Article

An Autonomous Wireless Device for Real-Time Monitoring of Water Needs

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Abstract: A The agri-food sector is in full renovation, continuously demanding new systems that allow farmers to facilitate their work. Efficient agricultural practices are essential for increasing farm profitability. Efficient agricultural practices can be increased by understanding and managing water neeeds. However, real-time monitoring of water needs is currently slow, and irrigation decisions are based on previous data or physical evidence. Furthermore, the prices of automatic systems for collecting data from several sources (soil and climate) are expensive and the autonomy is very low. Emerging Internet of Things (IoT) technologies such as wireless sensor networks can be used to collect vast amounts of data recorded via apps. By means of an LPWAN communication the farmer can know in real time the state of his crops thanks to a large number of sensors connected wirelessly and distributed across his farm. This paper presents a low consumption solution based on LoRaWAN technology. The wireless sensor node, called BoX, exhibits very low power since it has been optimized both in terms of hardware and software. The result is a higher degree of autonomy than commercial motes. That will allow the farmer to have all the information necessary to achieve an efficient management of his crops with full autonomy.

Keywords: LoraWAN; IoT, agriculture 4.0; wireless sensor network; low consumption

1. Introduction

Some of the main problems that the world population faces today and in which researchers from all over the world are working are globalization, global warming and the supply of food. In order to address the last of these, it is necessary to develop modern solutions that allow optimizing costs and increasing yields, since the high rate of population growth will soon surpass current productive capacities [1].

In recent decades many researchers have been integrating the concept of the Internet of Things (IoT) into the field of agriculture, thus helping the development of what is known as precision agriculture. Precision agriculture aims to provide a decision support system that helps farmers to enable efficient agricultural practices with the aim of increasing profitability, reducing environmental risks and preserving natural resources [2].

So-called Smart Agriculture or Digital Agriculture uses intelligent networks and data management tools in order to employ all the information and experience available in order to enable

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the automation of sustainable processes in agriculture. This agriculture is based on connected and knowledge-based agricultural production systems and makes great use of Information and Communication Technologies (ICT) both for data collection and for subsequent processing. For this reason, the design and implementation of efficient and economic devices in agriculture is currently an important line of research [3].

Due to the characteristics of the agricultural sector, the use of wired systems for the collection of information is practically unfeasible, which is why work is currently underway to develop Wireless Sensor Networks (WSNs) in order to minimize the economic cost and impact of installation in agricultural environments and thus avoid hindering the work of the farmer [3,4].

The current solutions for collecting different parameters in agriculture suffer a series of limitations such as low autonomy, high energy consumption and a limited range of devices, three areas in which we must work in the future [5].

In order to solve the problems mentioned above, this paper presents a solution based on LoRa technology. Specifically, we developed a WSN with very low consumption and high autonomy to control water needs in intensive irrigated crops in southern Spain. Thanks to the use of this technology and the use of low cost components, a system with very low consumption and a wide range of communication has been developed.

2. Wireless Sensor Networks in the Context of Smart Agriculture

We can see different solutions for monitoring crops using wireless sensor networks. Many of these proposals have only been tested in the laboratory and still have to be developed and implemented on real crops. Robles et al. [6] created a low-cost, small-scale system to remotely monitor and control a greenhouse. In this study the information was collected by an Arduino Mega and sent to a web page through Ethernet communication. Through this web page you could see all the parameters of the greenhouse as well as having access to the main actions that could be performed on it such as ventilation, irrigation, etc. Sakthipriya [7] developed a system based on SMS communication using a GSM module. In this study parameters such as soil moisture, pH and atmospheric pressure were measured. With this data irrigation could be controlled and the farmer informed of the state of his crops.

One of the most widely-used technologies for creating wireless sensor networks in agriculture is the ZigBee technology. García Sánchez et al. [8] developed a video surveillance system based on ZigBee to identify possible intruders that could enter the plantation. In this study a node is also presented for monitoring the crop by measuring parameters such as soil moisture, PH, conductivity, salinity and ambient light.

Currently ZigBee wireless communication protocol is considered one of the best technologies to be applied in precision agriculture given its low consumption. However, one of its main disadvantages is the short reach between nodes, 100 metres in open spaces and reduced to 30 metres in closed spaces [9].

The radio has also been used for communication. In López et al. [3] a system of nodes is developed called GAIA2. This system is composed of three types of devices: The Gateway, responsible for receiving information from the nodes and passing it to the Internet, the "high density mote" (HDM) equipped with a short-range radio module and the "Long distance mote" (LDM) which establishes long-range communications. The HDM is intended to measure soil parameters while the LDM takes measurements of the quality of the irrigation water.

GPRS technology can also be used in agriculture to create networks of wireless sensors. On the other hand, apart from the high cost, its high power consumption means it is little used in the creation of high autonomy nodes. Gutierrez et al. [10] developed an automated irrigation system to optimize the use of water in crops by combining ZigBee and GPRS technologies. By means of this system the humidity and temperature of the land were measured and a solenoid valve operated to allow or cut the water flow. In addition, these data are transmitted to a web application from where the farmer can consult them.

Navarro-Hellín et al. [4] created a network of wireless nodes equipped with GPRS connectivity. Different sensors can be coupled to these nodes to measure a wide range of soil, plant or atmospheric parameters. This data is sent to and processed in a server that stores the information in databases, which allows consulting and analysis in a simple and versatile way.

SigFox is a new technology used in IoT applications. In Llaria et al. [11] a geolocation system was developed to locate herds of cattle. As advantages of the SigFox technology we can highlight its wide range of coverage and low consumption, which makes it very appropriate for IoT solutions.

With SigFox, LoRa technology is beginning to be used in precision agriculture in recent years as an alternative to previous protocols. It is a long-range and a low-power wireless communication system whose objective is to be used in long-term devices [12].

LoRa is not only applicable in precision agriculture. In Schroder et al. [13] its use in the field of "Smart Cities" is studied, reaching the conclusion that it is the most appropriate current alternative for this purpose.

If we focus on agriculture, in Ilie-Ablachim et al. [1] a device called "MoniSen" was developed based on the LoRaWAN technology. Through this solution, parameters such as ambient temperature and humidity, soil temperature and humidity and light intensity received by the plant can be measured. For its operation it uses the ATMEGA324P processor and the RN2473 chip to establish the LoRa communication. Its consumption in active mode and transmission is set at 7.5 mA and 15 mA respectively while in hibernation mode (where it spends most of the time) the consumption is 400 uA. With these data it is possible to obtain an autonomy of approximately 6 months using a 2400 mAh battery. Finally, with regard to coverage, distances of up to 3 km were obtained in urban areas.

3. Material and Methods

3.1. Hardware description

3.1.1. LoRa Technology

LoRa, whose meaning is "Long Range", is a long-range communications system promoted by the LoRa alliance [14]. This system aims to be used in devices where energy consumption is of the utmost importance. LoRa can commonly refer to two distinct layers [12]:

1. A physical layer that uses the radio modulation technique Chirp Spread Spectrum (CSS).
2. A MAC layer protocol (LoRaWAN); although the LoRa communication system also employs a specific access network architecture.

The LoRa physical layer, developed by Semtech, allows a wide range at low power. It operates in the ISM bands of 433, 868 or 915 MHz, depending on the country in which the system is operating. The payload of each transmission can vary from 2 to 255 octets and the data rate can reach up to 50 Kbps [1].

LoRaWAN provides a medium access control mechanism, which allows many devices (nodes) to communicate with a single gateway using LoRa modulation. A typical LoRa network shows a star topology, which includes three different types of devices, the nodes or end devices, the gateways and the server [12].

In the basic architecture of a LoRaWAN network (Figure 1) the nodes communicate with the gateway using LoRa with LoRaWAN and the gateways send LoRaWAN frames to a network server via Ethernet or GPRS [12].

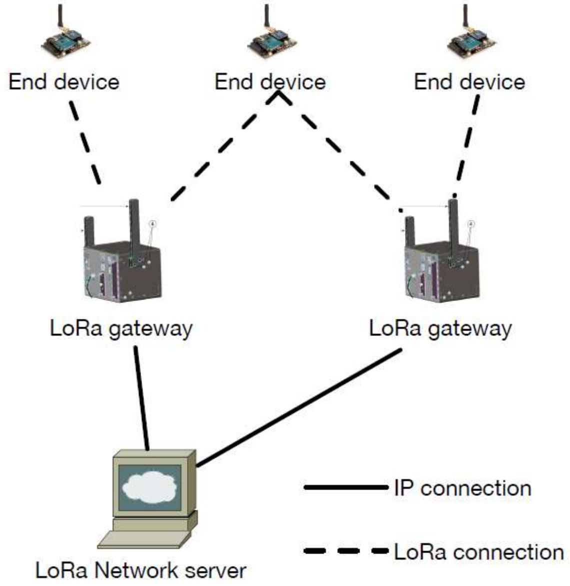

Figure 1. Communication scheme of LoRa technology.

3.1.2. Sensor Node

The node is the device in charge of collecting the necessary data in the field to later transmit to the Gateway. Its two main characteristics must be low consumption and being able to establish communication at the greatest possible distance.

Our node has a Moteino processor. This development platform is based on the popular ATmega328p chip being fully compatible with Arduino IDE. Moteino is also fully optimized for low power projects, which makes it ideal for IoT applications.

On the other hand, to establish the LoRa communication with the gateway the node has the RN2483 chip. This chip is also optimized to obtain the lowest possible consumption in addition to being certified by the LoRa alliance (figures 2 and 3).

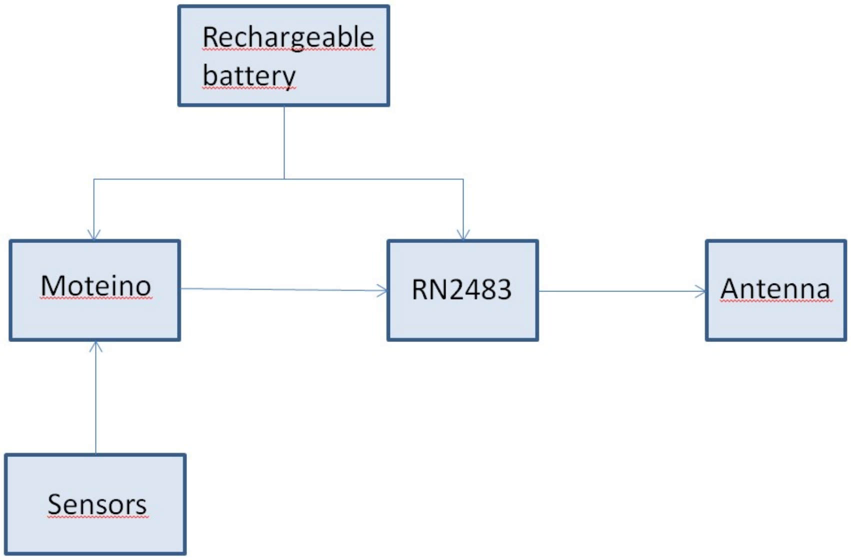

Figure 2. Block diagram of the hardware structure of the sensor nodes.

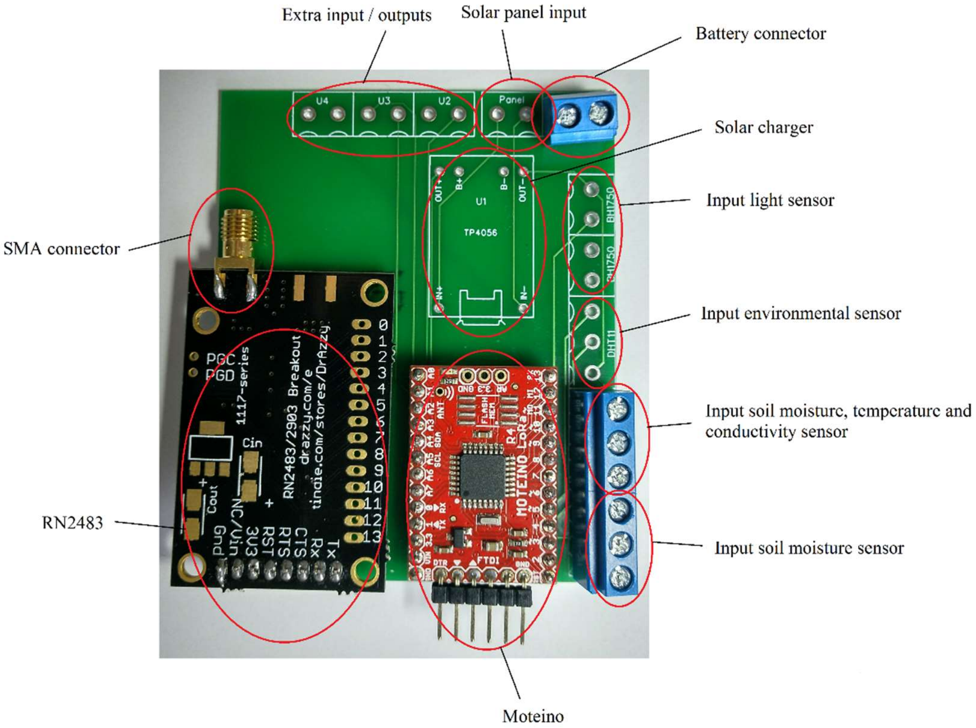

Figure 3. Photograph of the wireless sensor node.

This system can integrate numerous sensors that measure a large number of agricultural parameters, both soil and atmospheric. The main parameters necessary for a correct monitoring of the plant are:

- Soil moisture: To make this measurement the Decagon 10HS model can be used or the Vegetronix brand VH400, among others.

- Temperature and electrical conductivity of the terrain: To measure these parameters, the Decagon 5TE sensor can be used, which is capable of taking data on soil moisture, conductivity and temperature.
- Humidity and ambient temperature: In this case, the low cost sensors DHT-11 or DHT-22 can be used depending on the specific characteristics of each application.
- Ambient light: Two options can be used to measure the light received by the plant. On the one hand the BH1750 sensor, which can be used to obtain an exact measurement of the light received. On the other hand, to obtain a measurement with less precision a photoresist would be enough.

A LiPo battery with a nominal voltage of 3.7V and a capacity of 2000 mAh was used to power the node. As an alternative, Li-Ion batteries with 3.7V nominal voltage and a capacity of 2600 mAh can also be used, obtaining greater autonomy. LiPo batteries were chosen as they achieve a high load density with a very small weight and size. Additionally, with the implementation of a small solar panel and the TP4056 module the battery could be recharged continuously, increasing the device´s autonomy.

In order to guarantee correct communication the node was equipped with an omnidirectional antenna with SMA connection with an operating frequency of 868Mhz.

Finally, all the components were placed in a sealed box of ABS material with IP protection in which all the necessary holes were made to mount the connections of the antenna and the sensors.

Figure 4. Node sensor.

3.1.3. Gateway

The Gateway is the element in charge of receiving the information from the nodes and taking it to the network. It consists of a microprocessor, a concentrator and an antenna.

First, the antenna receives the information sent by the node and communicates it to the RaspberryPi microprocessor through the IC880a concentrator. Then the RaspberryPi is responsible for processing all the information necessary to upload the information to the network through the previously-installed software.

3.2. Software description

Since the Moteino driver is fully compatible with Arduino, it has been programmed using the Arduino IDE software with C++ programming language.

The software operation of the node is shown in the flow diagram (figure 5). When the device is activated the different outputs and inputs of the processor are configured. Next, the RN2483 chip is initialized, through which the information will be transmitted later. Then the necessary data information is collected from the different sensors that are connected to the node at that moment.

Since the sensors deliver a specific voltage depending on the physical parameter that you want to measure, it is necessary to transform this reading into specific physical units. For this, a data processing is carried out following the guidelines set by the manufacturers. Once the desired data are obtained, these are sent through the RN2483 module to the nearest Gateway.

After having sent the information the LoRa module enters into a "sleep" mode, through which it is possible to lower its consumption drastically. Then the same is done with the Moteino microcontroller. In this way, during the time between measurements the device has a minimum consumption, preserving the battery life well.

The time between measurements must be programmed to extend the battery life but also, in turn, to have sufficient precision to quickly detect changes in soil moisture or in weather conditions. Normally 20 and 30 minutes should be an adequate frequency for data acquisition.

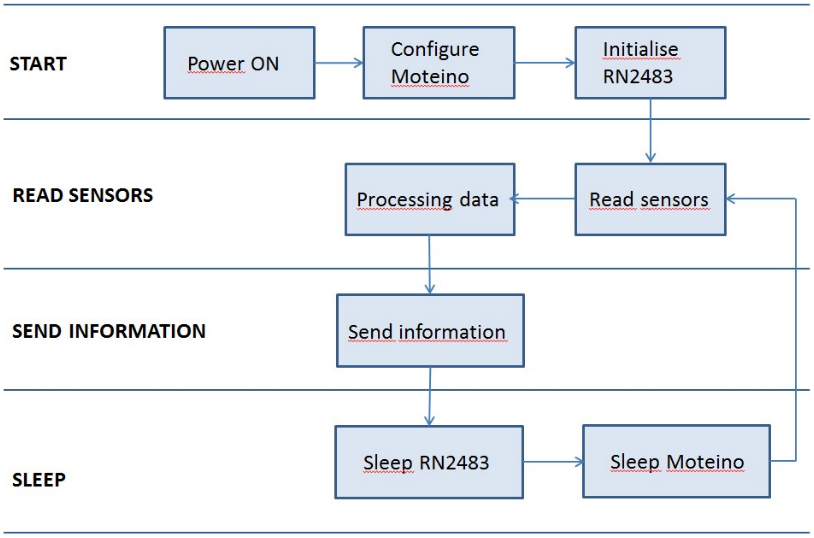

Figure 5. Flow Chart of the node sensors.

4. Results

The node used to perform the experiment consists of a Moteino microcontroller and a LoRa module with the RN2483 chip. To measure Volumetric Water Content, soil temperature and bulk electrical conductivity data, it was decided to use Decagon D5TE and D10HS sensors, which are widely used in agriculture. As regards the battery, a lithium battery with a nominal voltage of 3.7V and a capacity of 2000 mAh was available.

To perform the experiment the node was configured to take measurements every 93 seconds. It was decided to perform the test with such a short interval between measurements in order to decrease the total duration of the experiment. In order to save the maximum battery in the intervals in which the node is not working, the different components go to sleep mode, drastically lowering the consumption and preserving even more the battery charge.

The node was located in the laboratory at a temperature of approximately 20 °C with the Decagon sensors in the air and at an approximate distance between the node and the Gateway of 600 metres.

In order to correctly evaluate the consumption of the device, its process was divided into three groups:

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Active mode: In this mode the node configures the microcontroller and initializes the RN2483 chip. Once these actions have been carried out it proceeds to read the data provided by the sensors and performs the subsequent processing of the information.

Send Mode: This mode of operation will be the one that consumes the most energy since it is the moment in which the information is sent to the nearest Gateway.

"Sleep" mode: Unlike in the previous case, this mode has been created to save the maximum battery while it is not necessary to take or transmit measurements. To do this, both the microcontroller and the RN2483 chip fall “asleep”.

Figure 6. Node with Decagon Soil Moisture sensors.

In the first experiment measurements of consumption were taken in the different modes of operation, as well as the time that each one remains active. The results obtained are summarized in the table below.

Table 1. Average power consumption for the different modes.

MODE	CONSUMPTION (mA)	TIME (s)	% TOTAL TIME
Active	9.4	4	4.3 %
Sending	22.0	1	1.075 %
Sleep	0.036	88	94.62 %

In table 1 we can see how the node is most of the time in "sleep" mode having a consumption of 0.036 mA. This consumption increases up to 9.4 mA while the microcontroller is in active mode acquiring data through the sensors. Finally, while the information is sent through the LoRa module the consumption is 22 mA for approximately one second.

From the data shown in table 1 we can calculate the average device consumption for this time interval between data collection as follows:

$$Consumption = \frac{9.4mA \times 4s + 22mA \times 1s + 0.036mA \times 8s}{93s} = 0.674mA$$

Once the average consumption of the node is obtained, and knowing the capacity of the battery, we can calculate its theoretical duration:

$$Duration = \frac{2000mAh}{0.674mA} = 2967h = 123days$$

As will be seen later, this theoretical duration is only useful for performing a first estimate. Normally, the actual duration of the battery will be well below the theoretically calculated value.

The second test had as its objectives obtaining the curve of discharge of the battery and its real duration. For this, during the operation of the device measurements of the voltage supplied by the battery were taken periodically. In this way we were able to estimate its state of charge, as well as the time that the device can operate without needing maintenance or battery change. Next, the voltage values measured against the number of days that it was in operation were plotted on a graph.

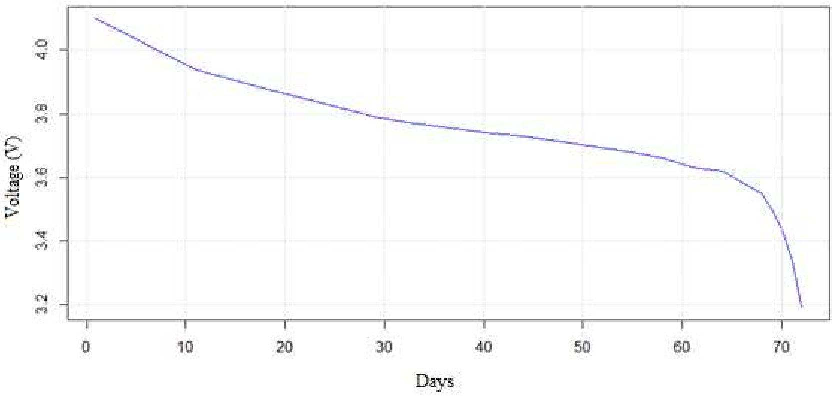

Figure 7. Node battery voltage.

As can be seen in Figure 7, the voltage supplied by the battery starts at 4.1V to decrease rapidly during the first few days. Meanwhile, as we get closer to the nominal voltage of the battery (3.7V) the curve decreases more slowly towards this value. Once the voltage drops below the nominal value of the battery, it drops drastically. This behavior is typical of lithium batteries as is the case here.

During the experiment the node ran for a total of 72 days during which it took measurements each 93 seconds. In this time more than 49,000 measurements were made.

If we compare the battery life obtained in the real experiment with the theoretically calculated one, we can verify that the real life is approximately 60% of the theoretical one. This data may vary depending on the characteristics or battery condition and environmental conditions. For example, in [1] a value of 70% is taken to estimate the duration of the battery. In contrast, [15] did not use any correction factor to calculate battery life.

During its operation in a real environment, the node will take data every 30 minutes approximately. Thus, if we use the data previously measured in the different operating modes we can calculate the average consumption of the device for a time between measures of 30 minutes in the following way:

$$Consumption = \frac{9.4mA \times 4s + 22mA \times 1s + 0.036mA \times 1795s}{1800s} = 0.069\ mA$$

Taking into account the calculations performed previously, and assuming that the actual duration is 60% of the theoretical, the estimated duration of the battery for a time between data collection of 30 minutes would be the following:

$$Duration = \frac{2000mAh \times 0.6}{0.069mA} = 17391h = 724\ days$$

With this autonomy the node would be able to operate for two years without the need for battery change or any maintenance.

5. Discussion

The results achieved in this research improve the recently published ones. Thus, [15] present a node formed by the Msp430F1611 Texas Instruments processor and wireless communication at 2.4 Ghz with a gateway. To measure the different terrain parameters they used two Hydra Probe II sensors. The measurements were taken every 30 minutes, obtaining an average consumption of 0.5035 mA. The calculated autonomy was 223 days, achieved by installing a 2700 mAh battery.

In [1] a device using LoRa communication is developed to measure temperature and humidity parameters and soil data. With a time between measures of 60 minutes, the average consumption of the device is 0.4026 mA, achieving a range of 73 days for a 2400 mAh battery. Unlike the previous case the author has corrected the duration of the battery by the factor 0.75, thus achieving a result closer to reality.

In [3], the GAIA2 system communicates via radio at 2.4 GHz with a gateway. In laboratory tests, with a node and a humidity and temperature sensor SHT71, an average consumption of 0.089 mA was obtained. On the other hand, a real field experiment was carried out in which two MPS-2 sensors were used, capable of measuring the water potential and soil temperature, obtaining a total battery life of 56 days.

We have presented a system capable of having an average consumption of 0.069 mA, capable of providing a battery life of up to 724 days. If we compare these results with those obtained in previous articles, we can see that consumption has been reduced significantly, along with a significant increase in battery life.

6. Conclusions and Future Research

In this paper we have presented a low cost system based on LoRa technology capable of taking measurements of the parameters most used in precision agriculture such as humidity and ambient temperature, light received by the plant and soil temperature, soil moisture and soil conductivity.

The results obtained show better consumption than that of commercial wireless sensors. The consumption of the node has been measured in its different operating states and the battery discharge curve has been obtained, obtaining as a conclusion that it is capable of remaining for 72 days taking measurements every 93 seconds. If measurements were taken every 30 minutes the approximate duration of the battery would be 724 days.

In order to increase the battery life a solar panel could be installed in the node and evaluation performed on how it affects the consumption of the battery.

Another line of work is related to the type of battery installed. In this case the operation of the node can be compared with another type of power such as alkaline batteries or lithium-ion batteries.

Finally, it would be interesting to perform a distance test in order to know the coverage provided by a Gateway in a rural environment.

Author Contributions: Juan D Borrero conceived, wrote and improve the paper. Juan D Borrero and Guillermo Fernández conceived and designed the experiments. Guillermo Fernández and Camilo Rodríguez collected the data. Guillermo Fernández built the devices. Camilo Rodríguez developed the software.

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