Hybrid LPWAN Communication Architecture for Real-Time Monitoring in Power Distribution Grids

Guillermo del Campo
CeDInt
Universidad Politecnica de Madrid
Madrid, Spain
gcampo@cedint.upm.es

Igor Gomez
CeDInt
Universidad Politecnica de Madrid
Madrid, Spain
igomez@cedint.upm.es

Guillermo Cañada
CeDInt
Universidad Politecnica de Madrid
Madrid, Spain
gcanada@cedint.upm.es

Asuncion Santamaria
CeDInt
Universidad Politecnica de Madrid
Madrid, Spain
asun@cedint.upm.es

***Abstract*—This work presents a LPWAN communication architecture for monitoring systems in power distribution grids, in the framework of the MAIGE project. MAIGE main goal is the experimental evaluation of innovative technologies for their massive deployment. The project describes a variety of use cases that demand different communication requisites. Taking into account the diversity of the sensors, as well as the availability of power and internet connections, we have designed a hybrid 3G-LoRa-SigFox communication architecture. Finally, we show the experimental results of the performance and timing analysis of the proposed solution.**

Keywords—LPWAN, LoRa, SigFox, Internet of Things, real deployment

I. Introduction

The MAIGE Project (Advanced monitoring system for gas and electricity infrastructures and distribution) aims to develop and test a variety of robust, low cost, low power consumption sensing, communication and management technologies to optimize the distribution grid management in Spain. The goal of the project is to validate these technologies in experimental deployment with the aim of future application in the entire grid (i.e. massive deployment). The sensors are oriented to verify the status of components located at the transformation centres and electrical substations. Besides, the project seeks to detect the location of faults and loads unbalance on networks, and to monitor different parameters at high and medium-voltage power towers.

Remote access to the sensors requires the use of a communication system that has to comply with low-cost and low-consumption requisites while covering all the geographic areas where the electrical facilities are located (i.e. high dispersion and low density). To satisfy these requirements, Low-Power Wide-Area Network (LPWAN) technologies are the logical choice [1]. While there are many research works [2] and commercial solutions oriented to monitoring of Smart Grids, they are mainly focused on smart metering and pricing. On the contrary, there is a lack of monitoring systems for the power distribution grid [3].

After analysing different LPWAN technologies [4], and attending to the sensor requisites and factors such as availability, cost and coverage, we have selected LoRa (LoraWAN)[1] and SigFox[2]. NB-IoT[3] also was considered due to its promising future, but its current coverage in Spain is very limited.

Regarding LoRa and SigFox scenarios, we have found a wide range of applications, including tracking systems [5], smart grids [6] or health monitoring [7], although their use in power distribution monitoring systems is completely new. Therefore, and having in mind the evaluation goals of the MAIGE project, we propose a new hybrid LPWAN communication system.

II. MAIGE Project

A. Context of the Project

The main objective of the MAIGE project is the development and experimental validation of innovative solutions and technologies to enable remote monitoring and management of electricity distribution grids. Therefore, several types of sensors to monitor distribution grid parameters and different communication technologies will be evaluated in terms of accuracy, performance, scalability and viability. Selected solutions and technologies will be considered for massive deployment. Leaded by Naturgy Energy Group, a Spanish natural gas and electrical energy utilities company, the project defines different use cases (see Table I). Each use case comprises the monitoring of various parameters in specific electricity network facilities.

These use cases demand different requisites, which can be divided in two main categories: facility characteristics (availability of power and connection to the Internet) and communications constraints (variable bandwidth, data size, periodicity and bi-directionality).

1 https://www.lora-alliance.org/technology
2 https://www.sigfox.com/en/sigfox-iot-technology-overview
3 http://www.vodafone.com/business/iot/nb-IoT

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TABLE I. MAIGE USE CASES

Location	Electricity Distribution Grid Facility	Parameter Monitoring
Puente Princesa (Madrid)	Transformation Centre 1	Optical sensors
		Loop resistance sensor
	Transformation Centre 2	Ground resistance sensor
	Electrical Substation	Battery electrolyte level
Illescas (Toledo)	High voltage power tower 1	Grounding resistance sensor
		Electric discharge sensor
	High voltage power tower 2	Electric field sensor
		Grounding floating voltage sensor
Urda (Toledo)	Medium voltage power tower	Fault detector
		Fault indicator

Regarding the electricity network facilities, two different cases may be depicted:

- Transformation centres and electrical substations have both power (main line) and internet (3G/4G) connections available.
- High and medium-voltage power tower have neither power nor internet connections.

Considering the communication constraints, the following scenarios are described:

- Optical sensors 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.
- Electric field sensors, fault detector and fault indicators demand sending a relatively high amount of data covering different electrical parameters. Fault detector/indicator transmissions are event-based while electric field measurements will be sent at least on an hourly basis. Bi-directionality is required for control duties and for on-demand monitoring.
- Grounding resistance sensors, loop resistance sensors, battery electrolyte sensors, electric discharge sensors and grounding floating voltage sensors send a small amount of data generally on a daily basis (also event triggered). Bi-directionality is sporadically required for control duties.

B. SCADA data common format

Data collected from sensors will be transmitted to a supervisory control and data acquisition system (SCADA). This SCADA will store data and connect to external services such as a smart system for the diagnosis and maintenance of energy assets of the power distribution grid.

The SCADA demands a common data format (“*LOCATION”_”SENSOR”_”SIGNAL”*), i.e. all the messages arriving from the different sensors, with independency of the communication technologies, must comply with it (see examples in Table II).

TABLE II. EXAMPLES OF SCADA DATA FORMAT

TAG	Location	Sensor	Signal
AT001_DAT01_AMP	High power voltage tower 1 in Illescas	Electric discharge sensor	Amplitude of the discharge (kA)
CT002_RPT01_RES	Transformation centre 2 in Puente Princesa	Grounding resistance sensor	Grounding resistance (Ohm)
SE001_NEL01_COM	Electrical substation in Puente Princesa	Battery electrolyte level sensor	Communication failure

III. COMMUNICATION ARCHITECTURE

Taking into account the previous requisites, and with the MAIGE evaluation purposes in mind, we have proposed a hybrid communication architecture that combines 3G/4G, LoRa and SigFox (see Fig. 1).

At Puente Princesa location (Madrid city), the optical sensors in the transformation centre 1 are powered by the main line and communicate using 3G via an Ethernet interface. The loop resistance sensor communicates using the LoRaWAN network. Similarly, the grounding resistance sensor at the transformation centre 2 integrates a LoRaWAN interface. Taking advantage of the power and 3G connection availability, the LoRa gateway is located in this facility. Regarding the battery electrolyte level sensor in the electrical substation, and for analysis purposes, it communicates trough the SigFox technology. These sensors are powered through the main line.

At the high power voltage towers in Illescas location (Toledo region), the electric field sensor communicate using a 3G module, while the rest of sensors make use of SigFox technology. The choice of SigFox instead of LoRaWAN is motivated by the difficulty of establishing a LoRaWAN gateway in a rural area.

At the medium voltage power towers in Urda (Toledo region), the fault detectors/indicators communicate using a 3G connection.

All the sensors installed at the power towers are battery powered and include a photovoltaic panel.

A. 3G

Sensors using 3G connectivity integrate a 3G module that communicate to an intermediate server (located at AT3W, MAIGE project partner) where data are transformed into the common format and sent to the SCADA via a REST interface.

B. SigFox

SigFox is a LPWAN technology that has deployed its own cellular infrastructure and requires a subscription fee. Before choosing the implementation of SigFox as a communication technology for the project, we analysed its coverage in Spain and carried out specific tests at the three project locations, not registering communication failures. Sensors using the SigFox network are connected integrating a LoPy node from Pycom. These nodes include 1-year subscription to the network enabling the transmission of up to 140 messages per day and a payload of 12 bytes.

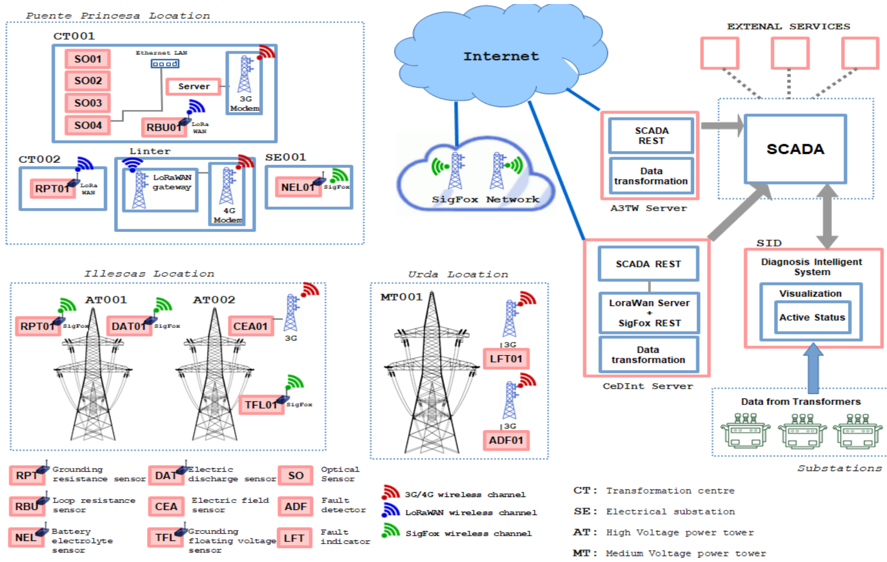

Fig 1. MAIGE Communication Architecture

In their path to the SCADA system, SigFox messages have two intermediate steps: SigFox server and CeDInt server. The first one is the SigFox backend database server, which can be accessed via a web application. In this application, we have configured two types of callback actions: message arrival notification via email and message forward to the CeDInt server using a REST interface.

At the CeDInt server, hosted in our facilities in a Debian 8 station, the message data is transformed to the common data and transmitted to the SCADA via a REST interface. At the same time, data (both sensor and communication parameters) are stored in a Graphite database for further analysis.

C. *LoRaWAN*

It has been necessary to deploy our own LoRa network infrastructure, as unlike in other countries, in Spain, there are not companies that offer these services. Prior to the deployment in Puente Princesa facilities, we have carried out a detailed analysis of LoRa coverage in suburban areas [8]. The Lora gateway, which has been located inside the first floor of an office building, is a commercial solution offered by IMST[4] that integrates a Lora IMST iC880a transceiver and a Raspberry Pi3. For the transmission nodes, we use the LoPy[5] 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.

The LoRa gateway receives the message from the node, transforms it into MQTT format adding encryption and sends it to the LoRaWAN server (hosted at CeDInt server) through the Internet. At CeDInt server, LoRa messages are decrypted and stored. Similarly, in the SigFox case, data are transformed to the common format and sent to the SCADA.

4 https://wireless-solutions.de/products/long-range-radio/lora-lite-gateway.html

5 https://docs.pycom.io/datasheets/development/lopy4.html

IV. Results

A. *Performance of SigFox and LoRa communications*

The sensors at the transformation centres and the electrical substation in Puente Princesa location have been deployed and working since July 2018. The sensors of the Illescas and Urda locations are yet to be deployed.

Fig.2 shows the received signal power level (RSSI) and signal to noise ratio (SNR) of the sensors in Puente Princesa since its deployment (sending one message per day). In the above chart (RSSI), it can be observed how the sensor using SigFox (NEL01) presents a lower and more variable RSSI level. On contrary, in the SNR chart (below), it can be seen that the sensors using LoRa (RPT01 and RBU01) achieve lower (even below zero) and more constant values. This behaviour can be explained by the nature of the modulation of both technologies. LoRa employs spread spectrum techniques, expanding the signal into a wide spectrum with chirp modulation, allowing signal demodulation even with negative SNR. On the other hand, SigFox is based on ultra-narrow band techniques, demanding a high-sensitivity and selective receiver, increasing the required SNR but allowing lower RSSI. Spotting the green line (RBU01), we can detect two anomalies: a decrease of the RSSI and SNR around the 20th of July, and missing data during consecutive days, especially during the month of October. RBU01 communicates using LoRa and is located at transformation centre, very close to the building where the LoRa gateway has been installed. The decrease of the RSSI and SNR levels can be caused by the antenna movement or loosening. After analysing the LoRa gateway logs, we have not found any communication try from the sensor node, therefore the most probable cause of the loss of messages could be its disconnection by facility workers.

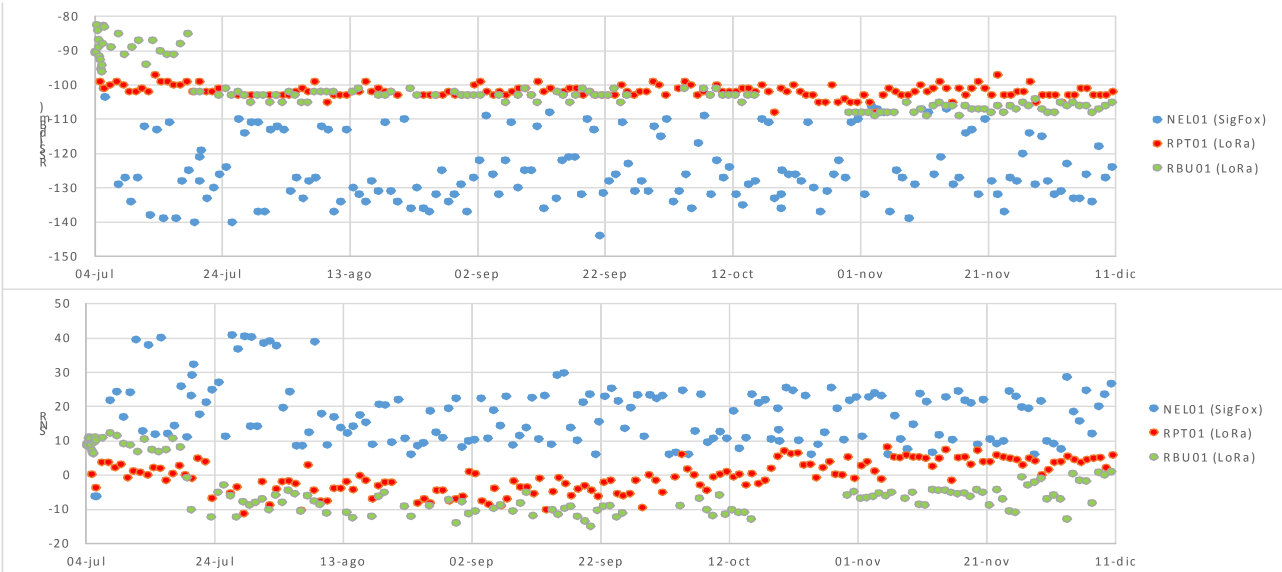

Fig 2. RSSI (above) and SNR (below) of LoRa and SigFox sensors in Puente Princesa

Although from the performance in Puente Princesa location, we would suggest the use of SigFox, further analysis is required.

We have replicated MAIGE communication architecture in our facilities to test different scenarios (variable sending frequency, payload, etc.) and study the probable causes of RSSI and SNR deterioration. Fig.3 shows the communication performance from the 27th to the 29th of November. The LoRa sensor (blue) sends one message every 2 minutes while the SigFox sensor communicates every 15 minutes. During this period, we have applied alterations to the devices status, such as the direction movement of the antenna, the loosening of its connection or the change of location. As it can be observed, the only visible modification occurs around 2 p.m. of the 28th of November, resulting in a fall in both RSSI and SNR values for the LoRa sensor. This behaviour corresponds to the loosening of the antenna connection, which may explain the similar performance at the MAIGE deployment the 20th of July.

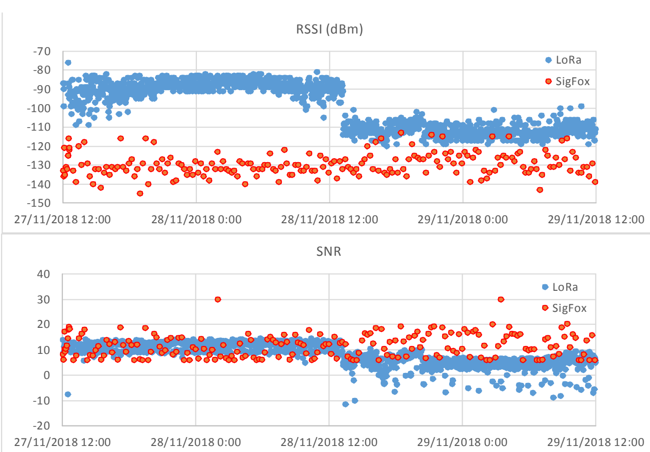

Fig 3. RSSI and SNR of LoRa and SigFox sensors in of testing deployment

However, the antenna connection loosening does not affect the performance of the SigFox sensor. Verification of this behaviour and the study of the effect of other alterations require further analysis.

B. *Timing analysis*

Two of the most deciding values when choosing the LPWAN communication technology to be used for massive deployments are power consumption and latency.

Power consumption is strongly defined by the time the sensor has to stay awake for communication, while latency is determined by how long does it takes the message from the sensor to the SCADA. Table III represents the times for the different steps during the time the sensor is awake. It can be observed that LoRa messages arrive earlier to CeDInt server.

This time difference is caused by the transmission rate of each technology: 100 bps (SigFox) and 1760 bps (Lora SF9). Likewise, the LoRa sensor goes back to sleep mode significantly earlier than the SigFox one, contributing to reduce power consumption. The final time difference increases because SigFox uses frequency hopping, broadcasting each message 3 times on three different frequencies.

TABLE III. LoRa and SigFox Communication Times (seconds)

Step	SigFox	LoRa
Sensor wakes up	0	0
LoPy module ready	8.29	8.44
Message arrives to CeDInt server	11.49	8.96
Arrival of ACK/ End of SigFox transmission	16.71	9.86
Sensor to sleep mode	16.95	10.1

V. CONCLUSIONS

This work, in the framework of the MAIGE project, presents the first deployment results of an LPWAN-based communication system for the monitoring of electrical parameters power distribution grids. The main objective of the MAIGE project is the experimental evaluation of innovative technologies for their massive deployment.

Taking into account the communication requisites diversity of the different sensors, as well as the availability of power and internet connections, we have proposed a hybrid 3G-LoRa-SigFox communication architecture.

As the constraints of the deployment in real world environment, difficult a precise analysis of communications, we have duplicated the MAIGE communication architecture in our facilities

Comparative analysis of LoRa/SigFox technologies does not clarify the LPWAN choice for this type of systems. Both LPWAN technologies comply with the communication requirements of monitoring application for power distribution grids (e.g. long range, low throughput, low power consumption, and low cost). While SigFox present better communication performance, LoRa requires shorter transmission times.

When selecting the LPWAN communication technology, different factors have to be considered: coverage, cost, transmission rate, bi-directionality, etc. Regarding coverage, we would suggest the use of SigFox, as it covers nearly all the Spanish territory, while LoRa would require the deployment of a private network (i.e. a grid of LoRa base stations/gateways). On the other hand, if the transmission rate or the power consumption prevail over communication performance, LoRa is the appropriate choice.

However, in the future, with the advertised arrival of 5G technologies, that is, the increase of the NB-IoT coverage in Spain, new practical studies should be conducted in order to define which is the best LPWAN solution for power distribution grid monitoring and other final applications.

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