XXXVII SIMPÓSIO BRASILEIRO DE TELECOMUNICAÇÕES E PROCESSAMENTO DE SINAIS - SBrT2019, 29/09/2019–02/10/2019, PETRÓPOLIS, RJ

Performance of a LoRa Network in a Hybrid Environment - Indoor/Outdoor

Nícolas S. G. Santos, Marcos W. R. da Cunha, Bruno H. C. Faria , Robson D. Vieira e Paulo H. P. Carvalho

***Resumo*— A ascensão da Internet das Coisas traz consigo um novo conceito: o LPWAN (Low Power Wide Area Network). Essas redes são caracterizadas pelo seu longo alcance, baixa taxa de transmissão e baixo consumo de energia. Este artigo visa estudar o desempenho e os limites da tecnologia LoRa, promissora para tais aplicações. Devido a uma carência de artigos que avaliem o comportamento dessa tecnologia em ambientes com características mistas, esse trabalho analisa o desempenho de um sistema de comunicação LoRa (Long Range) em um ambiente híbrido, com características tanto indoor como outdoor, localizado no campus da Universidade de Brasília. Os resultados mostram que as particularidades desse tipo de local trazem instabilidades no recebimento de pacotes e comprometem o alcance da rede, que só consegue cobrir até 86% do prédio com apenas um gateway no melhor caso.**

***Palavras-Chave*— LoRa, Ambiente híbrido, Indoor, Outdoor, RSSI, Vazão, Internet das coisas, IoT, LPWAN.**

***Abstract*— The rise of the Internet of Things comes along with an important new concept: The Low Power Wide Area Networks (LPWAN). These systems are featured with long range, low power and low bit rate. In this paper, we evaluate the limits and the performance of the LoRa (Long Range) communication, which is a promising LPWAN technology. Due to a small number of studies that discusses LoRa's performance in a hybrid environment, this paper aims to evaluate the performance of a LoRa network in an environment with outdoor and indoor properties, located at the University of Brasília. The results show that the particularities of this type of environment cause an unstable throughput and compromise coverage, reaching only 86% of the building with just one gateway, in the best case.**

***Keywords*— LoRa, Hybrid environment, Indoor, Outdoor, RSSI, Throughput, Internet of things, IoT, LPWAN.**

I. Introduction

The continuous growth of Internet-connected devices, just as the rise of new challenges for the humanity in the most diverse areas during the 21st century, has created multiple opportunities for implementing solutions based on the Internet of Things (IoT). In constant advance, IoT is defined as an infrastructure designed to allow services that require interconnection (physical and virtual) of things, possible by communication technologies currently available or under development [1].

An IoT application can reach a lot of humanity issues, like farming, health, education, urbanism, etc. In all these fields, IoT projects offer improvements to many areas, for example, more comfort in smart homes, better production systems for smart farms and smart industries, better quality of life in smart cities, among others.

Nícolas Silva G. Santos, Brasília - Brazil, sgsnicolas@gmail.com; Marcos W. R. da Cunha, Brasília-Brazil, marcoswrc2@gmail.com; Robson D. Vieira, Brasília - Brazil, robson.vieira@ektrum.com; Bruno H. C. Faria - Brasília, Brazil, bruno.faria@ektrum.com; Paulo H. Portela Carvalho, Brasília - Brazil, paulo@ene.unb.br.

In this context, there is a growing demand for technologies that meet the requirements of IoT projects. The variety of solutions require a diversity of devices covering different systems niches, which are differentiated by the following requirements: cost, coverage, data rate and power consumption. Among these technologies, some highlights are: LoRa [2], Sigfox [3], NB-IoT [4], Zigbee [5], NFC [6], and others. The technology chosen for this paper is the one provided by devices from LoRa Alliance, that offer long range, low cost and low power consumption [2].

A. Related Work

All the papers related to this work are studies that empirically evaluate the performance of LoRa networks in an indoor or an outdoor environment. Similarly, our paper wants to confront the boundaries of a LoRa communication, but using an environment that has both indoor and outdoor setting. Thus, the coverage obtained will include the effects of particularities of the environment, such as openings, pillars and others obstacles that approximate our study to a more realistic scenario.

The paper [7] showed results on the coverage of a LoRa network in a reinforced concrete building, located in Prague, Czech Republic. Gregora's paper [7] studies how the RSSI (Received Signal Strength Indication) level changes throughout the building, with two different locations for the base station. In a similar way, the paper [8] also does the same procedure, differing only by the fact that, in [8], the studies were made from six different locations for the base station in the building. The results of these two papers show that the range achieved by the LoRa network in an indoor environment is shorter when compared to an outdoor environment and, in some cases, can not cover the entire building. In this way, the papers [7] and [8] established the initial motivation for our work: evaluate the coverage of a LoRa network in a hybrid environment, using RSSI values.

The paper [9] set up a LoRa network in Calgary, Canada. The system performance was evaluated in terms of Packet Delivery Ratio (PDR) for indoor and outdoor environments. The article [10] also talks about throughput in a LoRa smart city system. While Pasolini [10] shows a relation between received packets and the offered traffic, Yousuf [9] discusses how the PDR changes with an increasing payload size. These two works show that the throughput of the system decreases when the payload size [9] or the information traffic [10] increase. Thus, to complement these works, the second motivation for our article is to analyze the throughput of the system as a function of the distance between the end node and the gateway, in an indoor/outdoor environment.

B. Project Proposal

As discussed in Section I-A, this article attempts to evaluate the performance and limits of LoRa in a hybrid environment. Fig. 1 shows the building where the work was done. It is a reinforced concrete construction that has a large number of accesses and is 700 m wide, located in the city of Brasília, Brazil. The results collected describe how the RSSI level and the throughput change when the base station is fixed and the end node varies its position in the whole building using 3 different spreading factor (SF) values, with the maximum payload allowed and minimum time between packets.

Fig. 1. Images of the Central Institute of Sciences of the University of Brasília

The following sections show the procedures and results of this work. First, in Section II, there is an overview of the most important topics of LoRa Technology. Then, Section III gives more details about the chosen environment and explains how the measurements were made to get the results that are shown in Section IV. After the result analysis, the Section V discusses how the hybrid characteristics of the environment can compromise the technology performance, and also talks about the future works planned.

II. The LoRa Technology

LoRa (Long Range) is a radio frequency technology powered by Semtech [11] that is used for long range and low power communications, like a Low Power Wide Area Network (LPWAN) technology. LoRa devices use Chirp Spreading Spectrum (CSS) [12] technique to provide longer ranges, interference immunity, robustness in multipath fading, low power consumption and coexistence with another systems that use different Spreading Factors (SF). Choosing an specific SF (7 to 12) and the bandwidth, which can be 125 kHz, 250 kHz or 500 kHz, defines the bit rate in which LoRa will operate. This choice can be set manually by the user or the system itself can decide which SF and bandwidth is the best. The latter option is called ADR (Adaptive Data Rate), which changes SF and bandwidth according to the system performance: if packets are not being received, the system can automatically increase the spreading factor to improve coverage. On the other hand, switching SFs values also changes the bit rate of the transmission.

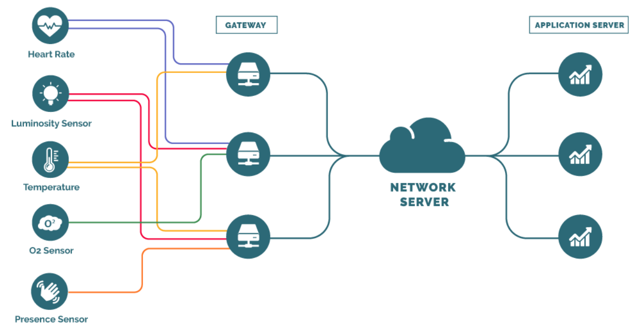

Fig. 2. General Schematic of a LoRa Network

A. General Schematic

Figure 2 shows the star topology in which LoRaWAN network architecture is deployed. The end nodes (usually sensors) sends their information to the base station, which has an internet-connected gateway that forward incoming data to a network server, which finally sends the package to an application that interprets this information. In this paper, the chosen network server is the The Things Network [13].

The Things Network is defined as an open infrastructure for LoRaWAN systems, continuously developed by the members of its community, made up of developers, business and students. The website is an online environment where it is possible to communicate with a LoRa device, processing uplinks and downlinks. Furthermore, the platform offers the possibility of integration with appropriate IoT services that register and interact with the information provided by the end nodes.

B. Limitations

Despite the huge versatility that LoRa can offer, the technology has some limitations which directly impact the results that are going to be shown in Section IV. These limitations occur due to the LoRaWAN protocol itself and the frequency plan established. The following Sections II-B.1 and II-B.2 describe some of them, using information that can be found in the manuals [14], and [15].

1) Protocol: LoRaWAN devices are available in three classes: A,B e C, which are different especially by the way how downlinks are made. In this work, the class A was used, which is more common. Fig. 3 shows how the protocol of this type of LoRaWAN device is:

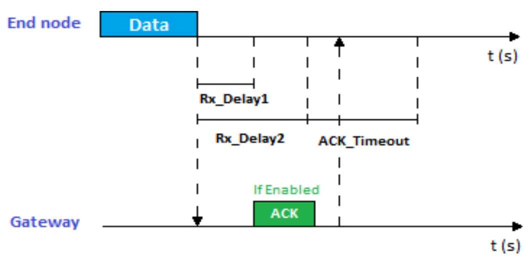

Fig. 3. LoraWAN Class A Protocol

As shown in Fig. 3, uplinks are made in the same way as the Pure Aloha protocol: without sensing the channel state. After an uplink, the LoRa device waits for two slots of time to receive packets from the server. In general, the total wait time is 2 s [14]. Therefore, between two packets from the same end node, there is always an interval of at least two seconds that directly affects the throughput of the system.

Beyond that, it is also possible to set the device for sending confirmed packets. In this situation, the end node waits for a downlink with an acknowledgment (ACK), indicating that the packet was successfully received. If no acknowledgment is received by the end node until the final of the $ACK-Timeout$ slot, the packet is retransmitted until a confirmation arrives or until the end node reaches its limit of retransmissions, that can be set by the user.

2) Frequency Plan: LoRa devices use the ISM radio band and are governed by regional frequency plans that set limits for most of LoRa parameters. The variables that are regulated by Frequency Plans are the $Rx\text{-}Delay$, duty cycle, maximum payload, frequencies, header, among others.

The plan used in Brazil is the Australia Frequency Plan: AU915-928, which is the recommendation given by The Things Network for Brazilian users [13]. In this plan, the transmission can be done in 64 different frequency channels with a 125kHz bandwidth, spaced by 200 kHz, according to [14]. However, the frequencies used also depend on the network server. For The Things Network, the uplink frequencies available can be chosen between $916,8$ MHz and $918,2$ MHz.

Having different channels allows the system to vary the uplink frequencies in order to avoid interference between two or more nodes. The user can choose manually which channels will be available for the transmissions, and is up to the device to send packets always in different frequencies between the chosen ones.

III. Performance Evaluation Methodology

A. The Central Institute of Sciences Building

The Central Institute of Sciences (ICC, in Portuguese), located in the University of Brasília (UnB), is the place chosen for the LoRa performance evaluation. The choice was made for its hybrid features: it is an open place with a lot of obstacles. The building shown in Fig. 1 and 4 is about 700 m in width, with concrete pillars every 3 m away.

The building has 2 blocks, A and B, 25 m apart, illustrated in Fig. 1. Each block has 3 floors: 1st floor, ground floor and underground floor. Blocks A and B are structurally similar, except for the underground floor, which is very different depending on the block. The gateway is located on the edge of the first floor in Block A in all measurements, and the end node position varies between the others floors and blocks, which are described below.

1) Underground floor - Block A:

- Predominantly closed, with just a few openings;
- Mainly composed of classrooms;
- Separated from the ground floor by a 15 cm concrete block;
- Floor located 4,85 m below the gateway.

Fig. 4. Base Station, end node and floors of ICC

2) Underground floor - Block B:

- Predominantly closed, with passage for cars and cargo.
- Mainly composed of offices and rooms.
- Floor located 4,85 m below the gateway.

3) Ground Floor - Blocks A and B:

- Predominantly open.
- Mainly composed by auditoriums.
- Floor located 2,7 m below the gateway.

4) 1st Floor - Blocks A and B:

- Predominantly open.
- Mainly composed by offices.
- Floor in which the gateway is located (only in Block A).

B. Measurements and Data Collection

The measurements of this work consists of collecting RSSI and throughput values through all ICC, in the three floors available, for three different SF value in both blocks.

Data was acquired by the MQTT server of The Things Network, along with a Python program developed to register and store the values of RSSI, SNR, lost and received packets. After this, the results were processed and plotted as is shown in Section IV. There are two graphics for each floor: RSSI level and throughput as a function of the distance.

1) RSSI Performance: For the RSSI performance measurement, the following procedure was adopted:

1) The LoRa device is turned on and placed on the next point of measurement.
2) 10 packets are transmitted for each Spreading Factor: 7, 8 and 10.
3) The device is moved 6 m away from the previous point and the procedure is repeated.

All the RSSI values are registered by the Python script, which calculates the average and standard deviation until no packet reaches the network server.

2) Throughput Performance: For the throughput performance measurement, the following procedure was done:

1) The LoRa device is turned on and placed on the next point of measurement.

2) For approximately 30 s, the device is free to transmit with SF7, generating the maximum of packets as possible. The same thing is done for SF8 and SF10, four times for each one of them.
3) The device is moved 30 m away from the previous point and the procedure is repeated.

After the procedures, the throughput of each 30 s is calculated by the relation between the number of bits arrived and the time spent. Then, the average and standard deviation of the 4 measurements is calculated.

C. LoRa Parameters

The LoRa module used was the RN2903A, powered by Microchip [15]. The base station is composed by an omni-directional antenna and its gateway, powered by Kerlink [16]. In all measurements, the LoRa parameters were the same, and are exposed in Table I.

TABLE I
LoRa Parameters

Parameter	SF7	SF8	SF10
Bit Rate (bps)	5.470	3.125	980
Payload size (Bytes)	140	140	24
Frequency (MHz)	918,2		
Bandwidth (kHz)	125		
TX Power - End Node	18dBm		
TX Gain - End Node	4,5 dBi		
RX Sensitivity - Gateway	-123dBm		
RX Gain - Gateway	6 dBi		

The Bit Rate values in Table I are available in LoRa [14] and Microchip [15] manuals. As discussed in Sections I-A and I-B, this paper aims to evaluate limits and performance of the system for maximum values of payload and minimum time between packets. Therefore, the parameters were all fixed for each SF. In order to minimize the time between transmissions, acknowledgment packets were deactivated, thus the device doesn't have to wait for confirmations to send the next packet. The ADR was deactivated to keep the SF value constant. Finally, the payload size was set to the maximum possible for the RN2903A module, to obtain the highest throughput.

IV. Results

The results show that, in the best situation, the maximum coverage was about 600 m. As described in Section III, 12 context of measurements were considered: RSSI and throughput evaluation for all floors and all blocks. All the graphics obtained have a general similar behavior and, in this article, only the graphics for the best and worst coverage are going to be exposed.

The Fig. 5 shows the RSSI performance when the end node and the gateway are on the same floor. In this case, there was no difference between the coverage of SF7 and SF8. However, SF10 achieved a value 73 m higher, which is 14,6% greater than SF7 and SF8.

For the same case of Fig. 5, the throughput performance is shown in Fig. 6. The result obtained shows the maximum throughput of the technology: making the device transmit continuously, restricted only by its own protocol, for 30 s with

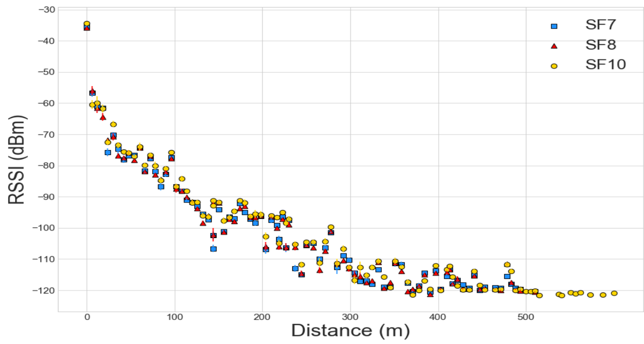

Fig. 5. Relation between RSSI and distance when the gateway and the end node are on the same floor and block.

maximum payload size, the highest throughput is approximately 272bps for SF7 and SF8, and 50bps for SF10. The huge difference between the throughput and the bit rate is due to the protocol of LoRaWAN itself and the Frequency Plan, that establishes long times slots between packets.

Moreover, Fig. 6 shows that SF10 can keep its throughput constant for a greater range than SF7 and SF8, which have packets loss from 120 m (SF7) and 311 m (SF8). The graphic also shows how the hybrid environment can compromise the reliability of LoRa communication, since the throughput of the system, especially SF7, varies over most of the ICC. Although SF7 and SF8 have more instability, they can achieve throughput values 544% highers than SF10.

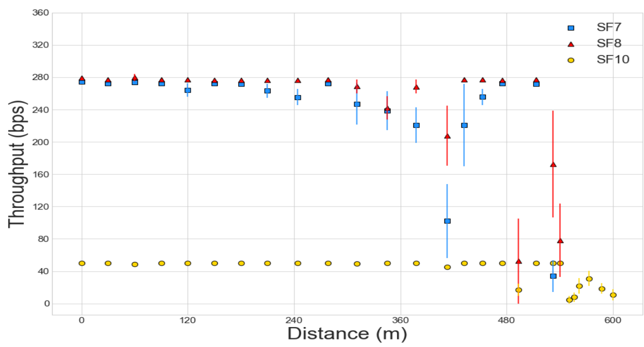

Fig. 6. Relation between throughput and distance when the gateway and the end node are on the same floor and block.

The worst performance occurs when the end node is on the underground floor of block B. The Fig. 7 shows the results for this situation, in which it is possible to notice that the maximum coverage is 276 m for SF10. The curve has the same behavior than Fig. 5, but decreases faster.

For the same situation, the throughput performance is presented in Fig. 8. It can be noticed that all SFs present stability throughout the distance points on the figure, although the system does not receive any packet after 243 m.

The remaining 8 measurements are summarized in Table II. The coverage value is obtained from the last point where the SF still receives packages, and the first instability point represents the first distance where there are packet loss.

Table II shows that SF10 always achieves greater coverage

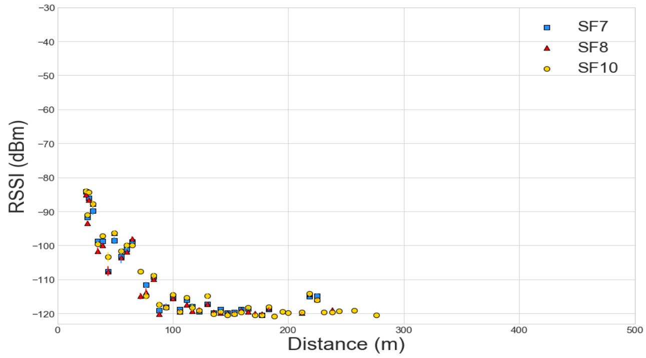

Fig. 7. Relation between RSSI and Distance when the End Node is in the underground floor of block B

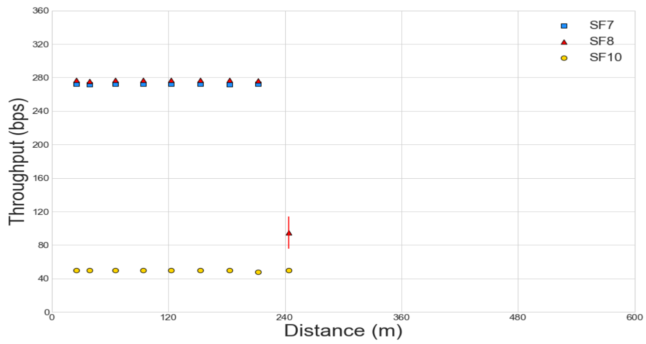

Fig. 8. Relation between throughput and Distance when the End Node is in the underground floor of block B

and becomes unstable after all the other SFs. In addition to that, SF7 and SF8 have similar performances, specially in throughput: for half of the situations, the first instability point for SF7 and SF8 where the same. However, SF8 shows slightly better performance in other cases.

TABLE II
RESULTS

Block	Floor	Coverage (m)			First instability point (m)		
		SF7	SF8	SF10	SF7	SF8	SF10
A	1st Floor	527	527	600	120	311	493
	Ground	515	515	548	244	244	441
	Underground	365	403	478	120	120	345
B	1st Floor	370	401	425	146	146	307
	Ground	276	282	401	244	260	292
	Underground	225	238	276	212	243	252

It is important to highlight the fact that block B is more uniform than block A, because it has fewer rooms, elevators and obstacles, in general. This explains, in some cases, why Table II shows further instability points for block B, in relation to block A. Due to the obstructions presents in A, block B has more throughput stability, but still less coverage.

V. Conclusion and Future Works

This work presented an evaluation of limits and performance of a LoRa network in a hybrid environment. The results show that the technology is able to establish its maximum performance until a certain distance and, from them on, it starts to lose its initial reliability. In addition to that, the compromise between throughput and coverage was verified by the discrepancies of behavior obtained using different spreading factor values. Using SF10 allows higher coverage and less packet loss, but the maximum throughput that it can achieve is 81% lower than with SF7 and SF8, which are, on the other hand, more unstable.

Furthermore, the study shows how the particularities of a hybrid environment bring variability to the system. It can be noticed, from the throughput graphics, that sometimes the system drops its capacity levels and then achieves maximum capacity again in a further distance, which describes the points that have worst ways for the signal propagation. The obstacles present on the building cause multipath fading problems and, consequently, worse throughput. Therefore, in these situations, using ACK packets would help the system to reduce packet loss in these particular points of the environment. Also, for any application being developed in this type of environment, the results show that the best way to ensure that the uplink will be successful is to use SF10 and one more gateway, because when the end node is in the underground floor, the maximum distance reached is 276 m, which is only 39% of the total size of the building.

Finally, for future works, we plan to develop a simulation in which the environment can be described with a mathematical model, so then we can predict the performance of a LoRa network in the local described. In addition to that, as an outdoor promising technology, we want to study an IoT application in a rural environment using LoRa devices.

Special Thanks

The team thanks the company Ektrum for the assistance and all the material provided.

References

[1] ITU. https://www.itu.int/en/ITU-T/gsi/iot. Accessed on 23/04/2019.
[2] LoRa Alliance. https://lora-alliance.org. Accessed em 23/04/2019.
[3] Sigfox, Inc. https://www.sigfox.com/. Accessed on 23/04/2019.
[4] 3GPP™. ”Release 13”. Available: https://www.3gpp.org/release-13.Accessed on 23/04/2019.
[5] Zigbee Alliance. https://www.zigbee.org/. Accessed on 23/04/2019.
[6] NFC Forum. https://nfc-forum.org/. Accessed on 23/04/2019.
[7] L. Gregora, L. Vojtech and M. Neruda, ”Indoor signal propagation of LoRa technology” *2016 17th International Conference on Mechatronics - Mechatronika (ME)*, pp. 1-4, December 2016.
[8] L. H. Trinh, V. X. Bui, F. Ferrero, T. Q. K. Nguyen, M. H. Le,”Signal propagation of LoRa technology using for smart building applications” *2017 IEEE Conference on Antenna Measurements Applications (CAMA)*, pp. 1-4, December 2017.
[9] A. M. Yousuf, E. M. Rochester and M. Ghaderi, ”A low-cost LoRaWAN testbed for IoT: Implementation and measurements” *2018 IEEE 4th World Forum on Internet of Things (WF-IoT)*, pp. 361-366, February 2018.
[10] G. Pasolini, C. Buratti, L. Feltrin, F. Zabini, R. Verdone, O. Andrisano, C. De Castro ”Smart City Pilot Project Using LoRa” *European Wireless 2018; 24th European Wireless Conference*, pp. 1-6, May 2018.
[11] Semtech. https://www.semtech.com. Accessed on 23/04/2019.
[12] Semtech Corporation, “LoRa™ modulation basics,” 2015. Available:https://www.semtech.com/uploads/documents/an1200.22.pdf.
[13] The Things Network. https://www.thethingsnetwork.org/. Accessed on 23/04/2019.
[14] Lora Alliance, ”About the LoRaWAN™ Specification”, 2019. Available: https://lora-alliance.org/lorawan-for-developers.
[15] Microchip. https://www.microchip.com. Accessed on 23/04/2019.
[16] Kerlink. https://www.kerlink.com. Accessed on 23/04/2019.