Performance of LoRaWAN on a Highway Scenario

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***Abstract*—The current growing interest in Internet of Things (*IoT*) has facilitated the appearance of *Low-Power Wide Area Networks* (LPWAN). Networks based on the LoRaWAN (*Long Range Wide Area Network*) standard stand out among these. The aim of this article is to describe in detail these networks and to make an initial assessment of the performance in highway scenarios. In order to do this perfomance evaluation, a LoRaWAN network prototype has been created.**

***Keywords*—Internet of Things, LPWAN, LoRa, LoRaWAN, The Things Network, Highway, SNR, RSSI.**

I. Introduction

The evolution of technologies and the ability to interconnect different devices has led to the existence of networks capable of communicating and acting together, creating what is known as Internet of Things (*IoT*). Thanks to sensors and actuators, it is possible to measure our environment and share data which, collected by platforms, allows the developers to create useful applications for the society [1].
The critical point in many scenarios resides in the energy consumption due to the batteries which feed these *things*. This is why so-called LPWAN technologies, which permit low power transmission, have been developed. In return, the transmission data rate is reduced (e.g. hundreds of kbps) but it is still enough for many IoT applications. Because of their standardization and the usage of non-licenced spectrum, these technologies have become serious competitors of solutions based on cellular networks such as LTE-M (Long Term Evolution-Category M) or NB-IoT (NarrowBand-IoT) [2].

The most popular LPWAN technologies are Sigfox, LoRaWAN, Ingenu RPMA and nWave. Their main characteristics and differences, assuming European parameters, are shown in Table I.

The remainder of this paper is organized as follows. Fundamentals and characteristics of the LoRaWAN standard are explained in section II. Section III depicts our LoRaWAN network prototype. Section IV describes the performance evaluation experiment and results are discussed. Finally, section V concludes the paper.

II. LoRaWAN Performance

A. LoRa Modulation

LoRa® (Long Range) is a proprietary modulation which belongs to the company Semtech. It is based on CSS (*Chirp Spread Spectrum*) and aims at increasing the communication range while keeping the same low power characteristics of the FSK modulation.

TABLE I: Characteristics of LPWAN Technologies

Estndar	LoRa	Sigfox	RPMA	nWave
Banda Frecuencia	868/915 MHz ISM	868/902 MHz ISM	2.4 GHz ISM	Sub-GHz ISM
Ancho Canal	Ultra NB	8x125kHz Mod: CSS	1 MHz 40 canales	Ultra NB
Dispositivos por PA	1k	1k	Hasta 384k	1M
Rango	2-5k urbano 15k rural	30-50k r. 1000k LoS	500k LoS	10k u. 20-30k r.

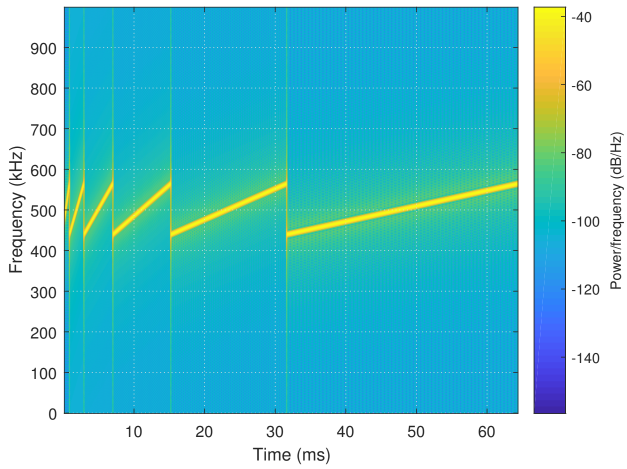


Fig. 1: LoRa Spreading Factors Comparison: SF7 to SF12 [3].

This modulation uses the full channel bandwidth to send signals, making a distinction between 'up-chirp' and 'down-chirp'. 'Up-chirp' refers to transmissions in which the frequency changes from the lowest to the highest value, and 'down-chirp' refers to the opposite situation. This technique allows LoRa to modulate its symbols in 'up-chirps' with a bandwidth of 125kHz, 250kHz or 500kHz (in the case of the European 868MHz frequency band) and with different *Spreading Factors* (SF) depending on the required data rate and channel conditions. Figure 1 shows how frequency, time and power vary according to the SF used.

The spreading factor is defined as $SF = log_2\left(\frac{R_C}{R_S}\right)$, where R_C is the chip rate and R_S is the symbol rate. Thus, a lower *spreading factor* implies a lower data rate but increases the maximum distance between the transmitter and the receiver [4].

B. LoRaWAN Networks

The LoRaWAN standard, which is managed by the *LoRa Alliance*, defines a protocol architecture (specifying the Medium Access Control layer or MAC) and a system architecture. This standard allows devices to use either FSK or LoRa as modulations on the physical layer.

Regarding its architecture, it uses a star topology with a central device known as *gateway*. On the one hand, end-nodes communicate directly with the gateway through the radio interface. On the other hand, the gateway uses a normal network interface (e.g Ethernet or Wi-Fi) to communicate with an application server through a network server. The usage of a star topology, instead of a mesh network architecture, increases the lifetime of batteries, network capacity, security and quality of service (*QoS*), among other charasteristics. In a mesh network, each node would act as an end-node and as a gateway (router) [5], which causes a greater number of hops and their corresponding packet forwarding, hence producing a higher power consumption.

Nodes are not associated with specific gateways. Instead, any message received by a gateway will be forwarded to its network server, and these, in turn, will forward it to its application server.

Bi-directional communication between nodes and gateways are allowed by LoRaWAN. In particular, there are three classes of end-nodes named A, B and C. Class A must be implemented by all the nodes, and all the classes are able to coexist in the same network. The charasteristics of each class, whose transmission is depicted in Figure 2, are defined below:

- **Class A:** It is the class that consumes the lowest possible power. It is used in applications with unidirectional communication (from nodes to gateway), allowing a transmission in the uplink direction just after the node has finished its transmission. This class is suitable for battery-powered sensors.
- **Class B:** It is characterized by the possibility of opening extra reception windows at certain moments, in order to increase transmissions from the gateway to the nodes. For this reason, the consumption is higher than that of class A. This class is suitable for battery-powered actuators.
- **Class C:** The devices that implement this class are able to receive data from the gateway at any time (except when the device is transmitting). This class is suitable for nodes connected to the electricity grid.

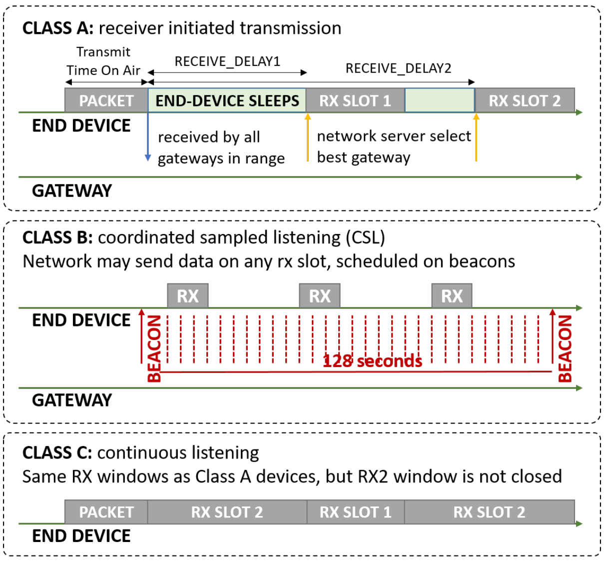


Fig. 2: LoRaWAN Device Classes and Packet Transmission.

C. LoRaWAN Security

LoRaWAN uses two security layers charaterized by protecting data at the link layer as well as at the application layer. As for the application layer, data is encrypted between the node and the application server, which implies end-to-end confidenciality. As for the link layer, a field, which allows to guarantee data integrity between the node and the network server, is included. Figure 3 summarizes LoRaWAN security, which is explained below.

- **Authentication:** A shared key is known by the node and the network, and it is used by AES-CMAC algorithms which are employed when a node joins the network. Two keys named *AppSKey* and *NwkSKey*, which are used for the data encryption and data integrity, are derived from the previous key.
- **Integrity and Confidenciality:** The previous session keys are used for protecting all the traffic in a LoRaWAN network. Therefore, the *AppSKey* is used for the end-to-end encryption between the node and the application server. Similarly, the *AppSKey* key is used to calculate a Message Integrity Code (MIC) in order to guarantee the integrity between the node and the network server. Furthermore, a sequence frame number is included to prevent replay attacks.

There are two activation methods for initiating the connection: *Over the Air Activation* (OTAA) and *Activation By Personalization* (ABP). OTAA uses the parameters *JoinEUI* (Application ID), *DevEUI* (Device ID), *NwkKey* and *AppKey* (end-nodes specific keys). The previos session keys are obtained from these parameters. On the other hand, ABP must

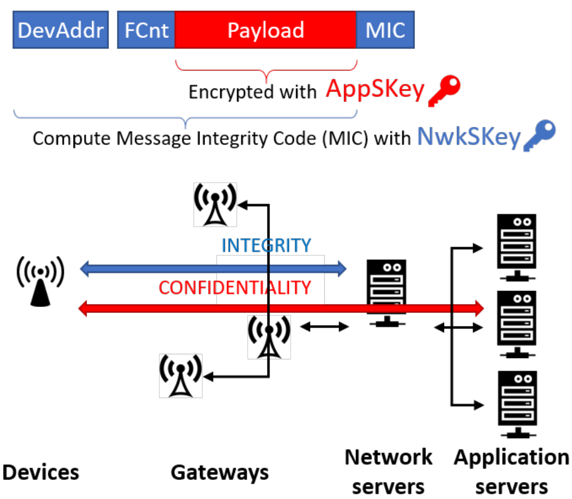


Fig. 3: LoRaWAN Security.

previously personalize these parameters (i.e saving them in both the node and the severs).

III. LoRaWAN Network Prototype

In this section, the implemented prototype is presented. This prototype will be used for the performance assessment in a highway scenario.

The first components of a LoRaWAN network are the nodes and the gateway. The components are shown in Figure 4 and are described below:

- **DIY multi-channel Raspberry Pi Gateway:** the chosen gateway is composed of a Raspberry Pi 3 Model B, an IMST ic880A concentrator and an 868 MHz antenna.
- **End-Device:** the used end-device is based on the development card 'Wemos D1 Mini', which uses the ESP8268 chip. A shield with the RN2483A chip, which implements both the physical and the MAC layers of the LoRaWAN standard, is been connected to the previous card.

A. The Things Network (TTN)

We have utilized *The Things Network* (TTN) network infrastructure, an open and colaborative LoRaWAN network [7], to implement the network and application servers. TTN is a community which offers open source software projects to its users to make possible the connectivity between different elements in a LoRaWAN network. One of its main strengths is the capability of connecting any LoRaWAN gateway to its network servers, so no extra infrastructure is required. In addition, it allows the configuration and data gathering through a simple but complete graphical user interface.
Figure 5 shows some packets sent by our node, which are retransmitted by our gateway and finally received by the TTN server. By selecting any of these packets, it is possible to read information like the frequency, the gateway ID, and the signal quality parameters, among others.

Even if TTN offers a simple and scalable solution for servers, they are still external and therefore data is shared with the organization.

IV. Results

This section shows the results of network performance registered in our test bench.

In order to evaluate the network performance and the received signal strength by the nodes, an obstacle-free scenario has been chosen. The selected scenario is a road environment very similar to a highway (See Figure 6). It has three lanes in each side and pedestrian and bike lanes which lets us moving away to take the measurements. The evaluated parameters have been the Signal to Noise Ratio (*SNR*), the Received Signal Strength Indicator (*RSSI*), the packets loss ratio and the coverage of the used end-device.

The path of the chosen scenario joins together the north zone of Granada's road named A-4006 with the street named Camino Nuevo (entrance of Maracena). The route has an approximate total length of 3.3 km with 74 m of gradient. The gateway, whose coordinates are (37.2136373, -3.5951833), is placed on a bridge which cross the road as shown in Figure 6. It is almost a straight route and without buildings or obstacles which interfere the signal reception.

Figure 7 shows the results obtained as a function of the distance taking the gateway as reference point. The x axis of Figures 7.a) and 7.b) represents the distance from the end-device to the gateway. By performing an analysis of the results (Table II) it is possible to split them into four distance ranges.

As we can see, at 1000 m from the gateway, it is obtained an average SNR of 8.56 dB and the maximum SNR obtained is 11 dB. In addition, Table II shows the 5 and 95 percentiles which means that the 95% of the SNR measured values are over and above 5.53 dB.

Regarding to the SNR, this value decreases as the distance from the gateway increases. At 2.5 km, we can observe negative SNR values which indicates that the noise level is higher than the received signal. Despite this, LoRa modulation robustness lets the gateway receives the packets correctly until a distance of 3.3 km. It should be pointed out that urban core of Maracena started at this point, so taking into account that it was a different environment and the presence of buildings

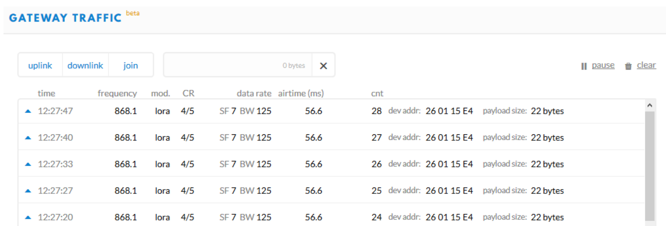


Fig. 5: Data Packets received in TTN

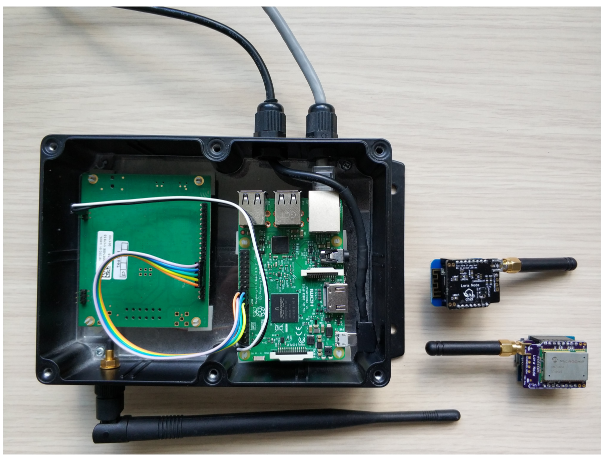


Fig. 4: LoRaWAN Components: Gateway and End-nodes.

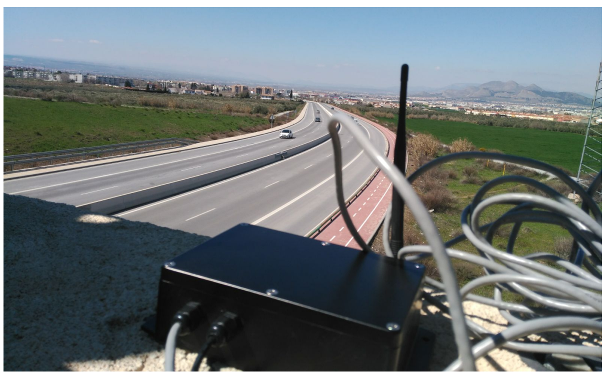
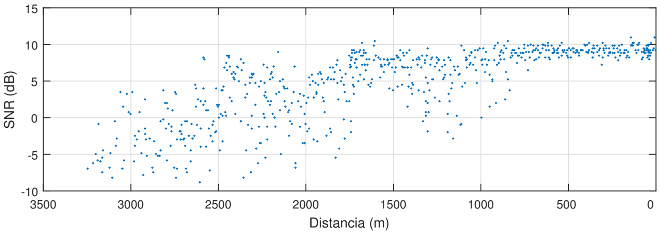
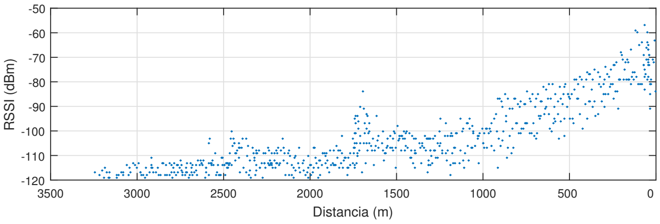


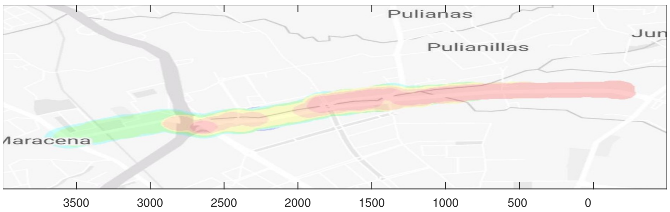
Fig. 6: Gateway Placed.



(a) SNR vs Distance.



(b) RSSI vs Distance.



(c) Coverage Map.

Fig. 7: `SNR` measurements (7a), `RSSI` (7b) and coverage map (7c) after the LoRaWAN network deployment.

TABLE II: Average Values and Percentiles of the Results per Kilometer.

Dist. (km)	SNR (dB)	P_5 (dB)	P_{95} (dB)	RSSI (dBm)	P_5 (dBm)	P_{95} (dBm)
0-1	8.597	5.53	10.2	-89.4	-107	-68
1-2	4.819	-2	8.66	-108.3	-116	-99
2-3	-0.539	-7.33	6	-114.5	-118	-108
3-3.3	-5.138	-8.2	-0.5	-118.1	-119	-117

significantly reduces the SNR and the level of the RSSI and therefore the data are not comparable to data measured along the highway.

Finally, Figure 8 shows the percentage of packets loss as a function of the distance to the gateway. As we can see, the number of wrong packets received by the gateway increases as the distance to the gateway increases, being these losses more problematic for the range of 3 to 3.3 km. This increase in packets loss can be due to several factors such as the distance, the environment characteristics or bounces of the signal when approaching the urban core of Maracena.

V. Conclusions

The aroused interest in LoRaWAN networks and the lack of practical experimental studies have generated the need of deploying these networks in several scenarios. The main purpose of these deployments is getting valuable information regarding to aspects of maximum coverage and network performance in order to be able of deploying efficient WSNs with the minimum number of devices.

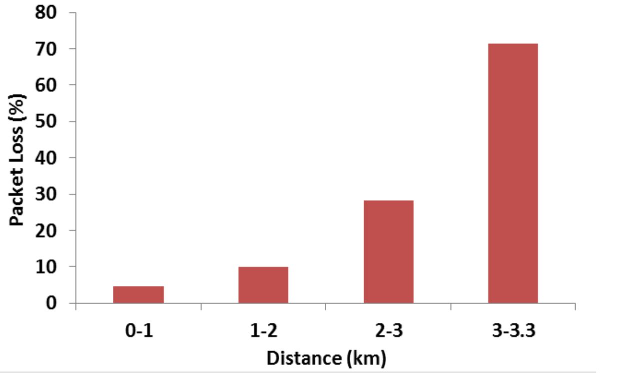


Fig. 8: Percentage of packet loss as a funtion of the distance.

Due to the lack of scientific papers with real tests about LoRaWAN networks, this article has presented the main characteristics of the LoRaWAN architecture and how these networks work, as well as, a real experimental study performed in highway scenarios. From results, we can conclude that, a LoRa network based on our devices could be cover a distance higher than 3 km since our gateway is still capable of receive packets correctly. Thus, LoRa networks would be an interesting solution for getting data in scenarios such as crops or rural areas where we want to cover a very large area and the variation of the measurable parameters is not fast, so it does not require a real-time system with fast transmission.

As future work, we would like to test new networks and application servers which allow us to deploy a completely private environments. Finally, we will perform real experiments in urban and indoor environments in order to compare the LoRa performance in several scenarios.

Acknowledgements

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References

[1] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions,"in *Future Generation Computer Systems* vol.29, no. 7, pp. 1645-1660, Apr. 2013.

[2] J. Navarro-Ortiz, S. Sendra, P. Ameigeiras, and J. M. Lopez-Soler, "Integration of LoRaWAN and 4G/5G for the Industrial Internet of Things,"in *IEEE Communications Magazine* vol.56, no. 2, pp. 60-67, Apr. 2018.

[3] S. Ghoslya, "All about LoRa and LoRaWAN,"(2018, April 12th) retrieved from *https://goo.gl/ACxaxx*.

[4] N. Sornin, M. Luis, T. Eirich, T. Kramp, and O.Hersent, "LoRa Specification 1.0,"*LoRa Alliance Std Spec.*, (2018, Abril 13th), retrieved from https://www.lora-alliance.org/.

[5] Ian F. Akyildiz and X. Wang and W. Wang, "Wireless mesh networks: a survey,"in *Computer Networks* vol.47, no. 4, pp. 445-487, Apr. 2005.

[6] A. Guzmn and J. Navarro-Ortiz and S. Sendra, "LoRaWAN Gateway and IoT Low-Cost Mote Prototype,"(2018, April 13th), retrieved from https://bit.ly/2qu8Fib.

[7] W. Giezeman, "The Things Network,"(2018, April 13th), retrieved from *https://www.thethingsnetwork.org/*.

[8] O. Brocaar, "LoRa Server,"(2018, Abril 12th), retrieved from *https://www.loraserver.io/*.