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LoRaWAN networks for smart applications in rural settings

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Abstract

The Internet of Things is becoming a key enabler for a wide range of novel applications. For example, Smart applications in rural environments can help optimizing agricultural resources. Given rural environment characteristics, the low power wide area network solution LoRaWAN is a perfect candidate, providing wide coverage of several kilometres, with low power consumption and robust communication. Nevertheless, rural scenarios introduce varying conditions that may affect during communication. This article characterizes applications and recommended configurations in rural settings supported using LoRaWAN networks, after validation with a network deployment on different areas that cover foreseen applications and environmental conditions.

Keywords

LoRaWAN, Low Power Wide Area Network (LPWAN), monitoring, sensors, rural environment, smart agriculture, smart farming.

1. INTRODUCTION

Information and Communication Technologies (ICT) nowadays play a fundamental role to increase the efficiency, reduce the environmental impact and simplify and automatize tasks. ICT can be used across all domains and use cases, not only for manufacturing or services and infrastructure monitoring, but also in agriculture and livestock sectors. These can be supported by tools such as Ubiquitous Computing, Satellite Monitoring, Remote Sensing or IoT [1]. Through the application of ICT solutions, what has come to be called a Third Green Revolution enable new opportunities for Smart Agriculture and Smart Farming. However, while in the United States between 20 and 80% of the agricultural community use this type of solution, in Europe it is estimated that only between 0 and 24% use them. Managing livestock poses several challenges as controlling the livestock, especially in extensive farming. Animals can be lost due to several reasons, including wildlife attacks, weather conditions, etc. Farmers should pay for GPS collars with cellular connection to monitor their livestock, but these systems are expensive, and they lack cellular network connectivity in great part of rural areas, especially in mountainous and high-altitude regions. From the farmer's point of view, smart agriculture should provide high added value, through decision support tools and efficient management of their farms. In this sense, systems planned for the collection, processing, storage, and dissemination of all types of data necessary to manage the operations and functions of agricultural holdings play a key role to expand Smart Farming and Agriculture applications. The natural environment around rural areas present further opportunities for these systems, as forest monitoring and other scientific applications, such as endangered animals monitoring, can also take advantage of technology. An IoT network infrastructure used for these applications can support a wide range of services and applications that suits the needs of potential users. Relevant Smart farming and other applications that should considered in rural areas [2], are the following:

- Livestock monitoring systems: adapting a sensor and tracking device gives farmers the ability to track key behaviours of livestock.
- Smart automation for crops and fields in remote areas. Furthermore, these types of sensors can also be used for early fire alert monitoring in forests and mountains.
- Tracking of wildlife animals: animals such as wolves, bears, or boars travel around these areas. These can present a danger for livestock and human population, but also can be endangered species that need to be protected from poaching and can be studied remotely in the wild.

Considering the distance and area to be covered, and the lack of communications infrastructure in the isolated rural regions where agroindustry operations can be found, a potential solution for deploying this IoT network is a Low Power Wide Area Network (LPWAN). Among the LPWAN candidates, LoRaWAN is a good answer to these types of applications, featuring a range of several kilometres, with reduced battery consumption. This technology is growing in popularity as LoRa nodes are quite affordable and allow the development of applications that require covering large areas.

The goal and contribution of this work is to categorize and characterize smart rural applications that can be operated with an IoT network based on LoRaWAN devices. To validate the feasibility of these applications, the system proposed is made up of LoRa nodes, connected to a LoRaWAN Gateway (GW from now on) to send their GPS coordinates and other gathered data. This GW relays the information to the public The Things Stack (TTS) network and application servers (which is the version 3 of the popular The Things Network [3]). TSS is a free implementation of the needed server infrastructure to manage and control LoRaWAN devices. From the data collected, the RSSI (received signal strength indicator), SNR (signal to noise ratio), power consumption and maximum range distance measurements is then analysed to validate the operation of the network, certify the fulfilment of application's requirements, and improve future deployments.

The region nearby the small town of Rubielos de Mora, in Spain, is chosen as it enables studying three different types of environments at the same time. Type A corresponds to high mountains with large valleys, type B, flat areas with dense Mediterranean forest and vegetation, and type C, flat areas without obstacles and with line of sight (LoS). In the described region, some areas are selected that match these three types, although in real life, the areas are usually heterogenous, having mixed environments in the same area, as can be seen later in the scenario description. These types aim to categorize and characterize smart rural applications, and the deployment proposed analyses the behaviour of the LoRaWAN network in different cases.

The rest of the paper is organized as follows. Section 2 presents Related Work on other tracking and monitoring systems and LoRaWAN deployments in both urban and rural settings. On the other hand, an introduction to LoRaWAN and the limitations imposed by TTS is made in section 3. In section 4 the described system and scenario is presented. Test results, to evaluate technology feasibility in these scenarios, are shown in section 5. Finally, application characterization and discussion, along with conclusions and future work, are presented in section 6.

2. RELATED WORK

This section presents monitoring systems analysing wireless networks in different types of environments, both in urban and rural areas with difficult access.

The physical and link layer performance of LoRa/LoRaWAN have been evaluated experimentally by many field tests in various real-world environments, from which rural and mountain [4 – 5] scenarios are relevant for the application under study. The experiments show communication ranges from 10 to 30 km in rural areas, when optimal conditions are met (line of sight, power, and data rate configurations). Furthermore, environmental factors, such as temperature and vegetation, have been found to negatively impact the communication ranges [5 - 7]. These tests either focus on characterizing the LoRa physical channel (LoRaWAN is not evaluated), only use one GW in the network deployment, or only consider location fixed devices, which limits the extrapolation of these results to the proposed use case.

Authors in [8] present a LoRaWAN network for the prevention and monitoring of fires in rural Spain. The designed system consists of a numerous LoRa nodes placed in the trees, while there is a central GW that connects to TTS. The deployment shown in tests is not as challenging, given the orography of the location of choice, and nodes mobility is not considered.

In [9], the author presents a project called Smart City installed in the city of Brescia (Italy). The system presents an OBD-II (On Board Diagnostics), a device connected to the vehicle's control unit, which provides real-time data regarding speed, vehicle coordinates, revolutions per minute, etc., which will then be transmitted through a LoRaWAN network. This study addresses an urban scenario different from a rural and high mountain environment.

In [10], authors present an IoT-based solution for intelligent farming, performing first an analysis of suitable technologies and proposing a protocol stack based on own developed MAC layer, with scheduled and random-access stages, over sub-GHz physical layer. While this work is overall interesting, in the end it relies on a tailor-made solution not interoperable with off the shelve IoT devices. Given the type of application, integration with other platforms, characteristics of the environment, scalability needed, and channel usage, LoRaWAN is still a better suited solution. In [11], authors present a fixed installation for temperature, humidity, altitude, and pressure control for an agricultural land using the ChirpStack platform. This project only presents the devices used as well as the applications but does not present any results on the operation of the nodes. [12] approach to Smart Agriculture presents the assembly and operation of a fixed weather station transmitting on LoRaWAN, which measures parameters such as temperature, humidity, and air velocity as well as atmospheric pressure. In addition, the characteristic parameters of the sensors integrated in the station are presented. The work shown in [13] presents the installation of different LoRaWAN sensors for precision agriculture in a greenhouse. Authors also use the ThingsBoard platform for data visualization and characterize battery consumption per LoRaWAN message. On the other hand, authors also study which is the best container for the nodes in obtaining data since depending on the characteristics of the material of the box the values obtained fluctuate. Another example is found in [14]. This article presents the installation of LoRaWAN nodes in a greenhouse and in vineyard using sensors for air and soil measurement. In addition, they present the configuration used and the data obtained experimentally from the measurements as well as some network statistics such as packet delivery ratio (PDR). Addressing tracking application for animals, in [15] authors evaluate the performance of LoRa transmission technology aimed at wildlife monitoring in a forest area. To characterize the communication link, they use the SNR, RSSI and PDR. Their results show that the link reaches from 860 m in the highly dense forest vegetation environment, up to 2050m in the non-dense area, but results in PDR achieved are lower than expected influenced by fading effects in longer payloads, using less power than the allowed and probably the position of the GW. In [16], authors propose cattle monitoring using LoRaWAN to identify strayed animals and monitor animal's vital condition.

In conclusion, there are many studies, deployments, and application proposals, as can be expected from emerging technologies. The present work has detected the need to categorize, analyse and evaluate response to application requirements and scenarios to improve LoRaWAN networks adoption in a challenging environment that needs further testing, to solve real life issues and improve working conditions for rural regions workers.

3. TECHNOLOGY OVERVIEW

This section presents an overview and the main characteristics of the communications technology selected, LoRaWAN. At the physical layer, the radio transceivers use Long Range (LoRa), a technology from Semtech, in which a wireless low power transmitter forwards small packets of data to a receiver, over long distances, up to several kilometres depending on the environment, in a point-to-point link. On the other hand, LoRaWAN is an open protocol defined by the LoRa Alliance, which works on top of LoRa modulation. LoRaWAN controls the joining of different LoRa devices managing their connection parameters: channels, bandwidth, data encryption, etc.

3.1. LoRa modulation

LoRa modulation is based on CSS (Chirp Spread Spectrum), using linear frequency modulation chirp pulses with high bandwidth to encode information. Chirp pulses are sinusoidal signals with varying frequency over time, determining symbols that represent the information. The number of bits that can be encoded in each symbol is given by the spreading factor (SF), with a relation 2^{SF}. The range of SF values admitted is between 7 and 12 [17]. The duration (in seconds) of a symbol, knowing the SF and the bandwidth (BW) can be calculated as:

$$Ts=2^{SF}/BW \qquad (1)$$

Derived from (1), increasing the SF value means lowering the bit rate and therefore, increasing the

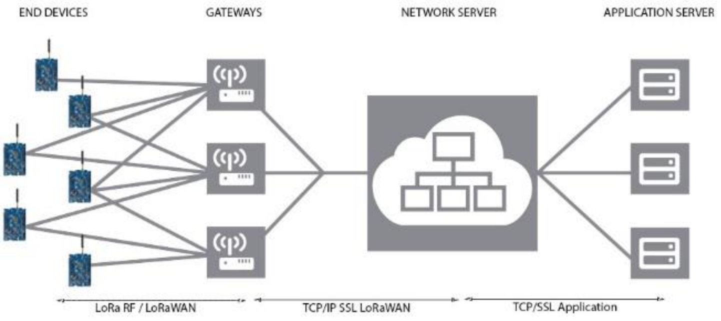

Figure 1 LoRaWAN architecture diagram

Time on Air (ToA) of a packet. BW also influences this, inversely as the SF (incrementing BW reduces ToA), but due to limitations in there the regional parameters of the LoRaWAN network infrastructure used [18], this parameter is always set to 125kHz. This also reflects in the power consumption of the device, as it needs to enable the radio interface for longer periods to send the data. On the other hand, the coverage range increases for higher SFs values as this increased ToA results in greater robustness against noise [19]. LoRa modulation has another important characteristic that makes it fitting to the proposed application, and it is its immunity against the Doppler Effect. The small frequency shift caused by this effect, when transmitter and receiver move at different speeds (the GW is fixed, and the sensors will be moving), hardly affects the baseband signal in the time domain.

3.2. LoRaWAN

LoRaWAN is a network protocol designed for LPWAN applications that specifies the OSI layers 2 and 3 network protocols working over LoRa technology and is supported by a central Network server that orchestrates all the devices (end nodes and GWs) of the network (for instance, selecting the best GW for a node). On top of these layers, the LoRaWAN architecture relies on applications servers to relay the information to other systems and networks, as shown in (Figure 1). The latest version of the protocol released by the LoRa Alliance is version 1.1 [20]. The GWs are connected to the network server through the conventional TCP/IP SSL network, while the end devices use LoRa to communicate with one or more GWs. Device to device direct communication is not supported, although communication is bidirectional with the GWs, so in case of need this type of connection can be managed at application layer. In this case, devices operate in Class A mode, which is the predefined option in these networks, where nodes start communication only when needed to transmit data. Other modes of operation are Class B and C, which are not optimized for battery operated nodes.

In the current version of the public Network Server (NS) provided by TTS, the GW Connector protocol, is used to between the GWs and the NS to exchange messages. This solution provides more security than the legacy UDP packet forwarded used in previous versions of TTS, messages can be exchanged through network protocols such as MQTT (Message Queuing Telemetry Transport) or using gRPC (Remote Procedure Calls, sup-porting TLS encryption natively). Another matter to keep in mind when sending and receiving messages in a LoRaWAN network is to comply with spectrum regulations. The Duty Cycle (DC), is the percentage of time a device is using or occupying the channel and is regulated in Europe as seen in (Table 1.) Depending on the application to use and the frequency, it is limited between 0,1% and 10%. In this case it is 1% with a maximum EIRP (Effective Isotropic Radiated Power) of 25 mW (or 14dBm), as the network operates in the 868 MHz band, corresponding to band G1. This choice allows end devices to use 8 different channels to improve resiliency to noise. Band G3, which allows a DC of 10%, is used as per recommendation for downlink traffic, that is, from the GW to nodes.

Table 1. Duty cycle regulations in Europe

Name	Band (MHz)	Limitations
G	863,0-868,0 MHz	EIRP < 25mW - DC < 1%
G1	868,0-868,6 MHz	EIRP < 25mW - DC < 1%
G2	868,7-869,2 MHz	EIRP < 25mW - DC < 0.1%
G3	869,4-869,65 MHz	EIRP < 500mW - DC < 10%
G4	869,7-870,0 MHz	EIRP < 25mW - DC < 1%

4. TESTBED AND SCENARIO

The scenario chosen to deploy the testbed is the area nearby the town of Rubielos de Mora, in the province of Teruel in Spain. (Figure 2) shows the map in satellite view, with the position of two GW marked. LoRaWAN sensors are installed in cattle found in herds that are freely grazing in the field. In the first place, they will be installed in a farms or grazing fields located between 2 and 5 km from GW #2, in four different areas. Secondly, a moving sensor representing moving animals is attached to a shepherd-dog that will be guided through pre-set routes around the region (so experiments can be reproduced as exactly as possible). The selected four fixed locations have different environmental properties, with different altitudes, density of obstacles, etc., that help characterize scenarios for several rural applications:

- Area 1: fruit-growing area with almond trees and truffle oaks. There is a farm with different animals. Although this is the area that is furthest from the second gateway, there is line of sight (LoS) between them, and the vegetation is not dense as in a forest, so good coverage is to be expected, mixing type B and C environments. It covers 7.1 hectares.

- Area 2: this is the largest farm in this region, with many different subareas, from a deep section with a river to large fields dedicated to cereal cultivation, passing through dense pine forests that may affect the signal. In this farm there are two types of cattle, dedicated to extensive breeding. This area has been selected because of the variety of obstacles that are found on the farm, with an unevenness in the terrain of 140 positive meters, being the lowest area where the river is located and the highest area where the cereal fields and node 6 are located. It covers 35 hectares, and mixes type A, B and C.
- Area 3: this area is the livestock farm that has the largest number of cattle. This area has been selected because it does not have direct LoS with the second GW, albeit being the closest one, since it has a couple of hills between them. Moreover, the animals from this location show the more diversity of paths and grazing areas. It covers 16 hectares, being a clear example of type A.
- Area 4: this area contains another farmland with grazing animals, fruit trees and fields. It has been selected for being further away from the GWs, to test coverage limits of the network, reaching distances of up to 5 km. Albeit having spots of type C, mixed with type B because of some fruit trees, its further location makes some LoRaWAN configurations to underperform, allowing to characterize better the deployments to match the requirements in such conditions. It covers 34 hectares.

As the main goal of the application is to check proximity or position of the herds of livestock and possible moving animals (wildlife), the testbed assumes the herd location information can be represented by a reduced set of nodes, without the need to install a device on each animal. This reduces costs, deployment and managing times greatly, and reduces the overhead and congestion in traffic exchanged having a high number of nodes sending data which can be considered redundant (coordinates of an animal are essentially the same as the surrounding ones). Note that for some types of livestock, such as cows, where animals are more scattered, a node should be tracking each animal. Nevertheless, in those cases, the number of animals (grazing freely at a time) is lower and can still meet the capacity of a LoRaWAN network.

Regarding the characterization of traffic in the network to provide the required service, the message is transmitted in a packet of 44 bytes of payload, enough to contain GPS coordinates and other relevant data, depending on the application. Each sensor device sends between 278 (SF7) and 85 (SF9) messages per day, depending on the network configuration. This value is calculated to comply with the defined duty-cycled limited trans-missions regulations set by the European Telecommunications Standards Institute (ETSI) for the EU863-870 MHz band. Communication is further limited by the TTN Fair Access Policy [3], which allows for at most 30 seconds uplink airtime and 10 downlink messages (including ACKs for confirmed uplinks) per device, per 24 hours. The SF selection determines the time on air of the message, which means a higher SF limits the message rate per day but allows for further distances and range. Therefore, SF should be carefully selected according to the application requirements. It is worth noting that although LoRaWAN features an ADR (Adaptive Data Rate) mechanism to select dynamically the SF, it is not recommended to activate it for moving nodes, at least the described in the standard, as this would mean configuring the devices with SF optimized for the obsolete RSSI and SNR conditions of previous node locations, because

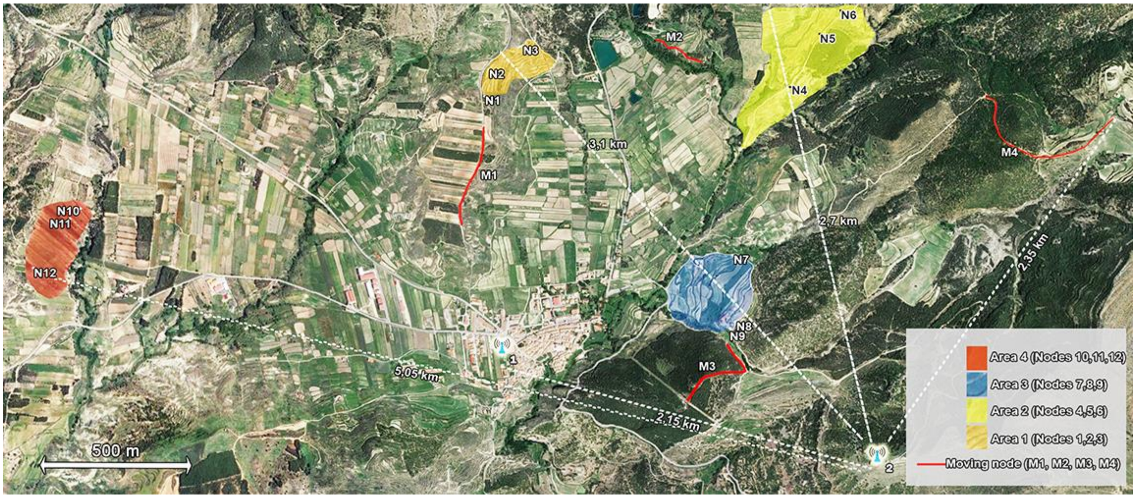

Figure 2 Satellite view of the scenario, with areas of interest, node's locations and moving nodes paths.

SF is chosen based on the SNR values of a certain number of previously transmitted messages [21]. Because the free version of TTS allows only from SF7 to SF9, keeping BW as 125kHz, these are the configurations tested and experimented with. Based on these results and the knowledge about this technology, in the last section an extrapolation on usability of all configurations is shown. While GPS can drain batteries fast, which is the main drawback when using this technology for positioning, in this case, as described, nodes are able to send data only every 5 minutes in the best case. Therefore, the device only calculates its position just before sending it through the LoRaWAN network, reducing greatly the energetic cost of operation and expanding its lifetime. Regarding the hardware used in the experiments, there are 16 end devices (12 fixed and 4 mobiles) and 2 gateways, consisting of the following elements: the end devices are based on the hardware LilyGO TTGO T-BEAM v1.1, which pack the popular ESP32 microcontroller, with the LoRa Chip SX1276 from Semtech, and GPS NEO-6M sensor to get location coordinates. This device is encapsulated with a 3D printed dedicated encapsulation to provide a collar form factor that can be used in animals and powered by a 9800mAh battery. As for the Gateways, they are Mikrotik wAP LoRa8, with an omnidirectional 6,5 dBi antenna in the 824 – 960 MHz band. These Gateways connect with the public TTS network and application servers for European region, which then inject collected sensor data into the Cayenne LPP (Low Power Payload) visualization platform.

5. RESULTS

To validate the operation of the network and the feasibility of using this solution to monitor the described scenarios, several metrics have been obtained during the experiments. These results are SNR (signal to noise ratio) and RSSI, linked to the receiving GW, timestamp, and sequence number to calculate Packet Delivery Ratio (PDR), and the nodes GPS coordinates to check and characterize signal quality depending on the surroundings, response time for locating a moving object, and power consumption, to extrapolate nodes possible lifetime. Focusing on the nodes located on the livestock areas to monitor, (Table 2) shows details on these link metrics obtained during one day of network operation. All nodes have connected with the network server through the GW2, even those in area 1 or 4, which are much closer to GW1. This is a clear indicator of the better location of GW2, in a greater altitude, and isolated from other nearby interferences from semi-urban environment of the village that affects GW1. Also, the attenuation introduced by vegetation and forest can cause great impact in received signal, as can be derived by the results of nodes in area 3, which is the closest to both GWs, but because of its environment (vegetation, uneven terrain, and poor visibility in every direction), features the worst mean RSSI and SNR than areas 1 and 2. As expected, nodes in Area 1 show the best results in RSSI, SNR and PDR, because the LoS and visibility is the best among the nodes of the network. It is also relevant that this area is much closer to GW1 (half the distance than GW2), but the orography and obstacles prioritize the GW that is not closer but better located in altitude. In Area 2 the difference between nodes in different terrains can be clearly seen, as the three nodes achieve different results. This is not only based on distance, but on the part of the farm they are located with respect to the low section with the river (node 4), the middle area which is higher (node 5), and the cereal plantation (node 6). Finally, Area 4 achieves the worst results, as it is the furthest of all, as expected. It shows that coverage is reaching its limits for SF7, and it is needed to switch to higher SF configurations to achieve PDR values suitable for any application. With the TTS limitation of SF9 up to 80,25% PDR can be achieved, so it is expected that with even higher SF, the PDR will perform over 90% and respond to robustness requirements.

Nevertheless, the robustness of LoRa achieves recovering the data with more than 90% PDR in all cases except area 4, which is a limit case, proving that this technology is a suitable candidate for the livestock monitoring application. (Figure 3) shows for the 12 nodes monitoring, the RSSI and SNR statistical analysis with a box-and-whisker plot, which is a standardized way of displaying a dataset based on a six-number summary: the minimum, the maximum, the sample median, the mean, and the first and third quartiles. The points that fallout from the box represent values that are not expected, based on the rest of the dataset. These anomalies can be caused in this case by factors such as a random passing obstacle. From the values in (Figure 3), nodes located in type C scenarios (flat terrain with good LoS), such as nodes 1, 2 and 3 in Area 1, show better RSSI and SNR results. Nodes in type C and B (flat terrain or with forest) zones of Area 2, with nodes 4 and

Table 2: Link metrics for fixed livestock nodes

Area	Node	GW	Distance	Mean RSSI	Mean SNR	PDR SF7	PDR SF8	PDR SF9
1	1	2	3040 m	-83,55 dBm	9,37 dB	95%	95,8%	96,4%
	2	2	3120 m	-88,31 dBm	8,96 dB	95%	95,6%	96,1%
	3	2	3100 m	-86,42 dBm	9,04 dB	96%	96,9%	97,5%
2	4	2	2230 m	-93,6 dBm	7,65 dB	96%	96,5%	97%
	5	2	2520 m	-85,45 dBm	8,5 dB	95%	95,7%	96,3%
	6	2	2630 m	-105,67 dBm	2,47 dB	95%	95,5%	95,9%
3	7	2	1420 m	-107,19 dBm	0,7 dB	92%	93,2%	94%
	8	2	1100 m	-107,5 dBm	0,27 dB	95%	95,5%	96%
	9	2	1070 m	-104,03 dBm	6,44 dB	94%	94,9%	95,4%
4	10	2	4880 m	-115,55 dBm	-8,25 dB	18,75%	33,75%	50%
	11	2	4740 m	-114,76 dBm	-4,6 dB	43,31%	78,9%	80,25%
	12	2	5050 m	-115,65 dBm	-10,2 dB	1,1%	26,3%	51,6%

5, also show this behaviour. While node 6 of this area and locates in a further spot of type A (mountains and valleys) presents lower results, as the rest of nodes, 7, 8 and 9 in Area 3, located in type A spots.

Finally, nodes in Area 4 show that even for devices in type C scenarios, distance also has an impact as expected.

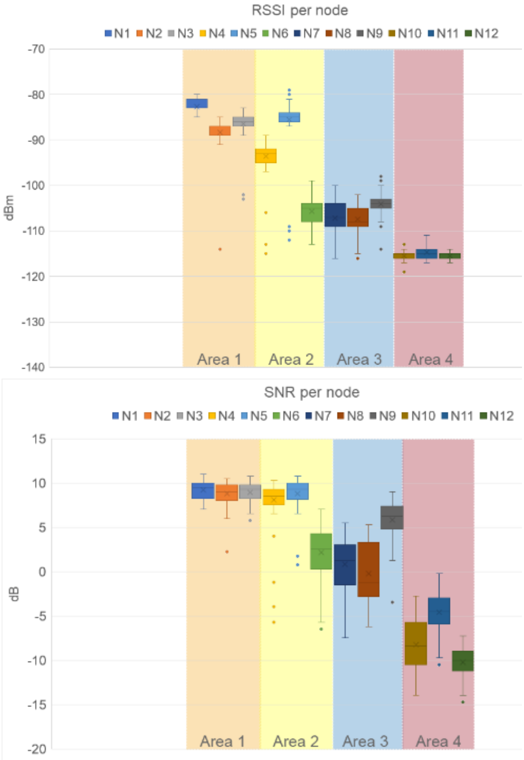

Figure 3 Statistical analysis of RSSI (above) and SNR (below) values for the livestock areas nodes.

Nodes 10 and 12 are in type B spots, and node 11 in a type C location. Due to distance, even node 11 with LoS achieve worse mean values in RSSI and SNR, causing these drops in PDR for lower SFs. It is also relevant that nodes in type A, with lower values in SNR and RSSI, and nodes in further distances, show wider and interquartile ranges, which means the dispersion of values in the received signal is higher, meaning those nodes feature more signal variability that affects the communication.

For the moving nodes, it is worth noting the M1 path connects only with the GW1, becoming weaker as the node approaches the livestock area 1, where all nodes achieved good connection with GW2 instead. On the other hand, the moving nodes have been studied following the four paths indicated in the map, which are moving towards/away from the livestock areas, to characterize animals in the surroundings that need to be detected and located. (Figure 4) shows over the map the RSSI computed by both GWs, and (Table 3) shows results of PDR and signal statistics obtained for the moving nodes. The color represents the strength of signal as shown in the legend with the colored circles or spots showing the GPS coordinate detected where the moving node is. Finally, the lines that connect with the GWs represent the signal strength perceived by that GW. If there is no line between a node and a GW, then for that location connectivity was not achieved (that GW could not receive data). If the color of the line matches the color of the circle, that means that line represents which of the two GWs is selected by the network server as the one giving coverage, so the packets received from it would be the ones used by the application server, and also will be the responsible from sending any downlink message if necessary. On the rest of the paths M2, M3 and M4 at least in one spot there is connection with GW1, but always GW2 is preferred with stronger signal. Finally, in order to validate the feasibility of this monitoring solution based on LoRaWAN, the energy consumption of the nodes must be characterized. In the application proposed, featuring an extended and long battery life is a given requirement, as batteries can be hard to replace.

Table 3: Link metrics obtained for moving nodes

Node	GW	Mean RSSI	Mean SNR	PDR SF7	PDR SF8	PDR SF9	Path length	Speed
M1	1	-100,34 dBm	10 dB	85,7%	89,4%	94,5%	890 m	4 km/h
M2	2	-87 dBm	11 dB	80%	86%	89%	787 m	4 km/h
M3	2	-93,14 dBm	2 dB	87%	91,6%	95,3%	417 m	4 km/h
M4	2	-96,57 dBm	6 dB	82,5%	88,22%	93,75%	1540 m	4 km/h

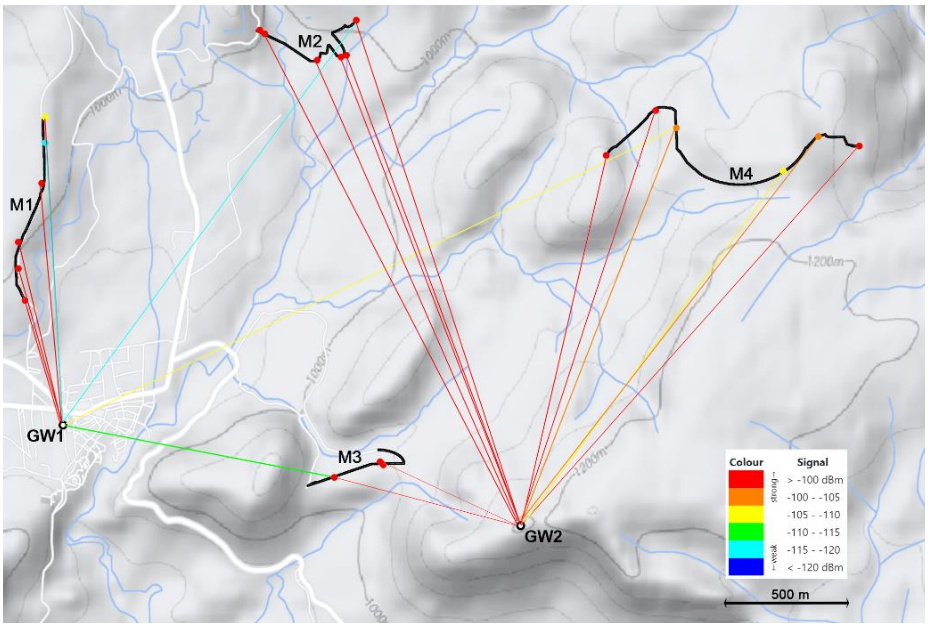

Figure 4 Map with RSSI for moving nodes, with dots showing transmitted coordinates.

As described, nodes spend in deep sleep state the time between messages, then they wake up, take the measurements needed, encapsulate the data, and send it to the GW, before going back to sleep. The GPS is initialized once when the node is powered on, and the relevant data about satellites constellations and other required information to get correct coordinates is stored in the flash memory of the node, making it persistent so there is no need to perform this stage every time it wakes up from deep sleep.

Following this approach, similar to the presented in [22-23], the battery life of a node can be characterized by (2).

$$C_A = \frac{N(T_{tx} * I_{tx} + T_{rx} * I_{rx} + T_m * I_m)}{T}$$

$$C_S = I_s\left(24 - \left(\frac{(T_{tx}+T_{rx}+T_m)*N}{T}\right)\right) \qquad (2)$$

$$BatteryLife(days) = \frac{C}{(cA+cS)*24}$$

C_A = consumption in Active periods
C_S = consumption in Sleep periods
C = Battery capacity (mAh)
I_s = Current when device is in sleep mode (mA)
I_{tx} = Current when device is in transmit mode (mA)
I_{rx} = Current when device is in Receive mode (mA)
I_m = Current when device is in measurement mode (mA)
T_{tx} = Time that device is in Transmit (TX) mode (ms)
T_{rx} = Time that device is in Receive (RX) mode (ms)
T_m = Time that device is in measurement mode (ms)
N = Number of times the device will be active per day
T = Milliseconds per hour = 3600000

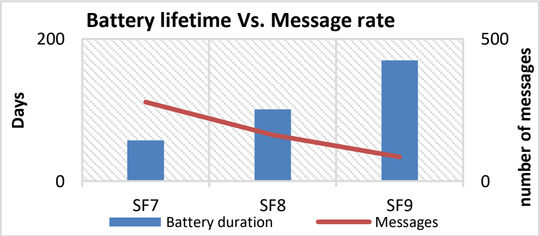

Figure 5 Expected battery lifetime and messages sent for the allowed SF by TTN.

This helps optimize battery life and make using GPS energetically affordable. (Table 4) shows the values needed to calculate and the result of

Table 4: Power consumption parameters for used nodes and SF7 and SF9

SF	Deep Sleep (I_s)	Active mode (I_m)	I_{TX} / I_{RX}	Time Active per message	Time TX per message	Time RX per message	Messages per day	Battery lifetime*
SF7	0,2 µA	9 mA	30/11 mA	7 seg	107,8 ms	2s	278	56,22 days
SF9	0,2 µA	9 mA	30/11 mA	7 seg	349,2 ms	2s	85	169,28 days

** Approximation for P_{TX} of 14dBm, 9800mAh batteries, and active time for measuring GPS and encapsulating the messages* the expected battery lifetime, measured during operation with the proposed configuration.

An expected lifetime of 56,22 days is achieved, which may serve well for the livestock, but can be considered short for tracking wild animals. Nevertheless, if the application does not require sending so often, battery lifetime can be extended up to years, for instance, sending one message per hour, the same node can last up to 1,9 years.

To better illustrate the energy behavior of the nodes, (Figure 5) shows the lifetime expectation if the SF configuration is selected among the allowed by TTS (always assuming the maximum messages per day allowed). Selecting higher SFs translates in longer airtimes per message, which increases energy consumption, but on the other hand, the node will be allowed to send less messages per day, which is the reason the lifetime is longer. Given the objective of the application focused on tracking and monitoring moving objects, the experiment selected a fixed SF7, enabling the faster data rate and the higher number of messages possible. Nevertheless, other applications may prefer a compromise between data rate and battery lifetime, therefore selecting SF8 or SF9.

6. CONCLUSIONS

After validating the operation of LoRaWAN technology and its configuration in a real testbed, (Tables 5 – 6) show the characterization of selected applications that can use this network, according to the requirements and peculiarities of each case. With SF7, a total of 278 messages per day can be sent, which means sending a message every 5,5 minutes. These specific parameters can be used for moving animals, such as hunting hounds, since dogs roam freely through the mountains and fields, guided by their nose behind wild animals, following random trajectories. Sending more messages per day is required when frequent updates on the assets tracked are needed.

In addition, the batteries of the device would only last approximately 56 days, requiring charging the battery of the device every 2 months. With this configuration an area around 28 km^2 can be covered. With SF8, a total of 153 messages per day, or a message every 10 minutes, can be sent. With this higher SF, the link can cover around 63 km^2 in areas with direct vision and around 39 km^2 in high mountain areas. By proposing several areas for the same network, several types of applications can be tested. For example, in areas with direct vision two types of applications can be studied, agriculture and livestock monitoring. On the other hand, with non-line of sight applications, the chosen areas feature safety devices for agricultural buildings and irrigation systems of large extensions of fields and plantations. These applications handle large amounts of sensor data, as well as motion detection and security devices.

These applications are very interesting for companies or farmers that have a variety of machinery in motion, since they could have them always located and know if they are stopped or are being used.

Table 5: Application of LoRaWAN in rural environments recommendations, part I

SF	Env. Type	Distances	Mobility	Nodes	Description
7 - 8	Type C Flat (LoS)	3,5 – 4 km	None (fixed)	As many as the user wants	Security system for agricultural / livestock warehouses. Registers if the doors are open or closed, as well as the location of the machinery. [12, 13, 14, 15] *
7 - 8		3,5 – 4 km	6 km/h approx..	Nodes on 10 % of cattle 5 % of sheep/goat	Monitoring system for extensive livestock farming on small farms. Registers the location of the animal, RSSI, SNR, and distance to the centre of the farming.[17]
8 - 10	Type B Flat Mediterranean forest	3,5 – 4 km	None (fixed)	One per water pump/ field	Irrigation system with remote control for extensive plantations. Registers the location of the farm, temperature, and humidity of the soil, to improve control over plantations growth. [12, 13, 14, 15]
7 - 10	Type A Great valleys / mountains	3 km	15-20 km/h approx.	As many as animals to monitor	Tracking system for hunting dogs. Registers the location of the animal, RSSI, SNR, and distance from the owner. [16, 17]
8 - 12		3,5 – 4 km	6 km/h approx.	Nodes on 25 % of cattle 10 % of sheep/goat	Monitoring system for extensive livestock farming in mountainous areas. Registers the location of the animal, RSSI, SNR, and the distance to the centre of the fence. [16, 17]
10 - 12		5 – 5,5 km	20 – 25 km/h	Two nodes per herd (wildlife)	Monitoring system for wildlife in mountainous areas. Registers the location of the animal, the RSSI and the SNR of the device. [16]

With SF9, the area covered is increased to a maximum of around 64 km^2 for mountain areas, but the number of messages sent is decreased to only 85 messages per day, one every 20 minutes. A possible application that matches these requirements is the monitoring of wildlife, such as foxes, wolves, bears, etc. This application can be very useful for researchers so they can study the behaviour of animals, as well as investigate the areas where they live. Also, for forest agents the monitoring hunting trophies to avoid poaching and illegal hunting. Application of higher values of SF can be derived from ToA and duty cycle regulations. For SF10 or SF11, the area covered is around 78 km^2 depending on the type of vegetation in the area, but there is a notable decrease in the number of messages compared to the previous SFs. With SF10 the number of messages sent is 45, while with SF11 only 21 messages are sent. With these characteristics, a possible application is a tracking system for hunting dogs. This application can be used both for locating hunting dogs or people participating in the hunt to avoid any accidents. Finally, SF12 would only support sending 11 messages in 24 hours, one every 2,5 hours approximately. In addition, the area covered is 95 km^2 in high mountains, so it is possible to cover many applications related to tracking animals or people, specifically where message rate requirements are more relaxed. For instance, in extensive farming livestock monitoring in mountainous areas, or for scientific experiments following endangered species paths and trails, where apart from the data itself, it is very relevant that batteries can last several years. With respect to the coverage area and link quality, LoRaWAN has proven to perform well in terms of PDR and distances achieved, responding to the requirements presented by the use case. On the other hand, battery lifetime of nearly 2 months can be considered short regarding the tracking of wildlife that are difficult to catch and may move out of the coverage area for great periods of time, in which case it would be needed to reduce the number of messages, sacrificing the capability of early detection. (Table 6) introduces further configuration guidance with battery duration versus message update rate. The experiment proposed adds a second GW, deploys nodes on areas with different characteristics, and considers also moving nodes, which require forcing the network to operate at the limit of the allowed duty cycle. This network operation results can help identify detection delay issues (based on expected message rate) and offer insight in expected accuracy and validity of the different applications for rural environments. As future work, further testing with higher number nodes and GWs, and deploying a private instance of the Network and Application server, to test further SF configuration will be tested. Also, moving GW mounted in cars or trucks, to provide dynamic coverage for moving devices that travel longer distances, is also in the scope of future experiments and studies.

Table 6: Application of LoRaWAN in rural environments recommendations, part II

SF	Application	Payload	Max Messages per day	Battery duration
7 - 8	Security system for warehouses	32B	324 (SF7) 182 (SF8)	Connected to the grid
7 - 8	Monitoring for extensive livestock farming	44B	278 (SF7) 153 (SF8)	56 days (SF7) 99 days (SF8)
7 - 9	Tracking system for hunting dogs	44B	278 (SF7) 153 (SF8) 85 (SF9)	56 days (SF7) 99 days (SF8) 169 days (SF9)
8 - 10	Irrigation system for fields and plantations	44B	153 (SF8) 85 (SF9) 11 (SF10)	Connected to the grid
8 - 12	Monitoring system for extensive livestock farming in mountainous areas	44B	153 (SF8) 85 (SF9) 45 (SF10) 21 (SF11) 11 (SF12)	99 days (SF8) 169 days (SF9) 291 days (SF10) 514 days (SF11) 758 days (SF12)
10 - 12	Monitoring system for wildlife in mountainous areas	44B	45 (SF10) 21 (SF11) 11 (SF12)	291 days (SF10) 514 days (SF11) 758 days (SF12)

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