Power Distribution Monitoring Using LoRa: Coverage Analysis in Suburban Areas

Guillermo del Campo, Igor Gomez, Silvia Calatrava, Rocio Martinez and Asuncion Santamaria
CeDInt
Universidad Politecnica de Madrid
gcampo@cedint.upm.es

Abstract

LoRa is an increasingly hot technology for LPWAN scenarios. In this paper, a low-cost, real-time monitoring system for power distribution grids based on LoRa and 3G/4G networks, is presented. Analysis of early experimental results of LoRa network coverage in suburban areas shows how communication range is affected by different parameters: LoS, vegetation, buildings and communication mode. Besides, the use of simulation tools to estimate LoRa coverage is evaluated.

Categories and Subject Descriptors

[**Networks**]: Network performance evaluation

General Terms

LoRa, communication range, experimental results

Keywords

LoRa, LoRaWAN, LPWAN, Internet of Things

1 Introduction

While there has been a considerable amount of research works [3, 17, 1] and commercial solutions oriented to monitoring of Smart Grids, mainly focused on smart metering and pricing, the high and medium voltage power distribution grids have been left behind. The scope of the MAIGE Project (Advanced monitoring system for gas and electricity infrastructures and distribution) includes optimizing the distribution grid management in Spain, enabling maintenance personnel to perform it remotely. Specifically, MAIGE aims to develop a set of robust, low-cost and low-consumption sensors to verify the status of components located at the transformation centres (TCs), to detect the location of faults and loads unbalance on networks, and to monitor different parameters at high and medium-voltage power towers.

In order to access remotely the sensor measurements, the communication system has to cover all the geographic areas where the electrical facilities are (high dispersion and low density) while complying with low-cost and low-consumption demands. Low-Power Wide-Area Network (LPWAN) technologies are the logical choice to satisfy these requirements. After analysing various LPWAN technologies such as SigFox[1], LoRaWAN[2], Weightless[3], NB-IoT[4], LTECat-M1[5] or Ingenu RPMA[6], the final candidates SigFox, LoRaWAN and NB-IoT where selected attending to the sensors requisites and factors such as availability, cost and coverage. Finally, LoRaWAN has been chosen as it presents the best compromise among the above factors.

Although LoRa is a relative new technology, it is increasingly gaining interest among the research community, including review works [13], interference analysis [5, 15], security mechanisms proposals [14] and latency evaluations [12]. Regarding the analysis of the LoRa coverage, there are a few studies focused on the use for LoRa in different scenarios: indoor [8], cities [16], mixed urban-suburban [11], mixed urban-sea [10], water close to the shores [7] or mountains [4]. However, none of them analyse the use of LoRa in areas with a mixed typology of terrain and variables that can affect communications, which is the main goal of this paper. Regarding LoRa applications, we have found a wide range, including tracking systems [6], health monitoring [9] or smart grids [2], although its use in power distribution monitoring systems is completely new. On the other hand, it is worth mentioning that although in other European countries and the US, LoRa is being widely deployed, in Spain there are no public or private networks.

Section 2 introduces the MAIGE sytem description, including the context of this work and presenting the different use cases of the project. In order to fulfil all the data transmission requirements of the sensors and use cases, a hybrid communication architecture is proposed. The different phases (setup and results) of the LoRa coverage experimental analysis in suburban areas are presented in Section 3. The effect of the different factors such as Line of Sight (LoS), buildings, vegetation, communication infrastructures

[1] https://www.sigfox.com/en/sigfox-iot-technology-overview
[2] https://www.lora-alliance.org/technology
[3] http://www.weightless.org/about/what-is-weightless
[4] http://www.vodafone.com/business/iot/nb-IoT
[5] https://www.gsma.com/iot/long-term-evolution-machine-type-communication-lte-mtc-cat-m1/
[6] https://www.ingenu.com/technology/rpma/

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Table 1. MAIGE use cases

Electricity distribution network facility	Parameter monitoring
Transformation centre	Optical sensors
	Ground wire continuity sensor
	Ground resistance sensor
	Electric discharge sensor
	Electric field sensor
High voltage power tower	Ground wire continuity sensor
	Ground resistance sensor
	Electric discharge sensor
	Electric field sensor
Medium voltage power tower	Infrared sensor
	Ground wire continuity sensor
	Ground resistance sensor
	Electric discharge sensor
	Electric field sensor
Electrical susbstation	Voltage sensor
	Fault indicator

and communication mode is discussed in Section 4.

2 MAIGE System Description

2.1 Context of the Project

The main objective of the MAIGE project is the development of innovative solutions and equipment to enable remote monitoring and improve the management of assets of the electricity distribution networks. Driven by Gas Natural Fenosa, the gas and electricity distribution company leading the project, various use cases comprising different electricity network facilities and parameter monitoring, have been defined (see Table 1).

The diverse use cases result in different communication scenarios with a heterogeneous set of requisites including data size, message frequency, bi-directionality, power source or internet connection availability.

2.2 Communication Architecture

The aforementioned use causes demand different requisites:

- Optical sensors at transformation centres and electrical substations aim to detect failures and non-desired access. Usually, they will process locally captured images and send a notification message, but the eventual transmission of images may be necessary. Transmissions will take place event triggered and regularly one per hour at most. Bi-directionality is required for control and verification duties.
- Fault indicators and voltage sensors located at electrical substations require sending a relatively high amount of data covering different electrical parameters. Fault indicator transmissions are event-based while voltage measurements will be sent at least on an hourly basis. Bi-directionality is required for control duties and for on-demand monitoring.
- Ground wire continuity, ground resistance sensor, electric discharge and electric field sensors send a small amount of data generally on a daily basis. Bi-directionality is occasionally required for control duties.

On the other hand, the electricity network facilities present different characteristics:

- Transformation centres and electrical substations have both power (main line) and internet (3G/4G) connections available.
- High and medium-voltage power tower have no power or internet connections.

Taking into account the requisites of the use cases (variable bandwidth, data size, periodicity and bi-directionality) and the characteristics of the facilities to be monitored (power and connection to the Internet availability), a new hybrid communication architecture (LoRaWAN and 3G/4G) is proposed (see Figure 1). At the transformation centres, the optical sensors will be powered by the main line and will be connected to the available 3G modem via an Ethernet interface. The electric parameter sensors will be battery powered and will communicate using the LoRaWAN network. Taking advantage of the power and 3G connections availability, a LoRa gateway will be located at the TCs.

Similarly, at the electrical substations, the fault indicators and the voltage sensors will take advantage of the power availability and internet connections to power and communicate them. When required, i.e. in the case of power towers located close to the substations, a LoRa gateway could be installed to benefit from the available connections.

At the medium-voltage power towers, the electric parameter sensors will communicate though the LoRa network while for the infrared optical sensor a 3G connection is required. Both LoRaWAN and 3G sensors will be battery powered using a renewable energy source (e.g. photovoltaic).

At the high-voltage power towers, the electric parameter sensors will communicate though the LoRa network and will be powered using batteries.

In order to cover the LoRa communications for all the high and medium-voltage power tower locations, it may be necessary to install autonomous LoRa gateways, with 3G connection and battery powered.

3 LoRa Coverage Experiment Design

As there are no LoRa network deployed in Spain in which the MAIGE communication system can rely on, it is part of the project to assure LoRa coverage. LoRa uses spread spectrum modulation and its range is defined by the channel bandwidth (BW) and the spreading factor (SF), which indicates the number of chirps per symbol used in the treatment of data before transmitting the signal. Theoretical range limit is 10 km, corresponding to BW=125 kHz and SF=12.

3.1 Coverage Metrics

In order to evaluate the coverage, we have used the following metrics:

- Received Signal Strength Indication (RSSI), available at the radio chip, which indicates the power level in dBm of the received signal.
- LoRa Signal to Noise Ratio (SNR), available at the radio chip, which indicates the quality (and thus the facility to be demodulated) of the received signal.

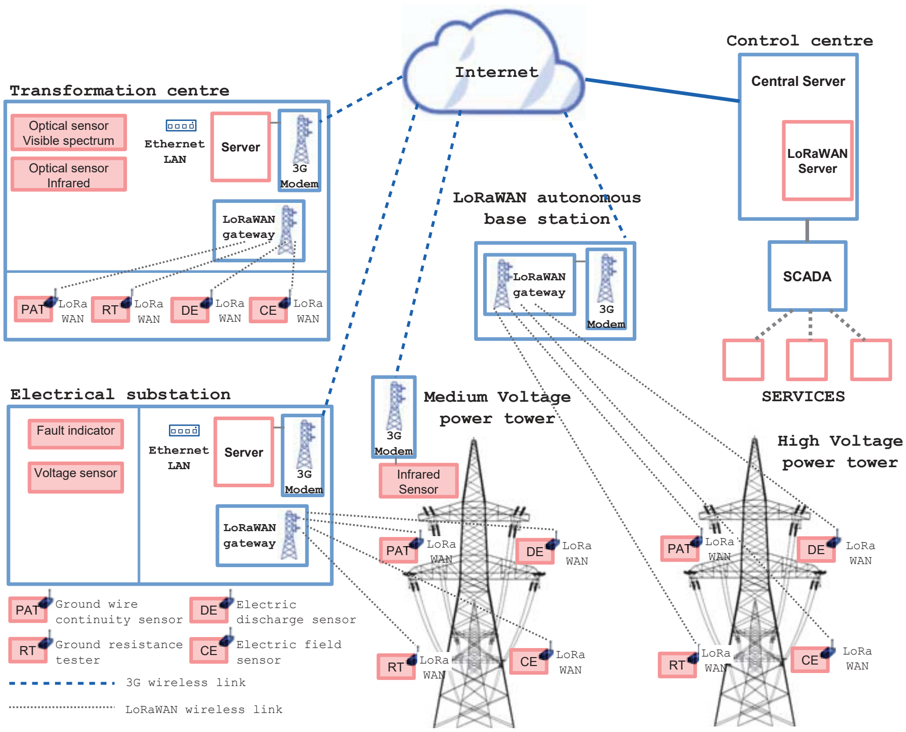

Figure 1. MAIGE hybrid communication architecture.

- Packet Delivery Ratio (PDR), which is the ratio between received and transmitted packets.
- Spreading Factor (SF), which defines transmission rate (i.e. the transmission time), being SF=7 the fastest (5.470 kbit/s) and SF=12 the slowest (250 bit/s).
- Range, which is the distance between the measurement locations and the LoRa gateway.

3.2 Experimental Setup

The communication platform used for the experimental measurements is based on the solution proposed by the ThingsNetwork[7]: a LoRa IMST iC880a transceiver and a Raspberry Pi3 constitute the gateway. For the transmission nodes, we use the LoPy nodes from Pycom. The band used is 868 MHz, which is the allowed band in Europe, and we utilize a BW of 125 kHz to increase the communication range. Both gateway and nodes make use of a dipole antenna with a peak gain of 2.7 dBi.

The LoRa gateway has been located at the rooftop of the CeDInt building (4024'16.3"N, -350'04.4"W) being the final altitude of 740 m. A mix of university buildings, gardens, forests, residence buildings, roads and commercial/industrial facilities surrounds the gateway location. The measurement locations have been distributed in a radius of 10 km from the gateway, covering a diverse orography and with the aforementioned characteristics of suburban areas.

[7] https://www.thethingsnetwork.org/

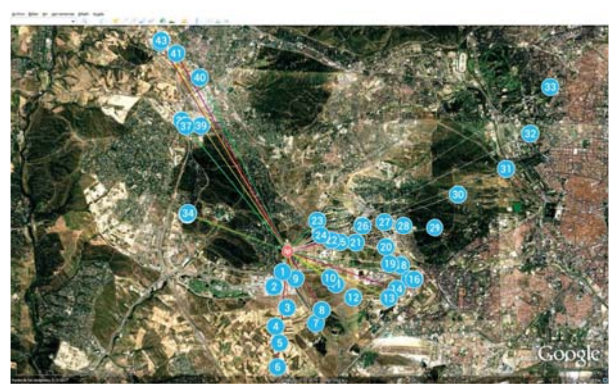

Figure 2. Map of initial measurement locations.

Table 2. Results for up to 200 m

SF	7	8	9	10	11	12
RSSI (dBm)	-89.7	-90	-91.1	-88	-91.1	-89.2
SNR	5.9	7.1	8.4	6.6	6.9	6
PDR (%)	100	100	100	100	100	100

3.3 Initial Measurements

As a first approach, random locations have been chosen (see Figure 2). Results are presented as a function of the distance between the gateway and the transmission nodes. For every measurement location and for each SF, we send 100 packets with a payload of 8 bytes.

Table 3. Results for between 400 m and 1.5 km

SF	7	8	9	10	11	12
RSSI (dBm)	-103	-103	-104	-102	-103	-104
SNR	1.5	2.3	2.6	4.9	5	3.8
PDR (%)	95	98	100	100	100	100

Table 4. Results for more than 1.5 km

SF	7	8	9	10	11	12
RSSI (dBm)	-112	-112	-113	-113	-112	-112
SNR	-4.6	-7.3	-8.6	-8.9	-9.6	-11.1
PDR (%)	18.1	35	48.7	59.3	67.5	68.1

3.3.1 Up to 200 m

Table 2 presents the average results (15 measurement locations) showing that for low range the PDR is 100 % while RSSI varies between -68 dBm and -102 dBm and the SNR ranges from 0.32 to 11.17.

3.3.2 Between 400 m and 1.5 km

Table 3 collects the average results (12 measurement locations) showing that there is almost no packet loss, corresponding the few losses to the lowest SFs (i.e. highest transmission rate). RSSI varies between -92 dBm and -108 dBm and the SNR ranges from -4.8 to 6.7.

3.3.3 More than 1.5 km

Table 4 presents the average results (16 measurement locations) showing that there are many packet loses (PDR=49.5 %). RSSI varies between -112 dBm and -113 dBm and the SNR ranges from -11.19 to -4.7. It is important to notice that from 30 % of the locations the number of received packets has been equal to cero. Preliminary analysis of results shows that there is not a direct relation between range and packet loss: for instance, there is measurement located at 7.3 km from gateway with a PDR of 100 % while another one at 3 km with PDR of 0 %. It can be deduced that the range depends directly on direct vision (i.e. Line of Sight - LoS) between the gateway and the transmission node.

3.4 Coverage Planning Tool

In order to estimate the coverage of the LoRa gateway, we have used the XIRIO[8] tool, which allows simulation of the coverage using high-resolution mapping. Different propagation models can be used (with LoRa characteristics) and coverage may be calculated using LoS or even SF outputs. Figure 3 shows an example of the output of the coverage map for SF=10.

3.5 Evaluation Measurements

Considering the simulated coverage maps, we have chosen new locations to evaluate the correlation between the estimated and the real coverage, i.e. to analyse reliability of the simulation tool. Obtained data may also provide insights related to the effect of different parameters such the LoS, building topology, vegetation density or other terrain landmarks. As for the initial measurements, for every measurement location (34) and for each SF, we send 100 packets with a payload of 8 bytes. Results are presented in table 5 (up to 2 km), table 6 (between 2 km and 5 km) and table 7 (more than 5 km). It si worth mentioning that results from 3.3 and 3.5 are not comparable, as the measurement locations are different.

[8] https://www.xirio-online.com/

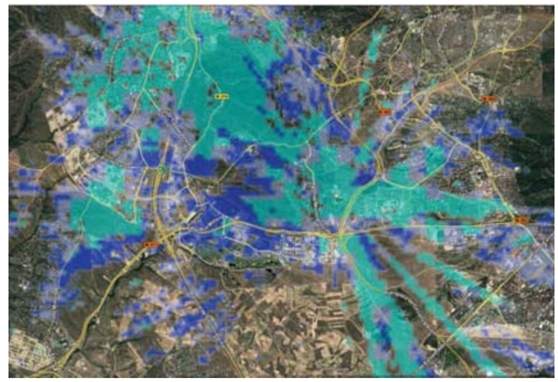

Figure 3. Map of estimation coverage for SF=10: darker blue represents worse RSSI.

Table 5. Results for up to 2 km

SF	7	8	9	10	11	12
RSSI (dBm)	-107	-106	-107	-107	-107	-107
SNR	-4	-4.5	-5.6	-6	-4.5	-5.2
PDR (%)	57.7	61.1	86.6	97.7	100	98.8

4 Results Discussion

4.1 Correlation between Estimation and Real Coverage

Figure 4 shows the correspondence between the estimated coverage and the experimental results. Figure 4a shows the LoS model while Figure 4b represents the RSSI model for SF=12. Coloured points represent the measurement locations. Light blue indicates higher PDR while dark blue points represent more packet losses. The correlation is high, existing slight differences that may be caused by the presence of buildings or trees not registered by the simulation tool.

4.2 Effect of Terrain Variables

4.2.1 Effect of LoS

As predicted, LoS is the most decisive factor. Figure 5 shows the terrain profile of two measurement locations. Figure 5a represents the profile of a measurement point located at 7 km of distance from the gateway, achieving a PDR of 100 %, while Figure 5b shows the profile of a measurement point 4.4 km away, with a PDR of 0 %. It can be observed the differences in the LoS of the two locations. This effect replicates when analysing the LoS profiles of other measurement locations.

4.2.2 Effect of Vegetation

Results analysis show that there is a dependency between the presence of high-density forests close to the transmission node location. Figure 6 shows the view in gateway direction

Table 6. Results for between 2 km and 5 km

SF	7	8	9	10	11	12
RSSI (dBm)	-105	-106	-107	-106	-107	-107
SNR	-1.6	-4.1	-7.3	-9.5	-8.6	-9
PDR (%)	30	45	45	67.5	78.7	83.7

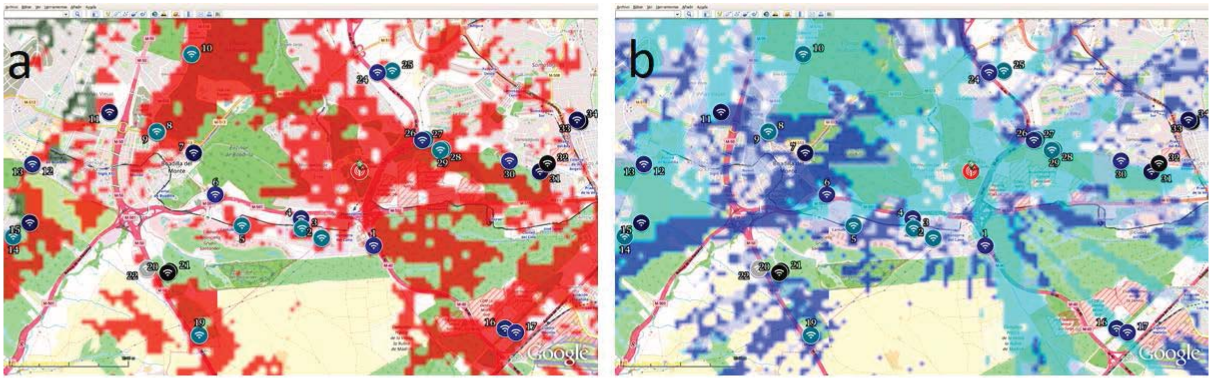

Figure 4. Correlation between simulation and real results: LoS model in a, RSSI for SF=12 model in b. Gateway represented by a red point, light blue points indicates higher PDR while dark blue points represent more packet losses.

Table 7. Results for more than 5 km

SF	7	8	9	10	11	12
RSSI (dBm)	-107	-107	-107	-107	-107	-107
SNR	-8.4	-9.3	-11.4	-11.4	-12.5	-13.2
PDR (%)	5.7	22.8	32.8	45.7	68.5	77.1

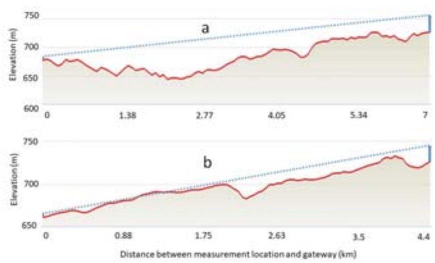

Figure 5. LoS comparison: PDR=100 % for node in a and 0 % for node in b.

Figure 6. Vegetation effect: PDR=85 % for node in a and 68 % for node in b.

from two different locations close one to each other (30 m): PDR is 85 % for location 6a while 68 % for location 6b.

4.2.3 Effect of Buildings and other Obstacles

The effect of buildings is strengthened if they are located close to the transmission nodes, even out of the LoS. Similar effects are observed if other elements such as fences or posts are present nearby.

4.2.4 Effect of Electricity Network Elements

Taking into account that the project sensors will be located at high and medium-voltage power towers, is necessary to evaluate the effect of these elements in the LoRa communication range. Figure 7 shows the transmission node just below a high-voltage tower, achieving a PDR of 98 %. Further analysis is needed to assure the lack of effect.

Figure 7. Location of the transmission node below a high-voltage power tower.

4.3 Lessons Learned

Summarizing, there are different terrain variables that affect the LoRa communication range. As expected, experimental results show that the range increases for higher SFs, i.e. for lower transmission rates. On the other hand, LoS appears to be the most defining factor, being necessary to have direct vision between the gateway and the transmission node to achieve reliable communications, even for low transmission rates.

Vegetation, especially high-density forest, buildings and other terrain landmarks affect the communication range when they are located close to the transmission node or the gateway. Thus, when designing the LoRa deployment, it is mandatory to seek high and isolated locations to increase LoS and avoid undesired effect by nearby elements. Although it requires a further analysis, first results show that the location of transmission nodes near electricity network facilities as high-voltage power towers does not affect the communication range.

Finally, after comparing the estimated coverage resulting from the simulation tool and the real measurements, we can guarantee that it can be used for real Lora network deployments, though it is advised to go through an experimental validation for low RSSI areas.

5 Conclusions

This work presents the design of a hybrid communication architecture based on LoRa and 3G to deploy a monitoring system to optimize maintenance operation in electricity and gas distribution networks. Considering the diversity of electricity network locations, we have evaluated the LoRa communication range in suburban areas (up to 10 km) comprehending different terrain typologies. Experimental results show that the most determining factor is the LoS while the presence of dense vegetation and buildings close to the communication nodes lower the range. Another contribution from this work is the validation of the use of coverage simulation tools to estimate LoRa range.

In the future, we plan to expand the analysis on how the electricity network elements affect the communication and study the joint use of LoRa and other LPWAN technologies such as SigFox or NB-IoT to increase communication range or transmission rate when needed while balancing deployment and long-term costs.

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