Application of LPWAN Technologies Based on LoRa in the Monitoring of Water Sources of The Andean Wetlands

Luis González[1(✉)], Andrés Gonzales[1], Santiago González[1], and Alonso Cartuche[2]

[1] Department of Electric, Electronic and Telecommunication Engineering, Universidad de Cuenca, Av.12 de Abril, 010203 Cuenca, Ecuador
{luis.gonzaleza,amauta.gonzales,santiago.gonzalezm}@ucuenca.edu.ec
[2] Carrera de Ingeniería Ambiental y El Centro de Investigaciones Tropicales del Ambiente y Biodiversidad (CITIAB), Universidad Nacional de Loja, Ciudad Universitaria Guillermo Falconí, 110150 Loja, Ecuador
victor.cartuche@unl.edu.ec

Abstract. This paper presents the design of a water source monitoring system based on LoRa technology for the Tres Lagunas Andean high-altitude wetlands ecosystem (Ecuador). The solution has been implemented using mainly an ATmega1284p microcontroller, an SX1278 transceiver and hydrological sensors. The data is transmitted from the study site to the TTN server and sent via the MQTT protocol to the Node-RED platform. On the other hand, a graphical interface has been developed that allows analyzing historical data of temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP) and hydrogen potential (pH). Furthermore, energy consumption tests and LoRa physical layer experiments have been performed with the prototype. Results reveal the proper operation of the prototype. In particular, it has been observed that SF9 and SF10 present packet reception rates higher than 97%. Regarding SF7 and SF8, they was discarded for this type of scenarios due to the packet loss rate higher than 10%. The main contribution of this work is the proposal of a portable, low-cost and open source prototype, focused on the transmission of hydrological data obtained in Andean high-altitude lakes through IoT technologies for the administration, management and control of water resources that represent a fundamental component of a smart city.

Keywords: LoRa · Monitoring system · Wetlands ecosystem

1 Introduction

Applications based on IoT (Internet of Things) technologies constitute a fundamental piece in the field of innovation and sustainable development [1]. In particular, water resource management technologies are vital components of Smart Cities [2], promoting the use of real time data through online platforms with

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significant efficiency compared to traditional methods [3]. These data are usually hydrogen potential, conductivity, dissolved oxygen, among others. These data are measured through sensors and allow determining the water quality [4]. As for water sources, they are usually located in remote areas of the city and lack services such as Internet access, electricity, among others, therefore, solutions based on IoT and sensor networks (WSN) would allow the creation of monitoring systems that improve the management of water resources.

On the other hand, the water resources of aquatic systems are vulnerable to climate change due to several factors, for example, the increase in temperature can contribute to the evaporation of the lagoons, reduction of the water table and alterations in water quality [5]. In this context, an economic valuation of water and carbon storage in the Ecuadorian wetlands was carried out in [6]. The study area covered the wetlands of the cantons of Nabon, Oña, Saraguro and Yacuambi, specifically the sectors of Tres Lagunas and the Shincata river. It should be noted that despite the existence of two INAMHI (Instituto Nacional de Meteorología e Hidrología) stations, one in Oña (M421) and the other one in San Lucas (M32), due to the location of these stations, it is not possible to determine the exact climatic conditions of the study area and therefore the understanding of these aquatic ecosystems is almost null. That is, the stations only cover the slopes of the Pacific and Amazon water systems in the study area. The data collected from these stations, possibly present discrepancies with the real conditions of the site, due to the contributions of rainfall, fog and drizzle.

In relation to Tres Lagunas, this ecosystem contributes to the subsistence of nearby populations due to its great ecologic, economic, social, and cultural value. The main contribution is the supply of water for domestic consumption and crop irrigation. In addition, it is a place of great cultural importance for the 3 cantons because it is considered a magical place, linked to ancestral religious traditions, the manifestation of power and energy of mother earth [7]. Currently, this wetland complex is threatened by several factors, for example, the road that connects Saraguro and Yacuambi crosses this area and represents a great risk for the conservation and protection of this sector. In this sense, it is essential to know the status of the lagoons in order to prevent a deficit of water resources, improve water quality, and mitigate the effect of anthropogenic contamination such as vehicle traffic, tourist waste, among others.

Tres Lagunas does not count with a system to monitor weather and water conditions; the nearest stations are located several kilometers away. Factors such as distance, adverse weather conditions, limitations in access to the mobile network and the Internet have prevented the implementation of any type of meteorological station in the lagoons of interest. Therefore, the deployment of monitoring stations in the sector represents a contribution to determine the current state and vulnerabilities to which the aquatic ecosystems of the site are exposed and to provide data that will allow us to assess the current state of the lagoons and the vulnerabilities to which they are exposed.

The company's strategic management and conservation of natural resources is a key factor in the implementation of the decisions of the government institutions.

In this context, the present work focuses on a technological solution to monitor the Tres Lagunas site, through a data acquisition and transmission device, from the study site to the Internet. This document is divided into 5 sections, the second section presents the state of the art, the third section indicates the monitoring architecture, the fourth section presents the results and the fifth section concludes with the conclusions.

2 Related Works

The integration of IoT solutions in Smart Cities allows the improvement of different services through new technologies. For example, the monitoring of water resources allows a sustainable management of water services. The best option when these sites are in remote areas is to use long-range networks such as LPWAN (Low Power Wide Area Network). For example, networks based on LoRa (Long Range), have characteristics to be able to adapt to various scenarios. In this context, relevant studies related to such applications are discussed below.

In relation to the recording of water parameters, data collection devices require special equipment called probes that are usually very expensive [8]. Therefore, it is essential to develop prototypes that offer greater accessibility for their use. In terms of implementation, the recording of these environmental data is performed by devices such as microcontrollers (MCUs), where the information measured by the sensors is preprocessed and stored internally in the station also known as node [9]. When the nodes are used in remote locations, the power supply is provided by batteries, in this context there are several works that have managed to increase the battery life time for periods longer than one year [10,11].

In this sense, in [12] a prototype is described, where low-cost sensors are used for the acquisition of physicochemical water data. During a period of 45 days, the device was tested together with a professional team, obtaining a high correlation between the data of both teams, verifying the quality of the prototype information.

On the other hand, monitoring of water ecosystems is very costly in terms of resources when sites are remotely located and manual access is required to collect data [13]. One solution is to use wireless communication technologies. In this context, a suitable transmission technology would be LoRa/LoRaWAN. The communication protocol and architecture of this technology support low-cost, mobile and secure bidirectional communication and is optimized for low power consumption and designed to scale easily [14]. Therefore, the use of LoRa/LoRaWAN is becoming more and more frequent in different applications and is adaptable to a wide range of applications.

For example, [15] highlights the importance of the advantages of LoRa in terms of coverage and energy efficiency, which facilitates its operation in poorly characterized sites, such as high mountains and glaciers, allowing to open new fields of research in these areas.

Regarding remote sites where there is no access to the power grid, the energy resource of the batteries is crucial for their operation, as discussed in [16], a study in which groundwater monitoring is performed, where the nodes record the variables and transmit them to a LoRa Gateway, obtaining 8 days of energy independence. Other methods increase the energy resources of the nodes through a combination of energy sources, for example solar and hydroelectric, as presented in [17], which provides up to 432 h of autonomy to its nodes.

In this sense, one of the factors of higher energy consumption in LoRa nodes is generated in the transmission stage. In [18], the importance of selecting the appropriate transmission parameters is highlighted, otherwise the useful life of the node is shorter. For example, the increase of power for packet transmission drastically affects the energy consumption as reported in [19], where their study focuses only on the rest of the parameters to improve communication. In this context, the use of low SF (Spreading Factor) values would allow improving the energy efficiency. For example, in [20] the authors recommend using low SFs (high data rate) and high transmit power only for nodes that are far away from the gateway. Another approach is described in [21], where different payload lengths and physical layer parameters were evaluated to reduce the ToA (Time on Air), the authors recommend leaving the BW (Bandwidth) fixed and only focus on the SF and CR (Coding Rate), on the other hand they indicate that it is necessary to decrease the payload.

Regarding mountain scenarios, in [22] an evaluation of LoRa parameters is presented, the authors show that the radio transmit power is not a dominant parameter affecting the network, instead BW, SF and CR play a more relevant role. In these mounting scenarios, 3 km coverages have been achieved as reported in [23], where they evaluated the LoRa technology using three data rates in the 433 MHz band, with a transmit power of 20 dBm, highlighting that line-of-sight is a relevant factor for this transmission technology.

In this context, it is observed that the use of LoRa for environmental data transmission is feasible and allows an adaptation to different environments due to its variety of properties that can be configured according to the requirements. In the present study, a prototype of physicochemical data acquisition focused on lagoons of the Andean wetlands in southern Ecuador was developed using LoRa transmission technology for monitoring water sources.

3 Monitoring Architecture

This section details the operation of the monitoring architecture, from the implementation of the prototype to the presentation of the data using cloud services.

3.1 Prototype Implementation

The hydro station was implemented using hardware and software tools that facilitate its reconfiguration. In the central part of the station, an ATmega 1284p MCU of the Pico Power family [24] is used. On the other hand, the measurement of physicochemical variables of the water is performed with analog and digital sensors. Figure 1 shows the integration of the prototype.

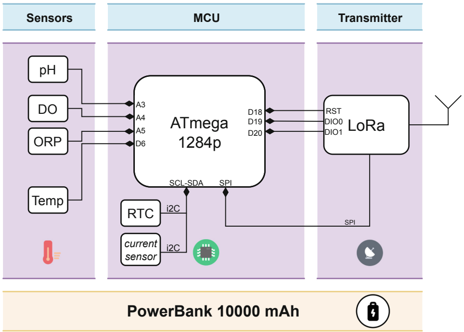


Fig. 1. Prototype design.

As shown in Fig. 1, the prototype consists of 4 sensors, three are analogical: Gravity pH [25], DO [26], ORP [27], and a digital temperature sensor DS18B20, the most relevant technical characteristics of these devices are presented in Table 1. On the other hand, a current sensor INA219 is added to measure the energy levels consumed by the peripherals and the water station in general. Additionally, a DS3231 RTC (Real Time Clock) module is incorporated to provide time stamps to the system. For the control of the sensors, open-source libraries available in [28] were used. Regarding the communication protocol, the digital sensors use the i2C protocol and the analog sensors are read with the 10-bit ADC (Analog-to-Digital Converter) incorporated in the MCU.

Table 1. Technical characteristics of the sensors

Parameter	pH	ORP	DO	DS18B20	Unit
Measurement range	0.1 a 14	−1500 a +1500	0 a 700	−55 a +125	pH, mV,%, °C
Accuracy	± 0.2	± 1	± 2	± 0.2	pH, mV,%, °C
Response time	0	0	0	750	ms
Energy consumption	3	3	3	1	mA

Regarding the network layer, it is composed by the LoRa RA-02 module [29] and its configuration is done through the MCCI-LoRaWAN-LMIC [30] libraries to work in a LoRaWAN network. This way the data is transmitted wirelessly to a Gateway that uploads the data to The Things Network (TTN) server. For the power supply, a PowerBank of 10000 mAh. Finally, a printed circuit board (PCB) was designed which collects all the components that facilitates the prototypes usage. Figure 2 shows how the PCB and its components are implemented.

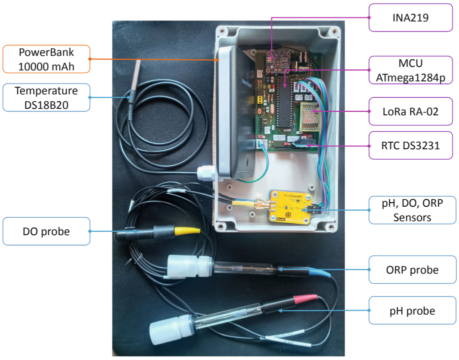


Fig. 2. Prototype components.

3.2 Water Monitoring System

Figure 3 shows a functional diagram of the monitoring system. For the programming of the ATmega, the Arduino IDE platform [31] was used, in this way the management of sensors and modules is more flexible from libraries available for the devices, promoting a more efficient development.

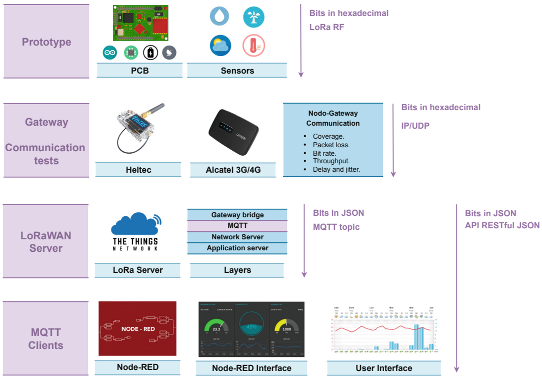


Fig. 3. Functional diagram of the system.

As for the TTN server, it is required to configure the LoRaWAN network equipment. In particular, first the node is configured in ABP (Authentication By Personalization) mode and its AppSKey and NwkSKey credentials are registered in TNN as well as in the node software, with these credentials the information is encrypted and travels from the node to the server. On the other hand, the Gateway is configured in TTN by means of the MAC (Media Access Control) address and is accesses the Internet through the mobile network.

The TTN data are decrypted and sent through a MQTT (Message Queuing Telemetry Transport) server to the Node-RED platform, where an API (Application Programming Interface) is implemented with the network nodes: http in and http response that provide endpoints with the stored data, which could be visualized in a more user-friendly way through an interface developed with JavaScript using the APEXCHARTS.JS library. Currently, for the purposes of the application, only one endpoint has been deployed with the GET method, which allows retrieving all the data of the available variables. In this interface the user can observe the changes of the variables with respect to time, analyze statistical results of the information, access historical data and download them easily. In this way the system is able to measure, transmit and present to the user physicochemical variables obtained in high Andean lakes.

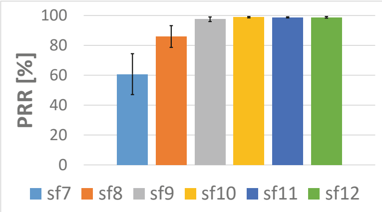
4 Evaluation and Results

This section presents the characterization of the prototype, both at the network level and in the data acquisition process.

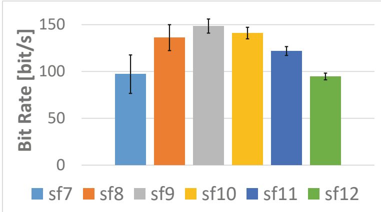
4.1 Analysis of LoRa Prototype Performance in Different Scenarios

This section examines the performance of the prototype under different meteorological weather conditions, distances and configurations of the SF and CR parameters both in a rural area and in the high plains, examining the PRR (Packet Reception Rate), throughput/bit rate, RSSI (Received Signal Strength Indicator), delay and jitter metrics, by means of histograms with confidence intervals.

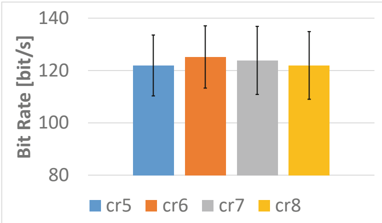
Rural Area. It was first considered evaluating the rural area instead of the wetlands because of the ease of locating the Gateway-node and thus obtaining reference data such as bit rate, coverage, antenna location, which allow us to appreciate the capabilities of the prototype when faced with different environments. The rural area was the Urdaneta parish in the Saraguro city.



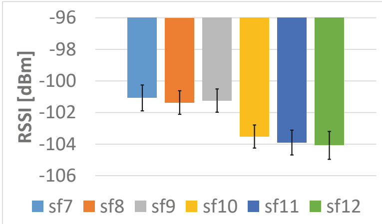
(a) PRR.



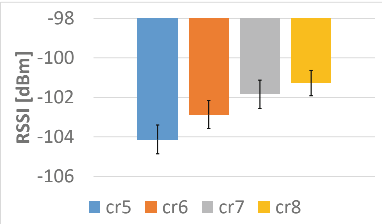
(b) Bit Rate in Rx by SF.



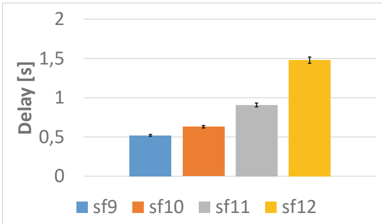
(c) Bit Rate in Rx by CR.



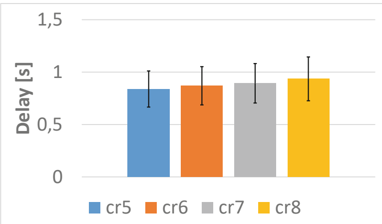
(d) RSSI by SF.



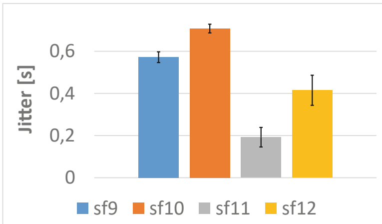
(e) RSSI by CR.



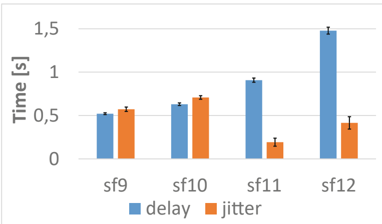
(f) Delay by SF.



(g) Delay by CR.



(h) Jitter by SF.



(i) Delay vs jitter.

Fig. 4. Results of the metrics obtained in the rural area.

Urdaneta is located approximately 30 km away from Tres Lagunas with an altitude of around 2490 m m.a.s.l. Regarding the environment in the rural area, many bushes and tall trees were observed between the node and the Gateway, however; they do not directly interfere with the line of sight. The experiments were conducted at 4 points at 500 m, 1 km, 1.7 km and 2.2 km distance between the node and the Gateway.

The general histogram of each SF is shown in Fig. 4a. It can be seen that both SF7 and SF8 have the lowest rate, therefore, they are the least recommended for this scenario. From SF9 onwards, an average PRR greater than 97 % is obtained with a very low confidence interval, which shows stability in the connection.

As for the overall results of the bit rate for each SF, Fig. 4b shows a bell shape, which is due to the packet loss obtained for the case of SF7 and SF8, therefore the bit rate is directly affected. On the other hand, for SF10, SF11 and SF12, the PRR is 99%. However, the bit rate at the transmitter decreases as the SF increases, therefore, the best choice for this case are the values of SF9 or SF10, since they are at an intermediate point and allow to obtain the highest possible bit rate. On the other hand, the bit rate decreases as the denominator of the CR increases (see Fig. 4c), with the exception of CR5.

In the results of the RSSI for each SF in Fig. 4d, it is observed that the power data have varied very little among themselves, however; it is clear the trend of RSSI reduction as the SF value increases. That is, the signal is slightly stronger when the SF decreases, while a higher denominator in the CR improves the signal power (see Fig. 4e), generating changes between each CR of approximately 1 dBm difference.

Figure 4f shows the average delay values for each SF. There is a clear tendency for the delay to increase as the SF increases, which corresponds to the theory, since a larger SF represents higher ToA. As for the CR, it can be seen in Fig. 4g that the delay is higher when the denominator of the coding rate is larger, since there are more bits for transmission. However, the variation is very small, going from 0.84 s to the maximum value of 0.94 s, so the impact of the CR on the delay is not considerable.

As for the results presented in Fig. 4h regarding the jitter, such behavior is related to the accuracy of the RTC. In particular, the RTC device (DS3231) has a minimum scale given in seconds, so the minimum delay is 1 s, which makes delays of milliseconds or more undetectable. Then, the closer the average delay is to integer values, the less probability of variance in the delay. As shown in Fig. 4i, the lowest jitter corresponds to the SF with the promised delay closest to 1 s, in this case SF11. But this does not mean that using SF11 will have less jitter and a more reliable connection, but it is an error in the accuracy of the RTC. However, the jitter does affect the communications with high bit rates or applications requiring real-time data, so for this case the jitter behavior does not affect the network.

High Wetlands Area. In the wetland zone, the environment is suitable for LoRa, as the results from the rural area show an excellent performance when the line of sight is completely clear and in Tres Lagunas there are no considerable interferences. The site is mostly covered with grass, small bushes and wild plants that do not represent an obstacle. The two points chosen for the location of the node and the Gateway are 1 km and 1.2 km apart.

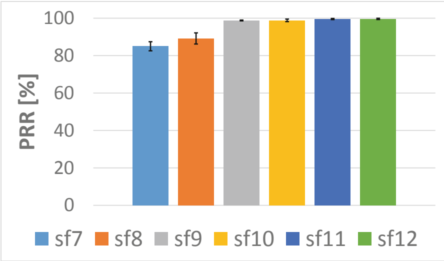
Figure 5a shows the overall PRR result for all points and CR combinations. The PRR tends to increase as the SF increases, reaching an average of 100 % of packets received in SF11 and SF12. In addition, it is observed that SF9 and SF10 have an excellent performance, presenting an average PRR of 99 % with confidence intervals close to zero. Therefore, with respect to PRR, it is recommended to use any SF greater than 9.

The overall throughput for the SF and CR values are presented in Figs. 5b and 5c, respectively. The bit rate tends to decrease as SF increases, with the exception of SF7 and SF8, due to packet loss. Therefore, SF9 remains the best choice with respect to bit rate for this scenario, since it provides the highest possible bit rate. Regarding the CR, the bit rate decreases as the denominator of the CR increases, but the variation between each CR is very small.

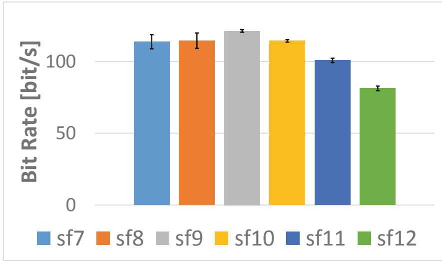
With respect to the RSSI values for each SF, the graph in Fig. 5d presents a clear trend of decreasing RSSI as the SF increases. However, the degradation is quite small, e.g., SF10, SF11 and SF12 have approximately the same mean. The CR values obtained in Fig. 5e show that the RSSI increases as the denominator of the CR is larger, although the difference is minimal. As in the rural area, a larger CR denominator improves the signal power.

Figure 5f shows the delay results for this scenario. The data corresponds to the theory, because as the SF increases, the ToA also increases, which generates a higher delay. The most interesting result is observed in SF9, where there is a delay of approximately 10 ms and a reduced variability, which is reflected in the confidence intervals. Looking at SF9 and SF10, it is evident that the delays are also very small compared to the rural area, reiterating the importance of line of sight for LoRa. With respect to SF12, the delay is approximately 1s. In contrast, Fig. 5g shows that as the denominator of the CR increases, so does the delay. However, in this case the confidence intervals are very wide as a consequence of the SF values, since the result corresponds to the mean of all the CRs for each SF and test point.

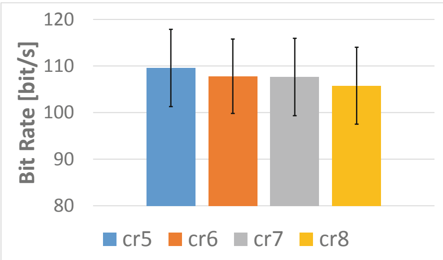
In Fig. 6, photographs taken during the development of the experiments in the study scenarios are presented.



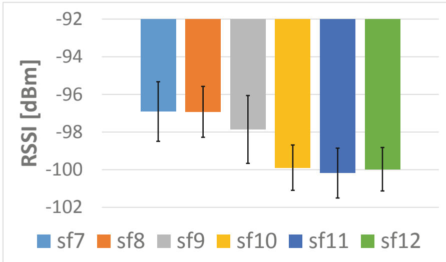
(a) PRR.



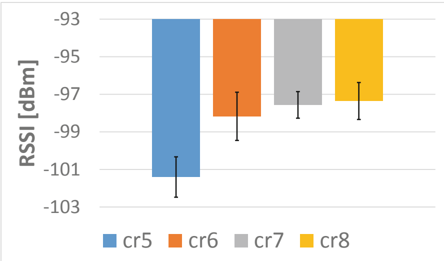
(b) Bit Rate in Rx by SF.



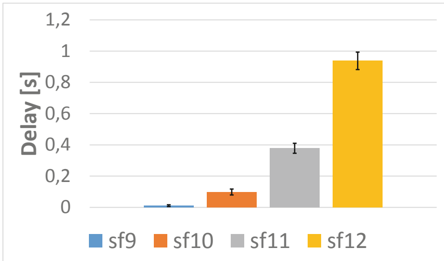
(c) Bit Rate in Rx by CR.



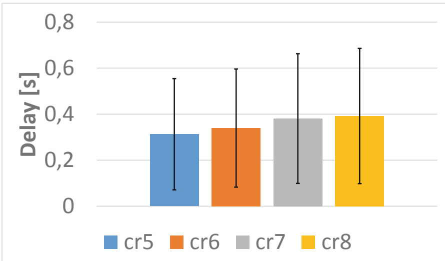
(d) RSSI by SF.



(e) RSSI by CR.



(f) Delay by SF.



(g) Delay by CR.

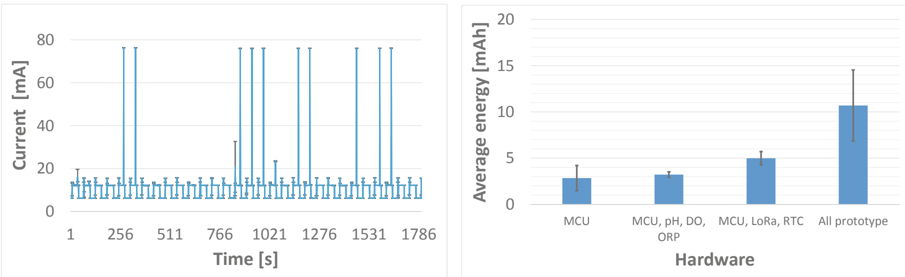
Fig. 5. Results of the metrics obtained in the high wetlands zone.

4.2 Energy Consumption

Considering that the prototype is powered by a battery, it is very important to have an overview of the power consumption during operation. Figure 7a shows the current consumption of the prototype during a 30 min period, the measurements were taken with a 1 s interval and the confidence intervals were plotted with 95 % reliability. As for the LoRa interface, SF9, BW 125 kHz, CR 4/5 and a power of 14 dBm at 433.175 MHz frequency are used.

(a) Rural. (b) Wetlands.

Fig. 6. Experiments carried out in both scenarios.



(a) Current demanded. (b) Required energy.

Fig. 7. Energy consumption of the prototype.

Figure 7a also shows maximum currents of 76.26 mA and minimum currents of 6.18 mA, the maximum is due to the current peaks caused by the LoRa transmission stage and the minimum is during the low power stages.

As for the modules, sensors and peripherals of the prototype, in order to determine the current power they require, several measurements were made, whose average current levels are shown in Fig. 7b. In relation to the MCU, its power consumption is 2.84 mAh and when adding the sensors its increase was not significant, reaching 3.22 mAh, on the other hand, when using the LoRa module with the RTC, it reached 4.99 mAh and the consumption of the entire prototype was 10.7 mAh.

Finally, tests were performed with a 10000 mAh power supply to verify the correct operation of the prototype, where only approximately 8 days of autonomy were obtained. Due to the internal losses of the PowerBank it was not possible to take advantage of all its capacity, however, the time was enough to perform the installation and evaluation of the prototype.

5 Conclusions

In this article we have presented a LPWAN application based on LoRa whose function is to monitor water sources in the Andean pampas, where the results show that it is possible to implement the system in these scenarios. During the analysis it was observed that in general SF7 and SF8 have the worst performance, also the PRR less than 85% is the most relevant aspect that forces to discard these factors. Among the remaining options: SF 9, 10, 11 and 12, all of them would be a good option, however, the bit rate decreases as the SF increases, for example SF12 in the span presents a bit rate of 81 bits/s and for SF10 of 114 bits/s, which evidences less packets transmitted and therefore, less received even though the PRR is almost 100%. Regarding the delay, it also increases as the SF increases, and this is clearly observed in the section, where there is a difference of almost one second between SF9 and SF12. These results reflect that higher SFs produce higher energy consumption, because they require more time for transmission. In the case of RSSI, it is observed that lower SFs have a stronger signal power, however, there is a higher packet loss. It is important to remember that low SFs are less resistant to noise and have fewer redundant bits. Then, based on the above considerations, the most appropriate is to choose the lowest SF that presents a high PRR, in the case of the rural area it would be SF10 and in the SF9 sector. With respect to the CR, the difference between choosing one or the other is minimal in all cases, unlike the SF, which does affect the network considerably.

Comparing the results for each point facilitates the choice of the best scene for LoRa, concluding that the best performance corresponds to those places that have a wide area free of interference and with a clear line of sight between the node and the Gateway. This is clearly reflected in the rural area, where the farthest point from the node presents better results than closer points, this is thanks to the free line of sight, since in addition the node and the Gateway were approximately at the same height.

The energy consumption analysis shows that by using a Power Bank, the prototype reached an autonomy of 8 days, which would limit its installation within months. To overcome this, other batteries could be evaluated and a charging system could be added, for example, using solar panels.

This study did not develop the design of a LoRa Gateway and was limited to the operation of only one node. As for future work, it is proposed to evaluate the network using multiple nodes and gateways, allowing to increase the number of monitoring points and a better coverage of the network.

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