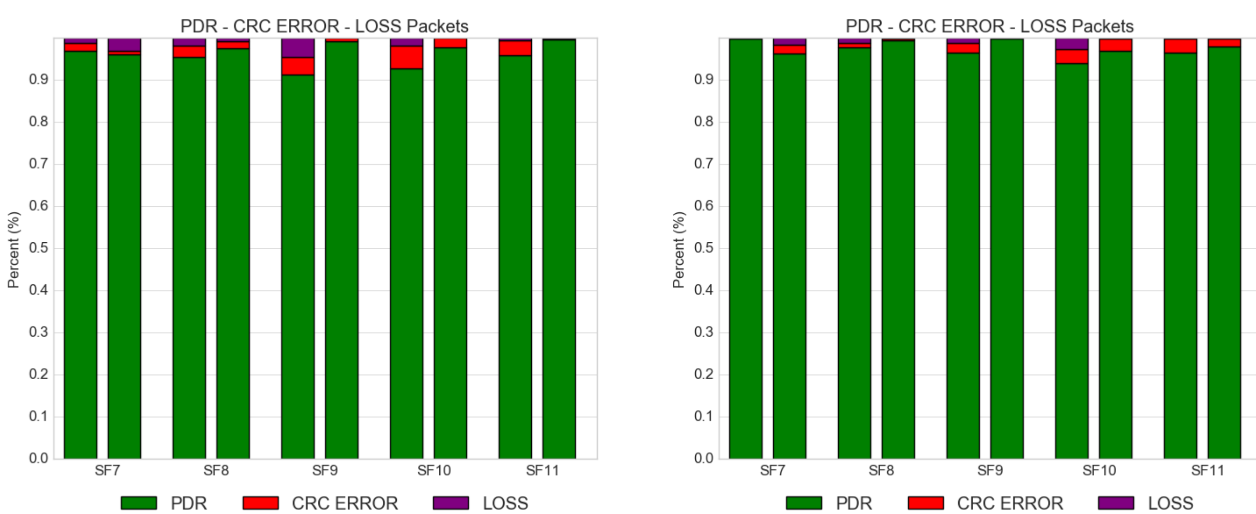
FIGURE 3 – RSSI & SNR over Time for Transmitter and Receiver

Spreading Factor	Bandwidth	Average		Variance		St. Deviation (SD)	
		Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)
7	125kHz	-113.52	-112.50	12.00	9.83	3.46	3.13
	250kHz	-109.91	-107.59	8.16	9.63	2.85	3.10
8	125kHz	-109.62	-109.14	22.19	16.83	4.71	4.10
	250kHz	-108.80	-107.82	12.46	9.81	3.53	3.13
9	125kHz	-108.90	-109.64	21.30	18.14	4.61	4.26
	250kHz	-106.10	-106.21	17.89	13.51	4.23	3.67
10	125kHz	-112.19	-112.08	24.62	15.75	4.96	3.96
	250kHz	-109.95	-109.80	20.29	18.00	4.50	4.24
11	125kHz	-110.12	-110.74	26.54	19.32	5.15	4.39
	250kHz	-107.75	-108.20	26.88	20.07	5.18	4.48

TABLE 4 – RSSI Statistics

Spreading Factor	Bandwidth	Average		Variance		St. Deviation (SD)	
		Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)
7	125kHz	-2.78	2.74	126.52	110.27	11.24	10.50
	250kHz	2.14	-12.38	74.39	93.24	8.62	9.65
8	125kHz	-6.89	9.21	210.53	168.19	14.50	12.96
	250kHz	-18.87	5.41	124.75	118.29	11.16	10.87
9	125kHz	-19.92	11.56	247.46	197.47	15.73	14.05
	250kHz	-16.07	10.19	206.28	149.15	14.36	12.21
10	125kHz	-21.85	6.64	244.95	217.75	15.65	14.75
	250kHz	-24.41	3.00	230.37	192.22	15.17	13.86
11	125kHz	-7.48	12.08	313.24	246.80	17.69	15.71
	250kHz	-14.63	7.60	309.81	204.56	17.60	14.30

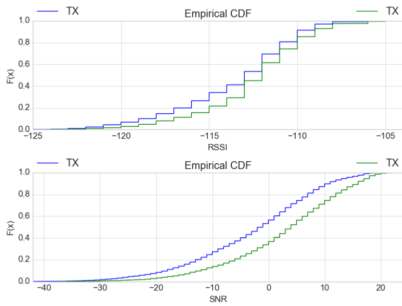
TABLE 5 – SNR Statistics



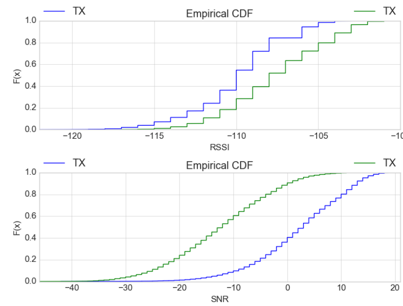
(a) PDR - PER (CRC) - P. Loss Rate

(b) PDR - PER (CRC) - P. Loss Rate

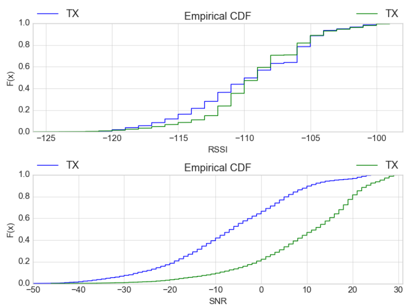
FIGURE 4 – Packet delivery ratio (PDR), Packet Error Rate (PER CRC) and Packet Loss rate



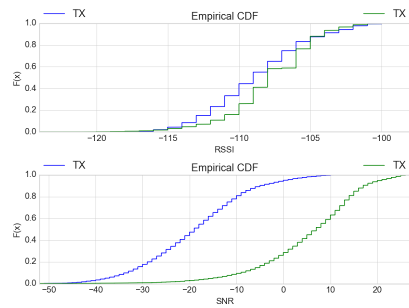
(a) RSSI & SNR (SF=7 BW=125)



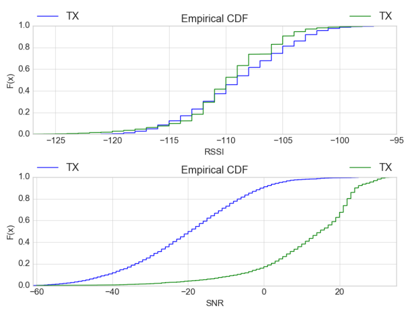
(b) RSSI & SNR (SF=7 BW=250)



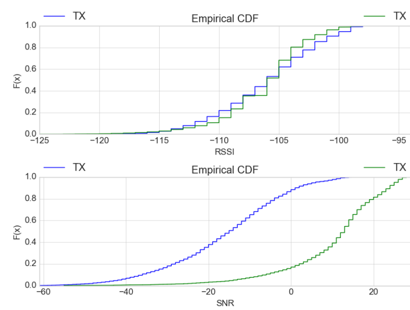
(c) RSSI & SNR (SF=8 BW=125)



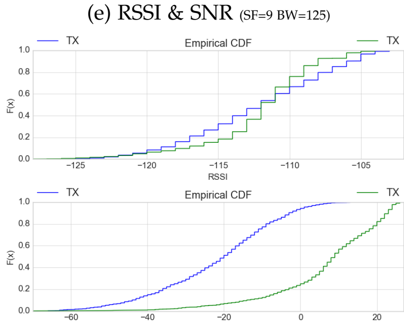
(d) RSSI & SNR (SF=8 BW=250)



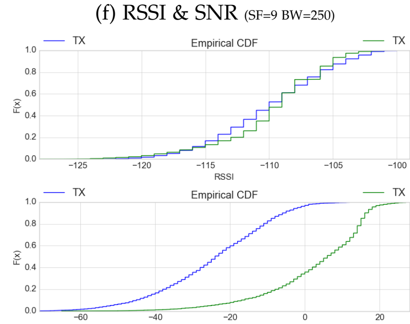
(e) RSSI & SNR (SF=9 BW=125)



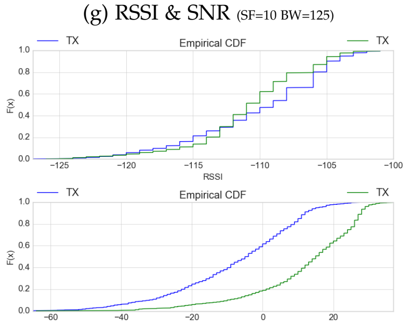
(f) RSSI & SNR (SF=9 BW=250)



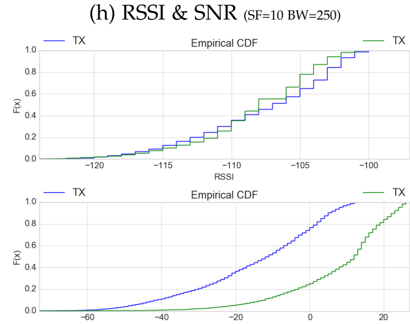
(g) RSSI & SNR (SF=10 BW=125)



(h) RSSI & SNR (SF=10 BW=250)



(i) RSSI & SNR (SF=11 BW=125)

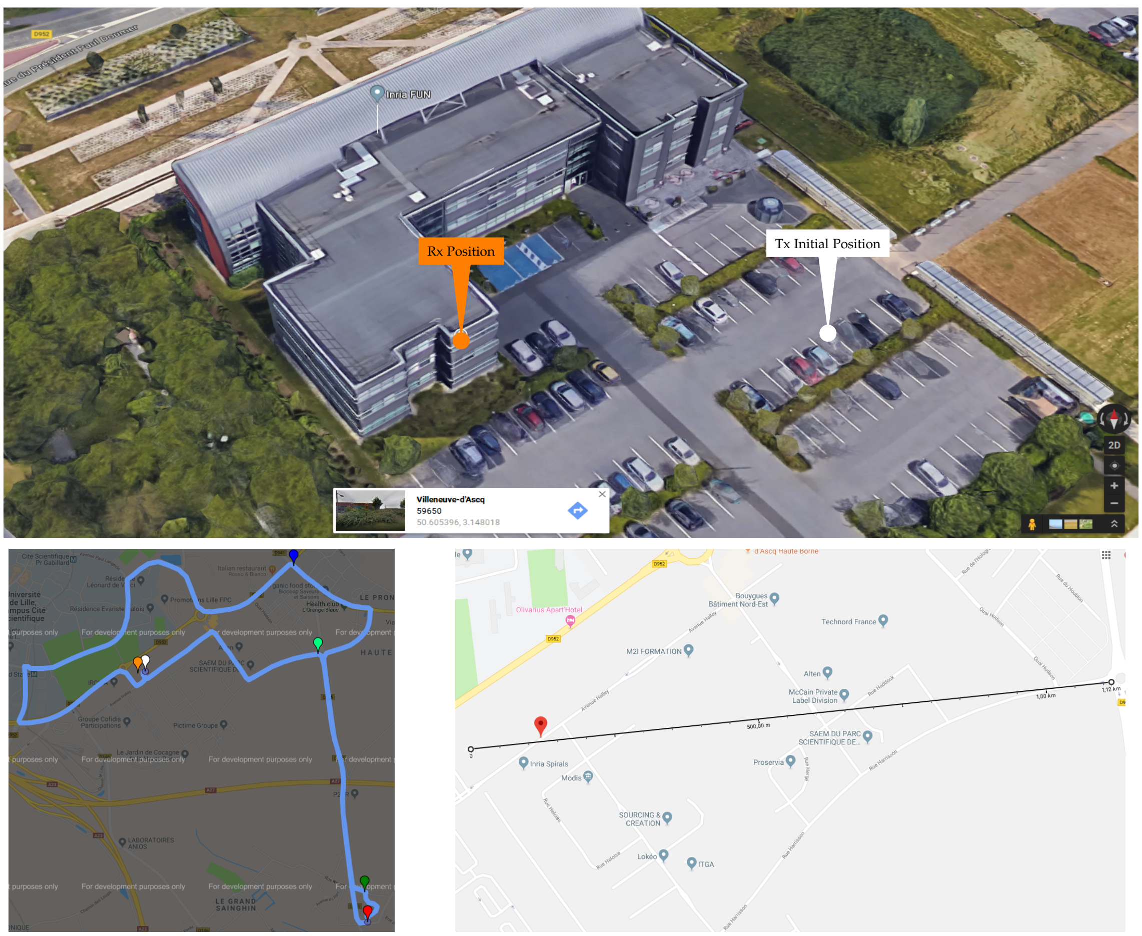


(j) RSSI & SNR (SF=11 BW=250)

Figure 5 – RSSI & SNR Empirical CDF for the Transmitter and Receiver

2.2 Peri-urban area with mobile of receiver

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 unnumbered figure of Fig. 6 and Fig. 6a. First, on unnumbered figure of Fig.6 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. 6a 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 by the 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', which means that it is 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 $2.069km$.



(a) The vehicle circuit (circuit) (b) Maximum communication range (R_{max})

FIGURE 6 – Packet delivery ratio (PDR), Packet Error Rate (PER CRC) and Packet Loss rate

2.2.1 results Analysis

Fig. 7 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 where there is a quasi-symmetric communication between the receiver and transmitter. During this moment, both signals are almost similar and it corresponds to the first 1.12Km as explained in Section 2.2. It last from the white marker visible on Fig. 6a) 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 phase corresponds to the moment where the vehicle is the closest to the light green marker. During this step, we can observe a symmetrical communication between the two devices. Results also show that as the transceiver become closer to the receiver, the RSSI value increases. At almost 1000s on Fig. 7 we can see that the computer logging data from the receiver suffered from an system failure, but it did not affect the receiver operations.

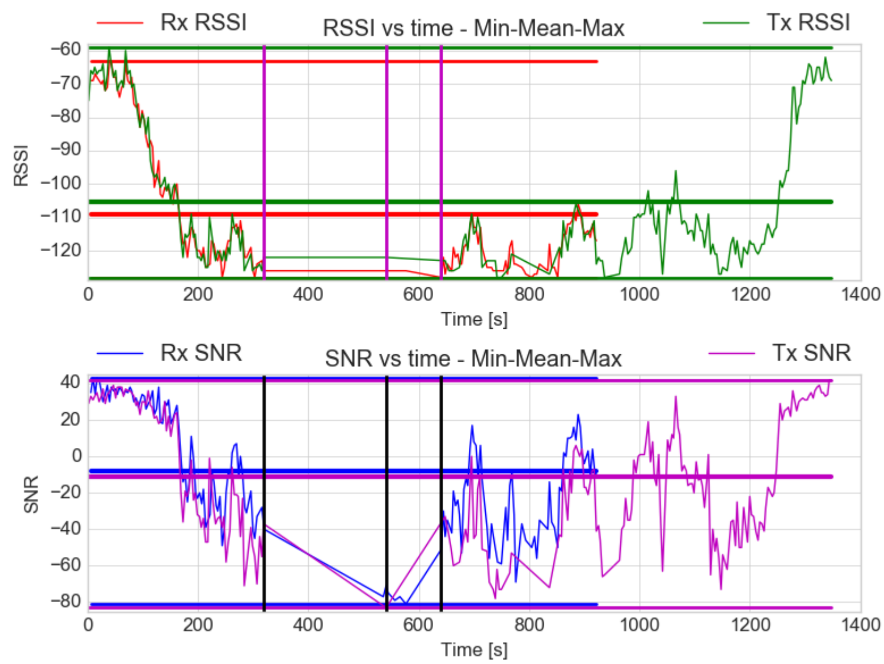


FIGURE 7 – RSSI & SNR over Time for both transmitter and Receiver (Mobile Scenario)

Spreading Factor	Average		Variance		St. Deviation (SD)		
	Bandwidth	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)
12	125kHz	-105.35	-108.97	412.05	389.89	20.29	19.74
	250kHz	-	-	-	-	-	

TABLE 6 – RSSI Statistics

Spreading Factor	Average		Variance		St. Deviation (SD)		
	Bandwidth	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)
12	125kHz	-11.39	-8.26	1150.38	1078.06	33.91	32.83
	250kHz	-	-	-	-	-	

TABLE 7 – SNR Statistics

2.3 High density urbain area

High density urban area : this experiment was conducted in an environment surrounded by several buildings and with a lot of human activity. We can see the map of this scenario in Fig. 8. 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 8.

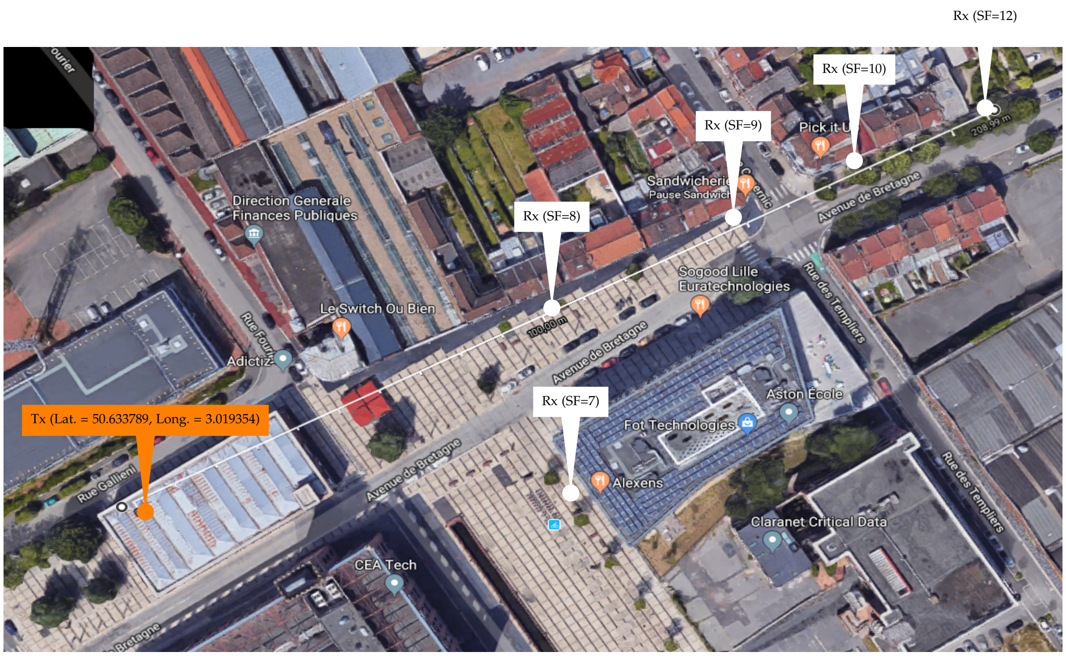


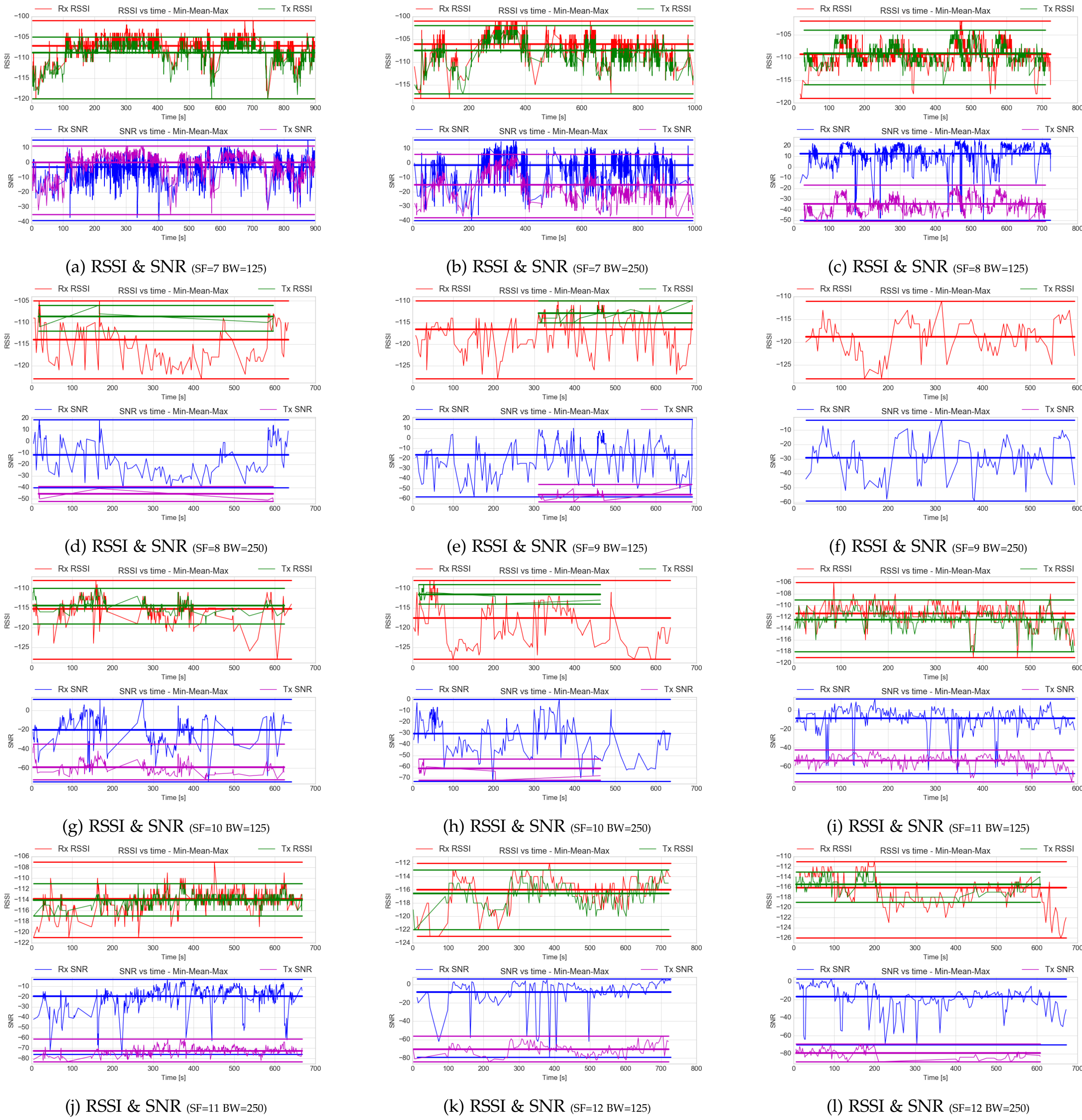
Figure 8 – High density urbain area

Spreading Factor	7	8	9	10	11	12
Max. Comm. Range (~m)	104.22	122.91	164.98	184.49	208.30	208.96

Table 8 – Communication Range versus Spreading Factor

2.3.1 results Analysis

Fig. 9 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. The greater the bandwidth, the more asymmetric the signals are. This is due to the fact that a bigger bandwidth allow 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) RSSI & SNR (SF=7 BW=125)

(b) RSSI & SNR (SF=7 BW=250)

(c) RSSI & SNR (SF=8 BW=125)

(d) RSSI & SNR (SF=8 BW=250)

(e) RSSI & SNR (SF=9 BW=125)

(f) RSSI & SNR (SF=9 BW=250)

(g) RSSI & SNR (SF=10 BW=125)

(h) RSSI & SNR (SF=10 BW=250)

(i) RSSI & SNR (SF=11 BW=125)

(j) RSSI & SNR (SF=11 BW=250)

(k) RSSI & SNR (SF=12 BW=125)

(l) RSSI & SNR (SF=12 BW=250)

FIGURE 9 – RSSI & SNR over Time for the Transmitter and Receiver

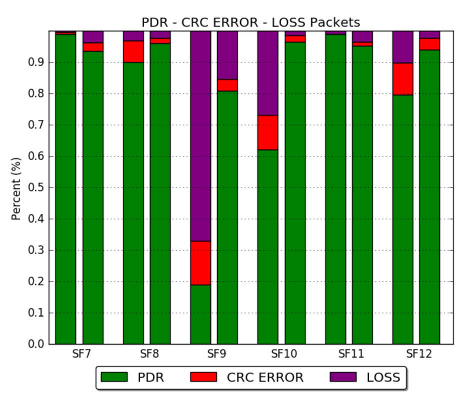
Spreading Factor	Average		Variance		St. Deviation (SD)		
	Bandwidth	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)
7	125kHz	-108.77	-107.12	5.18	6.04	2.27	2.45
	250kHz	-107.46	-106.05	6.44	5.87	2.53	2.42
8	125kHz	-109.06	-109.28	4.41	4.85	2.10	2.20
	250kHz	-108.61	-114.01	2.69	23.44	1.64	4.84
9	125kHz	-112.84	-116.54	1.15	19.10	1.07	4.37
	250kHz	0.0	-118.88	0.0	12.38	0.0	3.51
10	125kHz	-114.40	-115.28	2.97	8.36	1.72	2.89
	250kHz	-111.5	-117.54	1.93	31.72	1.39	5.63
11	125kHz	-112.48	-111.42	2.82	4.17	1.67	2.04
	250kHz	-114.02	-113.84	1.38	3.94	1.17	1.98
12	125kHz	-116.58	-115.98	2.78	5.00	1.66	2.23
	250kHz	-115.48	-116.11	2.05	9.06	1.43	3.01

TABLE 9 – RSSI Statistics

Spreading Factor	Average		Variance		St. Deviation (SD)		
	Bandwidth	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)	Trans. (TX)	Recev. (RX)
7	125kHz	0.034	-3.11	45.30	50.91	6.73	7.13
	250kHz	-15.09	-1.42	87.64	67.06	9.36	8.18
8	125kHz	-34.59	12.46	49.88	116.64	7.06	10.80
	250kHz	-45.69	-11.67	17.75	281.34	4.21	16.77
9	125kHz	-55.94	-16.73	13.74	325.33	3.70	18.03
	250kHz	0.0	-29.23	0.0	154.01	0.0	12.41
10	125kHz	-58.95	-20.15	44.75	229.85	6.68	15.16
	250kHz	-61.59	-30.47	19.80	285.80	4.45	16.90
11	125kHz	-53.62	-8.42	39.56	159.51	6.28	12.62
	250kHz	-72.64	-19.59	15.76	140.02	3.97	11.83
12	125kHz	-70.39	-8.40	38.61	230.24	6.21	15.17
	250kHz	-79.13	-16.44	24.82	215.41	4.98	14.67

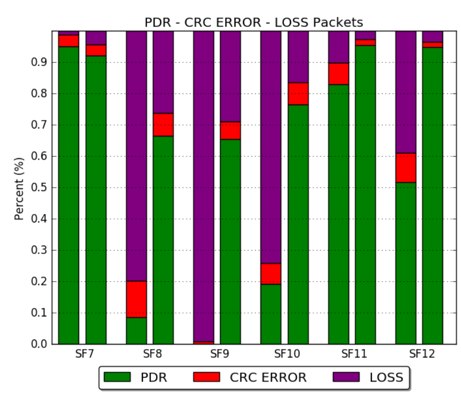
TABLE 10 – SNR Statistics

Packet Delivery Ratio



11

(a) PDR - PER (CRC) - P. Loss Rate



(b) PDR - PER (CRC) - P. Loss Rate

FIGURE 10 – Packet delivery ratio (PDR), Packet Error Rate (PER CRC) and Packet Loss rate

3 Discussion

From the previous results, we can deduce the following : First, that using two LoRa devices in a device-to-device fashion instead of the classic device-to-base-station greatly reduces the communication range. The maximum communication range was a lot shorter than the ones from previously cited studies that followed a standard device-to-gateway fashion. Secondly, that in compliance with [**?**], LoRa devices configured with a spreading factor of 12 and moving at a moderate speed ($\simeq$ 40km/h) does not disrupt LoRa communications. On the contrary, high speed ($\simeq$ 90km/h) movement breaks the LoRa link. And thirdly, the LoRa signal stability is greatly dependent of the environment. In a rural environment, the signal appears to be much more stable that in a urban one. We hypothesise that this is due to less obstacles in the surroundings, which means less signal reflection. Furthermore, an urban settings have more mobile obstacles, such as cars. We can thus conclude that LoRa geolocalization would be much more accurate in rural areas that urban ones, and more generally in a static environment than a dynamic one.

4 Conclusion Remarks

In this article, we presented the results we have obtained from in-field experiments to assess the LoRa signal characteristics in relation to the environment and understand how it could be used for alternative applications such as geolocalization. The main conclusion from this work is that the LoRa signal stability is greatly dependent on the environment, and that it is more stable in peri-urban areas than in high density urban areas. As future work, we wish to further test the impact of the environment on the LoRa signal, in terms of atmospheric conditions (air humidity, pressure, etc.).