Remote Monitoring and Control System of a Water Distribution Network using LoRaWAN Technology

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Abstract: - The problems related to the proper management and control in the distribution of potable water affect environmental sustainability generated by leaks and breaks in the infrastructure, causing leaks and loss of water. According to reports from the National Superintendence of Sanitation Services of Peru, more than 50% of complaints about the water service are related to billing problems and water leaks. It is for this reason that technologies such as the Internet of Things technology contribute to generating solutions for the automatic acquisition of data in residences and houses. That is why this paper aims to use long-range and low-power wireless communication systems to improve the service-oriented to the control of the water distribution network, monitoring of vandalism, and detection of anomalous events, reducing response time and economic losses. The paper's development methodology considers the implementation of a water controller node with flow control sensors and solenoid valves and a gateway with Lora communication. In addition, a solenoid valve control circuit and a remote visualization and control system are implemented. The results indicate that the implemented nodes allow adequate monitoring and control in real-time of the water flow, contributing to the adequate management of its consumption and supporting the detection of anomalous events using a Web application.

Key-Words: - Low Power Wide Area Network, Internet of Things, LoRaWAN, Arduino, potable water

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1 Introduction

There are many obstacles and inconveniences to face the problems related to the efficient management of potable water distribution (WDNP), [1], [2]. Analyzing the history of events related to the management of potable water in Peru, it is possible to obtain an x-ray of the obstacles faced today by the sector of water and sanitation services. During the last years, the amount of potable water that was stolen through clandestine connections in Lima and Callao in 2016 was able to supply 3,000 families in 12 months, making it very difficult to detect water connections that are outside the law because they are underground, [3].

To measure the environmental sustainability of the services provided by the water companies, the indicator of "non-billed water (ANF)" is used, which is not billed because of losses due to leaks and broken pipes, in addition to the existence of manual meters that generate errors. According to the Benchmarking report of the National Superintendency of Sanitation Services of Peru (SUNASS), in 2018 the company SEDAPAL registered a value of 27.8% in this indicator being the reduction of the level of the ANF an objective of the National Sanitation Plan, [4].

According to the reports reported by SUNASS in 2020, a total of 15,572 users of the potable water and sewerage service throughout Peru were served by the National Superintendency of Sanitation Services (Sunass), through its channels of remote care, during the 100 days of the state of emergency due to COVID-19, [4]. In this period, 47% of the attention are due to consultations due to billing problems, while 31% was due to operational problems due to lack of water, sewerage, and flooding due to pipe breaks, [5], [6].

Regarding the management processes of potable water resources, solutions have been developed based on the prediction of the minimum night flow for leak detection using Internet of Things (IoT) technologies and artificial intelligence algorithms (IA) for anomaly detection, [7], [8], [9], [10]. This type of study contributes to preventive leak detection processes in smart cities, integrating systems based on Geographic Information Systems

(GIS) and predictive analysis, [1]. Other studies investigate the optimization of energy consumption that potable water meters need, through the deployment of drones for data collection, [10], and the use of communication technology based on low energy consumption wide area networks for the transmission of data to Web services, [11], [12]. On the other hand, systematic review papers describe how the Internet of Things and machine learning (ML) technologies have the ability to improve the processes of acquisition, processing, and transmission of data in real-time from the most critical areas of a company water distribution network, [13], [14].

From what has been described above, it can be inferred that there is a problem in the efficiency of water management, where engineering, legal, economic, environmental, and social aspects are involved. Having identified this problem, the research seeks to contribute to a solution from the engineering aspect and answer the following question: How does the development of a low-cost electronic system based on LoRaWAN technology allow the monitoring and control of the flow of potable water? For this reason, this article describes the criteria for the implementation, design, and construction of the system and tests the electronic system with Low Power Wide Area Network (LPWAN) technology to evaluate its performance.

The objective of this paper is to develop a system that integrates an electronic circuit with LoRaWAN wireless network technology, which is used to manage water resources in a potable water distribution network. In addition, it performs flow reading processes, water flow control, and graphic analysis for decision-making based on historical data. This paper is organized into five sections as described below. In section 2 we present a brief review of related works. Section 3 shows the most important concepts related to the technologies. In section 4 the proposed system is described and in section 5 the results are mentioned. Finally, in section 6 the conclusions are presented.

2 Related Works

Efficient management in the distribution of potable water has been studied in many research papers. Thus, this section shows some of the studies found related to aspects such as the Internet of Things, artificial intelligence, and communication protocols for low energy consumption hardware devices.

In [15], the authors propose an architecture based on machine learning for the monitoring and control of a water distribution system based on dynamic operating conditions. This solution uses smart meters to generate data in real-time, through efficient software architectures.

In [2], the authors proposed a model based on comprehensive monitoring (SC) of water distribution networks with detection devices. This paper describes how monitoring relies on smart metering technologies and wireless sensors in battery-powered nodes, limiting high sampling rates. As a result, CS techniques can reduce process execution times by 50%, achieving significant energy savings.

According to [16], most drinking water losses occur during transportation, so IoT-based systems contribute to monitoring the status of drinking water distribution pipes. In addition, the water demand prediction process can be performed with deep learning techniques and traditional methodologies for time series such as autoregressive integrated moving average (ARIMA).

On the other hand, in [7], the authors describe a project to improve water supply and respond preemptively to drought and water loss by reducing pipe leaks and caring for aging pipes. To achieve this, data is collected by sensors connected to the Internet of Things devices using Multi-Layer Perceptron (MLP) and Long Short-Term Memory algorithms. In another direction, power optimization is critical when using low-power IoT devices, which is described in [17], where the authors describe the use of a wireless communication network between air vehicles and sensor nodes. Its communication is optimized by minimizing the energy consumption of the drone to obtain optimal data collection trajectories.

According to [18], the management of the drinking water resource is a great challenge that generates control initiatives at a global level as well as for sustainable development. In this context, Smart Cities solutions contribute to the rational consumption of water. This research proposes a system to monitor and identify leaks in WDNP through data inference techniques and Deep Learning. Similarly, in [19], the authors describe how the Internet of Things generates solutions in these areas, there being a factor related to citizen participation to support policies for sustainable and efficient use of aquatic resources. In addition, it is described that it is necessary to carry out a study of water consumption before, during, and after the period of confinement due to the COVID pandemic, being important to promote the design of educational activities and promote sustainable behaviors based on the analysis of the data collected.

3 Wireless Networks for the Internet of Things

The Internet of Things is an interconnection of various IoT devices with the Internet infrastructure using networks and communication protocols, [20] [21], [22]. Today there is a wide range of networks to connect devices and some of the most important are described below.

3.1 Bluetooth Low Energy

Bluetooth technology is also very well-known because it is used in many devices such as phones, hearing aids, or cameras. When used for IoT, the BLE (Bluetooth Low Energy) version is considered, which is a specification aimed mainly at small-scale IoT applications, such as portable devices, that require the sending of small data with minimal power consumption, [23], [24]. BLE provides data transfer rates of just under 1 Mbps, and operates in the unlicensed 2.4GHz band, which is ideal for use indoors and over short distances, and with an unlimited number of nodes, unlike traditional Bluetooth.

3.2 Narrowband IoT

It is a technology promoted by the 3GPP (3rd Generation Partnership Project), through mobile operators and large manufacturers such as Huawei, Ericsson, or Nokia to respond to the need for IoT communication, [25]. NB-IoT uses the cellular communication bands and has been designed to operate in the LTE band using the spacing between LTE channels, the guard bands, to make the most of the communications spectrum, [26].

3.3 LoraWAN Networks

LoRaWAN is a wireless technology for low-power wide-area networks. The name, LoRa, is a reference to the long-range data links that allow this technology long-range communications reaching up to five kilometers in urban areas and up to 15 kilometers or more in rural areas, with line-of-sight, [27], [28]. A key feature of LoRa-based solutions is the low power requirements, allowing the creation of battery-powered devices that can last up to 10 years, [29]. The specifications of this technology are summarized in Table 1.

In a LoRaWAN network, the nodes are not associated with a single specific gateway but can be received by multiple gateways, [30]. Each gateway will forward the received packet from the end node to a network server via a backhaul (either cellular, Ethernet, satellite, or Wi-Fi) (Fig. 1). The network server is in charge of the intelligence and complexity of the system, managing the network and filtering redundant received packets, implementing security controls, [31].

3.4 Applications and Web Services

Web applications allow IoT devices to store the data they generate without having to use space on physical servers. Being a distributed structure and not dependent on a single organization, it provides great redundancy and effective security systems for businesses, facilitating the adoption of the IoT, [32].

Table 1. LoraWAN Features, [33].

Characteristics	Parameters
Standard	LoRaWAN
Frequency band	not licensed: 433/868/915 MHz
Bandwidth	125KHz/500KHz
Transmission speed max.	250bps - 50kbps
coverage range	≤ 15 km
Penetration	high penetration
power consumption	very low consumption

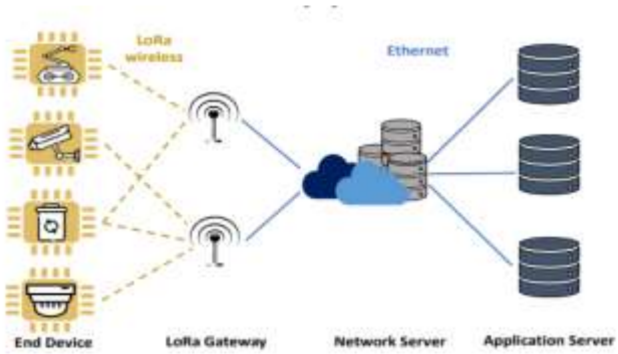

Fig. 1: LoRaWAN architecture, [31]

IoT cloud servers make it easy to communicate with sensor nodes, manage them, and integrate them with applications. If the different types of hardware, connectivity, and sensors are taken into account, a tool that allows to make changes, escalate processes and respond to incidents in a centralized way becomes essential, [34].

4 Proposed System

In this research, it is necessary to use flow measurement sensors and solenoid valves to control the passage and blockage of a certain water circuit. In addition, the data obtained by the sensors are managed by the nodes which integrate a microcontroller to carry out the transmission of data to the Internet using LoRaWAN.

4.1 Selection of Technologies

In the case of data transmission technology, LPWAN solutions are used, which provide an alternative that covers a wide range of coverage, low power consumption, and low cost, being chosen based on a comparative study with other solutions (Table 2).

Table 2. Features of wireless technologies

Feature	Speed	Coverage	Consumption
Quality	Low	wide	Very low
WiFi	High	Low	Low
BLE	Low	Low	Very low
ZigBee	Low	low	Low
NB-IoT	Low	wide	Very low
SigFox	Very low	wide	Very low
LoRaWAN	low	wide	Very low

There is a wide range of microcontroller models on the market according to each use case. In this case, the study was carried out among those available in the local market and that are tolerant to 5 volts because it is a voltage compatible with a greater number of sensors and actuators that were used in this investigation, selecting the Arduino UNO card. In addition, to provide transmission capacity to the Arduino card, one of the most outstanding boards in the field of LoRa technology called Dragino (Fig. 2) is selected, which allows us to achieve extremely long transmission ranges at low speeds. of transmission.

The system uses flow sensors which are used to measure different fluids (water, fuel, oil) and different volumes with greater or lesser precision. According to a study carried out on the available sensors, it was considered to choose the one that has a greater pressure capacity and greater size of connection threads, selecting the YF-S201 sensor (

Table 3). All sensors use a magnet located in the turbine, which generates a positive pulse each time it passes the Hall effect sensor. In this way, you can obtain the revolutions per minute generated by the propeller and then calculate the water flow.

Fig. 2: Dragino Lora Module, [35]

Table 3. Flow sensor comparison

	YF-S401	YF-S201	FS300A
Connection	1/4"	1/2"	3/4"
Flow	0.3 a 6 L/Min	1 a 30 L/Min	1 a 60 L/Min
Pressure (Máx)	0.8 MPa	1.75 MPa	1.2 MPa
Voltage	DC 5~18 V	DC 5~18 V	DC 5~18 V
Temperature	≤ 80°C	≤ 80°C	≤ 80°C

In the case of IoT platforms, there is currently a high availability of solutions that offer data storage and visualization features for an end-to-end IoT solution. The Ubidots account platform allows the analysis and processing of data and the programming of events, data analysis, and automatic execution of actions can be carried out. This platform is also compatible with various devices such as Arduino, Raspberry Pi, ESP, Particle, etc. It is for these reasons that it is chosen for the implementation of the system.

4.2 Sensors Nodes

Two kinds of nodes were implemented: (i) the end user node, which was located at the residence of each water service customer to measure flow and consumption, and (ii) the administrative node whose purpose is to control the flow of water, allowing the passage of water, blocking and metering.

Each end user node has a YF-S201 flowmeter, which internally has a rotor that generates pulses sent to the microcontroller housed on the Arduino Uno board (Fig. 3). Through a program written in C language, the calculation of the flow and water consumption is performed. Subsequently, these data are sent to the Dragino LoRa Shield module for transmission to a Gateway Lora device. The administrative node is like the one described above, but it has a solenoid valve to remotely control the flow of water over certain sections of the network. In this case, communication through LoRa technology is bidirectional and a 12 Volt source is required to power the solenoid valve, in addition to the 6 Volt battery that powers the rest of the circuitry (Fig. 4).

4.3 Flow Sensor Reading

The internal vanes of the rotor of the YF-S201 sensor are fully insulated to prevent water leaks and externally to the camera it has a Hall effect sensor allowing it to detect the magnetic field generated by the magnet, the vanes, and the movement of the rotor. As water circulates through the body of the flow meter it turns the turbine inside it and the magnet located in the turbine generates a positive pulse each time it passes the Hall effect sensor. In this way, you can know the revolutions per minute generated by the propeller and then calculate the water flow.

The flow sensor uses the Hall effect to measure the flow according to the equation: f (Hz)=7.5 x Q (L/min), where the variable f is the frequency of the generated signal and Q is the amount of water per minute, with a conversion factor of 7.5. An algorithm is developed that reads the pulse signal of the sensor in a time range "t" of 5 seconds. The flow diagram (Fig. 5) shows how the volume of water is calculated based on the flow multiplied by the difference in the sampling time of the water flow.

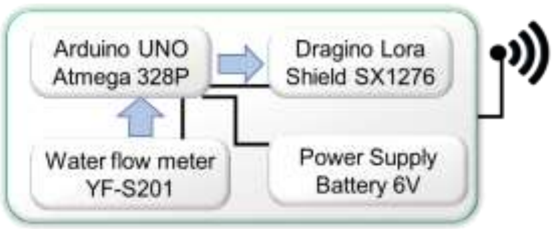

Fig. 3: End user node diagram.

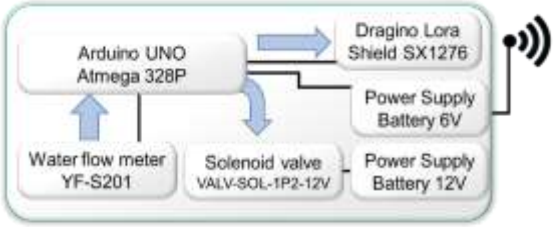

Fig. 4: Administrative node block diagram

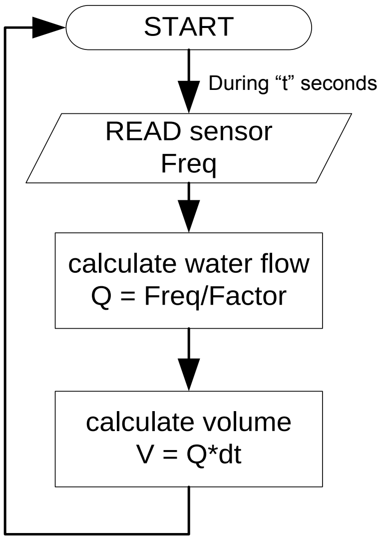

Fig. 5: Flow rate calculation

4.4 Data Transmission

This process is performed in the two kinds of sensor nodes described above. For this, the Arduino Uno board is used together with the Dragino Lora card to establish communication with the Gateway module using the 915MHz frequency (free band intended for IMS services throughout Latin America). To control the transmission module, the "LoRa.h" library and the transmission functions "LoRa.print" and "LoRa.begin" are used for any type of data. The implemented end user node (Fig. 6) sends the information to the system gateway every 5 seconds.

Fig. 6: End user node

4.5 Solenoid Valve Control

The control of the 12V solenoid valve (model VALV-SOL-1P2-12V) is carried out by the administrative node which has an actuator controlled by means of an output pin from the Arduino hardware to activate or deactivate it. The circuitry is based on a 5V relay that will close the circuit that feeds the solenoid valve from a 12V source. As the relay has a minimum operating current of 70mA, it will be necessary to use a current amplifier, using a model 13002 transistor (Fig. 7). The control process is started via pin 5 of the Arduino to inject a digital signal to turn the valve on. The 13002 transistor has a gain factor of 10, enough to guarantee a minimum operating current of 70mA. This is calculated using the 550-ohm resistor, ensuring a collector current of 78mA, enough to turn on the relay and put the solenoid valve into operation. This process is controlled by the microcontroller that enables the solenoid valve when it receives the indicated signal from the system gateway.

The solenoid valve is activated when the indicated signal is received from the system Gateway via LoRa wireless communication. The administrative node uses the "LoRa.receive()" command to receive the data from the Gateway. If the package has the message "LOW", pin 5 will go to the low state (0V) and if it has the message "HIGH" it will go to the high state (5V) turning on the solenoid valve. In this case, 6V is used for the hardware modules and 12V for the solenoid valve circuit.

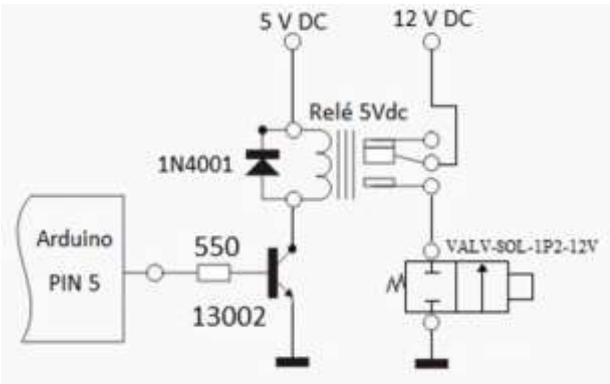

Fig. 7: Solenoid Valve Drive Circuit

4.6 LoraWAN Gateway Module

The gateway has a WiFi communication interface through the ESP8266 module which is controlled by the Arduino card to transmit the information from the sensor nodes to IoT servers in the cloud. Its functions include receiving messages from the IoT server and sending them to the nodes via LoRa to execute an action on the solenoid valve (Fig. 8).

The Ubidots Web service is used to receive data, on which the Gateway sends and receives information using variables registered in the Web platform through the Ubidots REST APIs

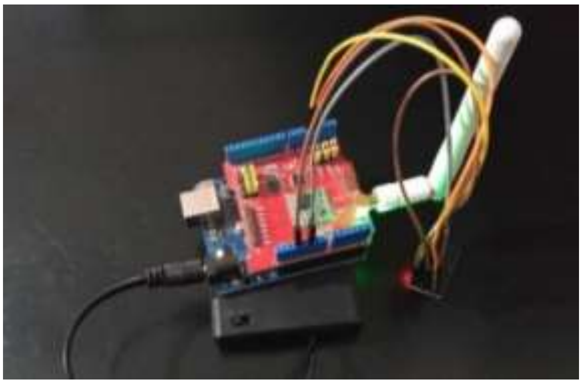

Fig. 8: Gateway LoRa

5 Results

The validation of the system built through a structure that simulates a water distribution network using 1/2" pipe circuits was conducted. The node is installed near the potable water supply of each home together with the YF-S20 flow sensor. On the other hand, the Gateway module is located on the lower floor of the test area, and due to the good penetrability of the signal, wireless communication does not represent problems (Fig. 9).

In the tests, the node is turned on and a constant flow of water is generated, executing the data transmission process towards the Ubidots Web service. The data is observed using a graph whose horizontal and vertical axes represent the time and the flow, expressed in liters per minute (Fig. 10). One way to visualize the data is through an online dynamic table, specifying the value read and the date the sample was taken, where the message arrives at the server every 20 seconds. This is due to the configuration of the gateway that is working in a bidirectional mode in communication with the server, being able to modify the sampling range to have readings every minute.

The tests of the administrative node were carried out utilizing a model placing the solenoid valve and the flow sensor in the water distribution circuitry (Fig. 11). This node was turned on and the communication with the server for the remote control of the valve was checked.


Fig. 9: End User Node Deployment

Fig. 10: Flow variation in Ubidots


Fig. 11: Administrative Node Tests

Valve control tests were carried out from the server, verifying the change in the flow rate registered by the sensor (Fig. 12, Fig. 13), where the Web interface has a control button to prevent the flow of water from passing. (Fig. 13) shows the presence of a registered flow rate, whose behavior shows a higher pressure in the piping circuit and then a reduction in this pressure.

Fig. 12: Valve in OFF state in Ubidots (No water flow)

Fig. 13: Valve in ON state in Ubidots (With water flow)

6 Discussions

The importance of the administrative node, in a potable water distribution system, is based on the contribution to monitoring the flow in sections by the operator to manage the water supply. In this way, it is possible to estimate the value of the normal flow of a common day by analyzing the data collected and by observing the graphs obtained on the Web platform, allowing the detection of possible leaks. In addition, attention to this type of event would have a much shorter response time, reducing economic losses due to non-revenue water.

In the case of the use of Lora technology, it allowed having records of the flow and remote control of the closing and opening of a section of the network in case of any unwanted eventuality. This technology has a long range with minimum power consumption for transmissions between the node and the implemented Gateway. Furthermore, the YF-S201 flow sensor is ideal for water distribution networks in residential applications.

7 Conclusions

The end customer benefits from the system, by having the ability to improve water management through real-time monitoring and verification of invoiced consumption, avoiding false readings or human errors during the sampling process of these variables. On the other hand, with the information generated, it is also possible to identify, after the flow decreases without reason for leakage, that it could be vandalism due to clandestine water connections and to identify the precise area of this event, based on the location of the administrative node. As a recommendation, the 12V normally open (NO) solenoid valve should be used to reduce energy consumption and the integration of batteries that guarantee an operating autonomy of years.

In future works, the implementation of machine learning techniques can be considered to perform the detection of anomalous patterns or anomalies in all the data collected from different sensor nodes.

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