LoRa Backscatter Automated Irrigation Approach: Reviewing and Proposed System

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ABSTRACT

A migration to new irrigation techniques is needed in sub-Saharan African countries like Mali. The current irrigation system used in the country has flaws that need to be remedied. In this paper we will first present a literature review of different existing approaches of automatic irrigation systems, discuss their limits. Besides, we will propose an approach to an automatic irrigation system based on backscatter communication, which is more efficient and has a long-range and low power consumption.

CCS CONCEPTS

• **Hardware**; • **Communication hardware, interfaces and storage**; • **Wireless integrated network sensors**;

KEYWORDS

LoRa, Wireless sensor network, Backscatter communication, irrigation system

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1 INTRODUCTION

The field automatic irrigation is getting more and more subject to many researches works because it treats an important subject such as water resource efficient management, crop yields, food security and human time [1–3]. As we know, with the growth of the world population estimated to 10 billion in 2050 [4]. The traditional irrigation systems will not respond to humans' demand in terms of food from the irrigated areas because of the inefficient systems in use. The water resource scalability can occur due to the wastage of water resources during the irrigation process or to climate changes. In particular, the predominant role of agriculture in the Malian economy and the growing food needs of citizens are pushing us to introduce advanced agricultural techniques to ensure food security.

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Figure 1: Water evaporation and infiltration

The study made in this work is conducted in selingué irrigated area. Selingué irrigated areas still use the traditional irrigation system. It is based on a mechanical system. It uses gravity to convey water to crop zones unlike systems under pressure, the simple slope trickles water through open canals which are the first source of water waste by evaporation and an important quantity of water is infiltrated by the ground as showing in Figure 1

Evapotranspiration in Sahelian can be very large. It regularly exceeds rates of 10 mm per day in the dry season (from November to May) when maximum temperatures reach 40 to 45 {°}C [5]. However, it is almost impossible to get a high efficiency of water-saving by using these traditional systems.

The remaining of this paper is organized as follows: in Section 2, a state of the art of recent automatic irrigation systems is presented. In this section, we will present some of these prior systems, and describe them briefly. In Section 3, the traditional irrigation system used in selingué irrigated area is presented. In Section 4, we will discuss on existing systems and propose a more efficient system which can provide better performance compared to prior systems. A conclusion is made in Section 5.

2 STATE OF THE ART

Recently with the enhancement of wireless sensor network (WSN), many projects based on WSN have been developed for different types of application including smart cities, environmental monitoring, health monitoring, animals tracking [6–8]. Most of recent systems used for irrigation, which are based on WSN, consist of a centralized control unit, communication gateways, and the sensor nodes/tags. The main issue when designing a WSN system is the

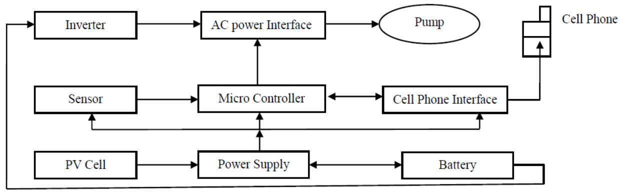


Figure 2: Block diagram of proposed circuit model

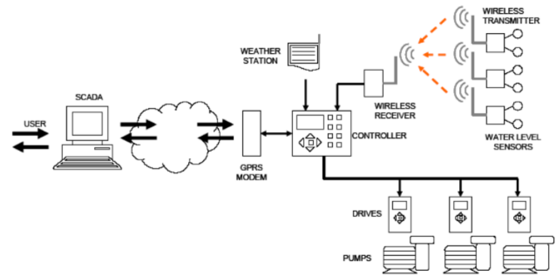


Figure 3: Schematic diagram of the proposed automation [10]

sensor node energy consumption. This directly impact on battery lifetime last.

In [9], the proposed system consists of a sensor, a micro-controller, a cell phone interface and a power source as showing in Figure 2. The sensor senses the water level of the field and sends a message to the user's cell phone to inform the condition of irrigation through the DTMF (Dual Tone Multi-Frequency) signaling. Farmer controls the motor sending assigned code to the micro-controller. To drive the system, a Photo Voltaic (PV) cell is the only source of energy. To cover the whole area, different sensors were placed in the paddy field. This system does not need any centralized unit (gateway) which is the case for most of the WSN systems. All of the sensor nodes interact directly with a given user through the cell phone interface.

The work [10] uses an automatic control system for irrigation and achieves significant improvement in terms of reduction of electrical energy consumption and water resource. The authors in this work proposed a system aiming high energy efficiency in rice crops as showing in Figure 3. The system uses water level sensors, a remote supervision system (SCADA) and wireless communication (GPRS) to measure environmental parameters and transmit to a remote user through the internet. The control of crop conditions is made by a dedicated controller, which eliminates the need for a computer on-site. In addition, the controller has an interface that allows access to its parameters and also switching over to a standard operation in case of loss of communication with the supervisory system. Communication between the controller and the supervisory system is through GPRS.

Table 1 presents a comparison between power and water consumption in four different irrigated areas in the south of Brazil where the first one uses a conventional control system and the last tree an automatic control system. According to Table 1 the reduction of water consumption was 70.7% in Area 2#, 85.2% in Area 3# and 68.5% in Area 4#, compared to the volume used in Area 1#. In terms of energy consumption, the results are correlated to those obtained in water consumption: 66.4% in Area 2#, 81.3% in Area 3# and 74.2% in Area 4#. Such a system can be used when energy consumption and efficient water resource management is an issue which is the case for most of the irrigated fields (located outside the city).

When we design an automatic irrigation system, one of the important parameters is the choice of the control algorithm since soil-plant-air is a complicated objective, diverse factors, such as soil texture, compaction, and species, may significantly impact on the water infiltration into the field. To make the system high control accuracy as well as rapid following response, the work [1] combines the on-off control algorithm and fuzzy control algorithm together.

The work [10] uses another control strategy in which three references for water level were considered: minimum reference (Refmin), maximum reference (Refmax) and average reference (Ref), two frequency values for the drive motors inverters were defined with the aim to keep the water level on the value defined by average reference (Ref) and reduce drive motors frequency according to water lever sensors value.

The automatic irrigation system of [1] includes FD (Frequency Domain) moisture sensor to determine soil water contents, actuators to control motor pumps connected to a relay station via RS-485 bus, and a pair of RF integrated module for data transmission and reception at the frequency of 433.3020MHz which act like a bridge to across the relay station and host computer as showing in Figure 4. For the relay station, there are three main tasks to perform. Firstly, it manages all data from the soil moisture sensors. Secondly, it sends commands to each actuator. Apart from both tasks, it exchanges data with the host computer by wireless communication. This relay station is also capable of setting point of regulated parameters; monitoring the dynamic values of soil moisture and turning actuators with on/off independently from the host computer. So, this system supports two kinds of operation models, i.e. host computer instruction model and automatic model. This system has been running for one year to monitor and control the Irrigation process in a greenbelt of the campus of Beijing Forestry University. According to the result of the work [1], we can see the need for a rainfall sensor to avoid useless irrigation when it will be going to rain. Otherwise, rain may occur after an irrigation process which will be a waste of system resources.

In [2], an automated irrigation system is proposed, which combines ZigBee and GPRS technologies to monitor irrigation field status on a web page by using distributed sensors nodes where each node is based on the micro-controller that controls the radio modem ZigBee and processes information from sensor devices, and water level sensor. And a central coordinated unit composed of a master micro-controller, a ZigBee radio modem, and a GPRS module to send information from different sensor nodes to a web page where the statuses of all these sensors are display graphically using graphical user interface. Figure 5(a) and 5(b) show a schematic diagram of the sensor node and the central coordinated unit, respectively.

Table 1: Comparison between traditional and automatic control irrigation system [10]

Area	Water consumption (m^3)	Power consumption (kWh)
1#	9,774	1,347
2#	2,859	452
3#	1,449	251
4#	308	347

Test period: 25/01/2011-12/02/2011.

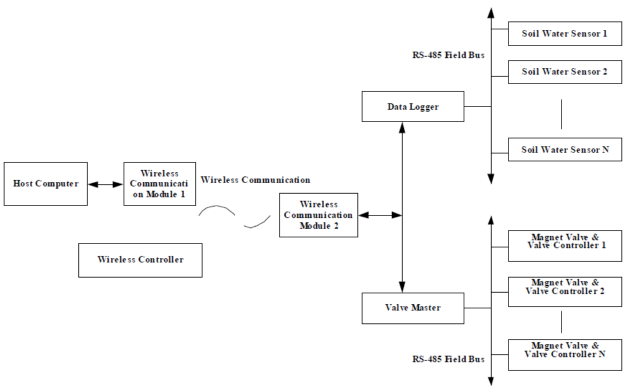


Figure 4: Diagram of precision irrigation control system [1].

A similar approach is developed in [3] to optimize water use for crops. Both of the systems are built around two main components which are wireless information unit (WIU) and wireless sensor unit (WSU) inked by radio transceivers that allowed the transfer of sensor data, implementing a WSN that uses ZigBee technology. The WSU in [3] consists of a soil-moisture sensor, soil-temperature sensor, ZigBee module and battery.

To maintain the charge of the WSU batteries, a solar panel was employed. The soil moisture and temperature data from each WSU are received, identified, recorded, and analyzed in the WIU. The WIU has a ZigBee module to receive data from sensor nodes and a GPRS module to transmit the received data to a web server via GPRS technology. The information can be remotely monitored online through a graphical application through Internet access devices. Figure 6 shows the architecture of the system.

The authors deployed several WSUs in-field to configure a distributed sensor network for automatic irrigation. The WSUs were configured such as end devices to deploy a networking topology point-to-point based on a coordinator that was implemented by the ZigBee module of the WIU.

The micro-controller of the WSUs was programmed in C compiler 4.12 (Custom Computer Services, Waukesha, WI) with the appropriate algorithm as showing in Figure 7(a). The algorithm description is as follows: when the WSU is launched for the first time, the algorithm inquires the WIU through the ZigBee module, the date and time to program the RTCC, and periodically updates it for synchronization. If the measurement time programmed in RTCC is achieved, the micro-controller enables voltage regulator, measure soil-moisture, soil-temperature, battery voltage and package the measured data with the corresponding identifier, date, and time to be transmitted via ZigBee module. After dis-enable the voltage regulator and sending data, the micro-controller is set in sleep mode for a certain period according to the sensor sampling rate desired, whereas the internal RTCC is running to allow energy savings.

Master micro-controller in WIU was programmed with the algorithm in Figure 7(b). The first task of the program is to download from a web server the date and time through the GPRS module. If a new WSU joint the network, it will be registered before and send it the date and time. If the measurement time programmed in RTCC of WIU is achieved, the WIU sends data to the webserver and get new values of WSUs, in case of scheduled irrigation, scheduled irrigation is performed. If WIU receive new data from the WSUs, the data will be recorded and the soil moisture and temperature data are compared with programmed values of minimum soil moisture and maximum soil temperature to activate the irrigation pumps for a desired period. If the push button on WIU is pressed, manual irrigation is performed.

Four different irrigation actions (IA) are implemented in the WIU algorithm:

(1) fixed duration for manual irrigation with the push button;

(2) scheduled date and time irrigation through the web page for any desired time;

(3) automatic irrigation with a fixed duration, if at least one soil moisture sensor value of the WSN drops below the programmed threshold level;

(4) automatic irrigation with a fixed duration, if at least one soil temperature sensor value of the WSN exceeds the programmed threshold level.

The above-mentioned techniques for automatic irrigation systems suffer from the constraints relative to the range and the power consumption. The range provided by the communication technologies (ZigBee, GPRS, GSM or Bluetooth) used for short-range communication (sensor node to Gateway or coordinator) scales with the power consumption of the nodes. Hence, in order to provide both a long range and low power consumption, a promising solution will be to use a Low Power Wide Area Network (LPWAN), for example, SIGFOX, LoRa or NBIoT [11].

The system proposed by [11] consists of sensor nodes distributed over the irrigation surface with a concentrator or gateway next to the pumping station, local nodes (hydrants and monitors) connected by LoRa technology to the gateway, consisting of a LoRa module. The authors use LoRa communications at the local level, and SIGFOX communications to access IoT platforms. These two communication technologies have better characteristics compared

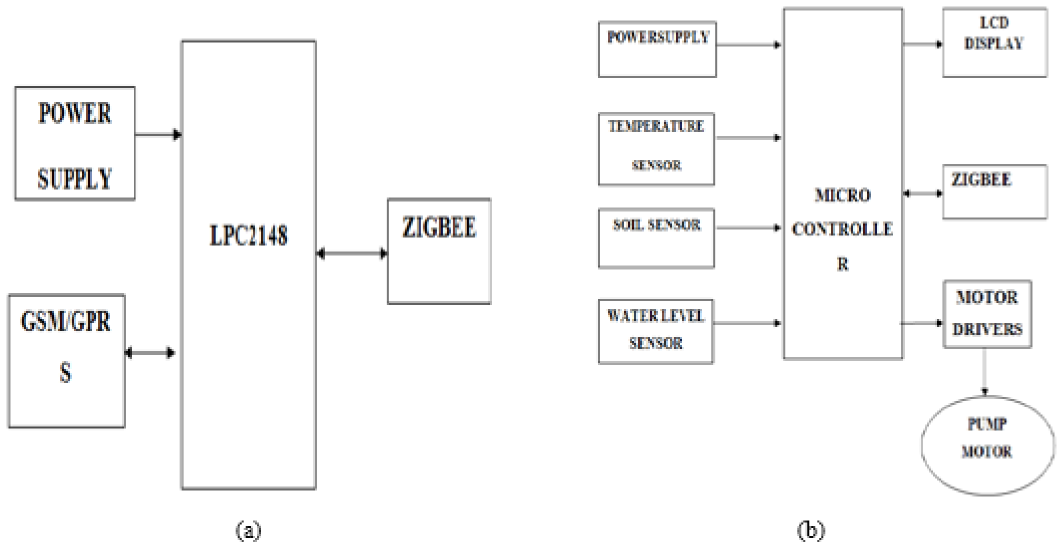


Figure 5: Schematic diagram of: (a) the sensor node and (b) the central coordinated unit (CCU) [2]

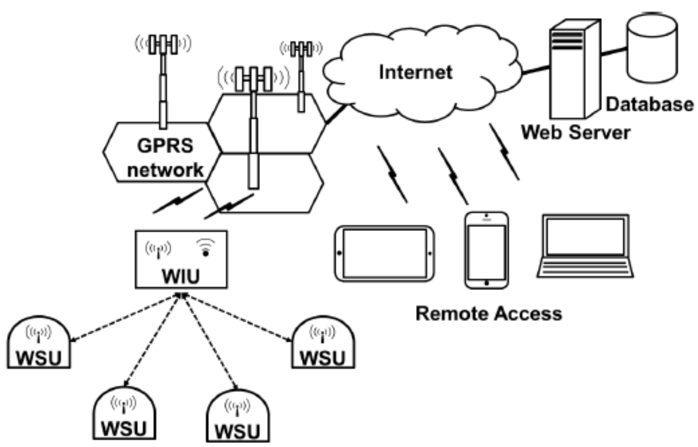
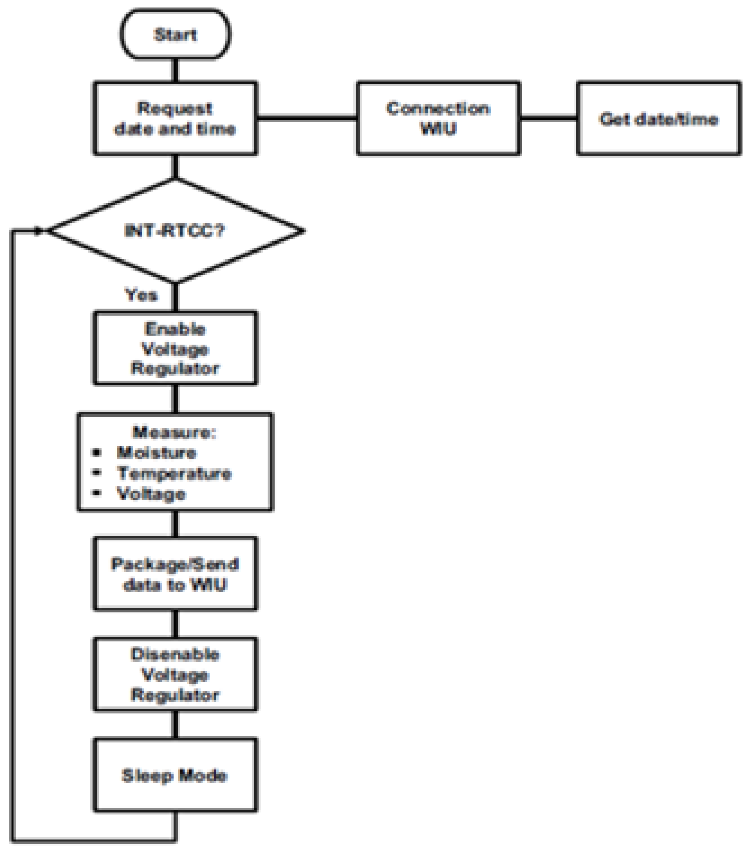
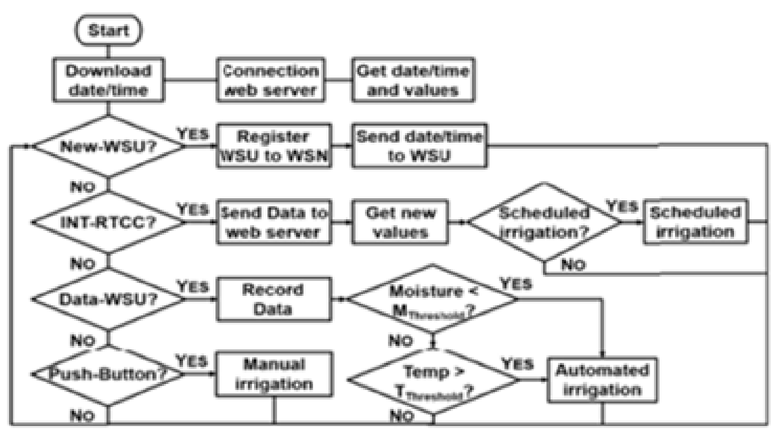


Figure 6: Configuration of the automated irrigation system. WSUs and WIU based on micro-controller, ZigBee, and GPRS technologies [3].

to WIFI, Bluetooth and ZigBee in terms of range and power consumption. For the sensor node part, there are two types of node: a monitor node and a hydrant node where the first one is consisting of the HELTECWiFi LoRa 32 board, a SHT15 (manufactured by Sensirion) sensor for soil moisture measurement the all powered from the TLP5110 module and the battery pack. The second one is designed similarly to the first one at a hardware level, although it is not equipped with a humidity sensor. The gateway or local concentrator consists of two devices, a Heltec ESP32 LoRa board, and an MKR1200 board. The Heltec ESP32 LoRa board operates as a LoRa communications concentrator. Through this element, communication is directed to hydrant nodes and from monitor nodes. This board communicates through the serial port with the MKR1200 board, which is the platform that communicates to the cloud. The authors use SIGFOX communications to access IoT platforms. The local gateway sends information to SIGFOX web platform which forwards to the IoT platform. This process is bidirectional; the backend (SIGFOX web platform) receives data from the IoT platform to be sent to the MKR1200 board (local gateway). The IoT platform chooses by the authors is ThingSpeak to receive information from field sensors and records it in its own database. At the same time, an application developed in MATLAB®analyses moisture data, generates priority and run time settings for each hydrant node. Figure 8 shows the global system architecture proposed by the authors.



(a)



(b)

Figure 7: Wireless sensor unit and the master micro-controller algorithms in the WIU system. (a): Master microcontroller algorithm, (b): Monitoring soil moisture and temperature algorithm [3]

Due to the energy limitation of WSN nodes and the difficulty of their battery recharging and replacement, one particular promising solution is backscatter communications (BackCom) that allows an IoT node to transmit data by reflecting and modulating an incident RF wave [12]. According to their architectures, Backscatter communications systems can be classified into three major types: monostatic backscatter communications systems (MBCSs), bistatic backscatter communications systems BBCSs, and ambient backscatter communications systems ABCSs [13]. A backscatter node (tag) has no active RF components and as a result can be made to have

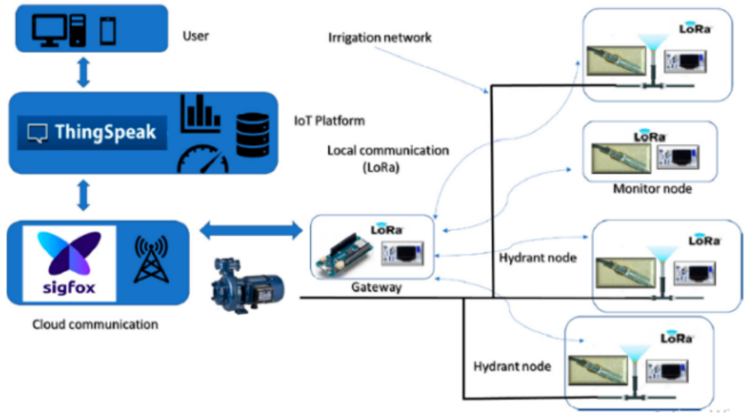


Figure 8: Global system architecture [11].

miniature hardware with extremely low power consumption, facilitating large-scale deployment at a flexible location or even in-body implantation. However, recent work by [14] proposes a novel hybrid transmitter design by combining the advantages of both ambient backscatter and wireless powered communications. The proposed design allows a highly flexible operation to perform RF energy harvesting, active data transmission/reception, and backscattering. In comparison with an ambient backscatter transmitter, the hybrid transmitter can achieve a longer range using active RF transmission when necessary. Despite the advantages of the hybrid transmitter, some technical issues arise. With a single antenna setting, the hybrid transmitter cannot backscatter, harvest energy, and perform active data transmission simultaneously.

In backscattering mode only, the tag is a passive node that harvests energy from an incident single-tone sinusoidal continuous wave (CW) or from ambient signal radiated either or not by the Reader, and also modulates and reflects a fraction of the wave back to the Reader. Specifically, the wave reflection is due to an intentional mismatch between the antenna and load impedance. Varying the load impedance makes the reflection coefficient to vary following a random sequence that modulates the reflected wave with Tag's information bits. Such a modulation scheme is named as the backscatter modulation. Figure 9 and Figure 10 show a backscatter communication system in [18] and the architecture of a backscatter tag in [12], respectively

The advantage of this technique for WSN deployment is the fact that they are free from the constraints due to recharging or battery replacements since one or multiple PBs (power beacons) can be deployed to simultaneously power all the sensors or otherwise they can operate on ambient energy harvesting [12].

Some recent systems for agricultural environment measurement using Backscatter communication have been proposed [15–17]. An example for this system is shown in Figure 11

In [15], a tag composed of a microcontroller (MCU), an RF front end switch and a specific sensor for air and leaf temperature measurement communicates with an RTL SDR reader wirelessly by backscattering. The communication part exploits backscatter Morse

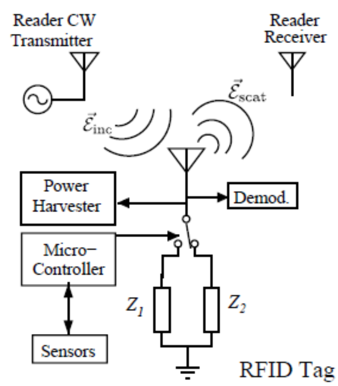


Figure 9: Backscatter communication system [18]

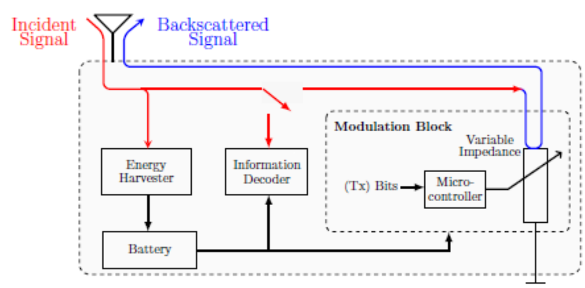


Figure 10: Architecture of backscatter Tag [12].

code modulation on an 868 MHz carrier emitter signal. The measurement of the moisture level of the plant is done by quantifying the difference between the leaf temperature and the air temperature.

As mentioned above, an ambient RF source such as WI-FI [19], Bluetooth [20], cellular, TV [21], LoRa [22] can be used to power up backscatter device and to backscatter tag's data over ambient RF

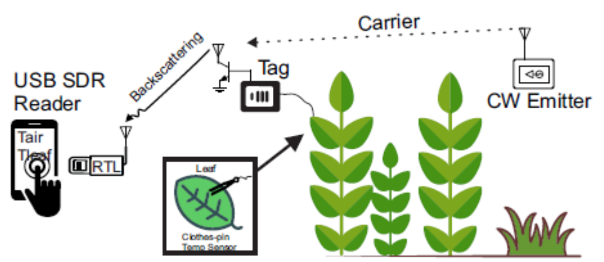


Figure 11: Backscatter communication for agricultural parameters measurement [15].

source. This will reduce the cost of the deployment since any carrier emitter is needed. The disadvantage of these systems is the range of communication between the tags and the readers typically tens of meters in the best scenario in most of the backscatter solutions. In terms of power consumption, the system with active radio such as Wi-Fi, BLE, ZigBee, Lora, and SigFox consume all between 10 to 500 mW while systems with backscatter including RFID, Passive Wi-Fi and the LoRa backscatter system consume only between 10 to 90 W [23]. In section IV, we will propose an automatic irrigation system based on RF source and backscatter communication and capable to achieve a better performance in comparison to the existing automatic irrigation system.

3 IRRIGATION SYSTEMS IN SELIGUE

Sélingué dam serves a variety of purposes, including production of electricity, agricultural development, better navigation on the Niger river, and the development of fishing and fish farming [24]. The dam has a total capacity of 2,630,000,000 m3 of water [25].

The irrigation network is fed by a water intake on the dam and consists of a set of concrete canals and compacted earth. It includes a main canal, thirteen secondary canals serving the sectors and forty-five tertiary canals. Each Tertiary canal simultaneously feeds four 5 ha traps each forming a sub-sector as shown in Figure 12

Selingué irrigated area still uses the traditional irrigation systems. It is based on a mechanical system. It uses gravity to convey the water to crops zone unlike systems under pressure on which simple slope trickles water through open canals. In the traditional irrigated system of selingué, to drive water to the crops zone, the farmer has to open each manual valve mechanically which will cost in human energy and time. Especially when the field is large, an important workforce has to be recruited and a colossal investment in equipment (Manuel valves and others related) is required, hence the overall cost of the system is increased. Our solution will reduce considerably human intervention in the field since users can perform irrigation process remotely using a Smartphone or a computer but also the overall cost of system deployment and maintenance as well as improve water use efficiency.

4 PROPOSED SYSTEM

As presented in Section 2, the existing irrigation control systems based on active radio communication are power-hungry due to the fact that they require analog RF components such as local

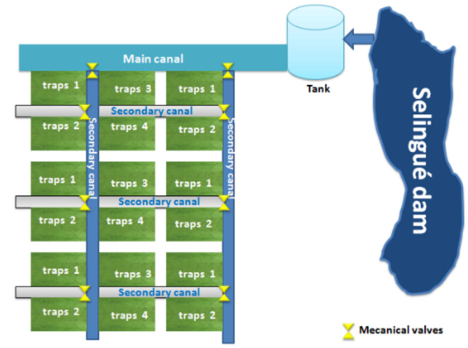


Figure 12: Schematic of irrigated area of selingué.

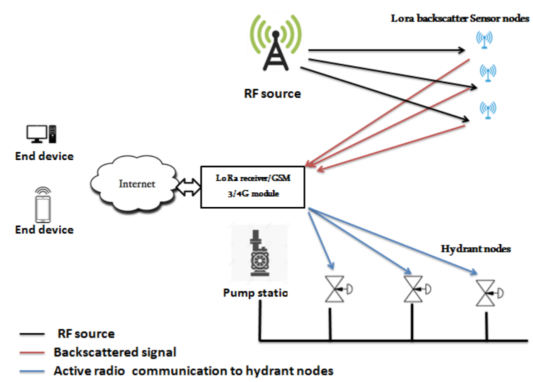


Figure 13: Architecture of proposed system.

oscillators, mixers, and amplifiers, hence limit their sensor node battery lifetime.

One promising solution to overcome these issues is the backscatter communication. Although the constraint with most of the backscatter communication system in such kind of application is the limitation of the range of transmission, it provides short-range communication with only tens of meters or less. After leveraging a large literature reviews in recent backscatter communication system to face these constraints, we came to the conclusion that the best solution for now which provide a very low power consumption (9.25 W) and a range up 2.8 Km with a cost at 10 cents per unit is the LoRa backscatter prototype presented in [23]. Hence our proposed system is based on LoRa backscatter communication presented by the authors to monitor the irrigation system. Figure 13 and Figure 14 show the global architecture of our system and the used LoRa prototype, respectively.

The proposed system consists of an RF source, LoRa backscatter nodes (sensors devices), the gateway and the hydrant nodes. The gateway consists of a LoRa receiver, a microcontroller, and a 3G GSM module. The motor pump and the gateway are powered by solar panel through a converter. The 3G GSM module enables the connectivity of sensor networks to the internet where users can use a web page or an android application to perform the irrigation process remotely. A control algorithm is implemented to perform irrigation automatically independently from users when the measured

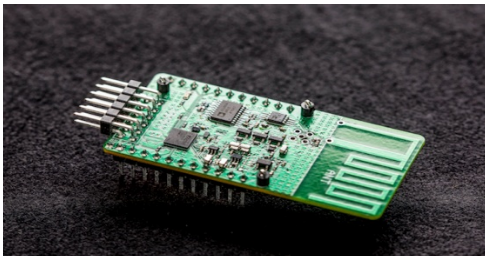


Figure 14: the used LoRa prototype [23]

data by sensors (soil moisture, soil temperature, air temperature) achieve a given value programmed in the micro-controller. This value is set by the farmer according to the crops requirement. In our proposed system, the measured data by sensor devices is sent by backscattering a single tone from an RF source to the gateway or controller as shown in Figure 13

Hence two types of irrigation can be performed: automatic irrigation and remote access irrigation through the internet by the user. In case of automatic irrigation, the microcontroller in the gateway process the received data from sensor nodes and compare to the threshold (programmed values in the micro-controller), if the received data meet the requirements set by the control algorithm, the gateway sends a signal to the corresponding hydrant nodes based on the geolocation sensor value by active radio communication. The geolocation sensor also helps to find defected nodes for maintenance or replacement of one of the component. In case of remote control mode, the data sent by the microcontroller through the 3G

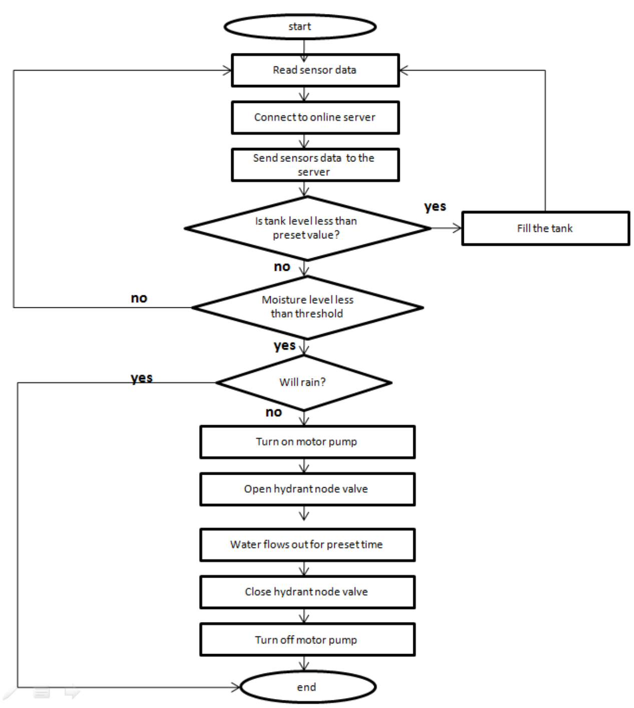


Figure 15: flowchart diagram algorithm of the system.

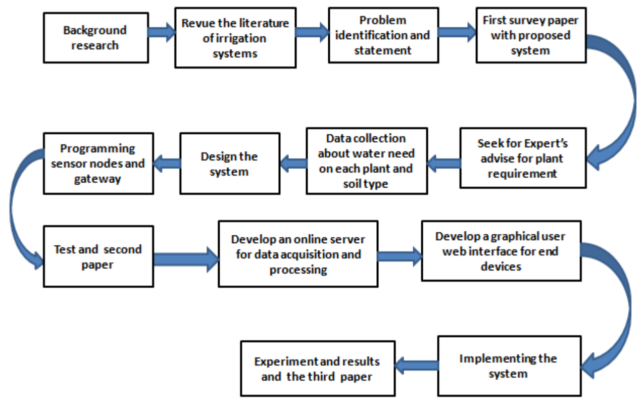


Figure 16: Research methodology diagram

GSM module to the online server are processed, and displayed on end device terminal's graphical user interface (GUI), so the user can simply press a start button to start irrigation process. Figure 15 shows the flowchart diagram algorithm of our system.

In the case of a large field, several RF sources and receivers are deployed. A rainfall sensor located at the gateway is used to avoid useless irrigation when it is going to rain hence reduce water and energy consumption. Figure 16 shows the research methodology diagram of the proposed system.

5 CONCLUSION

In this paper, a large literature review of existing irrigation systems has been presented with a brief description. We also present the traditional irrigation system currently used in selingué (Mali) to prove the necessity of migration to new technique of irrigation in order to reduce electrical power consumption, water wastage, human time and the cost of deployment in irrigated area. We finally propose an automatic irrigation system based on LoRa backscatter communication to enable long-range communication, low power consumption of sensor nodes as well as low cost of deployment. In a future paper, the proposed system will be designed and implemented.

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