# FEASIBILITY STUDY OF LORA BASED CONTROLLER FOR DRIP IRRIGATION SYSTEMS USING MULTI-HOP STAR TOPOLOGY NETWORK

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***Abstract:*** *The use of drip irrigation systems has become widespread in recent years, but controlling them on a large scale can be difficult. One solution to this problem is to set up a wireless sensor and actuator network (WSAN). However, using wireless technology in agriculture can be challenging, as it requires long battery life, long-range capabilities, and low cost. Recently, various technologies and protocols have been developed to address these challenges, such as LoRa, a proprietary wireless modulation technology. The LoRaWAN network protocol, which is built on top of LoRa, has been studied as a solution. However, this paper suggests a simpler and more cost-effective protocol specifically designed for controlling drip irrigation systems. The project described in this paper includes the implementation of hardware and software for wireless nodes and the development of a GUI app for controlling drip irrigation systems.*

***Keywords:*** *component; drip irrigation; lora; LoraWAN; WSAN; low power*

## I. INTRODUCTION

### *A. Basics of Drip Irrigation*

Drip irrigation is a method of microirrigation that has gained popularity in recent years due to its ability to increase crop yields and decrease water usage. Water is distributed through a network of valves, pipes, tubing, and emitters, and is dripped directly to the root zone of plants either from above or below the soil surface.

Figure 1 illustrates the general layout and components of a typical drip irrigation system [1]. The water is first pumped to the distribution network at high pressure, then it goes through a fertilizer solution tank and is filtered to prevent clogging of emitters. The filtered water flows through the main pipe and valves control its distribution to emitters in specific areas.

The average lifespan of a drip irrigation system is about 5-10 years, with an annual maintenance cost of about 3% of the installation cost [2]. This method of irrigation is preferred because it significantly reduces water usage, can be used on various types of terrain, and has the potential to be automated, reducing or eliminating human interaction.

Additionally, the precision of drip irrigation allows farmers to apply water and nutrients directly to the roots of specific plants, reducing the risk of water and nutrient waste. This also helps to minimize the potential for disease and pest issues, as the water is delivered directly to the roots and not on the leaves of the plants. Drip irrigation also allows farmers to apply water and nutrients at specific intervals, ensuring optimal growth and yields. Furthermore, drip irrigation can be used in conjunction with other irrigation methods, such as surface irrigation and sprinkler irrigation, to create a more efficient and effective irrigation system. Overall, drip irrigation is a cost-effective and efficient method of irrigation that has many benefits for farmers and the environment.

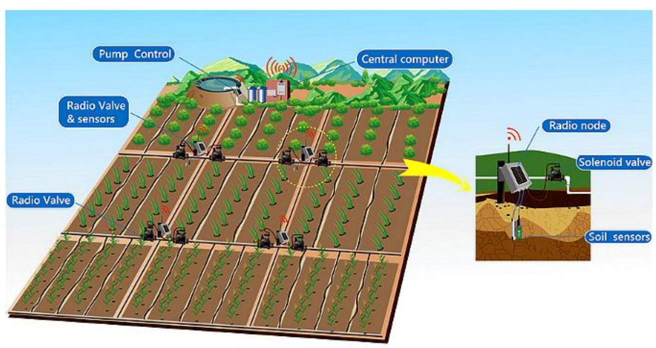


Figure 1. Typical drip irrigation system layout [1].

*B. Related Work*

The integration of computers and electronics in agriculture, particularly in irrigation systems, has led to new challenges in engineering and research. Specifically, wireless control of actuators for agricultural purposes poses technical difficulties due to budget and power constraints. However, in recent years, various technologies have been developed to effectively establish WSANs (Wireless Sensor and Actuator Networks) [3]. Additionally, multiple studies have been conducted to evaluate their impact on transforming agriculture [4].

In recent years, technologies such as ZigBee™ and Bluetooth have been widely used to establish low-power, short-range, multi-hop networks [5,6,7] that utilize a mesh network topology. While these standards are considered low-cost systems, their limited coverage (approximately 100 meters) is a significant drawback that makes them difficult to implement in large-scale irrigation systems. On the other hand, cellular networks such as GSM or LTE can provide long-range transmission to form WSANs, but they have been tested to control irrigation systems [8], they require solar panels for each node to compensate for the higher power consumption of cellular networks. Also, their dependence on the availability of mobile networks is questionable for some remote rural areas.

An alternative solution for establishing long-range, low-power and low-cost WSANs is the low-rate transmission technology referred to as LPWAN (Low Power Wide Area Network). The main differences between LPWANs and the previous technologies are the use of long-range radio links, deployment of star network topologies and low-rate data transmissions. Sigfox, Ingenu, NB-IoT, DASH7, and LoRaWAN are examples of LPWANs [9]. All of these technologies have coverage distances of several kilometers, each with their own advantages and disadvantages [10] in terms of cost, scalability, power consumption, data rate and so on.

As wireless control of drip irrigation requires very small data exchange, any of these network types can be used. Among them, Lora is a relatively new technology, on top of which the LoRaWAN protocol operates. It has the highest radio link budget and the best "cost vs. range vs. power" trade-off among its competitors [10].

That is why, for this project, the LoRa modem has been chosen as a radio link.

## II. TRANSMISSION PROTOCOL

### *A. Overview of Lora Physical Layer*

Lora is a proprietary spread spectrum modulation technique that is based on Chirp Spread Spectrum modulation (CSS) and designed by Semtech [11]. It works on unlicensed frequency bands, usually in the sub-GHz category.

The Lora modulation uses frequency chirps with a linear variation of frequency over time to encode information. This method sacrifices data rate for sensitivity within a fixed channel bandwidth [12-13]. It also implements a variable data rate by utilizing the adjustable parameter known as spreading factor, which allows network performance to be optimized within a constant bandwidth by trading data rate for range or power [14].

The linearity of the chirp pulses allows for the removal of frequency offsets between the receiver and transmitter, which are equivalent to timing offsets. This also increases the immunity to the Doppler effect, which is equivalent to a frequency offset. The decoder can tolerate an offset up to 20% of the bandwidth without impacting performance. This means that crystals in transmitters do not need to be manufactured to extreme accuracy, thus reducing the cost of Lora transmitters. Lora receivers can lock on to frequency chirps received with a sensitivity of -130 dBm [15]. The typical out-of-channel selectivity (the maximum ratio of power between an interferer in a neighboring band and the Lora signal) is 90 dB, and co-channel rejection (the maximal ratio of power between an interferer in the same channel and the Lora signal) of Lora receivers is 20 dB [11]. Compared to traditional modulation schemes such as Frequency-Shift Keying (FSK), Lora modulation excels at low-power and long-range transmissions. Additionally, Lora uses variable error correction technique that improves the robustness of the transmitted signal at the expense of redundancy.

Furthermore, Lora's ability to transmit data over long ranges, with low power consumption and at low data rates, makes it well-suited for applications such as IoT and M2M communications, where devices need to operate for long periods of time on batteries, and where data transmission rates are relatively low. Additionally, Lora's use of unlicensed frequency bands means that it can be used without the need for costly and complex licensing processes. This makes it an attractive option for applications in remote or rural areas where traditional wireless networks may not be available or cost-effective.

LoRa modulation bitrate $R_b$ is defined as:

$$R_b = SF * \frac{\left[\frac{4}{4 + CR}\right]}{\left[\frac{2^{SF}}{BW}\right]} \ bits/seconds$$

Where the different parameters are:

SF – spreading factor (7…12);

BW – bandwidth (Hz)

CR – coding rate (1…4)

Semtech's LoRa modules have a range of adjustable parameters that allow designers to select the optimal settings for their specific application. One of the key considerations for low-power applications is the use of a duty-cycled reception mode known as Channel Activity Detection (CAD) mode.

In CAD mode, the LoRa modem continuously monitors the configured channel for the presence of a preamble, which is a specific sequence of symbols that indicate the start of a transmission. When the modem detects the presence of a preamble, it alerts the companion microcontroller (MCU) which can then decide whether to keep the radio module awake and continue demodulation, or put it back to sleep. This allows the system to conserve power when no transmission is detected.

When the MCU puts the module into CAD mode, the LoRa switch to the CAD receiver phase and starts looking for the correct preamble on the configured channel. After some time, it enters the CAD processing phase and triggers a CadDone interrupt, which signals the completion of the CAD operation. Then, the module automatically puts itself into Standby mode. If the preamble has been detected, the CadDetected interrupt is also triggered and the microcontroller takes the responsibility to put the module into receiver mode, ready to receive the actual data transmission. If the preamble is not detected, the module is put into sleep mode to conserve power.

It's worth mentioning that, the CAD mode can be used in different scenarios, it can be used to detect if there's any activity in the channel before sending any data, or it can be used to detect if there's any interference or any unwanted data transmission in the channel.

Additionally, Figure 2 shows the current consumption level for one cycle of CAD operation [16], which can help designer to evaluate the power consumption of CAD mode and compare it with other modes.

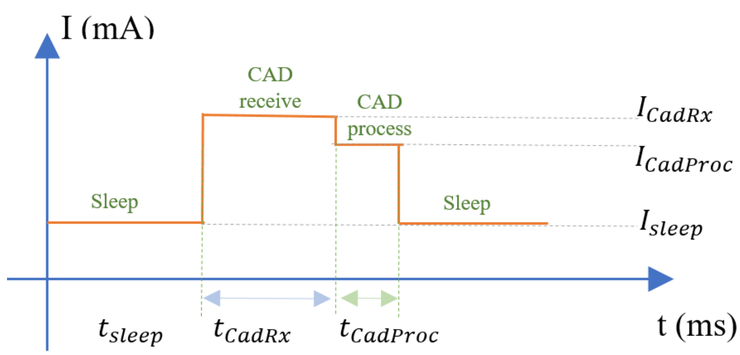


Figure 2. LoRa CAD timing.

Time and current values depend on the configured settings of the LoRa. They can be calculated as:

$$t_{CadRx} = \frac{32}{BW} + \frac{2^{SF}}{BW}$$

$$t_{CadProc} = \frac{SF * 2^{SF}}{1.75 * 10^6}$$

*B. LoRaWAN overview*

LoRaWAN is a medium access control (MAC) layer protocol that uses LoRa modules as a radio link between wireless nodes. In the Open Systems Interconnection model (OSI model), LoRa is considered as the "Physical layer" and LoRaWAN is considered as the "Data-link layer".

LoRaWAN is implemented as a "star-of-stars" topology, which consists of three main components: "end devices", "gateways (i.e. base stations)", and the "network server", as shown in Figure 3.

*End-devices* are the low-power consumption nodes that communicate with gateways using LoRa.

A *Gateway* receives packets from end-devices and forwards them to a network server over an IP backhaul interface, such as Ethernet or 3G, allowing for a higher throughput. Multiple gateways can be deployed in a LoRaWAN network, and the same data packet can be received (and forwarded) by more than one gateway.

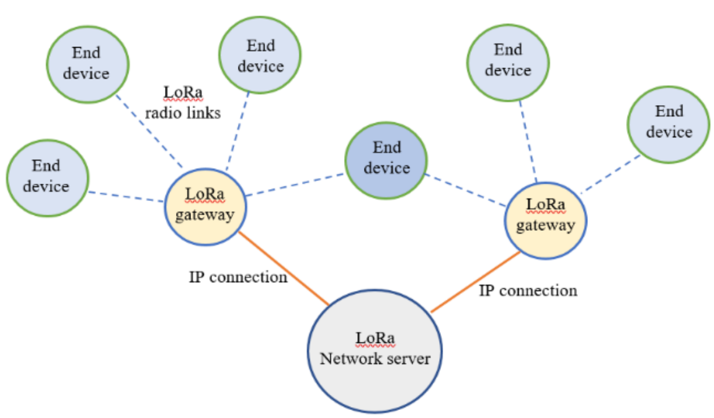


Figure 3. LoRaWAN system architecture.

The *Network Server* decodes the packets sent by the end-devices, removes duplicates, and generates reply packets through the appropriate gateway [17].

Gateways must be equipped with a multichannel receiver module to be able to receive messages simultaneously from multiple channels, with different data-rate and variable payload length. This makes gateways more expensive than other parts of the system. By deploying additional gateways, network coverage can be extended when single-hop transmission range is not sufficient.

The LoRaWAN protocol has three different classes of end-devices, Class A, B and C, to address the various needs of different applications. The most power-efficient type is Class A, where each uplink (from end-device to gateway) transmission is followed by two short downlink receive windows (from gateway to end-device). End-devices of this class are well suited for use in irrigation control systems. However, using the standard LoRaWAN protocol [17] requires setting up gateways and network servers, and connecting multiple gateways to the network server requires another kind of high throughput connection like 3G, which increases the overall cost of the system.

In order to decrease the cost, a simpler data transfer protocol can be used at the expense of lower flexibility. This can be achieved by simplifying the data transfer protocol and removing the need for gateways and network servers, making the system more cost-effective. The trade-off is that the system will have less flexibility and will not be able to handle as much data or support as many devices as a standard LoRaWAN network.

It's important to note that, LoRaWAN is one of the most popular protocols that uses LoRa technology for long-range, low-power communication.

*C. The deployed data transfer protocol*

A master (central) station has been designed to eliminate the need for gateways and network servers, by relaying packets between the control application on a PC and end-device nodes.

Figure 4 shows an overview of this simplified, low-cost communication architecture.

Unlike gateways in LoRaWAN, the master station does not have to handle simultaneous multichannel reception, as transmissions are always initiated by the master and the nodes only send back data when requested. If a larger area needs to be controlled, a longer communication range can be achieved by using repeater nodes. In this architecture, all the nodes can act as repeaters, eliminating the need for separate repeater modules or additional gateways, as in LoRaWAN.

The routing path of the packet is decided in the central PC and added to the packet itself, so that intermediate nodes know where to forward the packet. The flow of operations for the end-device is shown in Figure 5.

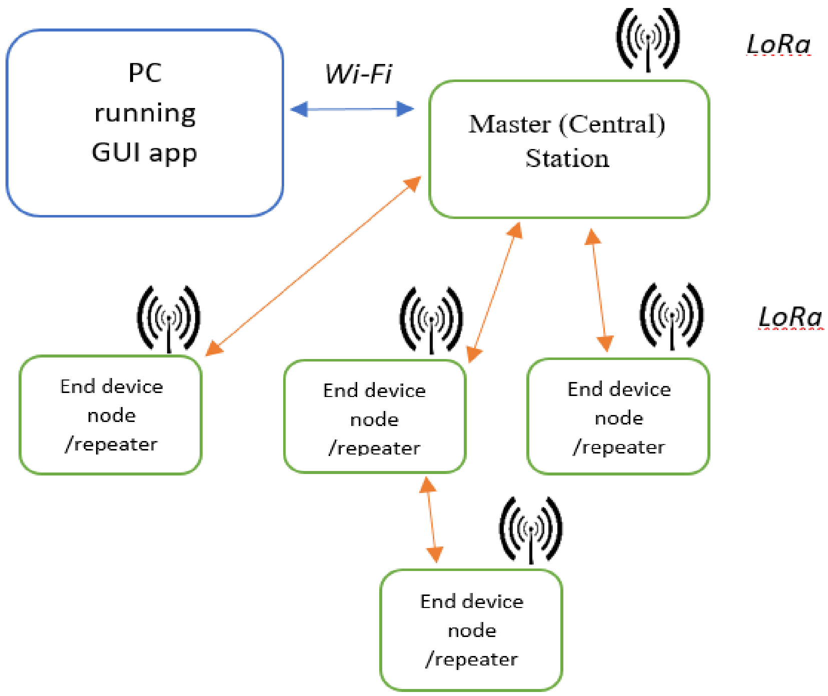


Figure 4. Communication architecture designed for the project.

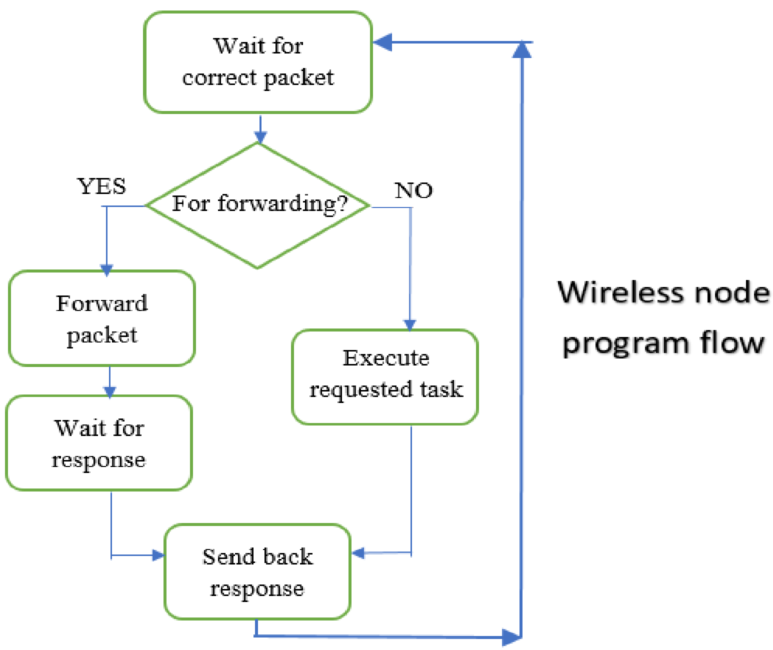


Figure 5. Wireless node program flow.

## III. OBJECTIVES

The objective of this project is to create an affordable system for managing drip irrigation systems, like the one illustrated in Figure 1. It is essential for the system to be dependable, simple to install, and easy to use, even for large-scale applications. The main objectives of the project include:

- Designing and creating wireless control nodes that can both monitor environmental data and control actuators;
- Developing firmware for the nodes that meets low-power requirements.
- Developing a graphical user interface application that allows for central control of the irrigation process.

The key specifications for the system include:

- A minimum battery life of two years, assuming that each wireless node receives commands four times a day and is equipped with four D-size, typical alkaline, non-rechargeable batteries.
- A range of at least 2 km with a single transmission and the ability to extend the range by using repeaters.
- Lower cost and easier setup compared to a LoRaWAN network.
- The ability to support up to 1000 different nodes in one system
- The ability to control up to four actuators independently in each node to reduce the cost of actuators that are placed close to each other.

### *A. System components*

The control of drip irrigation involves managing the actuators, which in turn alters the distribution of water through the valves. As high pressure and high-volume water flow must be regulated by battery-powered, low-energy units, selecting the appropriate type of valve is crucial.

Internally piloted solenoid valves [18], which are operated by latched solenoids, are the most commonly used option for controlling high pressure with low power. A latched solenoid typically has a permanent magnet to keep the armature in place once it has been moved, so no power is needed to maintain the state. The position can be changed by applying a short-pulsed voltage of the opposite sign to the coil.

The standard latched solenoids used in the system require a pulsed signal of 24V with a duration of 50 milliseconds, and the coil resistance is 9 Ω. Therefore, each wireless node must be able to produce a stable 24 volts from a lower supply voltage when needed, providing sufficient current without compromising overall low-energy consumption.

## IV. SYSTEM DESIGN

To comply with necessary specifications, components were selected based on their cost-effectiveness and energy efficiency, while still maintaining dependability. The functional blocks of each board are depicted in Figure 6.

### *A. Component Selection*

The *Ra-02* is a RF module that utilizes the Sx1278 LoRa chip developed by Semtech and functions in the 433 MHz frequency range. It connects to the microcontroller, which is the Atmega328P, through an SPI interface. The microcontroller was chosen for its low power usage and affordability.

The power source includes four D-size batteries connected in series, providing a 6V supply and a Low-dropout linear voltage regulator (LDO) with a fixed 3.3V output, which powers both the microcontroller and the LoRa module, which can operate within the voltage range of 1.8V to 3.4V.

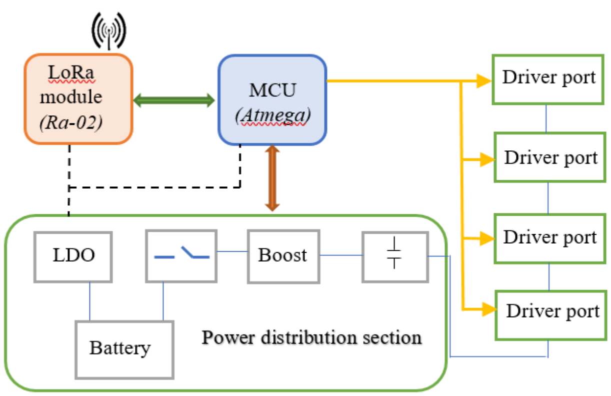


Figure 6. Board architecture of wireless end-device.

Furthermore, a boost converter is utilized to supply 24V to operate the actuators. The energy needed to change the position of the latched solenoid can be determined, disregarding the reactive components, using the following equation:

$$E_{\substack{state \\ change}} = \frac{{V_s}^2}{R_s} * T_s = \frac{(24V)^2}{9\,\Omega} * (50\,ms) = 3.2\,J$$

Supplying this energy in a brief time pulse necessitates a current of I=24V/9Ω=2.7A and an electrical charge of q=I*Ts=108 mC needs to be provided. Using the power directly from the alkaline batteries would result in voltage drops and system failures since they are not capable of providing high peak currents. To prevent this, a tank capacitor is added at the output of the boost converter to be charged over a longer period of time, and then release the current pulse as needed. The minimum value for the capacitor is:

$$C = \frac{q}{V_s} = \frac{108\,mC}{24\,V} = 4.5\,mF$$

A large electrolytic capacitor with a nominal value of 4700μF was selected. However, another issue arises when using a large output capacitor in the boost converter circuit, the start-up current will be excessively high, and many small boost converter ICs may malfunction. To overcome this, a converter with built-in soft-start functionality, such as the IC TPS61175 from Texas Instruments [21] was used, this increases the output voltage gradually, allowing the output capacitor to charge smoothly. The microcontroller turns off the converter when it is not in use, using the help of the high-side transistor switch.

The driver board was designed separately and can be connected to the main board through any of the designated driver ports. It is essentially an H-bridge with at least 2.7A peak current and operates with 3.3V logic level signals. The DRV8801 IC [22] fully meets the requirements.

*B. Component selection*

The same PCB board is used for both the master and end nodes. However, the master board also includes the ESP-01 (WiFi) module, and the functions of the two types of boards are determined by the firmware programmed into the microcontroller.

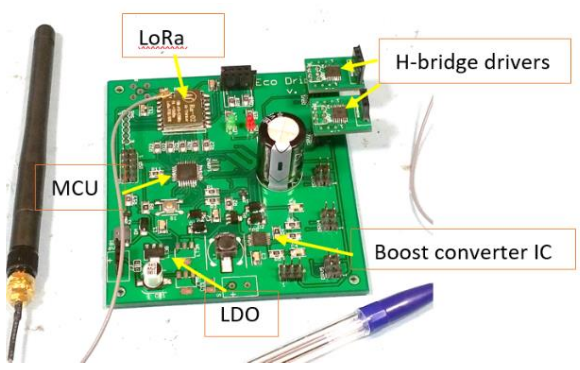


Figure 7. Assembled PCB of the wireless end-device (slave node).[25]

Figure 7 illustrates an end-device (slave node) board, with all components mounted, including two piggy-back driver modules, and Figure 8 shows the master board with the added WiFi module, but without the boost converter and tank capacitor.

The Master module establishes the WiFi Access Point (AP), receives packets from the computer and forwards them to the LoRa network, and vice versa. This allows for real-time monitoring and control of the end nodes, as well as the ability to configure and update the network as needed.

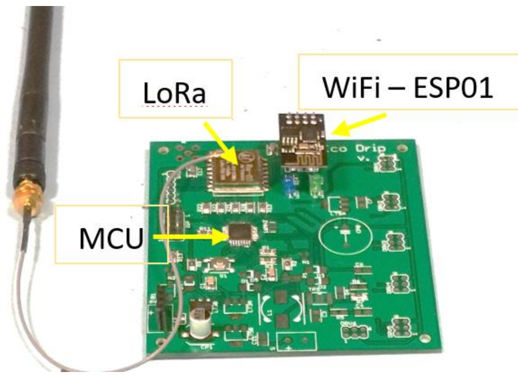


Figure 8. Assembled PCB for master (central) node.[25]

*C. Estimated Energy Consumption*

The energy storage of a typical D-size alkaline battery is around 50000 J [23]. However, taking into account the self-discharge rate of approximately 3% per year, and 10% residual, only about 85% of the initial energy can be utilized in a 2-year battery life, which is 42500 Joules for one D-size battery. In this project, 4 batteries of this type have been used, providing a total of 170000 J of battery energy, which should last for at least 2 years.

Assuming 4 daily activations and an overall efficiency of the power section of roughly 80%, the total energy spent on controlling a single solenoid actuator per day can be calculated as:

$$E_{control} = 4 * 1.25 * E_{\substack{state \\ change}} \approx 16\, J/day$$

To conserve power, end-devices employ a duty cycled CAD reception mode with a pre-defined sleep period of *750ms*. The preamble duration of the packet must be longer than the sleep period for proper reception. The packet payload is a maximum of 9 bytes, including the network ID, destination address, source address, command, output port selection, and at most 3 repeater addresses. Since the system can contain up to 1000 nodes, 10 bits of address field is sufficient. A response packet (4 bytes payload) is sent back immediately after executing the given command. The sender radio does not go to sleep mode until it receives the response or gets a timeout, therefore, a minimum preamble length is sufficient for the response packet.

As a result, the total time-on-air for both command and response packets are *970ms* and *231ms* respectively.

Table 1 shows time durations and estimated energy consumption for single radio operations, with LoRa configured with *BW*=125KHz, *SF*=10, *CR*=4/8, *TX_power*=+20 dBm.

TABLE I. ENERGY CONSUMPTION FOR SINGLE CAD OPERATION, ONE RECEPTION AND ONE TRANSMISSION

| **Operation** | **Current draw** | **Duration** | **Energy consumption (with $V_{battery} = 6V$)** |
|---|---|---|---|
| **CAD RX** | 11.5 mA | 8.5 ms | 0.59 mJ |
| **CAD Processing** | 6.5 mA | 5.9 ms | 0.23 mJ |
| **LoRa standby** | 1.8 mA | 1.6 ms | 17 µJ |
| **LoRa sleep** | 1 µA | 750 ms | 4.5 µJ |
| **MCU awake** | 5 mA | 16 ms | 0.48 mJ |
| **MCU sleep** | 10 µA | 750 ms | 45 µJ |
| **Single RX** | 16.5 mA | 970 ms | 96 mJ |
| **Single TX** | 125 mA | 231 ms | 173 mJ |
| **LDO regulator** | 12 µA | *always* | 6.22 J/day |

Considering 4 interrogations per day, the estimated daily energy consumption is equal to:

$$E_{daily} \approx 177.5\ J/day$$

Hence, *170 kJ* of total energy available in the batteries lasts approximately 958 days, which means more than 2 years of battery life.

## V. GUI APPLICATION

A graphical user interface application has been developed specifically to control a drip irrigation process. Kivy, a python framework for multitouch GUI application development [24], has been used to create it. Being a cross-platform framework, the application can be installed on different types of environments without modifying the source code. The app has been tested on Linux and Windows. In this first version of the application, the user can add, edit or remove information of solenoid valves, such as its address and output port through which the valve is controlled. In the app, wireless end-devices are divided into two types: Solenoid valve controller and Pump controller. Once the pump information is entered, it is controlled automatically based on the solenoid valves states. For example, if the user wants to turn off all the valves, the app will automatically turn off the pump and send "close" commands to other nodes. This ensures the safety of the irrigation process, preventing pump operation when all valves are closed. Figures 9 and 10 show some screenshots of the application.

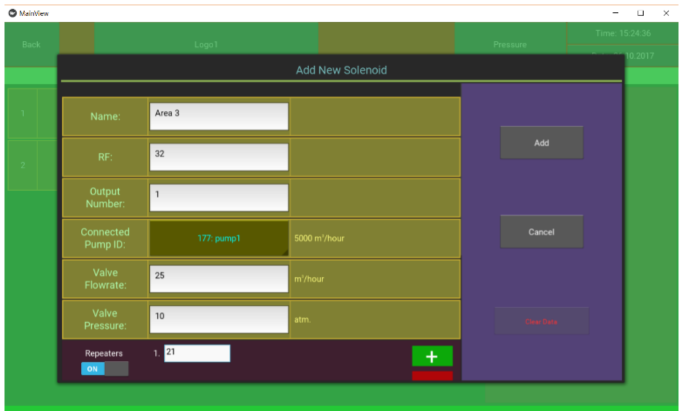


Figure 9. Adding new solenoid.


Figure 10. Control panel of all solenoid valves.

## VI. Conclusion

This paper has presented a solution for a cost-effective wireless control of drip irrigation systems that utilizes LoRa technology. The system was designed to establish a reliable radio link through the use of LoRa modules and a customized data transfer protocol that meets the necessary requirements. It has been demonstrated that this solution is more cost-efficient and less complex compared to the existing LoRaWAN protocol for this specific application.

In future developments, it is intended to integrate sensors that can gather environmental data, such as soil moisture and temperature, and enhance the control system to make automatic decisions based on the collected data. This will further improve the performance and efficiency of the irrigation system.

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