Evolution in Electrical and Electronic Engineering Vol. 2 No. 2 (2021) 959-967
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Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Internet of Things Based Electricity Monitoring System for Rural Distribution Networks

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DOI: https://doi.org/10.30880/eeee.2021.02.02.114
Received 04 July 2021; Accepted 17 October 2021; Available online 30 October 2021

Abstract: Electricity is essential in our daily lives and has an impact on economic and social development. This project aims to solve the incapability to monitor the absence of electricity in rural areas as it is out of coverage in terms of telecommunication. The proposed solution allowing the electrical energy operator/manager to monitor the absence of electricity and immediate action can be taken to restore the electricity. This prototype is an Internet of Things (IoT) monitoring system that perform long-range data transfer by utilising advanced low-power, wide-area network (LoRaWAN), sensor nodes that utilised the current sensor to detect the absence of electricity, NodeMCU ESP8266 as a gateway equipped with Wireless Fidelity (Wi-Fi), Microsoft Azure cloud storage and Microsoft Power BI for graphical user interface (GUI). Results obtained show that the prototype has the ability to transfer the data up to 150 meter with the battery lifetime sustain for 13 hours. Hence, it proves that this prototype can be further expanded for real implementation in rural areas.

Keywords: Internet of Things (IoT), Electricity Monitoring System, Low-Power Wide-Area Network (LoRaWAN), Microsoft Azure

1. Introduction

Electrical energy appears as a backbone towards more significant economic growth and social development. There are several sources of electricity, such as chemical, potential, kinetic and nuclear energy, or electrolytic and fuel cells. All of them were distributed to the consumer via distribution systems.

According to the implementing agreement on ocean energy system (IEA-OES) report, it is expected that global electricity problems will occur by 2030 [1]. Unstable electricity in rural areas will worsen the poverty of developing countries. In Malaysia, 3.8% of the population lives under the poverty line

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and mostly lives in rural areas [2]. For example, in Sarawak, almost 90% out of 95% of overall electricity distribution was in rural areas [3] that requires further attention.

Rural distribution networks (RDNs) require a long distribution line to cover a large area with higher electrical power. Because of this, RDNs constantly facing instability and the absence of electricity. Currently, no immediate action can be taken, as the information on the absence of electricity remains unknown by the electrical energy operator/manager until users have lodged any complaint, but this is also a big challenge in rural areas.

The goal of this study is to develop a prototype of Internet of Things (IoT) based monitoring system that can detect the absence of electricity at rural distribution networks. Data from cloud storage can be visualised and monitored via graphical user interface (GUI). It will help the electrical energy operator/manager to maintain their quality of services (QoS) as the absence of electricity can be monitored easily.

2. Methodology

The execution of this project involves three (3) main processes; node to node data transfer, gateway [4], and online monitoring system as shown in Figure 1.

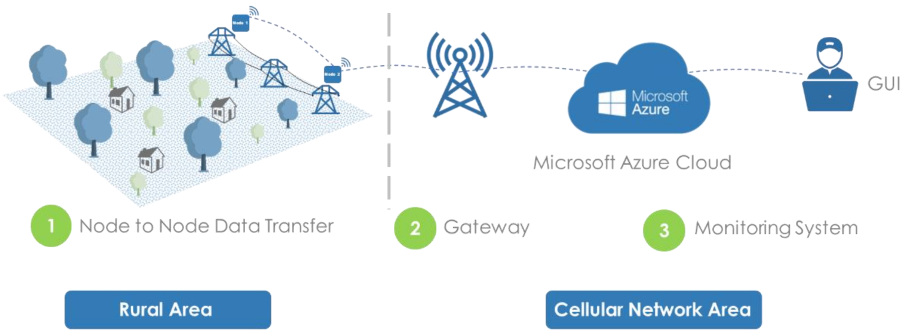


Figure 1: Project's main processes

To establish node to node data transfer, the following processes will be involved.

i. The first node will be installed with the current sensor, microcontroller board Arduino Uno as well as low-power wide-area network (LoRaWAN) [5] that has been attached at the rural areas.
ii. Once the absence of the electricty has been detected by the current sensor, the Arduino Uno will process the data and later the LoRaWAN will deliver to the mediator node.
iii. In mediator node, LoRaWAN will then receive the data from the transmitter node, and the Arduino Uno will process the data. Next, the LoRaWAN will send the data to the gateway that equipped with wireless fidelity (Wi-Fi) network.

LoRaWAN will be installed at the gateway [6] to receive the data from the second node. NodeMCU ESP8266 that has the Wi-Fi connection ability, used to process the data before transmitting it to the Microsoft Azure IoT Hub cloud. For the monitoring system, the data received from the Microsoft Azure cloud will be visualised via graphical user interface (GUI) through Microsoft Power BI to alert the electrical energy operator/manager.

3. Results and Discussion

To evaluate the proposed prototype, four (4) evaluations have been executed as follows.

i. Data transferring between sensor nodes and gateway
ii. Testing of the long range data transfer between sensor nodes
iii. Data management at the cloud (Microsoft Azure)
iv. Power consumption of the prototype

3.1. Data transferring between sensor nodes and gateway

To develop a prototype of IoT based monitoring system that can detect the absence of electricity at rural distribution networks, development regarding the connection between two sensor nodes and gateway is important to ensure the data transferring can be implemented in this project as shown in Figure 2 (a)-(f).

Figure 2: Connection between sensor nodes and gateway (a) First node (transmitter) hardware setup (b) First node serial monitor displays of current sensor readings (c) Second node (mediator) hardware setup (d) Second node serial monitor display of data received and transmitted (e) Gateway (receiver) hardware setup (f) Gateway serial monitor display of current data received

This evaluation has been conducted by developing sensor nodes and gateway. The first node (transmitter), the second node (mediator) and the gateway hardware setup are as shown in Figures 2(a), 2(c) and 2(e). The first node consists of SCT-013 current sensor to detect the presence and absence of the current, the Arduino Uno to process the data from the sensor, and the LoRa Ra-02 SX1278 to transmit the data to the second node. The second node act as mediator, whilst the Arduino Uno and the LoRa Ra-02 SX1278 used to receive and transmit again the current reading to the gateway.

For the gateway, LoRa Ra-02 SX1278 is used to receive the data from the second node and the NodeMCU ESP8266 as a microcontroller used to process that data. The data then being transmitted to the Microsoft Azure cloud using wireless fidelity (Wi-Fi). At this step, Wi-Fi is used because the gateway was located where the Internet connection available. For the software part, Arduino Uno as microcontroller board is fully established in Arduino software using C++ programming language. Figures 2(b), 2(d) and 2(f) show the serial monitor display that visualised the reading of current data transfer from the first and second nodes and the gateway.

3.2 Testing of the long range data transfer between sensor nodes

This testing is conducted to ensure the transmitter node can transmit the current data received from the current sensor and send it to the mediator node before to the gateway.

Due to the Movement Control Order (MCO), testing has been executed on-campus in Universiti Tun Hussein Onn Malaysia (UTHM) Parit Raja. With this limitation, the transmitter node is located outside of the students' residential college, close to the Pejabat Penerbit UTHM. The mediator node is located 50, 100, 150 and 160 meter (m) from the transmitter node. These distances have been chosen as this project trying to prove the data can be transferred up to 150 m from each node. Figure 3 shows the location of transmitter node and four (4) different locations with the specific distances to test the data transfer between these nodes.

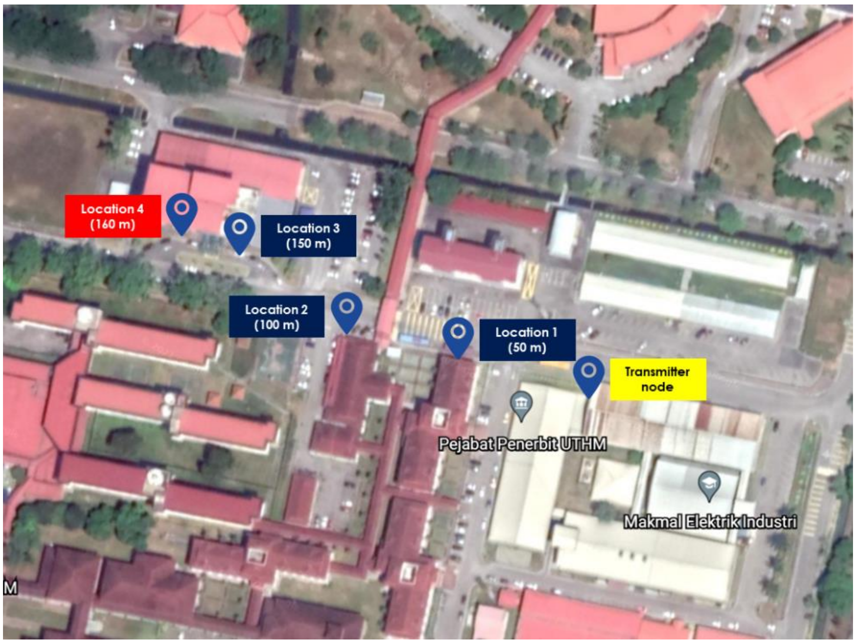


Figure 3: The location of the transmitter node and four (4) different distances of the mediator node

To show the strength for the signal of data transferring between the transmitter and the mediator nodes, the received signal strength indicator (RSSI) has been programmed in the mediator node. It shows the reading of RSSI data transferring between the transmitter and the mediator nodes. RSSI is the measurement of the power in a received radio signal. Based on the first test, the mediator node located at the location one (1) with the distance of 50 m from the transmitter node and the RSSI reading was -108 decibel (dB). The second test is conducted by locating the mediator node at the location two (2) with the distance of 100 m from transmitter node and the RSSI reading shown -120 dB. The third test is conducted with the distance of 150 m and the mediator node located at location three (3) shown the RSSI reading of -124 dB. The fourth test was conducted by locate the mediator node at location four (4) with the distance of 160 m away from the transmitter node and it was unable to indicate any reading from the transmitter node as this testing had reach the maximum distance between mediator node and transmitter node which is 150 m. It can be concluded that if the distance of mediator node increase, the reading of RSSI slightly reduced and the maximum distance of data transferring between nodes of this project prototype is 150 m. This might suggest that the propagation distance of 433 MHz LoRa signal in tropical environment is heavily attenuated [7]. If we wish to transfer for longer range, the obstacles between sensor nodes need to be considered as this testing was conducted close to the buildings and the signal was affected by electronic devices around it. Table 1 shows the details of the testing for long range data transferring between sensor nodes.

Table 1: The testing of long range data transfer between sensor nodes

Location	Distance (meter)	Data Received	Received Signal Strength Indicator (decibel)
1	50	✓	(-108)
2	100	✓	(-120)
3	150	✓	(-124)
4	160	×	-

3.3 Data management at the cloud (Microsoft Azure)

For the monitoring system, the data received from the Microsoft Azure cloud were visualised via GUI using Microsoft Power BI through Azure Streaming Analytics. Figure 4 shows the data flow in the Microsoft Azure that received from the gateway before it being exhibited in Microsoft Power BI that consist of three (3) main parts, and it includes ingestion, stream and interface.

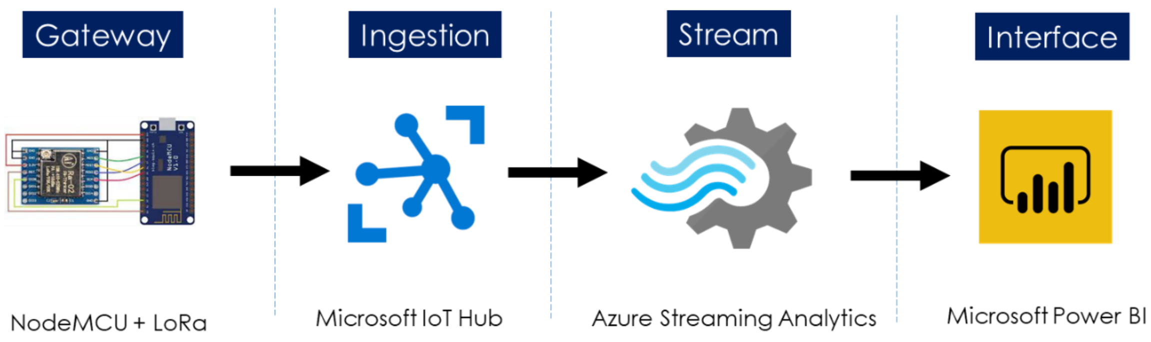


Figure 4: Route of data for monitoring system

The data received from the gateway will be sent to the Microsoft Azure IoT Hub using a Wi-Fi network. In Figure 5, the IoT devices shows one (1) device which is the NodeMCU ESP8266 as gateway is connected to the Microsoft Azure IoT Hub. Number of current data received (Message used today) are also shown in Figure 5 that indicates the data received by the cloud.

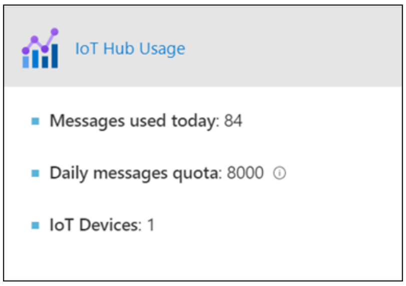
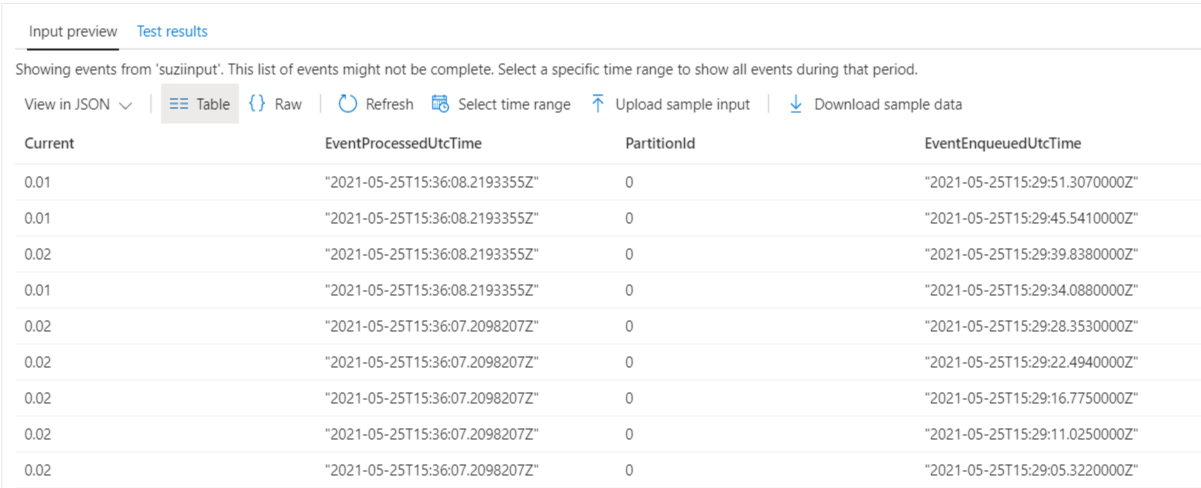


Figure 5: Gateway connected to the Microsoft Azure IoT Hub

Azure Streaming Analytics is used to stream the data from Microsoft Azure IoT Hub to the Microsoft Power BI. Figure 6 shows the data streamed in the Azure Streaming Analytics that consist of current and timestamp received reading before being sent to Microsoft Power BI for development of GUI.



Current	EventProcessedUtcTime	PartitionId	EventEnqueuedUtcTime
0.01	"2021-05-25T15:36:08.2193355Z"	0	"2021-05-25T15:29:51.3070000Z"
0.01	"2021-05-25T15:36:08.2193355Z"	0	"2021-05-25T15:29:45.5410000Z"
0.02	"2021-05-25T15:36:08.2193355Z"	0	"2021-05-25T15:29:39.8380000Z"
0.01	"2021-05-25T15:36:08.2193355Z"	0	"2021-05-25T15:29:34.0880000Z"
0.02	"2021-05-25T15:36:07.2098207Z"	0	"2021-05-25T15:29:28.3530000Z"
0.02	"2021-05-25T15:36:07.2098207Z"	0	"2021-05-25T15:29:22.4940000Z"
0.02	"2021-05-25T15:36:07.2098207Z"	0	"2021-05-25T15:29:16.7750000Z"
0.02	"2021-05-25T15:36:07.2098207Z"	0	"2021-05-25T15:29:11.0250000Z"
0.02	"2021-05-25T15:36:07.2098207Z"	0	"2021-05-25T15:29:05.3220000Z"

Figure 6: Data streamed in the Azure Streaming Analytics

In the Microsoft Power BI, the development of GUI to visualise the data is given in Figure 7. Additionally, Figure 8 shows that the visualisation of GUI in Microsoft Power BI can be also monitored in mobile phone. The current data is tabulated in the form of graph and gauge indicator to inform and alert the operator. The bar chart of current reading was designed in the GUI and the blue colour bar chart shown if there is a presence of current and red colour bar chart appears to indicate if there is absence of current. Based on this visualisation, the operator will be notified if there is any electricity problem in rural areas, hence further action can be taken immediately.

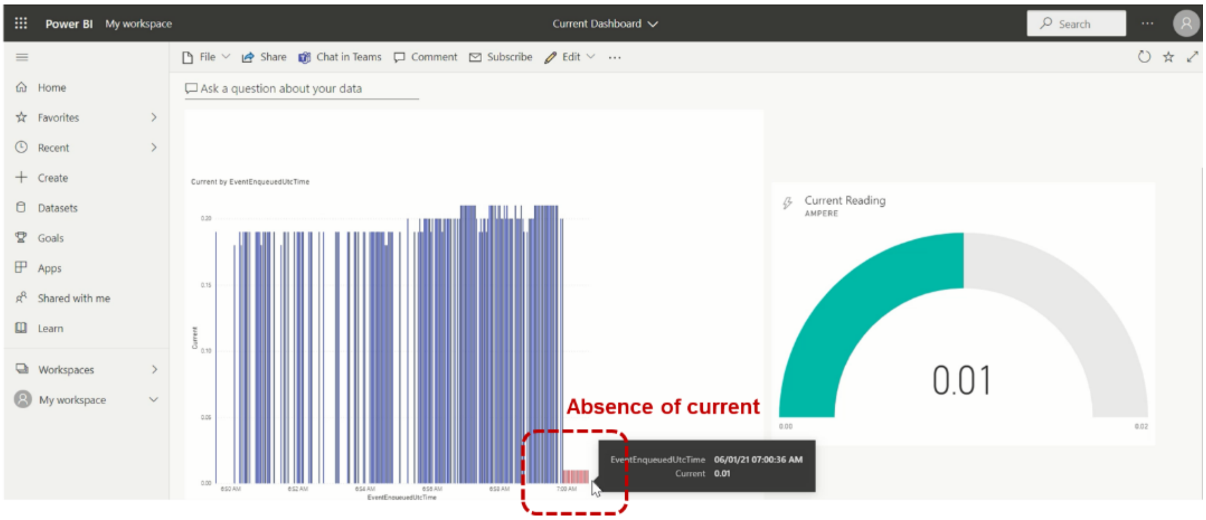


Figure 7: GUI using Microsoft Power BI

Figure 8: GUI visualisation in mobile phone

3.4 Power consumption of the prototype

This project also requires a prototype with low power consumption as it will be implemented in rural areas. The analysis of the power consumption for this prototype will be divided into two (2) parts, the power consumption at the transmitter and mediator nodes.

For the transmitter node, the 9 V (400 mAh) battery will be used as a power supply to Arduino Uno. While the current sensor and LoRa Ra-02 SX1278 are operated by the power supply obtained from the Arduino Uno. Table 2 shows the maximum current of the current sensor and LoRa Ra-02 SX1278 in the transmitter node.

Table 2: Maximum current of components in the transmitter node

Component	Maximum current
Current sensor	20 mA
LoRa Ra-02 SX1278	10.8 mA

Total maximum current at the transmitter node:

$$20\ mA + \ 10.8\ mA = 30.8\ mA$$

To calculate the lifetime by the battery, the following formula can be used:

$$Lifetime\ of\ the\ battery\ (h) = \frac{capacity\ of\ the\ battery\ (mAh)}{total\ maximum\ current\ (mA)} \ldots Eq. 1$$

Hence, the lifetime of the battery at the transmitter node:

$$Lifetime\ of\ the\ battery\ (h)\ at\ transmitter\ node = \frac{400\ mAh}{30.8\ mA} = 13\ hours$$

For the mediator node, the 9 V (400 mAh) battery will be used as a power source to Arduino Uno. The LoRa Ra-02 SX1278 and organic light-emitting diode (OLED) screen are operated by the power supply obtained from the Arduino Uno. Table 3 shows the maximum current of LoRa Ra-02 SX1278 and OLED screen in the mediator node.

Table 3: Maximum current of components in the mediator node

Component	Maximum current
Current sensor	10.8 mA
LoRa Ra-02 SX1278	20 mA

Total maximum current at mediator node:

$$10.8\ mA + \ 20 = 30.8\ mA$$

Hence, the lifetime of the battery at the mediator node:

$$Lifetime\ of\ the\ battery\ (h)\ at\ mediator\ node = \frac{400\ mAh}{30.8\ mA} = 13\ hours$$

Based on the calculation, the transmitter and mediator nodes can be operated less than 13 hours. It can be concluded that this battery lifetime is enough for this prototype. The power consumption could be upgraded by using the mini solar panel that uses solar energy as the main source to increase its operating hour.

4. Conclusion

This prototype is successfully transferring current data from sensor nodes to gateway and Microsoft Azure cloud, and finally exhibited on the Microsoft Power BI GUI. This achievement proves that the prototype can be implemented for real problem situation to monitor the absence of electricity in rural areas. To further improve the prototype, future works in terms of the increasing number of nodes as well as the power supply of the system to be significant importance.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic UTHM and ReCAA Research Laboratory, Microelectronics and Nanotechnology – Shamsuddin Research Centre (MiNT-SRC) UTHM for the facilities support.

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