Performance Study of LoRaWAN for Smart-City Applications

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Abstract—One of the verticals that will be more benefited with the arrival of upcoming 5G deployments are smart-cities. Under this umbrella, different applications for end-users will be developed in two principal scenarios in the city, namely, under mobility conditions or in static situations. In order to provide ubiquitous connectivity in these scenarios, the Low Power-Wide Area Network (LP-WAN) technologies have emerged, hence enabling the development of novel Internet of Things (IoT) services. In this line, LoRaWAN is one of the most prominent LP-WAN alternatives that is considered to be integrated within the 5G ecosystem. In this work, we focus on evaluating the performance of this technology under different working conditions. A comparison between two commercial LoRaWAN gateways is presented and the attained results in both deployments are compared and discussed. The outcomes place LoRaWAN as an outstanding solution to be adopted in smart-city deployments for supporting certain IoT applications.

Index Terms—smart-city, 5G, IoT, LoRaWAN

I. INTRODUCTION

A great number of novel services devoted to improve the Quality of Living (QoL) of end-users will be developed and integrated within the upcoming smart-city architectures. The inhabitants of a smart-city will use these applications in two main scenarios, namely, (i) in static or quasi static situations, e.g., at the office, in a restaurant, or walking by the street, among others, or (ii) under mobility conditions, e.g., using public transport, driving their vehicles, etc. To cope with this number of use cases, in a near future the majority of infrastructures in a city and personal devices will be equipped with sensors and actuators, and they will have communication capabilities that will incorporate them to the Internet of Things (IoT) ecosystem [1].

This will lead to a high number of connected devices that will be a great challenge for network operators and service providers in terms of both scalability and management. It is also especially critical the adoption of proper communication technologies for supporting these services. Recently, solutions based on the Low Power-Wide Area Network (LP-WAN) paradigm have gained momentum to provide long-range connectivity to IoT end-devices with stringent energy-efficiency requirements [2]. LoRaWAN [3] is one of the most prominent alternatives and its integration within the 5G paradigm is being currently discussed as another Radio Access Technology (RAT) for IoT applications. This technology provides great transmission distances and scalability with very low power consumption, which perfectly fits the needs of smart-city deployments. Differently from another relevant solution for providing IoT scenarios with long-range connectivity, namely, Narrow Band - Internet of Things (NB-IoT), LoRaWAN networks are deployed on-demand and both the infrastructure and data may be managed by the user hence avoiding the dependence on third parties (Telcos).

In this paper we address the use of LoRaWAN as a communication enabler for developing IoT applications within smart-city environments. To this end, firstly we present a theoretical transmission range study in the city of Murcia (Spain) by using a radio-planning tool aiming at studying the coverage provided by a single gateway placed in the city center. Then, we validate this study by discussing the results extracted from a series of trials in a real deployment with diverse end-device conditions (static and in-motion), with two commercial LoRaWAN gateways considering different transmission configurations. Therefore, the main contributions of this paper are the following: (i) a real deployment of a LoRaWAN network has been carried out with two different LoRaWAN gateways, (ii) a comparison between both commercial gateways, considering different LoRa configurations is presented, and (iii) a discussion regarding the impact of mobility in the transmissions reliability is given.

The rest of the paper is organized as follows. Section II is devoted to review the literature related to the use of LP-WAN technologies in smart-city scenarios. The LoRAWAN technology is briefly presented in Section III. A theoretical coverage study conducted with a radio planning tool is showed in Section IV. Section V describes the carried out deployment for our experimental evaluation. Section VI presents and discusses the attained results. Finally, the paper summarizes the most important findings and draws future research lines in Section VII.

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II. RELATED WORK

This Section reviews the most relevant efforts in the field of application of LP-WAN technologies on smart-city scenarios.

Works in [4], [5] studied the feasibility of smart-city deployments based on LoRaWAN technology. Both works focused on the system architecture and its availability considering the duty-cycle restrictions in the Industrial, Scientific, and Medical (ISM) radio bands, and packet collisions. In a similar line, work in [6] presented a planning study for the deployment of an intelligent lighting system. Authors considered LoRaWAN, Long Term Evolution for Machines (LTE-M) and Narrow Band-IoT (NB-IoT) as RATs. However, no performance results were presented to validate the proposed platform. A LoRaWAN-based IoT deployment covering a university campus was explored in [7]. In this case, authors considered a static deployment with non-mobile end-devices and presented the power level reception results considering different locations within the campus. A comprehensive work evaluating the feasibility of LoRaWAN deployments for large city monitoring applications was presented in [8]. Authors considered both technical and business perspectives, obtaining their results from a Matlab-based simulator. Some outcomes extracted from an experimental testbed are missed aiming at validating their proposal.

Most of the papers cited above have adopted LoRaWAN as transmission technology; nevertheless, NB-IoT technology is now gaining momentum due to its novelty and its direct integration in the 5G architecture. Works in [9], [10] presented two different air-pollution metering systems based on NB-IoT. In both cases, the system architecture and deployment details were given in addition to real measurements obtained from their solutions. Finally, authors of [11] inspected the use of dual-mode devices with both LoRaWAN and NB-IoT transceivers. A comparison between both RATs were given, focusing on power consumption issues rather than on the communication capabilities provided by each technology.

Different from the works above, we provide a more detailed performance evaluation of a real LoRaWAN deployment with different LoRa configurations and considering diverse end-device mobility conditions.

III. LoRaWAN

LoRaWAN [3], [12], [13] is an open specification for LP-WANs, which is promoted by the LoRa Alliance and targeted at constrained devices as defined in the RFC 7228 [14]. Concretely, it specifies a Medium Access Control (MAC) layer technology for Machine to Machine (M2M) radio communications that determines the network architecture. LoRaWAN employs a star-of-stars topology in which the end-devices are connected to one or several gateways that provide access to the corresponding Application Servers (ASs) through a LoRaWAN Network Server (NS). This topology, shown in Fig. 1, saves end-devices from the complexity of implementing routing algorithms as they are able to reach the gateway in one single hop. The intelligence of the system resides in the NS, which assumes all the network and traffic management tasks.

LoRaWAN employs LoRa at the Physical (PHY) layer, a Chirp Spread Spectrum (CSS) radio modulation that works in the free and unlicensed ISM radio band. LoRa is a modulation specifically designed for low-power, long-range communications in adverse radio conditions. LoRa transmissions may be characterized by different parameters, namely, Spreading Factor (SF), Coding Rate (CR), and Bandwidth (BW). The former defines how the signal is spread over the employed spectrum range, i.e., the BW. The CR indicates the amount of redundant data included in each packet for reliability purposes. These parameters notably determine the data rate of LoRa transmissions, ranging from few bits per second (bps) to dozens of kbps [15]. Depending on the regional zone and LoRa configuration, the maximum allowed application payload size varies, with a maximum length around 250 bytes [13]. Security in LoRaWAN is determined by a pre-provided root key shared by the end-device and the AS. This root key is employed during the LoRaWAN’s Join Procedure in order to generate a fresh pair of symmetric session keys that are used to encrypt the application data.

IV. THEORETICAL COVERAGE STUDY

As stated above, a coverage study of the city of Murcia (Spain) in the downlink direction has been conducted by using a radio-planning tool\(^1\). We have configured it to represent the characteristics of the real equipment employed in our experimental tests. These configuration parameters and their assigned values are shown in Table I. Fig. 2 presents the

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\(^1\)https://cloudrf.com/
coverage attained by using 5 gateways strategically distributed around the city. Observe that with this deployment, the whole city and its suburbs are fully covered. Thus, a medium-sized city with about 500,000 citizens may be theoretically covered without a big expenditure.

However, the focus of our study is on the city center, as it is the most populated area of the city and the most challenging in terms of transmission reliability due to high buildings and narrow streets. Fig. 3 depicts in detail the area covered by the gateway placed in this location; note that it corresponds with the central gateway in Fig. 2. The boundary of the zone covered by this gateway has been also drawn, it represents the most conflicting area where the reception level starts to decay. Precisely, a route along this boundary has been followed in our experimental test with the aim of studying the transmission quality with the less favorable conditions for the deployment under consideration. Thus, we have considered these theoretical results in order to define the studied area in our tests.

V. IMPLEMENTATION

To validate the coverage study presented above, we installed a real LoRaWAN testbed in the city. In this deployment, we used two different LoRaWAN gateways, namely, the Kerlink Wirnet Station IoT outdoor LoRaWAN Gateway and the Cisco Wireless Gateway for LoRaWAN. Both of them were similarly configured and installed, transmitting at 0.025 W (14 dBm) in the 868 MHz frequency band. An omnidirectional antenna model with a gain of 5 dBi was employed: in the Kerlink gateway we connected one antenna, while a pair of the same antenna model was attached to the Cisco equipment. On the other hand, the end-device was an Arduino-compatible board (SmartEverything Fox board (SME)), together with a RN2483 LoRa Transceiver Module by Microchip, which is a LoRaWAN Class A module certified for the 868 MHz ISM radio band. An omnidirectional antenna with a gain of 2 dBi was attached to this device (Fig. 5).

The gateways were alternatively installed on the roof of a building in the center of the city (Fig. 3) at a height of 10 m (Fig. 4). The end-device was carried by hand or installed in the roof of a car, depending on the experiment characteristics (quasi-static or dynamic conditions).

As explained above, we defined a circular route of approximately 5 km around the gateways with locations in which there was line-of-sight between the end-device and the gateway, while others were blocked by big obstacles, e.g., buildings or trees. The design of this route was motivated by the results of the theoretical coverage study, trying to find the overlap areas between the proposed emplacement and the other suggested locations. Following this idea, the route transits along the theoretical coverage limits of the gateway. Besides, due to the fact that it goes along the border of different cells, if the other gateways had been installed, the route would have been covered with more robustness.

Regarding the LoRaWAN setup, two LoRa configurations were used by varying the SF between 7 and 12. The first
TABLE II

<table>
<thead>
<tr>
<th>PDR (%)</th>
<th>SF7</th>
<th>SF12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cisco gateway</td>
<td>Kerlink gateway</td>
</tr>
<tr>
<td></td>
<td>Uplink</td>
<td>Downlink</td>
</tr>
<tr>
<td>Static</td>
<td>65.3±3.2</td>
<td>73.9±4.1</td>
</tr>
<tr>
<td>Dynamic</td>
<td>39.5±3.4</td>
<td>53.4±3.4</td>
</tr>
</tbody>
</table>

Fig. 5. LoRaWAN end-device.

one increases the data rate of the transmissions but decreases
the link robustness, and vice versa. The other LoRa PHY
parameters were constant: the employed BW was 125 kHz and
the CR was constantly set to a value of 4/5 [3]. The payload
of the packets, which were sent every second, was fixed to 50
bytes. With this configuration, a fixed number of trials were
conducted for each gateway and LoRa configuration: three
travels on foot and other three by car were done for capturing
samples from the end-device. Concretely, we evaluated the
Packet Delivery Ratio (PDR) as well as the received power
level in both the end-device and the gateways in terms of the
Received Signal Strength Indicator (RSSI).

VI. RESULTS

In this Section we show and discuss the attained results in
our experimental trials. Table II presents the average PDR and
the confidence intervals ($\alpha = 0.05$) obtained for the different
configurations under study. Focusing first on the tuned LoRa
parameter, i.e., the SF, a clear performance difference exists
when using SF7 or SF12. Observe that the PDR values attained
when using the greatest SF are always superior than those
obtained with the lowest one. This is the expected behaviour
as the link robustness is improved when using higher SFs [15].
In general, the attained PDR is better in the downlink direction,
although the difference with the uplink direction is not very
high.

Comparing the performance of both gateways, we do not
find significant differences between them in the static sce-
nario. In the dynamic one, the Kerlink gateway has a better

Fig. 6. RSSI measured in the Kerlink gateway (uplink direction) in the quasi-
static experiment.
may be justified by the sensitivities of both devices, namely, -141 dBm in the Kerlink gateway and -139.5 dBm in the Cisco one. The most notable performance difference is attained when considering the mobility characteristics of the end-device. Focusing on the case of employing SF7, observe the important PDR decrease when the end-device is carried by car, which leads to poor PDRs around 50%. Thus, the Doppler effect seems to have a non-negligible effect in this type of communications. The impact of mobility is reduced by using SF12, which permits to increase the PDR level above 75%.

Regarding the received power level, as an illustrative example, Fig. 6 depicts the RSSI measured in the Kerlink gateway (uplink direction) by travelling the route on foot (quasi-static experiment). Concretely, Fig. 6(a) presents the results when using LoRa’s SF7 and Fig. 6(b) when using LoRa’s SF12. The grey points represent lost packets, i.e., sent by the end-device and not received by the gateway. As discussed above, the use of SF12 confers the transmissions a greater robustness evidenced by a lower number of packet losses. While in the first case, i.e., SF7, certain areas present a lack of connectivity, when increasing the SF to 12 these problems are solved, except in the lower-left area. These coverage problems were caused by the presence of big buildings that severely obstructed the communications. Observe that the received power level is similar with both configurations but the use of a greater SF permits decoding packets with more robustness, which explains the attained results. As aforementioned, we have conducted our experiment in the boundary of the area covered by the installed gateway. From the theoretical study presented before, we may assume that this area will be overlapped with the cells served by other gateways in the city, hence, increasing the system reliability and scalability. In light of these results, LoRaWAN technology presents highly interesting characteristics to be adopted as a valid communication technology for smart-city applications, especially for those that do not require high mobility of the end-devices.

VII. Conclusions

Many novel applications devoted for improving citizens’ daily life are being currently developed under the umbrella of the smart-city paradigm. One of the key link of this service chain is radio communications. Transmission solutions based on LP-WAN have emerged as firm alternatives to provide ubiquitous connectivity to IoT devices within a city. In this work, we have studied the performance of one of the most prominent LP-WAN-based technologies, namely, LoRaWAN. We have presented a theoretical coverage study showing that with five gateways a medium-sized city can be covered. After this previous study, we have showed and discussed the results extracted from an experimental test in which we have considered several configurations. The PHY LoRa characterization has erected as an important factor to be considered when deploying a real system. The end-device mobility conditions also notably determine the performance of the system. A noticeable decay in the PDR has been detected in vehicular scenarios. Even so, we consider that LoRaWAN is a robust technology that permits to support a plethora of upcoming smart-city services. As future work, we consider to work with other LP-WAN technologies such as NB-IoT as well as integrating our experiments within a real smart-city platform.

References


