A Simulation of an IoT-based Solution Using LoRaWAN for Remote Stations of Peruvian Navy

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***Abstract*—Peruvian Navy uses a Supervisory Control and Data Acquisition (SCADA) system to monitor and control its remote meteorological and luminous stations which are out of town and powered by photovoltaic systems. They use cellular gateways with high energy consumption to transmit data to a control center using the services of a mobile service provider. The storage of the obtained information and system management is done in a single location. This paper focuses on the design of an IoT-based solution using LoRaWAN technology and a cloud IoT platform to replace the current system and give mobility, redundancy and efficiency characteristics. The path loss and coverage for the farthest remote station is calculated using the Okumura-Hata propagation model and two radio propagation simulators. A LoRaWAN end-node with meteorological sensors is simulated and a web page is developed to show the information to the users.**

***Index Terms*—Internet of Things, LoRaWAN, remote station, link budget, remote monitoring**

I. Introduction

The Internet of Things (IoT) is a global network that connects identifiable objects with sensing, acting, processing and communication capabilities with other devices or computational resources using multiple communication technologies to generate advanced applications and valuable information [1]–[3]. It enables the automation and digitalization of production processes. The global IoT market increases every year and market shares show industrial applications are one of the main sub-sectors with 24% of the market, becoming the second most important category after smart cities [4]. In Latin America, the IoT and M2M market is estimated to increase from $14.2 billion in 2013 to $44.4 billion by 2019, at a compound annual growth rate of 19.9% for the referred period [5].

Similarly, the improvement of small, cheap, and low-energy consumption communication devices has allowed the development of Low Power Wide Area Networks (LPWAN). LPWAN are networks that provide extensive coverage over reduced bandwidth using small amounts of energy, which are suitable for IoT applications. The LPWAN nodes achieve a range in the order of kilometers and the coverage depends mainly on the type of area (urban or rural) where they are deployed. The use of a star topology network and modulation techniques such as Chirp Spread Spectrum (CSS) and Ultra Narrow Band (UNB) allow LPWAN to achieve long-range communication between the transmitter node and the receiver node. They can be deployed on licensed frequency bands corresponding to cellular frequencies or on unlicensed bands, corresponding to Industrial, Scientific, and Medical (ISM) frequencies [6], [7].

Several works have been proposed for monitoring energy and meteorological systems using IoT. In [8], an analysis is presented between an IoT environmental unit and an automatic meteorological station, comparing their temperature, relative humidity, and atmospheric pressure measurements, achieving a similarity for each parameter higher than 95%. In [9], an IoT based SCADA system is proposed employing IPv6 Low-Power Personal Area Network (6LoWPAN) nodes and fog computing routers with cloud gateway capabilities for the monitoring of an electrical power distribution system. In [10], an IoT architecture is designed for an energy management system using LoRa. The coverage is evaluated in an urban industrial area, resulting in greater communications distances compared to legacy Wide Area Networks (WAN) technologies. In [11], an analysis of propagation link is performed for remote weather stations through a LoRa gateway, calculating the free space path loss and the theoretical maximum distance for nodes communication using the Friis transmission equation. In [12], is presented the architecture and the implementation of an IoT system for a wind turbine and a meteorological mast, providing a complete system deployment. Based on the analysis of the related works, it is noticed the existence of few LoRaWAN works for real-life applications of organizations with ongoing systems such as SCADA. Besides, there is a reduced analysis of the outdoor coverage using a radio propagation model, a complete network architecture for a real scenario, and a precise procedure to implement an entire solution. Therefore, a solution is proposed considering the previous details for a government institution such as the Peruvian Navy.

In this paper, two alternatives to replace the current monitoring system of the Peruvian Navy are analyzed: A SCADA as a Service and an IoT system solution. The contributions of this research are: a) A comparative analysis between the two alternatives is developed, revealing an IoT system using LoRaWAN is superior to a cloud-based SCADA solution; b) An IoT-LoRaWAN architecture is designed for the specific case; c) The path loss using the Okumura-Hata propagation model for the worst scenario and the link budget are calculated for the farthest remote station; d) The link budget results are validated with two coverage simulators; e) A LoRaWAN end-node is created on a simulator and a LoRaWAN server

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is configured to forward the payload data to an IoT cloud platform to process, store and display the information to the end-users through a local website running on a virtual machine. In summary, this paper proposed an IoT system using LoRaWAN communication technology and cloud computing services to replace local SCADA systems.

The rest of this paper is organized as follows. Section II introduces the current SCADA system, its electronic devices, communications infrastructure, and system limitations. Section III presents the two solution alternatives and their analysis. Section IV describes the IoT architecture and the selected devices for the solution. Section V presents the link budget and the coverage simulations. Section VI presents the simulation of the IoT application and the procedure performed. Section VII concludes this study and presents the suggested future work.

II. Current system description

Peruvian Navy has a SCADA system for twenty-eight remote stations located along the coast of the country. Twelve stations are meteorological type (weather stations) and sixteen stations are luminous type (lighthouses). Most of the stations are located on hills or amid deserts, powered by photovoltaic systems. Fig. 1 presents a meteorological remote station.

Meteorological stations have five sensors to acquire data of air temperature, relative humidity, atmospheric pressure, wind speed, and wind direction. Luminous stations have several voltage and current sensors to monitor the operation of the light device and their power system supply components (batteries and solar modules). Control devices including contactors and relays are also used to turn on/off devices remotely. The electrical signals coming from sensors are processed by a data logger or a Remote Terminal Unit (RTU), packaged in IP packets, and sent to a cellular gateway.

The services of a mobile carrier are contracted to send the data through its network to the Control Center using Subscriber Identity Module (SIM) cards and port forwarding method. A personalized Access Point Name (APN) is used

Fig. 1. Meteorological remote station

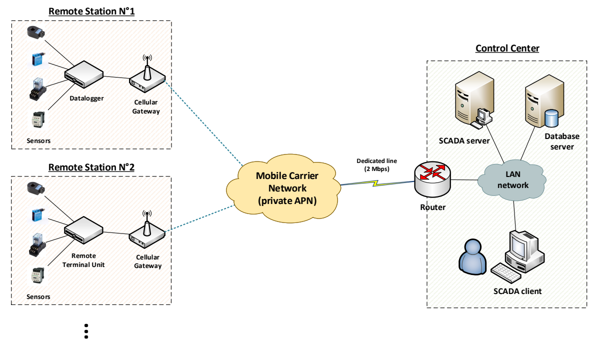


Fig. 2. Current SCADA system architecture

by the mobile carrier to create a private network and establish communication using a dedicated line with a router in the control center. A SCADA software and a SQL database are used in local servers to provide data processing and storage services to the users responsible for monitoring the remote stations. Fig. 2 illustrates the current SCADA system architecture.

The actual system has severe restrictions that limit its performance and scalability, e.g., i) The system access and management are carried out in a single location (control center); ii) Only one APN can be used; therefore, only one mobile carrier can provide the services, and there is no possibility to access the system through the Internet; iii) Sensors data obtained from all the remote stations are stored in local databases without a backup in other database or a cloud storage service; iv) The client software only runs on a Windows operating system; v) Cellular gateways are always on and required a reasonable photovoltaic power supply.

Based on the previous description, an improvement of the current system is required to give users the ability to access and manage the system through the Internet, store sensors information in the cloud and reduce the energy consumption of remote stations using new communication devices.

III. Alternatives evaluation

An analysis of possible solutions is carried out, taking into account the capabilities of the current cellular gateways, server, client software, and the power supply limitations existing in remote locations. In this regard, solutions such as using a cloud computing platform to host the current SCADA server software is not an entire solution because of limitations with the present gateways and software, as well using Wi-Fi radios in remote locations due to their high power consumption. Therefore, two system alternatives are analyzed:

A. *SCADA as a service*

The first alternative involves hiring the services of a SCADA service provider to use its cloud platform to host the entire system. It is also necessary to replace the outdated data loggers, RTUs, and cellular gateways with high energy consumption that are used at the remote stations. New end-nodes are adopted incorporating an industrial embedded computer with a Linux distribution, Message Queuing Telemetry Transport (MQTT) protocol and electronic terminals with analog and digital inputs/outputs for acquiring electric signals coming from sensors [13]. Furthermore, 4G cellular gateways with lower power consumption than current gateways are used to send data to the cloud of the SCADA service provider.

It is necessary to pay for an annual subscription to develop, store, and access the system and database in the cloud platform of the service provider [14]. Furthermore, conventional cellular data plans of any mobile carrier can replace the current service. A private APN is not required. End-users will be able to access the system through the Internet without a dedicated line. Fig. 3 shows the architecture of the SCADA as a service solution.

B. *IoT system*

The second alternative proposes an IoT platform in the cloud in conjunction with LoRaWAN technology. LoRaWAN end-nodes will be used at remote stations to transmit sensor data to LoRaWAN gateways placed at intermediate stations—called "receiving stations"— located in regional offices of the Peruvian Navy in cities with internet access. LoRaWAN gateways will forward data to a LoRaWAN cloud server to process and send the payload to an IoT cloud platform.

LoRaWAN end-nodes include electronic components to acquire electric signals from sensors. LoRaWAN devices run following regional parameters corresponding to AU915-928 channel plan for 915-928 MHz frequency band [15]. In addition, LoRaWAN gateways will be able to transmit data to the cloud through a fixed or mobile internet connection, and end-users will be able to access the monitoring information using a website over a connection to a web server.

C. *Comparative analysis*

In Table I, a comparative analysis is made between the two solution alternatives based on the type of communication, energy consumption, and service features required.

Based on the previous analysis, it is noticed the IoT-based system has better features compared to the SCADA as a service solution, e.g., the service coverage depends on the location of the LoRaWAN gateway, it is not required third-party communication services for remote stations, LoRaWAN end-nodes has less amperage consumption, the licensing on the cloud platform depends on the number of resources consumed,

TABLE I
COMPARATIVE ANALYSIS OF POTENTIAL SOLUTIONS

Features	**N° 1: SCADA as a service**	**N° 2: IoT system**
End node communication technology	Cellular	LoRaWAN
Service coverage	Limited by coverage of mobile carrier	Limited by LoRaWAN gateway coverage
Communication services for remote stations	Cell phone data plans contracted annually	No required
End node maximum amperage consumption	1.15A	0.6A
Licensing cloud services	Annual subscription to SCADA service provider	Payment for resources consumed in the cloud
Functionalities and system personalization	Dependent on the service provider	Configurable by specialist staff of the institution

personalization and specific functionalities can be set up by the own staff of the institution. Therefore, the IoT system is the most appropriate alternative to solve the current situation.

IV. SOLUTION ARCHITECTURE

The network architecture of the proposed IoT-based solution is presented in Fig. 4. Each remote station transmits its sensors data to a receiving station using a LoRaWAN device. Through an internet connection, gathered data is sent to cloud services to process and present it to the users through a website.

The LoRaWAN end-nodes and gateways used in the solution must be built for long-term employment without external intervention, with low power consumption requirement, suitable transmission power, a high degree of sealing protection, and capable of operating in the 915-928 MHz frequency band. In this regard, the Libelium end-node and the Kerlink Wirnet Station gateway are the devices proposed for the technical solution because they meet the requirements; therefore, their specifications are used to calculate the link budget.

LoRaWAN network server used is The Things Network (TTN), an open-source network for LoRaWAN development responsible for managing end-nodes, processing, and routing data to several IoT cloud platforms [16]. Furthermore, the

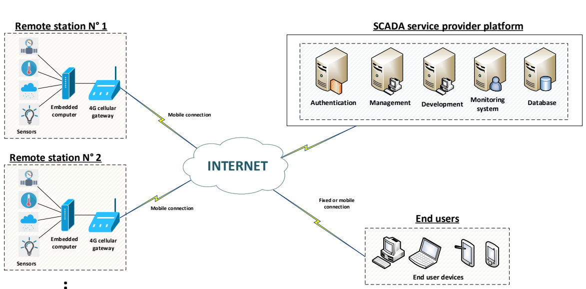


Fig. 3. SCADA as a service network architecture

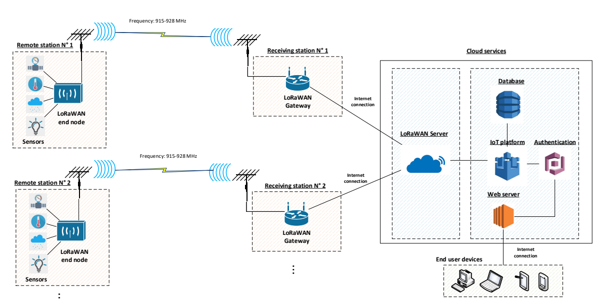


Fig. 4. IoT network architecture

IoT cloud platform selected is Amazon Web Services (AWS) IoT Core. It supports MQTT protocol, it has many Software Development Kits (SDK) for programming, and the service can be provided from different regions of the world.

V. Coverage Analysis

The coverage analysis is elaborated for the outermost station, which is a lighthouse located at the top of a hill of an island. The receiving station is located in the main headquarters of the institution, in a coastal city. Both stations are separated by a large portion of the sea and the distance between them is 9.79 kilometers. Path loss calculation between both stations was made using the Okumura-Hata radio propagation model. This model is applied to calculate path loss in the frequency range between 150 and 1500 MHz [17]. The environment considered for the calculation is a metropolitan area, which has the highest loss of all the scenarios contemplated by the model. For this scenario and frequencies higher than 400 MHz, the path loss is calculated according to (1):

$$\begin{aligned} PL =& 69.55 + 26.16 \cdot \log(f_c) - 13.82 \cdot \log(h_b) \\ & - [3.2 \cdot (\log(11.75 \cdot h_m))^2 - 4.97] \\ & + [44.9 - 6.55 \cdot \log(h_b)] \cdot \log(d) \end{aligned} \quad (1)$$

Where PL is path loss expressed in decibels, f_c is the frequency of operation in megahertz (915.2 MHz), h_b is the height of the base station antenna in meters (30 m), h_m is the height of the mobile antenna in meters (10 m) and d is the separation distance in kilometers (9.79 Km). Replacing the previous values in (1), the path loss obtained is 152 decibels. Similarly, the link budget is calculated considering the previous value and the parameters indicated in Table II.

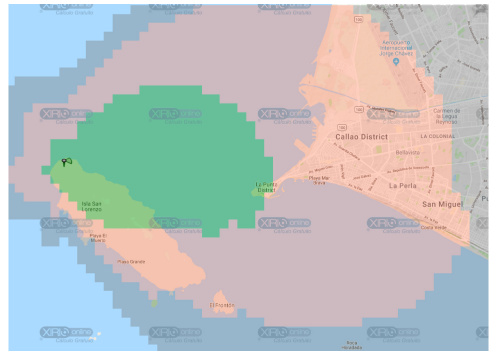
The link budget is the calculation of all gains and losses between transmitter and receiver [18]. It is calculated by (2):

$$P_{Rx} = P_{Tx} - L_{Tx} + G_{Tx} - LP + G_{Rx} - L_{Rx} \quad (2)$$

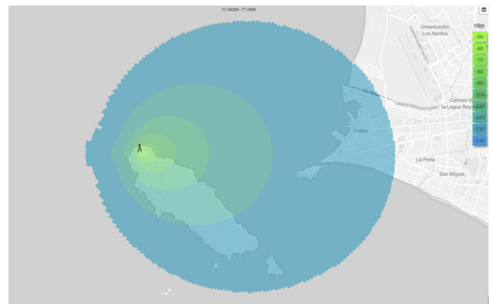
Where P_{Rx} is the received power in dBm, P_{Tx} is the transmit power in dBm, L_{Tx} is the total system loss in dB at the transmitter, G_{Tx} is the antenna gain in dBi at the transmitter, LP is the propagation loss in dB, G_{Rx} is the antenna gain in dBi at the receiver and L_{Rx} is the total system loss in dB at the receiver. Using the values in Table II, the link budget for the uplink (UL) and downlink (DL) applying (2) are -123 dBm and -121 dBm respectively.

TABLE II
PARAMETER VALUES FOR LINK BUDGET

Parameters	End-node	Gateway
Tx Power	18 dBm	20 dBm
Antenna gain	8 dBi	6 dBi
Rx sensitivity	−136 dBm	−140 dBm
Insertion loss	1.5 dB	1.5 dB



(a) Xirio Online simulation result



(b) CloudRF simulation result

Fig. 5. Uplink radio coverage obtained with simulators

TABLE III
RECEIVED POWER OBTAINED FOR UL AND DL

Link	Link Budget	Xirio Online	CloudRF
P_{Rx} Uplink	−123 dBm	−116 dBm	−120 dBm
P_{Rx} Downlink	−121 dBm	−120 dBm	−96 dBm

The previous results are validated with two simulators: CloudRF and Xirio Online. The same path loss model and parameter values are using to calculate the received power. The uplink radio coverage maps obtained with Xirio Online (5a) and CloudRF (5b) simulators are shown in Fig. 5.

Table III presents the received power for the uplink and downlink obtained with the link budget using the Okumura-Hata path loss and the Xirio Online and Cloud RF simulators.

According to the results presented in Table III, the received power for the uplink is between -116 dBm and -123 dBm. This range is suitable for establishing communication with the LoRaWAN gateway because the referred device has a receiver sensitivity up to -140 dBm; therefore, the fade margin for uplink is 20 dB on average. Additionally, the received power for the downlink is acceptable because end-node has a receiver sensitivity up to -136 dBm and its fade margin is significant.

VI. System Simulation

The simulation of the IoT system presents an end-to-end scenario with the main elements that are part of the solution. This work is based on the premise the physical layer between end-node and gateway meets all the requirements to establish

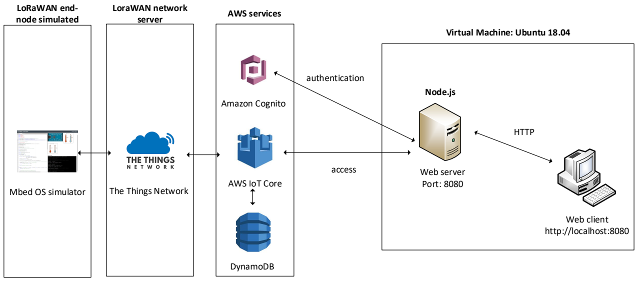


Fig. 6. IoT simulation diagram

a communication link and focuses on the development of the system. It proposes the simulation of a LoRaWAN end-node, the programming of a LoRaWAN network server and an IoT cloud platform. Additionally, a local web server is executed to allow web clients to access the system information. Fig. 6 presents the IoT simulation diagram.

A. LoRaWAN end-node

The simulation of the end-node is executed in Mbed OS simulator, an online tool designed by ARM company. A meteorological station is developed with a simulated LoRaWAN end-node and five sensors: Temperature, humidity, wind speed, wind direction, and atmospheric pressure. A light-emitting diode (LED) is included to represent a digital output. Security credentials are configured in the end-node including a 64-bit device unique identifier (DevEUI), 64-bit application unique identifier (AppEUI) and a 128-bit application key (AppKey) used by Over-the-Air-Activation (OTAA) method to generate dynamic credentials every session [19]. Data simulated by sensors are divided and buffered in an integer array before sending to the network server. Fig. 7 shows the sensors and the LoRaWAN end-node configured in the simulator.

B. LoRaWAN network server

The Things Network is the LoRaWAN network server used to decode the end-node payload and set a connection with the IoT cloud platform. An application is created for the configuration of the end-node and a link is established using its security credentials. Data from the end-node require a code function to retrieve sensors data. Split values are joined to recover original data and set in JavaScript Object Notation (JSON) objects to be forwarded to the IoT platform. Furthermore, another function is set up to encode an instruction to activate the digital output of the end-node.

C. IoT cloud platform

The AWS IoT Core service is responsible for receiving the payload from LoRaWAN network server and interacting with applications, such as web application. An instance is created to host the service and security credentials are established to communicate with the network server. It manages the established connections, types, number, and direction of messages employed. Its MQTT client enables getting data in JSON format for the corresponding topic, which is formed by the names of the application and the device.

D. Web application

A web server running on a local virtual machine with Ubuntu operating system version 18.04 is employed to handle web requests from users. The runtime environment set up on the server-side is Node.js. An HTML5 web page is built using Javascript AWS SDK for IoT development. Javascript functions establish a connection to AWS IoT core, subscribe to incoming messages and publish data to end-node. Fig. 8 presents the code lines of the subscription function to retrieve the temperature value of the JSON message.

A user control service manages user authentication and authorization to access the web application. To access the website, the user needs to sign-up and sign-in. After a successful login, the user accesses the main page and subscribes to the uplink topic. When the LoraWAN end-node sends a message, the web client automatically receives the information through a WebSocket and updates the web page, displaying sensors data. The gathered information is stored in a table of Amazon DynamoDB service, which is a key-value NoSQL database that is useful for storing information from IoT applications [20]. Fig. 9 presents the web page developed with the values of the parameters set up in the simulated end-node.

Similarly, web users can also send data to the end-node using the topic related to downlink messages. A clickable button allows sending a message to the IoT cloud platform

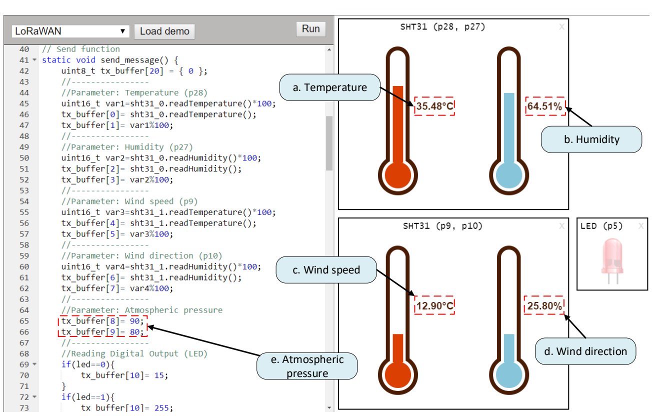


Fig. 7. LoRaWAN end-node simulation

```
function subscribeMessage(device, topic) {
device.subscribe(topic, function (error){
device.on('message', function(topic, payload){
//Retrieving payload
var payload = JSON.parse(payload.toString());
//Retrieving temperature data
var temperature = payload.payload_fields.temperature;
//Setting up temperature value on canvas graphic
var gauge_temp = document.getElementById('temperature_canvas');
gauge_temp.setAttribute('data-value', temperature);
//Setting up temperature value on html elements
document.getElementById('msg_temp').innerHTML = "Temperature: "+temperature +" ºC";
document.getElementById('table_temp').innerHTML = +temperature +" ºC";
});});}
```

Fig. 8. Subscription function to retrieve temperature data

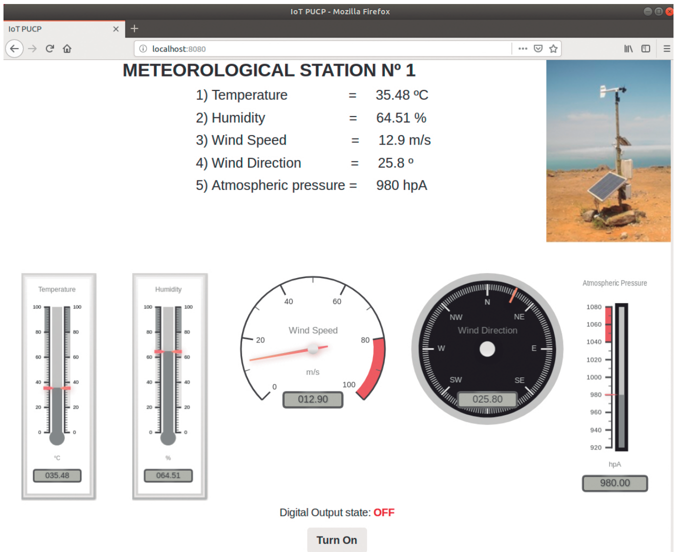


Fig. 9. Web page with LoRaWAN end-node information

to activate a digital output of the LoRaWAN end-node. When the message is received by the end-node, the digital output represented by the LED lights up.

VII. Conclusions and Future Work

This work presents the design and simulation of a cloud-based IoT solution with LoRaWAN technology to replace a local SCADA system for control and monitoring of remote stations of the Peruvian Navy. Two solution alternatives are analyzed to solve the restrictions of the current system. As a result, the IoT-based solution is shown as the best alternative, due IoT end-nodes consume less energy and it is not required to contract access communication services or a fixed subscription cloud service to a third-party company. In addition, the IoT-based solution is a valid replacement for the current SCADA system because users can access it through Internet, increasing the response time to failures, the information is stored in a cloud database avoiding data loss, LoRaWAN end-nodes required less energy than current nodes, and the contract of a private APN to a mobile carrier is avoided.

The analytic results employing the Okumura-Hata path loss model and the link budget calculated for the farthest remote station establish a suitable receiver sensitivity for the uplink and downlink. These calculations are validated by the two coverage simulations developed in CloudRF and Xirio Online simulators. The obtained results determine it is feasible to use LoRaWAN devices for communications between remote stations and receiving stations in the environment presented.

The simulation of the proposed IoT system for a meteorological station, considering the LoRaWAN end-node developed in a simulator, the configured cloud services, and the website built for the access of end-users, validates the end-to-end network design, presents a tested model ready to be implemented in production and describes the process required to carry out the implementation of the solution.

For future work, it is expected to conduct a comparison between the theoretical analysis and the measurements data gathered from the implemented IoT system in the real scenario. Additionally, a detailed study of radiofrequency settings and conditions can provide a better understanding of range, timing performance, and energy consumption of end-nodes employed.

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