IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 5 March 2025, accepted 24 April 2025, date of publication 1 May 2025, date of current version 9 May 2025.

Digital Object Identifier 10.1109/ACCESS.2025.3566020

RESEARCH ARTICLE

Dynamic Use of RSSI in LoRa Networks for Decision Making in Outdoor Applications

CARLOS MUÑOZ[1], (Member, IEEE), CRISTIÁN PESCE[1], IGNACIO HUIRCÁN[1], OSCAR VILLAGRA[1], RODRIGO VILLALOBOS[1], AND JAVIER RIEDEMANN[2]
[1]Department of Electrical Engineering, Universidad de La Frontera, Temuco 4780000, Chile
[2]Department of Electronic and Electrical Engineering, University of Sheffield, S10 2TN Sheffield, U.K.

Corresponding author: Cristián Pesce (cristian.pesce@ufrontera.cl)

This work was supported in part by ANID/FONDECYT Regular under Grant N°1220178, and in part by the Basal Funding for Scientific and Technological Center of Excellence, IMPACT and DIUFRO, under Grant \#FB210024 and Grant PP23-0044.

ABSTRACT Livestock monitoring is an important task since it enables real-time tracking of animal health and behaviour, improving productivity, reducing losses, and ensuring better resource management in farming. This paper proposes a strategy to reduce the energy consumption of a microcontroller designed for livestock monitoring in a controlled environment using LoRaWAN and GPS technologies. The aim is to extend the monitoring period implementing a novel method based on the RSSI parameter. The strategy estimates the distance of the livestock to a gateway avoiding the need of continuously using a GPS. Experimental test for different periods of time were carried out, considering variable duty cycles depending on the position of the livestock with respect to the RSSI zone. An important reduction on the energy consumed by the microcontroller was obtained, validating the effectiveness of the proposed method.

INDEX TERMS LoRaWAN, RSSI, GPS, energy management, microcontroller.

I. INTRODUCTION

With the widespread adoption, global positioning system (GPS) tracking has achieved a notorious impact on a variety of applications, going from commercial truck fleet coordination and control [1], [2] to the tracking of people trough mobile phones and even animals [3], [4], [5], [6], [7]. The tracking devices are composed of a GPS receiver for location estimation triangulated according to the delays of signals received from a satellite system broadcasting synchronized pulses at regular intervals [8]. These tracking devices also include a transceiver, a digital mobile network widely used by mobile phone users, such as global system for mobile communication (GSM), to share the computed coordinates with a monitoring station with a geographic information system (GIS) that maps the position of the tracked units. These communication systems must have the study zone under coverage, and the amount of energy consumed by the GPS and the GSM significantly limits the operation time of the tracking units [9]. The maximum energy stored in the device is limited by the battery pack installed, which must ensure a life cycle according to the tracking task.

Precision livestock farming (PLF) involves information and communication technology to monitor and continuously supervise livestock in dairy farms, allowing reduction of labor requirements, minimizing animal stress, and decreasing the carbon footprint [10], [11]. Wearable devices dominate the PLF market among the technologies available because they allow individual real-time monitoring of animal health and welfare [12]. Tracking devices have been successfully applied to monitor the behavior and preferences of animals such as cows, sheep, and goats [12]. In addition, GPS devices offer a viable solution for farm animals that are occasionally lost, avoiding economic and safety losses. However, achieving good precision with GPS requires high energy consumption, which has been a limiting issue for this type of application [13]. These communication technologies have gradually evolved towards developing smaller, lighter, and low energy-consuming integrated modules. On the premise of satisfying data recording, short-distance wireless communication and long-distance wireless communication coexist. Among them, short-distance communication is represented

The associate editor coordinating the review of this manuscript and approving it for publication was Ye Liu.

by Bluetooth and ZigBee, while long-distance communication is represented by NB-IoT (5G standard), sigfox, LoRaWAN, etc. [14]. The main challenges for the massive introduction of these active technologies in PLF are the low coverage of communication networks in isolated farming fields and the power requirements of these devices. There are commercial options for GPS tracking for livestock and they have an appropriate battery life, ranging from 8 months to more than 10 years (see Table 1). However, this is heavily influenced by the data processing capabilities of the modules, local sensors, communication coverage, and time intervals to send the estimated position. Including additional functions or shortening the interval of localization could significantly reduce the battery life of the tracking devices. In some cases, such as the RUMI [15], the devices include a solar powered cell to extend the battery life, allowing to maintain a reduced set of functions for a very long time.

TABLE 1. **Commercial options and their battery life.**

Manufacturer/Model	Battery Life	Reference
Ixorigue	up to 3 years	[16]
Digitanimal	8 to 18 months	[[17],[18]]
LPWANSpace	3 to 5 years	[19]
RUMI	More than 10 years (solar)	[15]
FARMRanger	6 to 8 months	[[20],[21]]

A. TRACKING WITH LORAWAN IN PLF

LoRaWAN technology (Long Range Wide Area Network) has been introduced in PLF due to its low-cost, low power consumption and extended coverage, allowing the deployment in farms that are far from cities and have extensive grazing fields (tens to hundred hectares, even in some cases achieving the thousands of hectares) [22]. Hattarge et al., [23], argued that the main hurdle in deploying traditional GPS trackers is the maintenance cost, which can significantly be reduced by using LoRaWAN instead of GSM/GPRS modules. McIntosch et al., [3] performed a field study of three months duration, involving 43 cows grazed seasonally over 4000 ha of desert range and pasture.

The research team deployed a network to study cattle wearing LoRaWAN-enabled Abeeway Industrial Trackers powered via a single 19 A hours/3.6-V lithium-thionyl chloride type D battery. The author's experience showed the advantages of counting with real-time herd localization. The learnt lessons showed that data communication could be improved through enhanced infrastructure and equipment configuration. For example, typically observed loss of data due to terrain features, such as the presence of green trees, buildings, deep canyons, or long distances to a gateway, suggest that an approach to improve LoRaWAN communication may come from a greater number of gateways, taller antennas, and gateway configurations that include multiple communication channels, repeated communication attempts, and mixing of spreading factors (SF; the rate of data transmission). The main issue related to the maintenance of these systems is the replacement of batteries because it implies more hand labor and stress for the herd. In this sense, it is relevant to increase the time between battery replacement by reducing the power drains of the trackers using one of these approaches:

- Reducing the power used to transmit the coordinates to the remote monitoring system. This could be reduced by efficient use of a LoRaWAN network [24], and with a better understanding of the power consumption of the microcontrollers upon activation and accessing the LoRaWAN network for message transmits [25].
- Looking for alternatives to GPS for location. Approaches to localize within LoRaWAN networks offer low power and low-cost advantages. This targets a very different set of use cases and applications on the market where accuracy is not the main considered metric. For example, Podevjin et al. [1] used the time difference of arrival (TDoA) with signals obtained from different gateways to perform the localization, which has poor accuracy, but it is inexpensive in energy consumption.

We are looking for energy-aware techniques to track animals in grazing fields including some constraints related to PLF, such as:

- The accuracy required for the cows depends on the location; for example, an accuracy of 100 m in a grazing field is acceptable considering a livestock density of 0.7 units per hectare (LSU/ha) [26]. The livestock density is increased when the cattle are around the parlor for milking (<50m).
- The grazing fields have irregular land, so deploying these systems is difficult.
- The grazing fields are typically divided into 2-4 ha slots and are delimited with wired fences. Usually, these grazing slots have patches with dense vegetable coverage, affecting the communication link's strength.
- According to producers, an update every 15 min of the location is very useful.

B. LOCATION BASED IN LORAWAN WITH RSSI TECHNIQUES

Location-based on LoRaWan Networks takes advantage of the RSSI index, which is obtained every time a message is transmitted from the end node. There are two main approaches to address the end-node localization with RSSI: Use of the distance estimated with the path of loss (PL) [2], [5], [27], and the fingerprint methods.

Gotthard and Jankech [2] applied this relation in a parking lot with a line of sight for short distances (<20 m), showing a very smooth linear relation for distances and a bump around 13 m, that according to the authors is caused by a disruption of the Fresnel zone by the ground. Dieng et al. [5] applied the path of loss method to estimate distances using RSSI relation showing high variability in the measurements of RSSI for a

100 m span, obtaining similar results to those obtained by Huircan et al., [27] when using RSSI in ZigBee networks.

LoRaWan networks enhance the coverage span over 100 m by changing the spread factor (SF). For example, when SF is changed from 7 to 12, the messages can reach distances over 3000 m. The drawback is the increment of the time to deliver the message by ten times. This technique adulterates the Path of Loss (PL) relation [28]. The grazing fields where the network is deployed make the PL relation unusable.

Janssen et al. [29] evaluate RSSI fingerprint-based and range-based location estimation algorithms regarding accuracy and computational performance. They deployed a 72 LoRaWAN gateways network in Antwerp, Belgium, and found that the fingerprint-based approach leads to a mean location estimation error of 340 m. Anjum et al. [30] used a network with three LoRaWAN gateways separated 300 m each. These authors used various fingerprint methods with very similar accuracy in the location: K-nearest neighborhood method, 47.57 m; Decision Trees, 46.82 m; SVM 48.31 m; and NN, 44.24 m. Aagnostopoulos et al., [31] used the same dataset of Anjum et al., to try other algorithms; they reduced the area of study involving only 68 gateways and got results slightly more accurately than those obtained by Anjun et al. Fingerprint techniques vary in the algorithms used, the size of historical data required, and computational burning. The fingerprint alone is not enough to fulfill the PLF requirements, but it has been shown that Fingerprint algorithms are the most suitable alternative to the GPS location.

C. ENERGY MANAGEMENT SYSTEMS FOR GPS-LORAWAN TRACKING

Energy consumption is a key factor in extending the operation cycle of the tracker's strap down to the cow collars. Battery replacement or recharging is an invasive operation for the cows because it stresses personnel handling and presents a risk point for the personnel as well for the animals.

Table 2 presents information on energy management strategies and a brief description.

TABLE 2. Techniques to reduce the energy consumption and optimize the GPS tracking.

Strategy	Description	Reference
Hybrid GPS-LoRaWAN Localization	Hybrid method combining GPS and LoRaWAN to track sport activities in open spaces	[32]
Map Matching and Compass Sensor Fusion	Fusion of data from maps and electronic compasses to optimize the geographic tracking with LoRaWAN	[1]
Energy-Efficient Strategy for Micro-controllers	Strategy for microcontrollers to improve the energy efficiency in LoRaWAN devices	[24]
Dynamic use of RSSI in LoRa networks for decision-making in outdoor applications in controlled environments	Uses the RSSI parameter to make the decision of activate the GPS antenna to track coordinates, avoiding its unnecessary use and saving energy	Proposed in this work

DiRenzone et al., [32] presents a platform for tracking based on one gateway and one device with GPS and LoRaWan connectivity. The authors propose using the distance estimated with the Path of Loss strategy based on RSSI-distance estimation to reduce the energy when the GPS is not in use. Podevijn et al. [1] include an e-compass in the end device to fusion the distance estimated with the TDoA technique. The authors aimed to increase the precision by reducing the total power consumption. Even though the sample rate for the electronic compass is high, the authors claim an increase of 10% in the system with only hardware LoRaWan. However, it is 14 times less than the tracker device with the combination LoRaWAN-GPS.

Wu et al., [24] address the problem from the energy management of the microcontroller of the tracker, increasing the system clock and the total time in deep sleep. They argue that in intensive computation tasks, the power consumption is not related to the clock speed, so they propose to increase the clock speed to reduce the total time with a high power drain. Machine learning techniques applied to location using RSSI-based fingerprints have emerged as a promising alternative to GPS due to the lower energy demand. This approach has successfully reduced localization errors from 400 meters to 280 meters [33], [34], [35]. Some studies have explored new topologies that facilitate direct communication between nodes rather than relying solely on a gateway [36]. This promising strategy involves integrating RSSI with AI-Edge technologies [37], turning the end nodes into an artificial neural network (ANN) to learn and mitigate the impact of weather on distance estimation, achieving an impressive localization accuracy of approximately 101 meters. Such precision is particularly beneficial for applications like tracking cattle during free grazing, but the cost is to turn the end nodes into exceedingly complex systems. While improvements in accuracy may lead to a replacement for GPS, the associated computational demands pose challenges due to the increased complexity at the end nodes. However, if RSSI-based localization systems are implemented as complementary tools to GPS rather than substitutes, it is possible to maintain lower computational requirements, keeping a low complexity at the end nodes. This approach can save energy while still providing acceptable accuracy for various applications.

Within this framework, in this paper we explore applications that use dynamic RSSI measurements in LoRa networks to help reducing the power consumption of LoRaWAN-GPS trackers for herd location. The combination of GPS, LoRaWAN, and energy efficiency strategies opens up a broad spectrum of applications in diverse contexts. We explore reducing energy consumption in microcontrollers integrating GPS and LoRaWAN, especially for livestock monitoring applications on specific farms. They play a crucial role in controlled environments, such as those where livestock are located. By taking advantage of the ability to control and assign ranges of RSSI values to specific regions of the property, efficient energy management is achieved.

II. LORAWAN RSSI PROPOSED STRATEGY

This section explores the use of RSSI fingerprints not as a location technique but to evaluate if it is necessary to reacquire the location using GPS. Animal tracking in PLF has specific requirements but also involves animal behavior. Animals tend to graze in the same areas, rest between some forests, or ruminate in some preferred slots. With this approach, we can use these cattle behaviors to reduce the use of GPS, using the features of RSSI signals to make decisions about new reacquisitions with GPS without giving up accuracy for the localization of the cows.

A. PLATFORM SETUP

The evaluation platform consists of End-Nodes strap-down to cow collar, linked via LoRaWAN to a gateway to gather the location data from the cows. As shown in Fig. 1, this data is acquired every 30 min with a gateway theoretically covering an area of 1km. Due to the irregularity of the land and the forest islands, the quality of the link is far from being regularly distributed. Some places have a fragile link, while others at the same distance present a strong one.

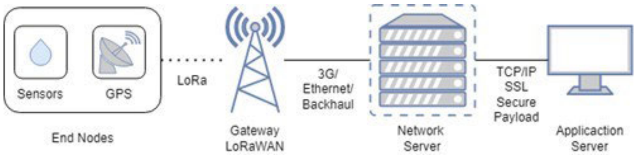

FIGURE 1. LoRaWAN network.

1) END-NODE

An experimental board was built as an end node based on Cubecell HTCC-AB02S module, which integrates an ARM Cortex-M0 microcontroller and an SX1262 for LoRaWAN 1.0.2 connectivity. The power is provided by a 3.7 V, 3200 mAh lithium-ion battery, as shown in Fig. 2. Although the HTCC-AB02S includes an Air530 GPS module, we use external antennas for GPS receiving and LoRaWAN connectivity. The LoRaWAN specification defines three types of devices: Class A, Class B, and Class C. All LoRaWAN devices must implement Class A, while Class B and Class C are extensions of the Class A device specification. The device used in this study is a Class C device, the one with the lowest energy consumption.

2) GATEWAY

The gateway is a multiprotocol RAK7829 model device with two LoRa antennas and one Wi-Fi antenna. It is compact and energy efficient and has long-range wireless connectivity. Using the web configuration tool the communication parameters can be tuned, such as the application and gateway keys, and set the spread factor behavior.

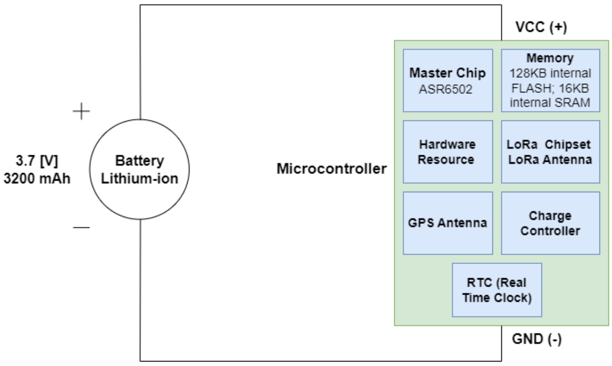

FIGURE 2. Setup test circuits.

3) POWER CONSUMPTION ANALYZER

The device used to analyze the energy consumption is a Joulescope JS220, which is capable of online high-speed acquisition of current, voltage and power. The instrument has a 16 bits analog-to-digital converter and has a sampling ratio of 20 MS/s. The analyzer must be connected to the test circuit as indicated in Fig. 3.

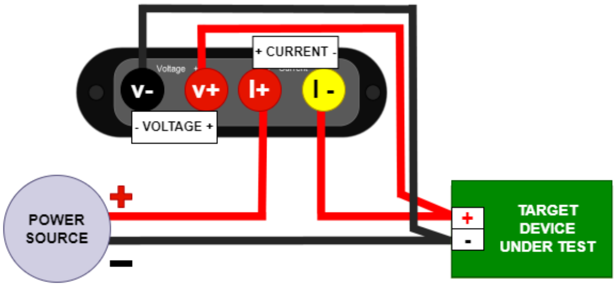

FIGURE 3. Joulescope analyzer connection.

B. ENERGY CONSUMPTION MODEL FOR THE END-NODE

The End-Node is a C-class LoRaWAN device, with a deep sleep cycle of 30 min. Every time the End-Node awakes, it performs a sequence of tasks until returning to deep sleep in the next cycle (see Table 3). Following the energy consumption model proposed in [25], but also considering the tasks related to the GPS operation. Fig. 4 shows a time diagram with the sequence of tasks between two deep sleep events. This figure includes the GPS tasks. The width of the blocks represents the time to complete the tasks and the height of the blocks models its power consumption.

Fig. 4 also shows two duty cycle sequences. The first one is the initialization sequence, which includes an additional task to perform the Over the Air Activation (OTAA) to negotiate with the gateway the authentication of the End-device in

TABLE 3. Tasks performed by the end-node.

Process	COMPONENT USED	Description
Turn on	Master Chip, Charge Controller, Memory, Hardware Resource	The tracker microcontroller turns on only the fundamental components
LoRa antenna and OTAA (Over the Air Activation) connection process	LoRa Chipset, LoRa Antenna	The tracker microcontroller uses LoRa chip to link with the LoRa gateway via OTAA
GPS antenna and GPS search process	GPS Antenna	The microcontroller uses the GPS antenna to find the signal
Sending data and subsequent ACK (acknowledgment)	LoRa Chipset, LoRa Antenna	The localization data acquired by the microcontroller is transmitted to the Gateway and wait for the ACK (acknowledgment) to confirm the reception of the message
Deep Sleep	RTC (real-time clock)	The microcontroller turns to deep sleep mode, keeping only the RTC active, to manage the following wake-up procedure

the LoRaWAN network. Once the node is authenticated, this task is no longer required, at least, the end device goes to a hard reset.

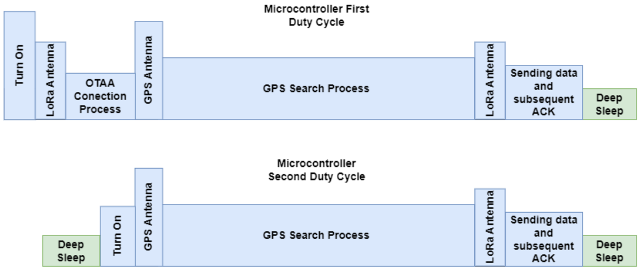

FIGURE 4. Duty cycle end-note energy consumption model.

C. ENERGY MANAGEMENT SYSTEM FOR LORAWAN-GPS TRACKER

The energy management system (EMS) uses the fingerprint-based RSSI, each time a communication is attempted from the End-node to the GateWay. The fingerprint RSSI pattern is compared with a model representing the physical zone in which the End-Node has been in the last measurements. Only if the pattern is too dissimilar to the established zone, the microcontroller will attempt to use the GPS for a new location reacquisition. This strategy tends to reduce the use of the GPS and improve the characterization of the preferred locations for the cattle. The procedure is depicted in Fig. 5, where new blocks are added concerning Fig. 4. The new blocks added are an RSSI implementing the fingerprint modeling of the location and a decision block based on the comparison between the fingerprint obtained and the models stored for some frequently visited locations.

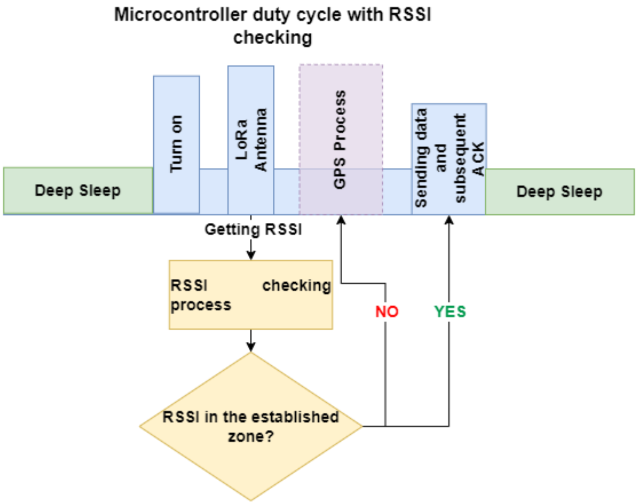

FIGURE 5. Energy management system for LoRaWAN-GPS tracker.

D. EXPERIMENTAL SETUP

The experimental setup consists in a gateway LoRaWAN, and two modified trackers; the first one includes the EMS shown in Fig. 5, and the other one uses the procedure the end node model, without the EMS, depicted in Fig. 4. Also, we characterize the terrain in which the LoRa Network is deployed with three interest areas as illustrated in Fig 6, named "area 1", "area 2," and "area 3". The approximate distances between the gateway LoRaWAN areas are 20m, 70m, and 110m.

The distances of around 50 meters between testing areas were chosen because the primary concern of the producers in PLF is to know the approximate location of the cattle. The grazing fields are typically characterized and surrounded by electric cattle fences; hence, the animals can move and graze in specific meadows. The producers are in interested in which one of the meadows is grazing their cows; in this sense, a precision of 50 meters concerning the last known location is enough.

This scenario will allow us to compare, in a semi-controlled scenario, the power consumption of the trackers considering the directives included in the energy management system and depriving this directive. Fig. 7 shows a picture of the experimental system.

To build the experimental setup, the following tasks were carried out:

- End-node configuration, one with the EMS and one without the EMS.

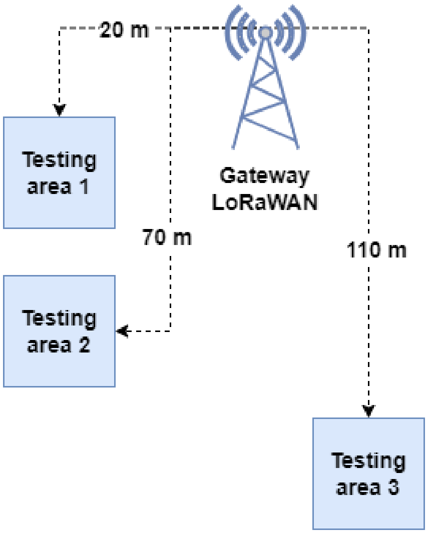

FIGURE 6. Distance between the LoRaWAN Gateway and the areas of interest.

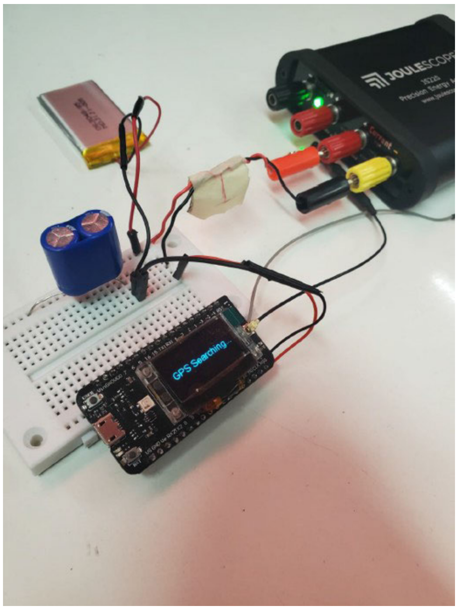

FIGURE 7. Energy management system for LoRaWAN-GPS tracker.

- Configuration of the RAK7829 gateway to deploy a local LoRaWAN.
- Configuration of two LoRaWAN Trackers, including the application key and network key, to authenticate in the deployed LoRaWan network. One node has the EMS, and the other one does not. We tested both end nodes in the laboratory without connecting the GPS to verify the proper configuration, and they both showed similar power drains.
- For the field tests, the battery was charged at full capacity.
- For the measurement of the End-Nodes power consumption's, we use the circuit shown in Fig. 3.

III. EXPERIMENTAL RESULTS

A. RSSI MEASUREMENTS

The results obtained from the tests in the three different areas are shown in Table 4. The maximum, minimum and average values are shown, together with the standard deviation of the measured RSSI

TABLE 4. RSSI values for each testing area.

Area	RSSI min [dBm]	RSSI max [dBm]	RSSI mean [dBm]	RSSI std [dBm]	IQR	Appro x. dist. [m]
Area 1	-63	-51	-55,03	1,85	3	20
Area 2	-75	-62	-65,82	2,71	4	71
Area 3	-94	-72	-82,83	4,85	5,5	110

Fig. 8 shows a whisker box diagram to observe the data distribution in each area. This provides further information about the dispersion and the presence of atypical values.

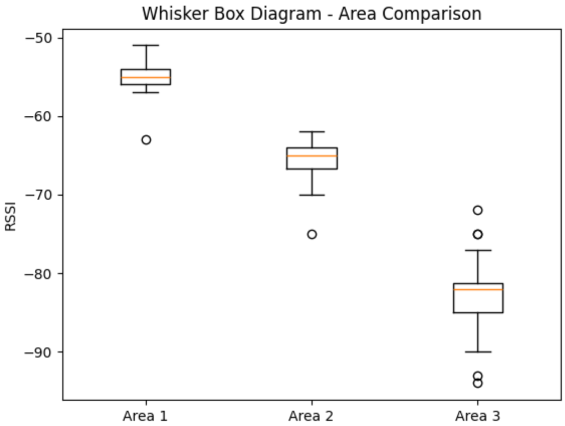

FIGURE 8. Whisker box diagram for the RSSI samples.

With the average RSSI values, the strategy to reduce the energy consumption (Fig. 5) is implemented.

1) TESTING AREA

The testing area to be used is area 2. This means that if the RSSI value is under the average (−65.81818), the GPS antenna should be activated to track the coordinates.

B. ENERGY CONSUMPTION ASSESSMENT

In this section, the power consumption results are provided. A comparison of the microcontroller efficiency before and after the test is shown. The circuit in Fig. 2 uses the battery fully charged, 3.7V, and 3200mAh. The tracker with the conventional method at the start of each new minute follows the sequence of tasks depicted in Table 3 and Fig. 4, ending with a deep sleep cycle. In contrast, the tracker with the proposed method follows the sequence illustrated in Fig. 5.

1) TESTING AREA

In the testing area shown in Fig. 6. For the tests, one sensor is configured to link with the gateway uninterrupted each 1 minute, staying for time lapses of 10 minutes in each area. The testing was performed for 6 hours each day in five consecutive days, with an average of 400 data acquired per area. One researcher will perform a walking with two trackers connected to a Joulescope as illustrated in Fig. 3, one tracker configured with the proposed method and one with the conventional method. The walking will be performed in time lapses of 10 min, 15 min, and 30 min, twice visiting each of the three testing areas. The tours will be repeated 30 times within 5 day time period. The aim is to analyze each tracker's performance and energy consumption in time. In each tour, starting with the 10-minute walking was always the first, including the cold start-up procedures, followed by the 15-minute walking and then the 30-minute walking. The initialization procedures are mainly affected by the elapsed time for the registration on the RSSI LoRaWAN network, and for the first GPS acquisition. To simplify the comparison, Fig. 9 provides a detailed description of the waveform. The average current and power consumed in different process are summarized in Fig. 10.

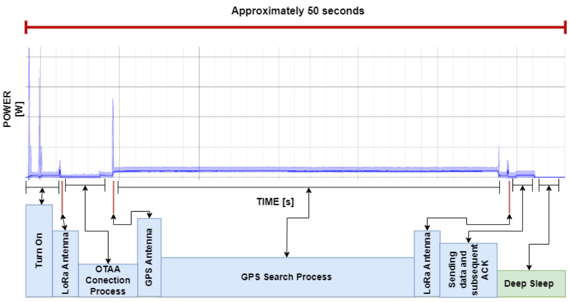

FIGURE 9. **Power required in time for each stage of the process.**

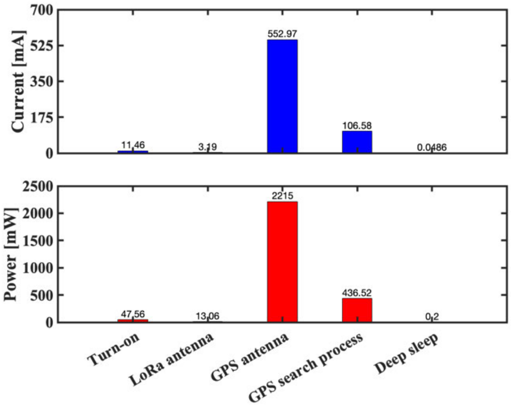

FIGURE 10. **Measured current (top) and power (bottom) consumed in different processes.**

The energy consumed in the different processes are:

- Turn-on: 0.0847 J
- GPS search process: 21.192 J
- Deep sleep: 0.00008546 J

With these results it can be concluded that the proper management of the GPS search process can importantly reduce the total energy consumption. Fig. 11 and 12 show the current, voltage and power waveforms of the microcontroller duty cycles. Fig. 11 corresponds to the 10-minute test with the conventional strategy, whereas Fig. 12 shows the waveforms when the strategy for reduced energy consumption is employed. In Fig. 12, we set the tracker with the modified method to acquire three times more RSSI than the conventional one, i.e., 3 times every minute. This modification increases the power consumption but gives the fingerprint of the location with the measurements reviewed in triplicate, using the median value of the RSSI to decide, Fig. 5. Further analysis for the energy consumption assessment of the tracker with the modified method is made using this timing configuration.

FIGURE 11. **Current (top), voltage (middle) and power (bottom) waveforms for a 10min test without applying the strategy for reduced energy consumption.**

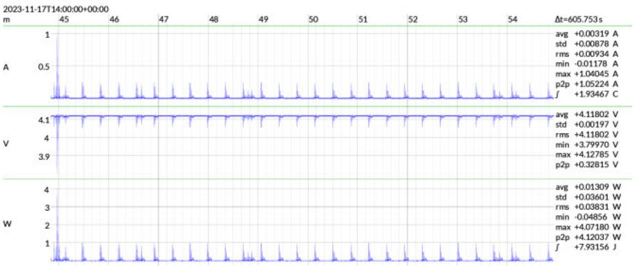

FIGURE 12. **Current (top), voltage (middle) and power (bottom) waveforms for a 10min test applying the strategy for reduced energy consumption.**

At the end of the right column of Fig. 11 it can be seen that the total energy consumed during the test was 197.628 [J]. On the other hand, the last row of the right-side column of Fig. 12 shows an energy of only 7.93 [J], representing a reduction of a 96% in the total energy consumed when the proposed strategy is used.

It is evident that the microcontroller follows a cyclic pattern which varies according to the actual task. The large reduction in the energy consumption is because when the microcontroller is in the RSSI zone, the GPS tracking is not activated.

Average current and power consumption values measured with the Joulescope instrument are shown in Fig. 13 for different time periods (10 min, 15 min and 30 min).

It is possible to observe a reduction of the power consumed in all the tests, validating the effectiveness of the proposed strategy. The energy consumed in the different test are summarized in Table 5.

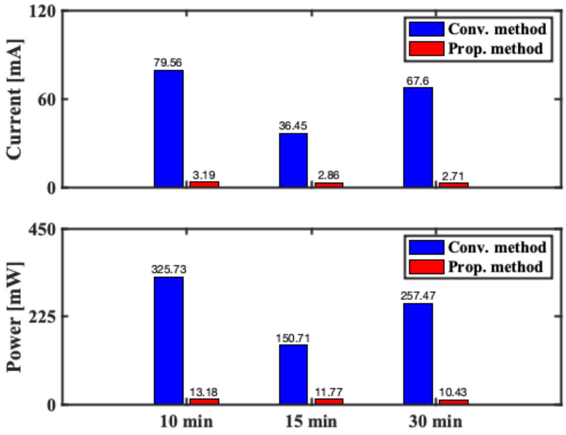

FIGURE 13. Comparison of measured current (top) and power (bottom) for different periods of time using conventional method and the proposed method.

TABLE 5. Comparison of the energy consumed for different test.

	Conventional method	Proposed method
Total time microcontroller operation	**Energy [J]**	**Energy [J]**
10 min	197.62	7.913
15 min	136.2	10.61
30 min	472.23	18.91

2) DISCUSSION OF THE EXPERIMENTAL RESULTS

The results obtained in this study reveal notable similarities and differences concerning strategies proposed in the bibliographic citations provided. The results obtained from the tests in the three different areas are shown in Table 4. The maximum, minimum, and average values are shown, together with the standard deviation of the measured RSSI.

Regarding similarities, several studies agree on the effectiveness of energy management strategies in LoRaWAN environments, highlighting the importance of efficient approaches to reduce energy consumption in monitoring devices. When comparing the different proposals, we can argue that Direnzone et al., [32] analyzes RSSI-based techniques as a GPS alternative location system, diminishing the power consumption, but with poor location accuracy. On the other hand, as proposed by Podevijn et al. [1], in which it establishes data fusion by combining the e-compass with the TDoA technique, seems to be an option to consider given the indicated difference in consumption compared to the combination of the mobile node with GPS, but, the e-compass requires a high update rate, with less draining of the battery consumption. However, it is still high in energy consumption. Another approach stated by Wu et al., [24] mainly attacks the problem from the energy management of the microcontroller of the tracker. However, the most important differences lie in the uniqueness of the strategy proposed in this study. The main difference is the use of RSSI-based fingerprint techniques to control the activation of the GPS antenna, especially in controlled environments. The EMS proposed in this work does not attempt to replace GPS measurement, but rather to use fingerprinting to decrease the frequency of GPS use, thus significantly reducing energy consumption without sacrificing location accuracy. The specific assignment of RSSI values to areas of the terrain emerges from fingerprint-based location methods based on RSSI. It is an aspect that can be improved by incorporating algorithms based on artificial intelligence that discover new areas of interest as cattle explore the fields. Note that when the cows move, they can significantly affect the measured RSSI due to terrain irregularities or patches of afforestation in the meadows, generating the need to activate the GPS. This strategy is adapted substantially to specific agricultural contexts and adds personalizing to adjust the system to particular environments after the deployment.

Fig. 8 shows a whisker box diagram to observe the data distribution in each area. This provides further information about the dispersion and the presence of atypical values. There are only six atypical data points, and as expected, the standard deviation increases with the distance to the gateway.

The strategy to reduce energy consumption (Fig. 5) is implemented with the mean values of RSSI depicted in Table 4.

IV. CONCLUSION

In this work, an energy management system (EMS) is proposed based on using RSSI-based fingerprints to activate the GPS antenna; the proposed EMS has proven to be highly effective in reducing energy consumption. The proposed method does not rely only on the RSSI but limits the use of GPS only to cases when significant changes in the RSSI are detected. This is consistent because when free-range grazing cows, their movements are slow when grazing or walking and almost null when lying or ruminating, so using GPS permanently is inefficient in terms of energy use. Although GPS makes high use of energy, it has significant advantages in terms of precision, so it is relevant to merge both methods, as shown in this paper.

The energy reduction allows the life cycle of the trackers to be lengthened, which the producers highly value. The tradeoff is to reduce the precision of the location with a significant reduction in energy consumption, which extend the life cycle of the IoT trackers. To get an accurate precision of cows when free-range grazing is not so relevant, but the long term location data is highly appreciated by the producers. This is consistent because when free-range grazing cows, their movements are slow when grazing or walking, and almost null when lying or ruminating. The relevant data is in which meadow are grazing the cows.

The adaptability of the strategy to controlled scenarios reflects a conscious consideration of the broader impacts of this technology, highlighting the importance of addressing not only technical efficiency but also the implications of the environment in which the LoRaWan network is deployed. The proposed strategy allows to keep adjusting the classification parameters of the fingerprint to learn about the preferred grazing locations of the herd.

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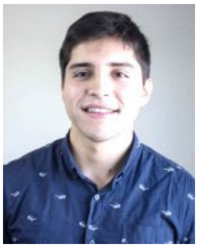
CARLOS MUÑOZ (Member, IEEE) received the Electronic Engineering degree in engineering sciences and industrial automation from Universidad de La Frontera, Temuco, Chile, in 1990, and the Ph.D. degree in engineering sciences and industrial automation from Pontificia Universidad Católica de Chile, Santiago, Chile, in 2000. He joined the Universidad de La Frontera, in 1996. He is currently an Associate Professor with the Department of Electrical Engineering.

CRISTIÁN PESCE received the degree in electric engineering from Pontificia Universidad Catolica de Valparaíso, Valparaíso, Chile, in 2003, the M.Sc. degree in electrical engineering from Universidad de La Frontera, Temuco, Chile, in 2010, and the D.Sc. degree in electrical engineering from the University of Concepción, Concepción, Chile, in 2017. He is currently an Assistant Professor with the Department of Electrical Engineering, Universidad de La Frontera. His research interests include the design and control of power converters applied to electric power transmission HVDC systems, electrical machines and drives, electric HVAC insulators, and PV energy renewable systems.

IGNACIO HUIRCÁN was born in Temuco, Chile, in June 1965. He received the bachelor's degree in engineering sciences and the Electronic Engineering degree from Universidad de La Frontera, Temuco, in 1989 and 1990, respectively. Since March 1993, he has been with the Department of Electrical Engineering, Universidad de La Frontera, where he is currently an Assistant Professor. His current research interests include embedded systems and the Internet of Things.



OSCAR VILLAGRA received the Electronic Engineering degree from Universidad de La Frontera, Temuco, Chile, in 2023. He is working in the productive sector.

RODRIGO VILLALOBOS received the Engineering degree in electrical engineering from University of Concepción, Concepción, Chile, in 2006, the Professional Master's degree in electrical engineering from Université Paris-Sud, Orsay, France, in 2008, and the D.Sc. degree from the University of Concepción, in 2024. From 2008 to 2015, he was a Project Manager for the power transmission industry in Chile, developing projects of power substations and transmission lines until 220 kV. Since 2015, he has been with the Electrical Engineering Department, Universidad de La Frontera, Temuco. His research interests include power transmission systems, insulation in power systems, and practical solutions equipment for the challenge of power transmission systems industry.

JAVIER RIEDEMANN received the B.Eng. degree in electrical engineering from the University of Magallanes, Punta Arenas, Chile, in 2010, and the Ph.D. degree from University of Concepción, Concepción, Chile, in 2015. He was a Lecturer in electrical engineering with the University of Bío-Bío, Concepción, from 2014 to 2017, and Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile, from 2018 to 2019. He was also an Associate Researcher with the Solar Energy Research Centre (SERC), Chile, from 2016 to 2023. He is currently a Research Associate with the Department of Electronics and Electrical Engineering, University of Sheffield, Sheffield, U.K. His research interests include the control of power electronics converters and variable speed drives for electric vehicles.

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