Development of a smart node IoT for agriculture appliances

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Abstract

Nowadays, with the growth of population and climate changes, it is necessary to create more efficient ways of farming. The use of information systems can reduce the waste in the agriculture process such water waste and the excessive use of fertilizers that stresses water resources and contribute to the erosion of soils. With new advancements in microelectronics and communication protocols, it is now possible to create ultra low power systems able to get data from sensors and transmit it to the Internet. New Low-Power Wide-Area Network protocols such as LoRaWAN and Sigfox allow each node to have a range of several kilometres. In addition, the use of low power regulators, with low quiescent currents, and a real time clock to generate interruptions, allow the system to achieve long periods of operation using a single battery charge. In this work an embedded system with a ultra low power sleep mode is proposed. Considering that physical variables in a farm present slow variations an embedded system used for precision agriculture can spend most of its time in sleep state. The ultra low power is achieved by disabling all the modules except the real time clock. In addition, the use of a DC-DC converter to power demanding modules allows optimal efficiency. The system was designed to be compliant with sensors that are used in precision agriculture.
Keywords: Embeded System, Ultra Low Power, Low-Power Wide-Area Network Protocols, Power Management

1. Introduction

The agriculture field will face many challenges in the years ahead. The climate change alongside with the population grow will create challenges that need to be overcome. It is necessary to reduce the waste of resources in agriculture, more precisely the use of water and fertilizers. With the use of sensors and actuators it is possible for the farmer to monitor the state of the farm. From the collected information it is possible to take more accurate actions optimizing the resources used. For instance, the data extracted from the field can point to the necessity of locally watering the plants or the need of a fertilizer in some parts of the field. With this application in mind, it is important that the hardware involved can operate for long periods of time using a single battery charge. For that to happen, the use of hardware parts that are highly efficient and operate in ultra-low power whenever possible are required. By deploying several of this nodes in an agriculture field, a good amount of information can be gathered to inform the farmer and reduce its costs and improve the overall efficiency of the agriculture activity. Two main topics are going to be studied. The first one is the development of an embedded system that can be integrated in an agriculture precision monitoring system. It will be study the main challenges when designing a system that needs to sustain external environmental effects such as temperature and humidity. A possible architecture will be proposed for an embedded system aiming to be supplied for several years from a single battery charge. Additionally, a design solution will be presented and different measurements will be taken in order to characterize the system. Manly current measurements in order to calculate power consumption and the battery life in the system. The second topic refers different Internet of Things (IoT) communication protocols. In recent years, several protocols emerge in the market clamming power saving features and long ranges. A study will be conducted in terms of IoT protocols. Then one of them will be implemented and tested in order to improve the information related to this protocol. The final objective is to have a, fully functional, embedded system that can be used in a agriculture field to monitor different physical variables such as the temperature and the humidity of the soil.

2. Background

Through this chapter, the needs of the agriculture market are presented, as well as IoT systems that are being used in several agriculture applications to increase the productivity and reduce the waste.

2.1. Precision agriculture

The Home Grown Cereals Authority (HGCA) defines precision farming as management of farm practices that uses computers, satellite positioning systems and remote sensing devices to provide information from which the farmer takes his decision. In [3] in the section case studies is possible to see different projects of precision agriculture. From a bee monitoring system that uses a microcontroller and some sensors to monitor the temperature of a bee hive, to a system that uses temperature, humidity sensors, light sensors, carbon dioxide concentration sensors, soil temperature sensors and PH sensors to monitor a greenhouse there are many different projects in precision agriculture

2.2. Internet of Things

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction [4].

2.3. Hardware considerations for precision agriculture

In [7], recent advances and futures challenges of IoT in agriculture are presented. The different types of hardware used alongside with the different communication protocols used are discussed. Namely, the microcontroller used and the transceiver used. It is possible to see that different types of microcontrollers, like the MSP430 from Texas Instruments alongside with microcontrollers from Atmel are also widely used. On the other hand, most of the boards used in precision agriculture bring an IEEE 802.15.4 transceiver module, except the LoPy platform that already brings a LoRaWAN transceiver. When taking into consideration the application of sensors nodes in agriculture, the important aspects are the accuracy and the shield against environmental factors, which can either produce false information or permanently destroy the node [7]. On the other hand it is also important to have in consideration the power source of the node. Normally, these nodes run on a finite source of energy, such a battery, and the ability for the farmer to reach the node and change the battery is very limited [7]. Having in consideration the previous reasons presented, the design of an hardware system to be used in precision agriculture needs to take in consideration the power consumption. The final code requires a profound knowledge in embedded engineering. The important aspects of a sensor node are its durability, stability, the number of inputs (analog and digital), the capacity to hold the energy of the battery for a long period of time and the ease to program the device [7].

2.4. Communication protocols

In [2] and [7] the communication protocols are divided in the following categories.

- Celular - The use of the GSM, 3G, 4G and 5G technologies to allow the sensor nodes to communicate with the Internet. If offers reliable communication and a good support. However it presents an higher cost of operation and it uses more power than the others.
- Mesh Protocols - In this typology if the sensor is too far away from the gateway it can not communicate with the gateway directly. It uses the closest node and it sends the information to that node. Then the node that received the information will send the information to the node that is closed and so on. When finally the information reaches a node close to the gateway the information is transmitted to the gateway and then to the Internet.Very used in home automation, smart lightning, HVAC systems (climatization), security, energy management and others.
- Point-to-point - Used to establish a direct communication between two nodes. It connects two devices directly without the need for a host. An example is the RFID technology that uses radio waves to transmit a reduce amount of data from a tag to the reader. Widely used in transportation, agriculture, industry and others.
- Wireless Personal Area Networks (WPAN) - A network that connects devices that are closer to each other and have some kind of radio communication. They have reduce range (approximately 10 meters) and require communication on the line of sight. Bluetooth, IrDA (infrared) are all examples of WPAN.
- Wireless Regional Area Networks (WRAN) - The protocol IEEE 802.22 is the most known protocol that is WRAN. This network is defined as a network technology that uses parts of the radio frequency spectrum that are considered white spaces in order to provide connectivity to the internet. White spaces refers to portions of licensed radio spectrum that licensees do not use all the time in the same localization. This category is also associated with cognitive radio (CR) meaning that is a radio that can be setup to use the wireless channels that present the best characteristics in order to avoid congestion and interference.

- Low-Power Wide-Area Network (LPN/LPWAN) - It connects devices that are battery power providing low bit rates over long ranges. Especially created for the market of IoT these protocols provide a long range to the sensor node creating a start topology network. The sensor nodes are able to connect to the gateway directly meaning that they do not communicate with each other. Examples of these networks are LoRaWAN, SigFox, MIOTY and NB-IoT.

The following figure that was taken from [2] is a comparative of the different categories presented before. In 1 the vertical axis represents the data

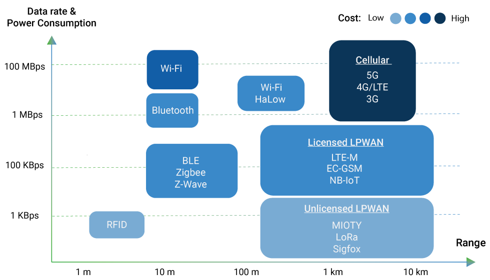

Figure 1: Wireless Technology used in IoT) [1]

rate and power consumption of the protocol. The higher position represents an higher data rate and power consumption: on the other hand, a lower position means a low data rate and power consumption. In the horizontal axis a representation of the range of the protocol is made. On the right the protocols that show and higher range and on the left the ones that present a smaller range. The most interesting protocols are the LoRa, Sigfox and MIOTY do to the long range an power consumption that they present. The LTE-M, NarrowBand-IoT (NB-IoT) and Extended Coverage Global System for Mobile Communications (EC-GSM) are also very interesting because they present a middle ground between power consumption and data rate. For these reasons they are all presented in the following sections in terms of strengths and faults.

3. Implementation

On the market, there are different types of embedded systems that can be used in precision agriculture. They have multiple input and output ports, and support both digital and analog sensors. They make use of sleeping, low power states in order to reduce the power consumption of the system, powering down some modules. They also support different communication protocols and aim for several years of operation using a single battery charge. However the system available on the market do not turn off the microcontroller. These systems use sleep states to reduce the current of the microcontroller. This implies that the RTC and microcontroller are always on. The proposed solution in this document uses a different solution in order to achieve a lower consumption when in a sleep state. The proposed solution turns off the microcontroller, the transceiver module, and the sensors without the need of any additional hardware such as a separated regulator or transistors. Additionally the system only uses two regulators. One of them is only used to power the RTC, which is always on. A second regulator is used to power the microcontroller, transceiver module, and the sensors. It uses the mechanism of a DC-DC voltage regulator, that when disable, disconnects the load from the input and a RTC to generate interruptions at specific periods of time to enable the DC-DC. The aim of this design is to reduce the sleeping current since the system spends most of its time in a sleep state. In addition it aims to reduce the hardware used in order to decrease the cost of the whole system. The design of the system is divided in the following sections:

- Power management
- Real Time Clock
- Communication module
- Microcontroller
- Interface of the sensors
- Working principle of the system

The Figure 2 is a block diagram of the embedded system of this thesis.

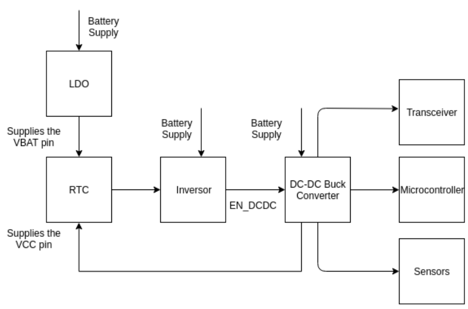

Figure 2: System schematic.

3.1. Power management

There are different types of regulators such as LDO (Low-Dropout Regulator) and DC-to-DC that converts a direct current (DC) from one voltage level to another voltage level at its output. LDOs always convert an higher input voltage to a lower output voltage. On the other hand, DC-DC converters can convert from a higher voltage to a lower voltage, as well as convert from a lower voltage to a higher voltage. The first corresponds to a buck converter and the second is called a boost converter. It is important to consider the efficiency of the regulators to be used as well as their quiescent currents (currents of the electronic system when there is no load at its output). Consequently the different types of regulators are going to be study in terms of efficiency and quiescent current in order to choose the best one for each regulator required in the system. Since the LDO (Low-dropout regulator) has a limited efficiency $\sim \frac{Vo}{Vi}$, LDO losses are only acceptable for lower currents. LDOS are ideal to regulate the voltage of always on and low power integrated circuits such as the RTC. The RTC is used to keep the time and to generate alarms in order to wake up the system. LDOs are not appropriated to supply current demanding circuits such as the microcontroller or the radio frequency circuit. For that reason another regulator should be used to increase the efficiency of the overall system. In order to choose between a boost converter and buck convert it is necessary to compare the range of input/output voltages and efficiency of the regulators for higher loads. The system uses AA alkaline batteries (at fully charge provide 1.5V) as power source. Normally a discharge alkaline battery has a voltage level of 0.8V. The system can also work with lithium batteries. For this batteries the voltage swings from 4.2V (fully charged) to 3.0V (discharged). Looking at the main modules of the system such as the microcontroller, the transceiver module and the RTC it is important to understand the input voltage range of these modules. The microcontroller works from 1.8V to 3.6V, the transceiver module works from 2.1V to 3.6V and the RTC works from 1.71V to 5.5V. The LDO will lose regulation when the input voltage is less than the output plus the dropout voltage. As for the DC-DC it will only lose the regulation when the input voltage is lower than the output voltage plus a threshold voltage. For this operation mode the DC-DC stops the regulation and the input voltage appears at the output of the regulator. Since a buck regulator compared to a boost convert is more efficient it was used to power the more demanding parts of system such as the microcontroller, LoRaWAN module and the sensors. The Fig. 3 and the Fig. 4 are efficiency curves for two types of DC-DC. Fig. 3 is a boost converter, namely the TPS61291 from Texas Instruments and Fig. 4 is a buck converter, TPS627431 also from Texas Instruments.

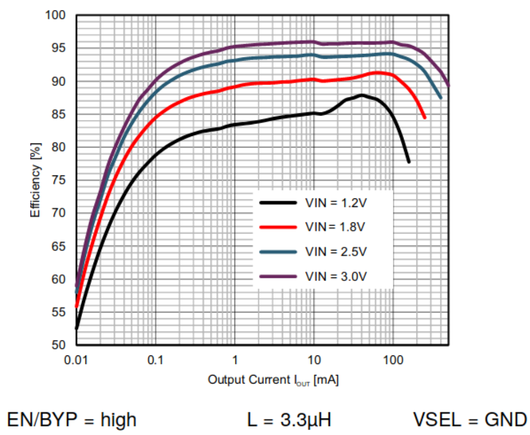

Figure 3: Efficiency curves of TPS61291 boost converter [5]

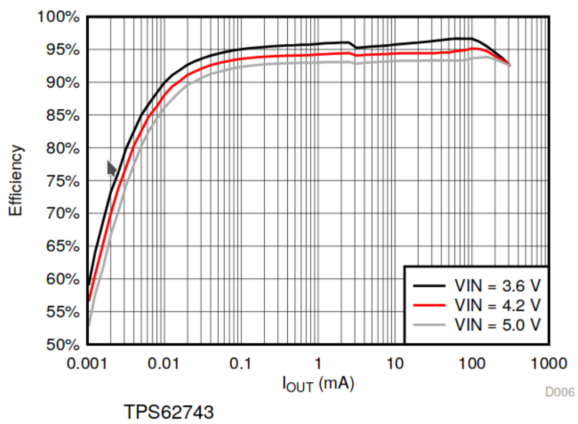

Figure 4: Efficiency curves of TPS627431 buck converter [6]

By comparing the two it is possible to conclude that for high power modes the use of a buck converter is a better option. This is due to the fact that the efficiency of a buck is typically higher than 90 %.

3.2. Real Time Clock

In order to generate interruptions to wake up the system, enabling the DC-DC buck converter that powers the microcontroller, the LoRaWAN module and the sensors, a real-time clock is used. A RTC is a integrated circuit that performs the time keeping and generates interruptions through the use of alarms. The configuration of the RTC is performed using I^2C or SPI by writing or reading the appropriate registers.

3.3. Communication module

Although the Sigfox protocol presents better characteristics, it is a paid protocol which requires a contract with the Sigfox company. Since the Lo-

RaWAN network is free to use, it is ideally to prove the concept of the Long Range Networks. If, in the future, another protocol is to be used the only change required in the system is the change of the transceiver module. For this reason, the module selected for the system was the RN2483 from MicroChip. It is suitable for simple long range sensor applications with an external MCU. The communication with the host MCU and the transceiver module is accomplish by sending commands from the MCU to the transceiver via UART. The transceiver then responds to the command letting the microcontroller know the result of the command given. The module is only compatible with LoRaWAN class A and supports LoRa modulation, GFSK (Gaussian Frequency Shift Keying) and FSK (Frequency Shift Keying) modulation. It has an operation frequency band from 863 MHz to 870 MHz or from 433.050 MHz to 434.790 MHz. The maximum sensitivity is -146 dBm which gives a range of 15 km at suburban zones and 5 km at urban zones.

3.4. Microcontroller

The microcontroller used is the PIC18LF46K22 a 8 bit microcontroller. As for the characteristics of the microcontroller it has 1024 bytes of EEPROM, four crystal modes, it can support a crystal with a frequency up to 64 MHz, an Analog to Digital converter (ADC), two analogue comparators and a Digital to Analogue Converter (DAC). The microcontroller only needs external components for the MCLR pin and for the supply pins where a decoupling capacitor is needed. For the digital part the microcontroller has I^2C, SPI, EUSART (Enhanced Universal Synchronous Asynchronous Receiver Transmitter) and input/output ports. In addition it was several analogue input ports that can be connected to an ADC in order to convert an analogue signal to a digital one. As for the programming the microcontroller is programmed using ICSP (In System Programming). In the case of a PIC microcontroller a Pickit can be used to transfer the program from a computer to the flash memory of the device.

3.5. Interface of the Sensors

Since the microcontroller has different types of connections from digital to analogue any type of sensor can be connected to the system. The only constrain is the voltage supply of the sensor. The system only provides a 3.3V voltage supply coming from the DC-DC. This means that if a sensor requires an higher voltage for working it will be necessary to use an external power supply for the sensor. For the communication with the microcontroller there are output pins for the EUSART, I^2C, SPI and digital pins that can be define as outputs. On the other hand for input pins there are comparators, analogue pins and digital pins that can be used to receive/measure data from the sensors.

3.6. PCB design

In order to connect the different elements of the embedded system, namely the RTC, microcontroller, transceiver module, and sensors a PCB was design and produced. In Fig 5 a 3D image of the PCB is presented. All the different modules used are identified.

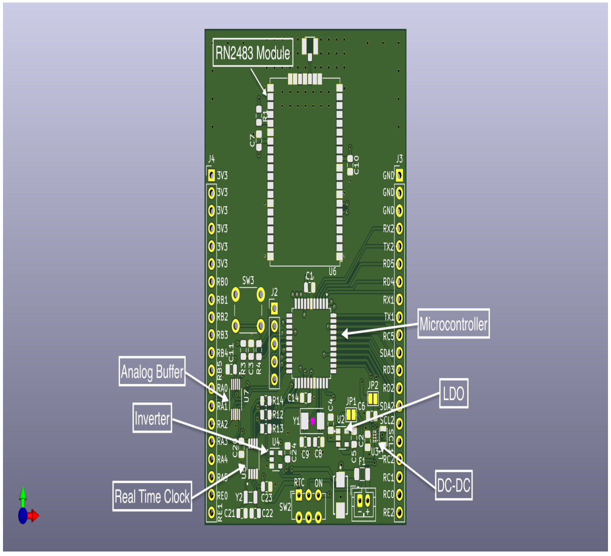

Figure 5: 3D view of the PCB.

3.7. Working principle of the system

The program of the embedded system needs to follow a specific logic. The Fig.6 is a graphical representation of the logic used to program the microcontroller. When the system is powered on for the first time the microcontroller and the RTC are not programmed. For that reason, the switch SW2 should be in the ON position, left position (In the PCB 3D image the SW2 is located at the bottom center of the PCB). This switch is used to change the enabling signal from the DC-DC. When at the ON position it connects the enable of the DC-DC to the battery. On the other hand, when the switch is in the RTC position the DC-DC enable signal is connected to the RTC. Following that procedure it is now possible to use the PICKIT to flash the microcontroller with the program. After flashing the microcontroller the program will run for the first time. Since the RTC is not configured the program will follow the right branch in the figure 6. The user will need to look at the network server for a message of the node that is being configured. After receiving a message at the network server the user knows that the node has successfully join the network and that the configuration of the RTC has been performed. At this time the user needs to switch the SW2 to

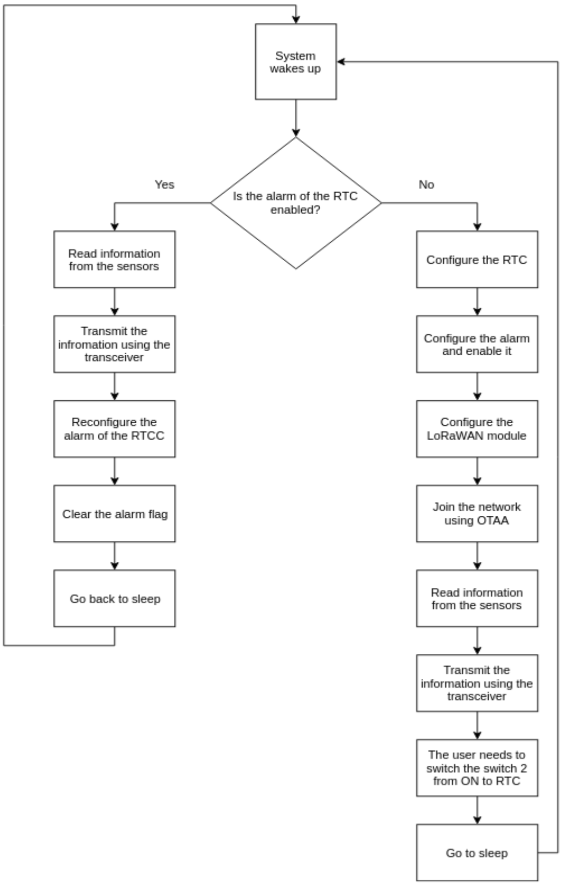

Figure 6: Program logic.

the RTC position (right position). From that moment on, the system will wake up when the alarm of the RTC fires, read values from the sensors, transmit those values using the transceiver and go back to sleep again. The user does not need to perform any action and the system will run until the battery runs out. In order to program the system several libraries were created.

4. Results

The system was tested in order to evaluate it performance.

4.1. Hardware measurements

At the input of the system, the sleep current measured with an UT39B multimeter from UNI-T was $370nA$. As for jumper two (a current probing point to measure the current from the DC-DC to the microcontroller, LoraWAN module abd sensors) a probe current connected to an oscilloscope was used in order to measure the current supply of the microcontroller, LoRaWAN module and sensors. In order to see the different variations of time and current, using different spreading factors a set of measurements were performed.

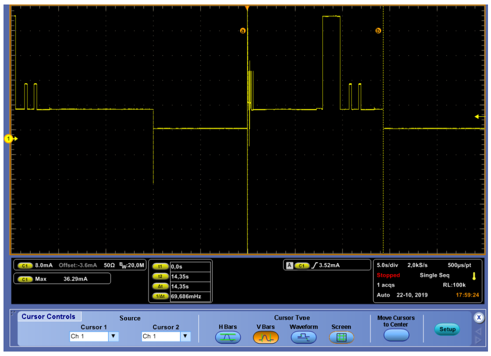

Figure 7: Oscilloscope image for a Spreading Factor of 12 with the wake up time

In Figure 7 it is possible to visualize the wake up time of the system. Moreover, it is also possible to visualize the current supply when the system is transmitting a message. In order to better visualize the time that a transmission takes, a second image of the oscilloscope was acquire.

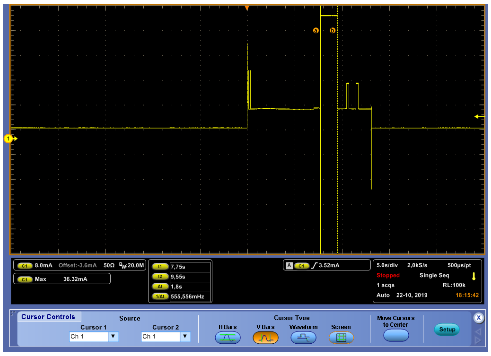

Figure 8: Oscilloscope image for a Spreading Factor of 12 with the transmission time

The same tests were performed for a spreading factor of 11, 10, 9, 8 and 7. Table 1 shows the values the were measured for the different spreading factors

Table 1: Measured values for different spreading factors

Spreading Factor	Time ON	Time transmitting	Transmitting current	Idle current
12	14,35s	1,8s	36,32mA	6,4mA
11	13,15s	1,8s	36,32mA	6,4mA
10	11,8s	450,0ms	36,22mA	6,4mA
9	11,6s	240,0ms	36,21mA	6,4mA
8	11,45s	140,0ms	36,27mA	6,4mA
7	11,4s	80,0ms	36,24mA	6,4mA

In order to calculate the battery life of the system it was necessary to calculate the average current of the system using the equation:

$$I_{avg} = \frac{I_{on} \times T_{on} + I_{sleep} \times (T_{ci} - T_{on})}{T_{ci}}, \qquad (1)$$

where the T_{ci} is the time cycle and T_{on} the ON time. Then after having the average current the following equation was used to calculate the battery life in hours

$$Battery\ Life = \frac{Battery\ Capacity\ (Ah)}{Average\ current\ drain}, \qquad (2)$$

The system transmits every hour so the time of cycle is equal to 3600 seconds. Using currents from Table 1, a sleep current of $370nA$ and a idle current of $6.4mA$, it is possible to calculate the battery life of the system for different spreading factors. If a battery of 3600 mAh is used, the battery life, for a spreading factor of 12, is equal to 10 years.

4.2. LoRaWAN tests

In order to test the LoRaWAN network, a set of nodes were deploy in an agriculture field. The field is located in Alcobaça more precisely in Quinta da Ruiva. Figure 9 shows the localization of the nodes and the gateway.

Figure 9: Sensor nodes localization using Google Maps

The gateway is an OLG02 Outdoor Dual Channels LoRa IoT Gateway. Despite of the name of the gateway, it only uses one channel to transmit and another channel to receive. Since the gateway used is a single channel gateway, it is not possible to fully evaluate the LoRaWAN network. A better gateway should be considered in order to measure the performance of the system. However, and considering the limitations of the gateway, the same gateway was configured with a spreading factor of 9 and a bandwidth of 125 kHz. The frequency of the receiving channel is 868.3MHz. For the transmitting channel the frequency is also the same. In order to be tested for the embedded system designed in this work with the gateway, all channels were disable excepted the channel that has a frequency of 868.3MHz.

5. Conclusions

The main achievements of this work was the development of an embedded system with an ultra low sleep current. There are several embedded system on the market and only a few of them have such a low sleeping current. With a sleeping current of 370 nA, the system produced in the scope of this thesis can operate for several years, with a single battery charge, depending on the capacity of the battery used. By using a Real Time Clock in order to turn off the microcontroller, a LoRaWAN module and sensors, with optimal power management, the system is able to reach a ultra low sleep current. The main difference to other systems available on the market is the ability to turn off completely the microcontroller. In addition the RTC is used to enable the DC-DC that turns on the microcontroller, transceiver and sensors. Most of the systems used in precision agriculture use the sleep mode of the microcontroller instead of power gating it. The RTC is used to wake up the microcontroller from the sleep mode. Moreover, by using a buck DC-DC convert, the efficiency of high power modes can reach 90% which also improves the overall performance of the system. Another important aspect is the way the embedded system uses the LDO. The LDO only has load when the RTC is in sleep mode. When the DC-DC wakes, it releases the load from the LDO by powering the RTC from the VIN pin. It is also important to refer that the system developed can work with several protocols, such as UART, SPI, I^2C, One-Wire and it is able to convert analog signals to digital ones by using an ADC in the microcontroller. This means that, despite the target application for the design being an agriculture IoT node, the embedded the system designed is very flexible since it can work with several types of sensors and can be used for a wide range of applications.

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