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RESEARCH ARTICLE

Design of NB-Iot Based Household Light Electric Energy Monitoring System

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Abstract

Energy is a vital part of human life, especially in the digital era that requires a lot of energy. Monitoring energy use, especially electricity, is an alternative step to improve energy efficiency This research aims to develop and implement Narrowband-IoT (NB-IoT)-based electrical energy monitoring. The proposed system allows users to monitor, analyze their electrical energy consumption efficiently. The methodology used in this research is system testing and Network Quality of Service (QoS) testing. The purpose of system quality testing is to determine whether the designed system functions properly. The system is considered successful if the parameters are fulfilled, which include the ability to monitor data measurements effectively, transmit data from end nodes to the application server, and display the data on the ANTARES web platform. The Quality of Service (QoS) testing will test three parameters, namely packet delivery rate (PDR), received signal strength indicator (RSSI), and latency, and delay, using 3 different distance variables (500 m, 1 km, and 1.5 km), to measure the network reliability. The result is the implemented system works well. The Quality-of- Service test results at 500 m get very good results, with the results: average received signal strength indicator (RSSI) of -62.8 dBm, average latency of 3.0667 seconds, and packet delivery rate (PDR) ratio of 100%. Quality of Service testing at 1 km gets pretty good results, with the results: average received signal strength indicator (RSSI) of -68.933 dBm, average- latency 3.24138 seconds, and packet delivery rate (PDR) ratio of 90%. Quality of Service testing at 1.5 km gets fewer good results, especially on received signal strength indicator (RSSI) and packet delivery rate (PDR) parameters, with the results: average received signal strength indicator (RSSI) of -84.80 dBm, average-latency 3.4667 seconds, and packet delivery rate (PDR) ratio of 83.33%. The Narrowband-IoT (NB-IoT) network is suitable for on-grid electricity meters in urban areas with an optimal distance of 500 to 1 km, while at more than 1.5 km it is better used for household scale.

Keywords: Monitoring, Energy, Narrowband-IoT (NB-IoT)

1. Introduction

Energy is the ability to make a work [1], for that energy becomes a vital part of human life, especially in the digital era which requires a lot of energy. This energy is used for more transportation and industry which reached 70% of the total energy use in Indonesia in 2021[2]. This is because energy is closely related to movement, and movement is closely related to progress. This means that the more advanced civilization of a nation, the need for energy in that country. This is proven with an increase in energy consumption in 2021 by 0.4% [3].

Energy can neither be created nor destroyed, this shows the eternal nature of energy in nature. energy is eternal in nature. Therefore, we are very dependent on nature in producing energy for our daily needs. produce energy for our daily needs. Energy sources are very much from the simplest such as the sun, to the most recent energy sources such as nuclear to today's most advanced energy sources such as nuclear. However, renewable, and non-renewable energy sources are renewable are the most common classifications. Coal and petroleum are examples of non-renewable fossil fuels, and Indonesia is still using these fossil fuels. This is evidenced by the use of fossil fuels as a electricity generation in Indonesia with a presentation of up to 69.94% by 2022[4]. With the high use of fossil-based energy and the depletion of fossil-based energy reserves, the fossil-based energy reserves, there is a need for several solutions to overcome these problems, such as the discovery of new renewable energy. these problems, such as the discovery of new renewable energy or improvement of existing energy efficiency. Monitoring the energy used, especially electricity, is an alternative measure to improve energy efficiency. Currently, the KWH-meter system in Indonesia as a monitoring system for the use of electrical energy is still using a PLC (Power Line Communication) as a method to integrate the data that is collected to the data center or grid.

IoT is becoming a popular communication technology nowadays. This is due to the versatility of IoT devices that allow users to connect with to monitor and even modify the system installed with IoT-based communication system remotely [5]. In addition, the costs incurred for IoT-based communication devices are also relatively cheaper because many industries are developing IoT-based devices, so production costs are cheap. This happens especially when the system has many devices that must be connected as well as long distances,

where the more systems connected means PLC-based communication requires more cables, and the farther the system is connected, the longer the cable needed. This will have an impact on the increase in material and operational costs for maintenance because we know that cable- based communication is vulnerable to interference due to extreme environmental conditions. In addition, in outermost areas where limited by geographical conditions and limited infrastructure availability, the use of wireless-based networks is also a solution [6].

One of the emerging IoT technologies is Narrowband-IoT (NB-IoT). NB-IoT stands for Narrowband - Internet of Things. NB-IoT is a communication protocol that enables machine- to-machine communication through 3GPP cellular communication protocols (2G, 3G, 4G, 5G) [7]. In Indonesia, NB-IoT itself is included in the 3GPP-based LPWAN along with LTE advanced and LTE M, so the frequency allocations given are as follows: Band 1 at 2,100 MHz, Band 3 at 1,800 MHz, Band 5 with 800 MHz, Band 8 with 900 MHz as well as Band 31 at 450 MHz and Band 40 at 2,300 MHz [8].

From the points above, NB-IoT is the right solution in providing a communication network for KWH-meters [9]. In this research, the author will design and build an electrical energy monitoring system based on NB-IoT. This research is expected to help the development of energy-efficient electric power monitoring tools that have reliable and wide-range connectivity.

2. Theory

2.1 Electrical Power

The definition of power is the ability to do effort or more precisely the amount of energy / work that can be done in a unit of time [10]. While the definition of electricity is the phenomenon of charge transfer (in this case electrons) called electric current due to the difference in the number of positive and negative charges that are static on two sides or poles commonly called potential difference / voltage [11]. So, by combining the two definitions above, we can conclude that electric power is the amount of energy needed to move charges from one pole to another.

In measuring electrical power there are three important elements that need to be known, namely voltage/potential difference, current, and phase. This is because the electricity used in homes uses AC type electricity, while in DC type electricity, because the phase is constant, it can be ignored [12]. In addition, the definition of electrical power itself when referring to electronics is the multiplication of voltage and current. This shows that

electrical power is the amount of energy absorbed / used by electrical components, in this case called loads in units of time.

2.2 Narrowband-IoT (NB-IoT)

Narrowband Internet of Things (NB-IoT) is a wireless communication technology specifically designed to support connectivity on the Internet of Things (IoT) [13]. Narrowband-IoT (NB-IoT) offers several advantages that make it highly suitable for IoT applications, especially in terms of low power consumption, wide coverage, and the ability to operate in environments full of interference. One of the main advantages of Narrowband-IoT (NB-IoT) is its high energy efficiency. By using techniques such as "Power Saving Mode" (PSM) and "Extended Discontinuous Reception" (eDRX) [14], Narrowband-IoT (NB-IoT) devices can minimize power usage when inactive, allowing the device battery to last for long periods of time. This is important for IoT applications that often operate in hard-to-reach locations and require long battery life [15].

3. Device Implementation

From figure 1, it can be explained that the two sensors used in this study are current and voltage sensors. They are used to measure the power and electrical energy used. The two sensors are then connected to the ESP32 microcontroller [16]. The ESP32

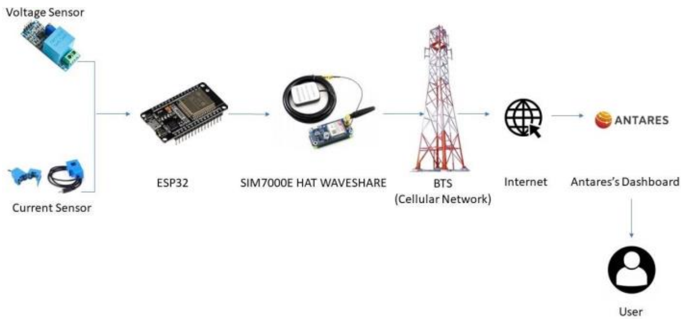

Figure 1. *Block Diagram*

microcontroller is used because it is widely used in IoT applications. Furthermore, an Narrowband-IoT (NB-IoT) cellular communication module, SIM7000E Hat Waveshare is connected to the ESP32. With this connection, it is expected that any values or quantities read by the sensors can be monitored live online to allow user to monitor via the internet when they are working or are away from home. The SIM7000E model used for the Narrowband-IoT (NB- IoT) module can connect directly with cellular networks, specifically LTE networks. The device will then connect to a BTS. From the BTS, data will be sent to ANTARES via internet connection using cellular network (3GPP), which then users can access it via website.

Using Narrowband-IoT (NB-IoT) type LPWAN communication, the Smart metering with Narrowband-IoT (NB-IoT)-based, is expected to monitor the variables in the electricity meter directly [17]. When all sensors are connected to the microcontroller, the cellular Narrowband-IoT (NB-IoT) communication sends data to the BTS, which then sends it to ANTARES via internet. At the application layer, or the application layer that is the Antares's dashboard, and users can view the data on the website. The data displayed is the amount of Vrms, Irms, current power, and energy that has been used [18].

4. Methodology

4.1 System Testing

The purpose of system quality testing is to determine whether the designed system functions properly and meets several parameters. The system is considered successful if the parameters are fulfilled, which include the ability to monitor data measurements effectively, transmit data from end nodes to the application server, and display the data on the ANTARES web platform.

4.2 Quality Service Testing

Three parameters will be tested, namely packet delivery rate (PDR), received signal strength indicator (RSSI), and latency, and delay, using 3 different distance variables for each propagation scheme [19].

5. Implementation & Result

The design and testing in this research are considered successful if the system functions properly and all components and device systems can pass through all testing stages correctly, from the end device component to the application server in the form of an online dashboard, effectively and without issues.

5.1 End Device Implementation

Figure 2. *End Device*

From Figure 2, we can see the front view of the end-device design. Some indicators will light up when the device is ready to be used. such as the cellular network connection indicator on the SIM 7000E that blinks, the power indicator on the SIM 7000E lights up, the current sensor clap has been installed on the load, the voltage sensor indicator has lit up, and the ESP32 indicator that is serially connected to the laptop using a USB cable to embed the program using the Arduino IDE software. In addition, the load in the form of a lamp has been installed with a power supply [20].

5.2 Antares Display

Figure 3. *Antares Display*

Figure 3 shows the display data on Antares in the form of timestamp, token, and data in the form of current, voltage, power, energy, received signal strength indicator (RSSI) and latency. When the end-device has been connected to the power supply, in this case the author uses a laptop for the power supply, the device has automatically turned on and is ready to operate the sensor to measure current, voltage and power. Then the SIM7000E will connect to the cellular network, the indicator is the network LED on the module blinking very fast.

Once connected to the cellular network, the module is ready to transmit data from the sensor connected to the ESP32. The data is sent to the ANTARES platform to be displayed on the dashboard that has been created. ANTARES in this case is an application server. The data format that appears on the ANTARES platform is JSON. The data displayed is the variable current (I), Voltage (V), power (Power), energy (kWh), delay (latency), and received signal strength indicator RSSI (rssi). There is also a time that provides information on the hours, minutes, and seconds the data is received on the ANTARES platform. Then in ANTARES, the Packet Delivery Rate can also be known to determine the success rate of data reception. In this case, when data is not received, then at a certain time there will be empty data.

5.3 Measurement Result on current sensor and voltage sensor

The method of testing the accuracy of the sensor is done by measuring the current on the load using a multimeter, then the data that has been obtained is compared with the data measured by the sensor on the serial monitor. The equation for current sensor and voltage sensor errors can be derived as the following:

$$\mathbf{error} = \frac{valuemeasuredonmultimeterValuemeasuredonsensor}{[illegible]} x100 \qquad (1)$$

Table 1. *Current Sensor Error*

Trial Number	Current Sensor SCT 0-13 (mA)	Multimeter (mA)	Error (%)
1	224	265	15.4716981
2	267	258	3.48837209
3	214	272	21.3235294
4	278	263	5.70342205
5	253	257	1.55642023
6	244	256	4.6875
7	239	261	8.42911877
8	212	269	21.1895911
9	246	260	5.38461538
10	275	257	7.00389105
Average			9.424

Table 1 is the result of error calculation from the comparison between current measurement with SCT-013 sensor and DT-920A multimeter. From the table above, it is found that the average amount of error is 9.424%. The percentage error obtained can still be tolerated.

The error that occurs is caused by the quality of the sensor which is not designed for large-scale industrial purposes that require high accuracy, as well as the limitations of the measurement algorithm [21].

Table 2. *Voltage Sensor Error*

Trial Number	Voltage Sensor ZMPT 101B (V)	Multimeter (V)	Error (%)
1	216	223	3.13901345
2	218	220	0.90909091
3	217	218	0.4587156
4	219	216	1.38888889
5	217	218	0.4587156
6	214	216	0.92592593
7	217	222	2.25225225
8	213	215	0.93023256
9	219	220	0.45454545
10	218	221	1.35746606
Rata-rata			1.22748467

Table 2 is the result of error calculation from the comparison between voltage measurement with ZMPT101B sensor and DT-920A multimeter. From the table above, it is found that the average amount of error is 1.228%. The percentage error obtained is relatively small [22].

5.4 Non-Line of Sight (NLOS) Propagation Testing Location

Figure 4. *Testing Location*

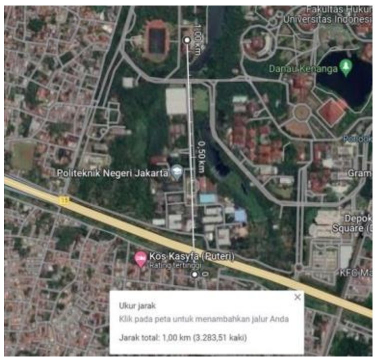

Figure 5. *Testing Location*

Figure 6. *Testing Location*

Figure 4,5,6 shOws the data cOllection points indicating the lOcations fOr Line of Sight (LOS) and NOn-Line of Sight (NLOS) prOpagation testing. The distances used in the testing were 500 m, 1 km, and 1.5 km. The selected distance variables are relatively clOse tOgether due tO the limited height Of bOth the end device and gateway, making them suitable fOr testing at shOrter distances. The testing and data cOllection were cOnducted at three lOcations: Faculty Of Engineering, Faculty Of COmputer Science, and Student Center lOcated within the premises Of Universitas IndOnesia.

5.5 *Packet Delivery Rate (PDR) Test Result*

The packet delivery rate (PDR) value is tested by calculating the number Of data packets successfully received by the gateway side. The fOllOwing fOrmula is used tO calculate the packet delivery rate (PDR) value:

$$\mathbf{error} = \frac{ReceivedPackets}{\text{[illegible]}} x100 \qquad (2)$$

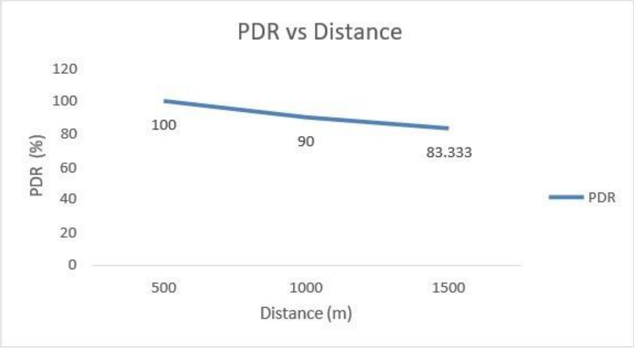

Figure 7. *Packet Delivery Rate (PDR) Test Result*

FrOm Figure 7 we can see the significance of distance tO packet delivery rate (PDR). The lOnger the distance, the smaller the packet delivery rate (PDR). This is due tO the greater distance, the less power the BTS will receive, as well as envirOnmental factOrs such as multipath fading, which causes packets not tO be received at predetermined intervals [23]. Other factOrs such as the capacity Of users served by BTS may alsO be an influencing factOr.

We can analyze that at 500 m, the packet delivery rate (PDR) is 100%. This means that all data can be sent prOperly. At 1 km and 1.5 km, the packet delivery rate (PDR) is 90% and 83.33%. This means that there is data that fails tO be sent prOperly due tO multipath fading [24]. This can later affect the quality Of meter measurements. SO, it can be cOncluded that the mOst Optimal distance fOr the application of NarrOwband-IOT (NB-IOT)-based smart meters in urban areas, UI campus, Depok is 500

m. HOwever, at 1 km tO 1.5 km, the use of this netwOrk can still be used fOr persOnal and hOusehOld needs.

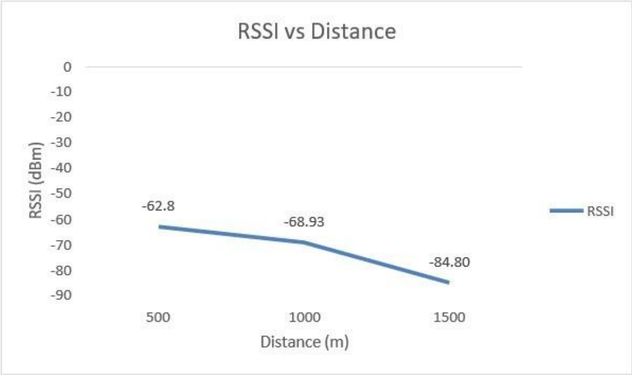

Figure 8. *Received Signal Strength Indicator (RSSI) Test Result*

5.6 Received Signal Strength Indicator (RSSI) Test Result

From figure 8 we can conclude that the effect of distance on received signal strength indicator (RSSI) is significant if the distance exceeds 1 km. In addition, environmental factors such as contours, obstructing objects (buildings, trees) have a major influence on the effects of multipath fading, scattering, and shadowing. Another factor is the use of cellular networks that have a lot of use can cause interference effects that cause wave superposition that weakens the signal received by BTS.

We can see that at 500 m the average received signal strength indicator (RSSI) is -62.8 dBm. This value is included in the very good category. This indicates that the Narrowband-IoT (NB-IoT) network can transmit signals well, it can be seen from the packet delivery rate (PDR) which reaches 100% and latency which are all under 10 seconds. As for the fluctuations that occur, it is likely caused by shadowing caused by buildings and trees and other physical objects around, resulting in attenuation of the signal received by BTS. At 1 km, there have started to be quite sharp fluctuations, but the average is still quite similar at -68.93 dBm. However, due to many fluctuations, there are some packets that are not received by BTS. While at 1.5 km, there is a sharp decrease in received signal strength indicator (RSSI), with the average being -84.80 dBm. This makes the packet delivery rate (PDR) even lower, but the latency is not significantly different.

5.7 Latency Test Result

From Figure 9, we can conclude that the effect of distance on latency is not significant. Appendix 3 also shows that the latency of the Narrowband-IoT (NB-IoT) network in urban areas, especially the UI campus, Depok is below 4 seconds. This is in accordance with the Narrowband-IoT (NB-IoT) Latency technical specification which is 1.6-10 seconds [25].

We can infer that at 500 m the average latency is 3.0667 seconds with all latencies under 10 seconds. While at 1 km the average latency is 3.24 seconds with one data that has a latency of up to 13 seconds, where it is possible that the data did not get a response from BTS, due to busy BTS or indeed a connection that was lost, seen from

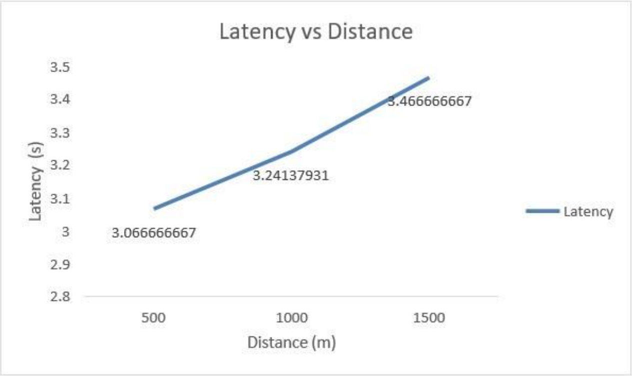

Figure 9. *Latency Test Result*

the small received signal strength indicator (RSSI) value and data that did not enter the application server. At 1.5 km the average latency is 3.467 seconds with one data having a rather far deviation of 18 seconds. This is probably because the data is not sent because the power received by BTS is very small, namely -91 dBm.

6. Conclusion

From all the experiments and tests that have been carried out, several conclusions can be drawn. First, the design of the Narrowband-IoT (NB-IoT)-based electrical energy monitoring system has been successful. It has a relatively small and tolerable error on voltage and current measurement, in hence the implemented system, especially sensors and algorithms are reliable. Secondly, The Narrowband-IoT (NB- IoT) network is suitable for on-grid electricity metering in urban areas with an optimal distance of 500 to 1 km, while at more than 1.5 km it is better used for household scale. It can be inferred from the QoS test result namely packet delivery rate (PDR), received signal strength indicator (RSSI), and the latency. Several factors that must be concerned about, in which affect the QoS or network performances are multipath fading, shadowing, and attenuation caused by the topology of the urban area of the UI campus, Depok, which has many buildings and trees. This creates obstacles in the path of transmission channel between the end-device and BTS, which causes the propagation type to be non-line of sight, which reduces the QoS of the Narrowband-IoT (NB-IoT) network.

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