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DEVELOPMENT OF NON-INTRUSIVE LOW-POWER DIGITAL WATER METER READING SYSTEM BASED ON WIRELESS MESH NETWORK AND INTERNET OF THINGS

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Abstract

The application of WMN and IoT technology to the metering infrastructure is proven to provide convenience in data collection, access to information, and management of metering devices. Unfortunately, the use of this technology is still minimal in developing countries like Indonesia. In this study, the development of a digital meter reading system that focuses on low-power non-intrusive reading devices and the application of WMS in the water meter reading system is carried out. This system consists of a series of meter reader sensors that are connected mesh to a gateway where meter data can be monitored in real-time and remotely. This sensor circuit is an integrated circuit added to the existing mechanical water meter which allows recording the volume of water consumption digitally. This circuit consists of an optical sensor, real-time clock (RTC), microcontroller, Lora Transmitter, and power supply. The use of solar cells to supply energy for meter reading devices is another interesting aspect of the development of this system. A gateway is a circuit built to bridge the transmission of meter data from a radio-based sensor network to the internet. The result of this research is the establishment of a meter reading system capable of accurately reading water consumption, low power where the meter data is easily accessible using a device connected to the internet. This system has been evaluated for every part of development such as reading water consumption, power consumption, and also communication in the mesh network. The contribution of this research is that it can be used as a reference for developing a digital meter system that is more effective, has low power, and has easy access to meter data

Keywords : WSN, IoT, Digital Water Meter, Sensor Circuit, Gateway

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INTRODUCTION

The development of digital-based water meter infrastructure continues to be intensified by the government, industry, and scientists. This system is proven to be able to streamline processes and costs in managing energy sources and facilitate access to information and metered data and provides other benefits [1], [2]. Some of the conveniences of this system for utilities are the ease of collecting metered data to calculate customer water consumption payments, real-time monitoring and management of metering devices, and full support for utility management decisions based on field data. From the customer side, this system provides complete information on the amount of water consumption that has been used to increase customer awareness in saving water resources. If there is an error in the consumption calculation by the utility, the customer can file a complaint based on the recorded data. Unfortunately, the use of this technology is still minimal in developing countries like Indonesia.

The development of digital water meter infrastructure can at least be grouped into three main elements, namely the development of water meter devices, the development of data communication infrastructure, and the meter data management system (MDMS). The development of this water meter focuses on developing a digital-based water volume reading system. The addition of a sensor device to the water volume reading system is an important part developed by researchers. Some of the previously developed meter reading methods are meter arrow pointers [3], magnetic [4], and image processing [5]. The development of a non-contact meter reading system is preferable because it is carried out without disassembling the metering device. This system is good for customer requirements because it is easy to install on existing water meters. On the other hand, the development of metering communication infrastructure has been studied previously, such as meter communication infrastructure based on wireless sensor network (WMN) [6] and Wi-Fi [7]. The meter data communication network uses radio frequency (RF) which makes it easy to collect customer meter data. To enlarge the scope of data transmission, we are also developing a network based on a LoRa-based mesh topology [8]. The mesh topology can increase the data transmission range of the meter due to the nature of the autoroute. This means that when the meter cannot reach the data transmission target, it can perform a data transmission jump using the nearest meter [9], [10]. LoRa is a spread factor based radio frequency transmission system. The advantages of LoRa compared to other transmission systems are that it has a large transmission range, is resistant to noise, and has low power [11], [12].

This research proposes a breakthrough that combines the development of a meter reading system and water meter data communication infrastructure. We propose a sensor design that can measure water volume non-intrusively and can also send data to utilities using WSN and IoT. In addition, the concept of low power circuits and energy harvesting are also added values in this research.

METHOD

The method used in this research is a structured experiment. The stages of the research can be seen in Figure 1.

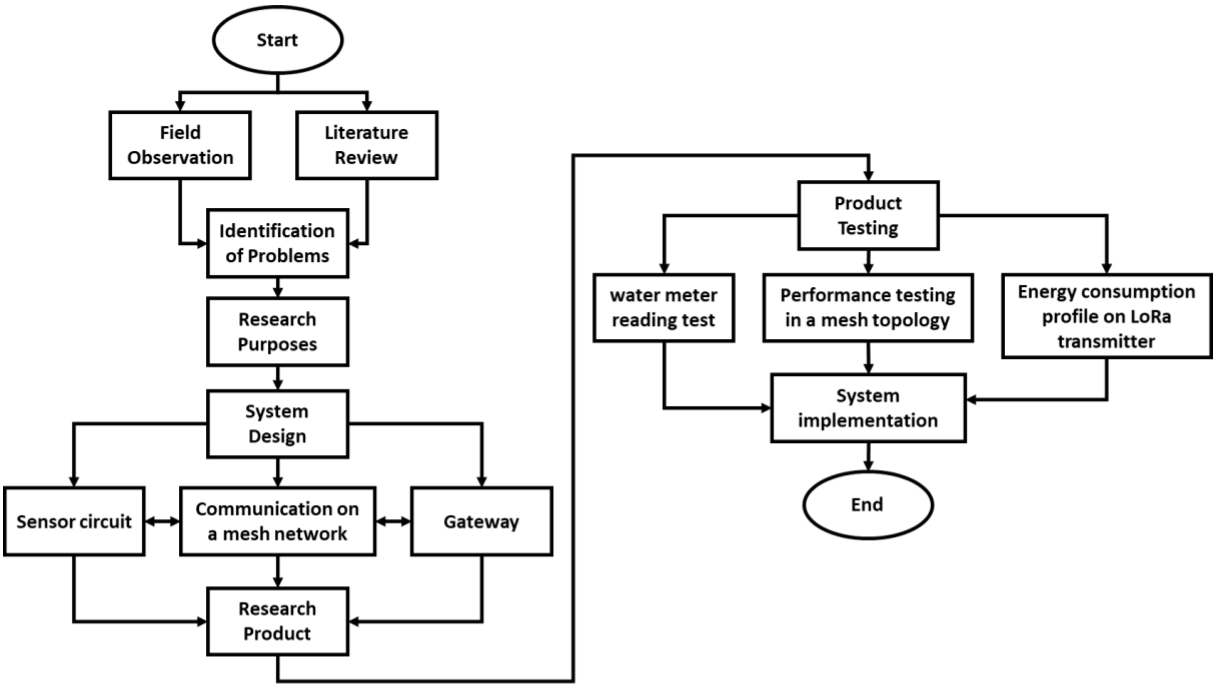

Figure 1 Research stages

This research started from field observation in a company Water Treatment Plant (WTP). This observation focuses on the state of the water meter device that still uses human power to collect water usage information by customers. These observations are also reviewed in the literature to find the core of the problem and then look for alternative solutions that can be applied to the actual situation. Observations and literature review will identify the main problem in this research, namely the absence of a real time monitoring system that can accurately measure customer water consumption. This research focuses on developing a system that can monitor in real time the water consumption of WTP customers using WMS and IoT technology [13]. The designed system consists of a series of sensors, a mesh network and a gateway. These three parts are interrelated so that they become one integrated system.

The system built is measured to determine performance and as a reference for further system development. These measurements consist of measuring the performance of the water meter, mesh network and energy consumption on the transmitter device used. The system that has been measured and meets the needs in the field is then implemented in the actual situation.

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System Design

This system generally consists of an existing mechanical water meter device which is added to a series of sensors so that it can record digitally, where the meter data will be sent to the internet via a LoRa mesh network and IP-based gateway. Data meters that are already on the internet can be accessed by utilities and customers. The sensor circuit is nonintrusive and low power which is described in the section below

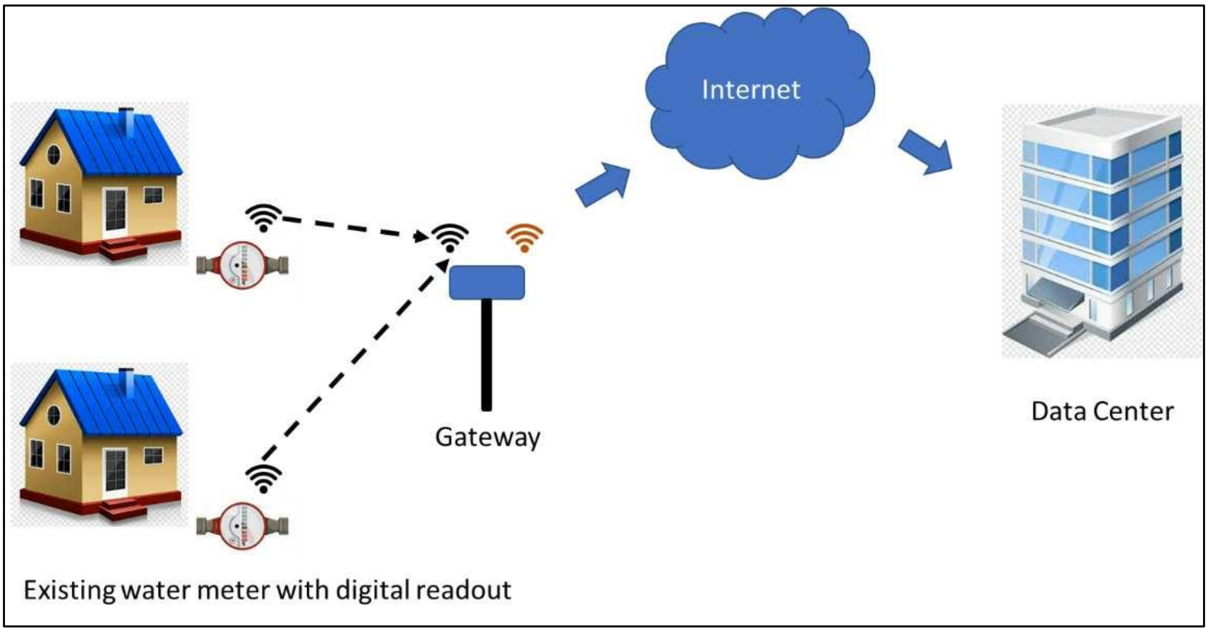

Figure 2. The overall system

Sensor circuit

The sensor circuit is an integrated circuit added to the existing mechanical water meter which allows recording the volume of water consumption digitally. This circuit consists of an optical sensor, real-time clock (RTC), microcontroller, Lora Transmitter, and power supply as shown in Figure 3.

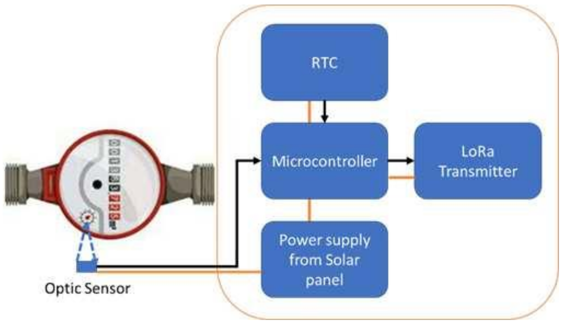

Figure 3. Sensor circuit

The type of optical sensor used in this system is the TCRT5000 infrared module type. This sensor is often used for Line follower robot sensors. The output of this sensor is an analog signal. In the TCRT5000 sensor, there are 2 infrared sensors, each of which functions as a transmitter and receiver, shaped like a small LED. When the sensor is confronted with an object, this means that the transmitter drops light on the object then the object reflects the light on the receiver [14]. If the sensor is faced with an object that cannot reflect light, the InfraRed light will not be transmitted. Or more simply, the output of the sensor will be HIGH when faced with a color that cannot reflect light, for example, black. then when faced with an object that can reflect the light output from the sensor is LOW. The TCRT5000 sensor is mounted directly above the water meter arrow which is usually red. Each change in the high and low values will form a pulse. Each pulse will count 1 count value which indicates the volume of water that has passed the meter as much as 1 liter. The RCT in the sensor circuit functions as a timer. The type of RTC used is DS3231. DS3231 is an RTC model that is often used by electronics developers because it has a fairly high accuracy even though it has been used for quite a long time. This module has an IC EEPROM type AT24C32 which can be used as a time data store. The interface to access this module is using i2c [15]. This DS3231 RTC module is generally already available with a 3V CR2032 battery which functions as a backup RTC when the main power supply goes out.

The meter data that has been generated by the sensor is temporarily accommodated by the microcontroller before the data is sent. The type

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of microcontroller used is STM32. Microcontroller based on a 32bit RISC ARM processor core from STM electronics. This microcontroller has a high clock frequency, generally in the range of 72MHz or more [16]. The choice of this microcontroller is in anticipation of a fairly large processing work that is not handled by a smaller processor microcontroller. In general, there are two jobs from the microcontroller, namely recording meter data every time, the communication process between the meter and the surrounding meter as well as the meter with the gateway.

The programming language used in the sensor circuit is Arduino IDE. It is a simple and effective programming language that facilitates sensor reading, data processing, data communication, and also some interfacing. The flow of the microcontroller programming on the sensor circuit can be seen in Figure 4.

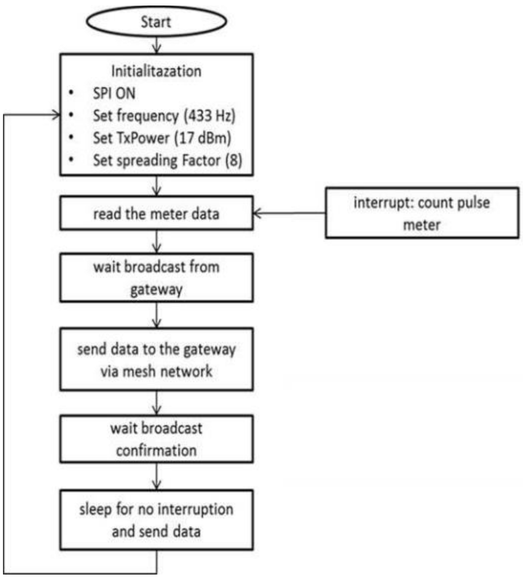

Figure 4. Sensor circuit programming algorithm

Programming begins with the initiation process of hardware devices and also wiring with microcontrollers such as I/O ports for sensors and RTC and SPI for Lora Transmitters. Furthermore, the program will focus on building a network communication using a radio frequency of 433 Hz. Then the program will adjust the power on the transmitter and the spreading factor. After the initiation process is complete, the process carried out on the microcontroller is reading the volume of the water meter. This meter reading process uses the interrupt method to keep the meter reading continuing even if the meter is in a sleep or standby state. The value of the water volume reading will enter the main programming process based on the recording time. The process of sending meter data to the gateway will be carried out after the sensor circuit receives a broadcast requesting data. This is so that the system in the sensor circuit can save power. When the broadcast is received, the meter data with the last time is sent to the gateway via the mesh network. If the data transmission has been done, the microcontroller will wait for confirmation through the broadcast gateway. If successful, the microcontroller will sleep.

Communication on a mesh network

There are three main advantages of a mesh topology on a sensor network, namely increasing data transmission coverage, ease of deployment, and auto-routing [17]. Increased coverage, namely data transmission can be carried out more than the maximum distance from a transmitter. For example, the ISM band transmitter with a maximum distance of 100 meters can be expanded with the system hop on the mesh network. The easy-to-deploy nature of the mesh network is due to the system automatically configuring the nearest nodes as possible routes to transmit data. If a node that was previously configured as a route suddenly shuts down or cannot continue sending data, other nodes around the dead node will automatically replace the data transmission function. The nature of the mesh like this is referred to as auto-routing.

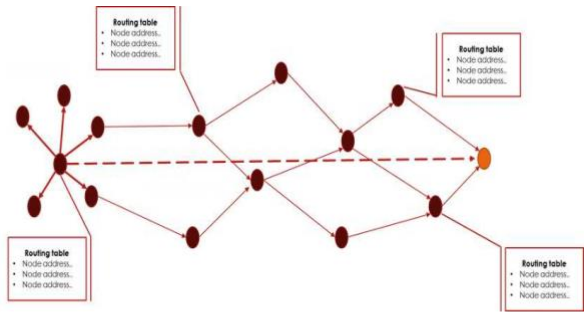

Figure 5. Mechanism of mesh network formation

The mechanism for the formation of a network mesh can be seen in Figure 5. Each node that has the mesh program installed and is active will configure itself in the route list group. The route list is a list of addresses of adjacent nodes available for sending data and capable of forwarding data from surrounding nodes. This process is known as the acknowledgment (ACK) process. The ACK process can also identify the route for sending data from the sending node to the target node. If a node is going to send data to the target node, the first thing to do is to check the route list. If it is available, the transmitter will use it immediately. If not, it will restart the ACK process or it is called route discovery.

Gateway

A gateway is a circuit built to bridge the transmission of meter data from radio networks to the internet. The gateway circuit schematic can be seen in Figure 6. The gateway consists of a LoRa transmitter, a microcontroller, a wifi module, and a power supply and a wifi router as the backbone of the internet. The wifi module used in the gateway circuit is nodeMCU. NodeMCU is a System on Chip (SoC) board ESP8266 that functions as a microcontroller and also a Wi-Fi-based communication module. NodeMCU operates at 3.3 V and consumes no more than 150 mA of current [18].

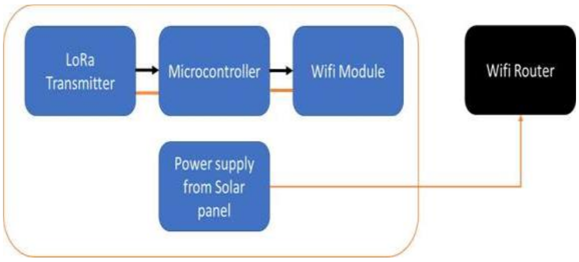

Figure 6. gateway circuit schematic

The process carried out in a gateway consists of several stages, including sending a broadcast to the entire series of sensors in the network to request that meter data be sent and then confirming each meter series whose data has been received. The meter data will then be prepared to be sent to the internet via the wifi module. The ability and quality of sending data to the internet by the wifi module depend on the capacity of the available wifi router. If the data has arrived on the internet or can also be called the cloud, the next gateway will sleep.

Data that has been received by the gateway will be sent to cloud computing. This study used Node-Red. Node-RED is a browser-based tool for creating Internet of Things (IoT) applications where the visual programming environment makes it easy for users to create applications as "flow". Created based on nodejs and Flow stored in JSON form. Node-Red can collect data from various sensor nodes. This sensor node can be a sensor installed with a microcontroller and a network communication module (either WiFi or Ethernet). Node-Red can also present the data collected in a variety of visual data, which can be in the form of line charts, gauges, and so on easily and practically [19], [20].

RESULT AND DISCUSSION

This section describes the results and discussion of this research which is divided into hardware, system tests, and implementations.

Hardware

In this study, a meter reader device has been designed as shown in Figure 7. This device can read the volume of water consumption digitally and send it to the internet via a sensor network. The water meter used is a mechanical water meter paired with an optical sensor. The installation of the sensor on the water meter is not accompanied by the disassembly of the mechanical meter device. This is commonly referred to as a non-intrusive concept which is the breakthrough of this research. This water meter reading device is supplied by a power supply that gets energy from solar cells. This device is supplied with a voltage of 5 volts and a current of approximately 150mA.

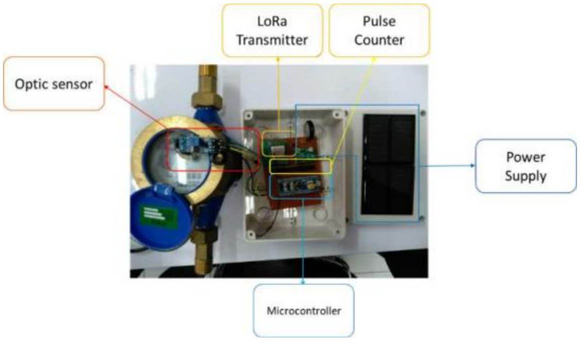

Figure 7. Non-intrusive water meter reading device

To find out how well the sensor readings on the meter reader device are tested. This test is in the form of reading the sensor output signal and also reading the volume by the device. In testing the sensor output signal reading, it is done by connecting the sensor output to an oscilloscope where the water meter flows water as shown in Figure 7.

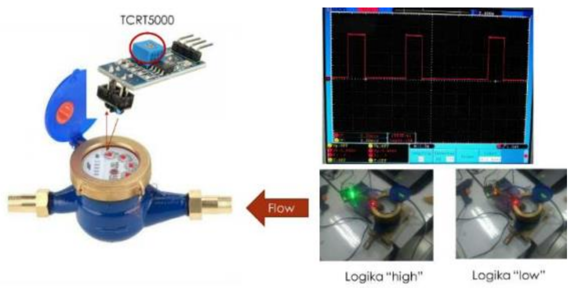

Figure 8. the procedure and the results of the sensor output signal reading

From Figure 8, it can be seen that the optical sensor readings used have good accuracy. The sensor is placed right above the red meter arrow in a matter of liters. The sensor is very good at detecting any color changes that are in front of the sensor. When the red reflection is read by the sensor, the output is logic high. On

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the other hand, when the sensor detects a white reflection, the logic goes low. Every logic high received by the microcontroller will be counted as 1 liter of water.

The next test is to compare the readings manually and readings through the water meter reading device. The results of this test can be seen in Figure 9.

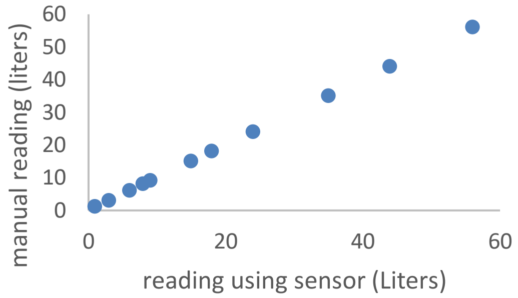

Figure 9. Testing the water meter reading

Figure 9 is a comparison chart of meter readings manually or visible and readings of water consumption calculations by meter reading devices. Based on the graph, it can be seen that each manual reading value is the same as the reading calculated by the reader. This indicates that no volume of water has been missed by the sensor. From the results of this test, it can be concluded that readings using a water meter reader are working well.

Performance testing in a mesh topology

We have successfully developed a mesh network in a residential area. To test its performance, some measurements on PDR and ping time were taken. The measurements aim to determine the ability of the LoRa-based nodes to transmit data through multiple hops. The measurements were taken in Jl. Konstitusi (UNPAD Residence), Cigadung, Bandung, at 02.00-04.00 PM as shown in figure 10.

Figure 10. Location of Lora-based nodes data transmission measurements using mesh topology

An illustration of the Lora-based node deployment mechanism in residential areas is in figure 10. Each node that is deployed has been programmed to transmit data using a mesh topology. The nodes are installed randomly and placed at a height of about 1.5 m from the road surface. Node M is set to send 100 data to each target node on the network (Nodes 1 - 8 in figure 8), and each target node is also set to send received data back to node M. Then, we measure the ping time and packet delivery ratio (PDR) for each transmission data. PDR is the percentage of the number of packets that have been successfully received by the transceiver to the total number of packets sent by the transmitter. PDR is the opposite of PER. When PER is measured by 0% in data transmission, it will be equal to a PDR percentage of 100%. The use of the term "PER" and "PDR" usually depends on the pleasure of choosing the term. All nodes in the network are configured using a Tx power of 17 dB and SF 8. The time interval between data transmissions is set to 1 second. The two measurement results for each target node address can be seen in figure 11.

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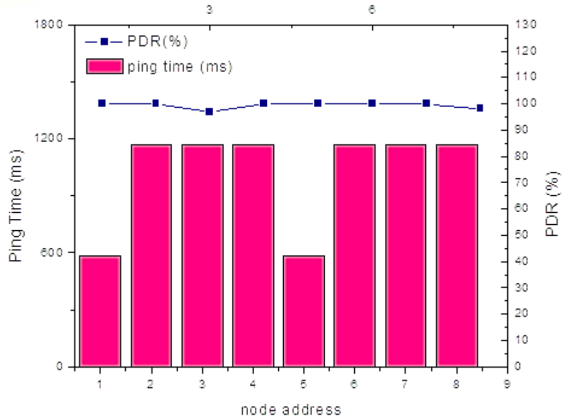

Figure 11. Graph of ping time and PDR measurement results using mesh topology

The ping time and PDR measurements on the developed LoRa mesh network are shown in figure 9. The measured ping times for nodes 1 and 5 are approximately 582 ms, and for nodes other than 1 and 5, about 1171 ms. While the measured PDR percentages for nodes 3 and 8 are 97% and 98%, respectively.

Energy consumption profile on LoRa transmitter

One of the concerns of research using WSN is the power on the device or node. In this section, the measurement of power consumption by the water meter reading device is carried out. This test is done by measuring the current flowing in the device using an ampere meter. This test is carried out for 1 time period of sending meter data to the gateway. The results of this measurement can be seen in Figure 12.

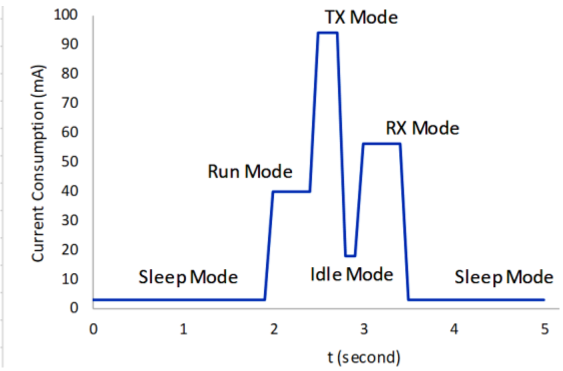

Figure 12 measuring the current flowing in the meter reading device

Figure 12 shows the current flowing through the meter reading device in graphic form. The graph includes a description of the processes running on the water meter reader such as sleep mode, run mode, sending mode (Tx mode), idle, and receiving mode (RX mode). The current values in each mode are 0.8 mA, 40 mA, 96 mA, 17 mA, and 53 mA, respectively. The total current value in one data transmission period is 206.8 mA. If the value of the working current on the sensor, microcontroller and RTC, each of which is 1 mA, 150 mA, 0.3 mA, m, then the total is 358 mA. The operating voltage of the water meter reading device is 5 V. The total operational power of the meter reading device is 1.7 watts. From the results of these measurements, it can be concluded that the low-power water meter reading device.

System implementation

In this section, the implementation of a digital meter reading system is carried out in one of the houses on Jl. Constitution (UNPAD Residence), Cigadung, Bandung, Indonesia. This system is installed in one of the residents' houses that uses a mechanical water meter. The installation of this system can be seen in Figure 13. This system is installed for six days.


Figure 13. Implementation of a digital water meter reading system

Figure 12 shows the implementation of a digital water meter reading system. This system uses solar cells to supply energy to the reader. The reading device is housed in a waterproof case where the sensor section is positioned directly above the mechanical water meter liter arrow. Every liter of water used by the house will be read by a meter reader where the data will be sent to cloud computing to be accessed remotely. The results of reading water consumption for six days are shown in Figure 14.

Figure 14 shows the results of reading water consumption in one of the residents' houses using the system that has been developed. There are 2 visualizations shown in graph 13, namely historical data and cumulative data. Historical data is derived from daily water use, while cumulative data is data on cumulative water consumption during the implementation of the system. Based on the graph in Figure 13, it can be concluded that the digital meter reading system has been successfully implemented and records existing water consumption in real-time and remotely.

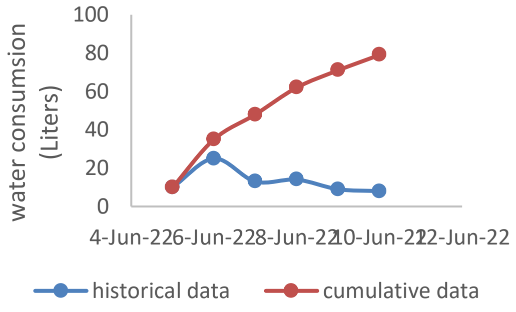

Figure 14. digital water meter reading results based on implementation for 6 days

CONCLUSION

The development of a non-intrusive low-power digital meter reading system on existing WSN and IoT-based meters has been successfully carried out. The use of optical sensors in reading the value of water consumption on the reader works well without losing data. The mesh topology applied to the system also works well with a PRD value of around 98%. The total operational power of the meter reading device is 1.7 watts. this indicates success in designing low-power devices. This system has also been implemented in real terms in the field. Visualization of meter readings using this system can be accessed in real-time, mobile, or remotely using internet-connected devices.

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