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LoRaWAN Implementation for Smart Electric Meter in Rural Area

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Developments of technology forces all society elements to mitigate future risks by applying green technology and concerning energy sustainability. The rapid change of the internet allows people to take advantage of the Internet of Things (IoT) in energy management. The public has widely used IoT-based smart meters to monitor and control energy consumption in many households. The architecture of an IoT system consists of three main layers: device, network, and application, which are implemented to manage utility. The IoT-based smart meter device functions to monitor the use of electrical energy and enable kWh balance top-up. The smart electric meter is implemented to substitute post-paid conventional electricity meters with pre-paid ones. The smart electric meter device is embedded with a LoRa (long-range) communication module to send electricity data via the LoRaWAN (long-range wide-area network). LoRaWAN is confirmed as one of the most reliable connectivity for IoT use in rural areas. LoRaWAN meets the needs of low-power, remote, efficient and affordable IoT technology in utility energy monitoring. The LoRaWAN network was built in the Musi Banyuasin area to meet the needs of implementing LoRaWAN-based smart electric meters. According to the results of the LoRa study, the gateway can optimally meet the connectivity needs of smart electric meters in rural areas. A gateway can reach a maximum distance of 1.58 km, with an RSSI of −99.40 dBm ±4.56 dBm. LoRa gateway availability can achieve 100% by implementing a gateway protection system. The data sent through the LoRa gateway is then consumed by the user at the application layer, where all electrical energy data are stored in the IoT Platform. Then by utilizing the API (Application Programming Interface), users can seamlessly consume data and display all monitoring results on the monitoring dashboard. The monitoring dashboard has features that read energy consumption on the smart electric meter and recap all energy usage. The dashboard also allows users to top-up their kWh balance when the electric balance in each home is nearing the limit.

Keywords: smart electric meter, LoRaWAN, LoRa gateway, IoT, pre-paid smart meter

1. INTRODUCTION

The consumption of worldwide electrical energy per capita has increased during the last four decades, including in Indonesia [1]. There is an urgency to save energy for accomplishing sustainable energy security. One of the efforts in energy-saving management can be made by energy consumption monitoring. Measuring electrical energy consumption has also been carried out on household electricity meters, using conventional meters. Along with the development of IoT technology, the need to monitor electrical energy consumption can be met. With an IoT-based smart meter device, the process of monitoring

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electrical energy consumption is more convenient. Compared to conventional meters, smart meter advantages are digital display data, two-way communication, unlimited control, and multi-sensor [2]. The implementation of smart electric meters has been widely occurred, including smart homes [2], smart cities [3], and smart grids [4]. This IoT-based smart electric meter has been successfully implemented in urban areas [5]. Meanwhile, very few studies have stated their success in implementing smart electric meters in rural areas.

Indonesia's electrification ratio had achieved 99.2% in 2020. This implies that electrification has reached most parts of Indonesia, both in urban and rural areas. It includes one of the rural areas in Musi Banyuasin, Palembang. Musi Banyuasin's local government also manages electricity consumption by utilizing IoT technology. IoT-based smart electric meters for rural areas certainly have specifications because not all rural areas have reliable internet connectivity. Thus, an IoT electricity smart meter system is needed, with wide-range coverage and optimum cost specifications. The IoT connectivity includes GSM/Cellular, Wifi, Bluetooth, or LPWAN (low-power wide-area network) are commonly used today. Based on the need for implementing smart electric meters in rural areas, LPWAN (low-power wide-area networks) is the most suitable technology because of its wide range, low power consumption, and cost-effectiveness. Telkom Indonesia has implemented a LoRa-based electricity smart meter system, an IoT connectivity system based on LPWAN, in the Musi Banyuasin area. Besides the problems regarding network connectivity, several issues need to be addressed in Musi Banyuasin. The power source in Musi Banyuasin often occurs blackouts due to the hilly contour lands, making it difficult to install the electrical system optimally. So that, planning the optimal LoRa gateway electrical system is also a challenge in this research. A private company supplies the electricity system in Musi Banyuasin. The company has implemented post-paid metering for villagers, but they face problems when users are late in making payments or are in arrears. So pre-paid smart electricity meters are used to automatically help companies and users monitor and control the use of electrical energy. Currently, there are 10,000 electricity meters spread across seven sub-districts in Musi Banyuasin. Therefore, it requires reliable connectivity, low cost, and a wide coverage area to integrate the smart electric meter. The pre-paid smart electric meter allows the user to automatically top-up the electricity balance by conducting control using the internet. Pre-paid will regularly monitor the electricity usage on the dashboard and notify the user whenever the electricity balance is near its lower limits. Thus, the user can automatically top-up the electricity balance via the internet.

2. LITERATURE REVIEW

2.1 Smart Electric Meter and LPWAN

Traditional electric power company uses human resources to record the electricity usage (kilowatt-hours – kWh) in every household. With the advancements of technology, a smart meter system is being used to replace the traditional one. A smart electric meter refers to a system that measures electricity usage and controls electricity supply and cut-off. According to [6], a smart electric meter's features are: real-time or near real-time monitoring of electricity usage, remote controllability, the ability to capture events such as device status or power quality, and a reporting system as the user interface. The smart electric meter is also the foundation of a smart grid system where electricity companies can provide better services based on their performance data and communication systems [7].

Smart meters have been adopted to develop various features to improve efficiency and billing calculations where GSM connectivity is used [8, 9]. The billing calculation formula can be seen in Eq. (1). However, these studies have limitations due to GSM coverage and power consumption issues. The other data communication type can also be used, for example, wi-fi [10, 11], but these systems' coverage of Wi-Fi and its high-power consumption are the drawbacks. Specific technology for IoT communications has been developed based on the connectivity issues to support long-range and wide area network purposes or LPWAN. The LPWAN technologies are designed for IoT communication where sensors can deliver or receive data to/from IoT gateway with more efficient bandwidth, low power, and wide-area [12, 13]. There are many types of LPWAN known in IoT connectivity, for example, Sigfox, NB-IoT, and LoRaWAN. Sigfox is an ultra-narrow band of 100 Hz bandwidth and a maximum 100 bps data rate. Sigfox has a limitation in data sending, which is 140 uplink messages per day, and each message can only afford 12 bytes of data length [14]. With these characteristics, Sigfox is not fit for smart meter use cases since smart electric meters typically require about 150 bytes of data size [15].

Meanwhile, NB-IoT is a narrow-band technology specified in 3GPP Release 13 (June 2016) with 20 kbps and 200 kbps uplink/downlink data rate, no messages per day limitation, and maximum 1600 bytes payload length. Technically, NB-IoT is capable of accommodating smart meter requirements. Still, it is considered as high-cost connectivity since it uses licensed LTE frequency spectrum, not unlicensed spectrum like Sigfox or LoRaWAN [14]. Meanwhile, LoRa (or LoRaWAN), which is chosen to be used in this research, has technical characteristics as follows [14]: maximum 50 kbps data rate, no messages per day limitation, and a maximum 243 bytes payload length. LoRa typically uses an unlicensed frequency spectrum to make it a cheap communication mode preferred by many IoT providers. The comparison of these three LPWANs is depicted in Table 1.

LoRaWAN has begun to be widely applied by smart meter manufacturers as connectivity for prepaid and post-paid electricity meters. Indeed, in Indonesia, users of post-paid electricity meters have migrated to prepaid electricity meters. This research was conducted in Musi Banyuasin, Palembang, Indonesia, on a prepaid electricity smart meter using LoRa. The smart electric meter specifications in this study are shown in Table 2 below, while the illustration of the smart electric meter is shown in Fig. 1 [16].

$$Billing = kWh\ usage \times price\ per\ kWh \tag{1}$$

Fig. 1. Single phase LoRaWAN smart electric meter [16].

Table 1. Comparison table of Sigfox, LoRa, and NB-IoT [14].

	Sigfox	LoRa	NB-IoT
Modulation	BPSK	CSS	QPSK
Frequency	Unlicensed ISM bands (868MHz in Europe, 915MHz in North America, and 433MHz in Asia)	Unlicensed ISM bands (868MHz in Europe, 915MHz in North America, and 433MHz in Asia)	Licensed LTE frequency bands
Bandwidth	100 Hz	250 kHz and 125 kHz	200 kHz
Maximum data rate	100 bps	50 kbps	200 kbps
Bidirectional	Limited/Half-duplex	Yes/Half-duplex	Yes/Half-duplex
Max messages/day	140 (Uplink), 4 (Downlink)	Unlimited	Unlimited
Range	10 km (urban), 40 km (rural)	5 km (urban), 20 km (rural)	1 km (urban), 10 km (rural)
Interference immunity	Very high	Very high	Low
Authentication & encryption	Not supported	Yes (AES 128b)	Yes (LTE encryption)
Adaptive data rate	No	Yes	No
Handover	End-devices do not join a single base station	End-devices do not join a single base station	End-devices join a single base station
Localization	Yes (RSSI)	Yes (TDOA)	No (under specification)
Allow private network	No	Yes	No
Standardization	Sigfox company is collaborating with ETSI on the standardization of Sigfox-based network	LoRa-Alliance	3GPP

Table 2. LoRaWAN-based smart electric meter specifications [16].

Type	Single-phase electricity meter
Communication interface	LoRaWAN; RS485 protocol
Working temperature; humidity	–25ºC~ +55ºC; <=85%
Power Consumption	< 1.0 W
Operating life	> 10 years
Accuracy class	2.0
Voltage	220/230/240 V
Frequency	50/60 Hz

2.2 LoRaWAN Connectivity

LoRaWAN is a network technology based on the open standard Media Access Control (MAC) layer, which complements the physical layer technology called LoRa. LoRa works for low-power, long-range transmission, which Semtech Corporation licenses. The principle of LoRa modulation is based on the chirp spread spectrum (CSS), a modulation scheme by utilizing the chirp signal where the frequency increases (up-chirp) or decreases (down-chirp) with time [17].

LoRaWAN architecture consists of three main elements, as shown in Fig. 2, the end nodes or end-device, LoRa gateway, and LoRa network server. First, LoRa gateways are connected to the network server through a standard IP connection. Second, the end-nodes or end-devices utilize the characteristics of LoRa as long-range wireless communication, which provides two-way communication from the end-device to many gateways. Finally, the application of dashboard form as user interface allows the application server to obtain data from the network server via a standard IP connection and then launch the application via HTTPS protocol.

The consideration of applying LoRa in this study is due to several advantages offered in the LoRa connectivity specifications, as shown in Table 3. LoRa is confirmed as the most reliable connectivity for IoT use cases. Since it has a long battery life of up to 10 years, it may differ according to the data rate selection or reporting interval. LoRa also covers a wide range of areas, with a maximum line of sight up to 30 miles. All data sent by LoRa are fully encrypted using network security, licensed by AES128 (128-bit Advanced Encryption Standard). LoRaWAN connection in each region is regulated to specific frequency ranges and included in ISM (industrial, scientific, and medical) radio bands, wherein Indonesia, the frequency is specified on 923-2 MHz channel bands [18].

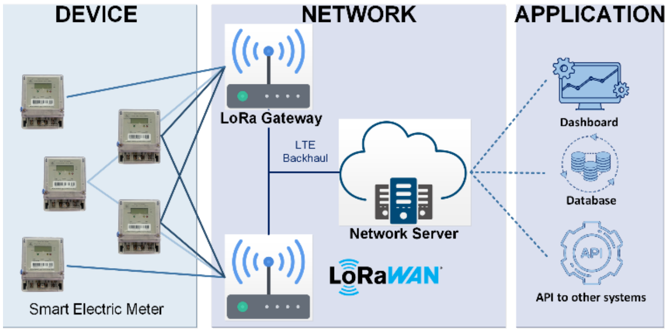

Fig. 2. LoRaWAN architecture.

Table 3. LoRa technical specifications and advantages.

Specifications and Advantages	
Battery lifetime	up to 10 years
Area coverage	up to 30 miles in rural areas
Security	full network security [AES128]
Modulation spectrum	CSS (allowing GPS-free location)
Frequency band	ISM radio bands [433; 868; 915; 923 MHz] (high-capacity, low-cost operation, and highly optimized ground-up design)
Application development	availability of open standards and ecosystem

3. DESIGN AND IMPLEMENTATION

The main intention of the smart electricity meter in Musi Banyuasin is to create a prepaid electricity system for the residences. As 10,000 devices need to connect to the system, it needs effective and efficient technology. The high-level architecture of the system consists of devices, networks, and applications, shown in Fig. 2. The used devices are smart electricity meters embedded with a wireless communication module. A smart meter sends the data through the network layer using LoRaWAN connectivity to the application layer, where the end-users have various credibility for data processing and governing.

The system's main objective is to monitor electricity usage and allow users to top-up kWh balance. In the system, two features are needed: (1) kWh usage monitoring and (2) kWh balance top-up. Electricity Usage Monitoring is a feature to monitor kWh usage of a house. Electric power usage will be used to cut the kWh balance in the smart meter. When the balance reaches 0, the consumer cannot use electricity until they top-up kWh balance. kWh Balance Top-Up is a feature that allows consumers to increase their kWh balance. The consumer can keep using electricity if they have enough balance. Fig. 3 is the data flow diagram to represent these features.

The LoRaWAN system architecture describes the whole system consisting of a smart electric meter as the device, LoRa gateway, LoRa network server and Antares IoT platform as the networks, and main dashboard as the application, which is illustrated in Fig. 4. Since this system will be implemented in a rural area, fiber connection cannot be used as a backhaul option for the LoRa gateway. Instead, the mobile network supports the backhaul connectivity (3G and 4G connection).

In accomplishing network coverage for 10,000 devices in 7 sub-districts, LoRa gateways must be planned strategically to cover as many devices as possible with as few gateways as possible. In this implementation, the limitation is the placement of the LoRa gateway installation. Since the LoRa gateway needs to be placed in a specific tower for maintenance and power availability, the LoRa gateways will be placed in existing towers in the area. Fig. 5 shows the LoRa gateway site planning design. The design process used a coverage calculator. From the site planning below, it can be concluded that eight gateways are needed to cover the area by design.

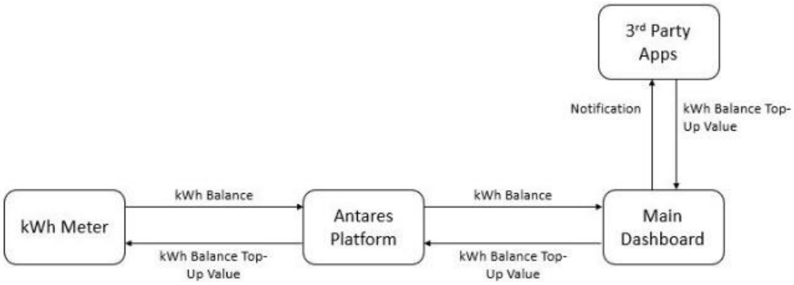

Fig. 3. Data flow diagram.

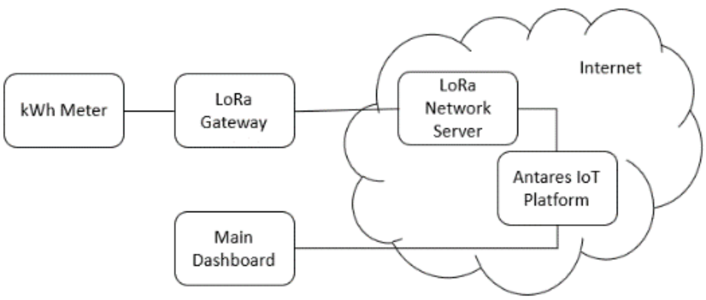

Fig. 4. System architecture.

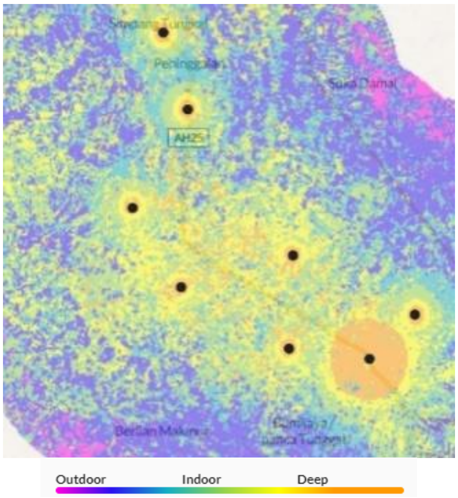

Fig. 5. Gateway site planning.

LoRaWAN specification has been stated by LoRa Alliance [19] for many use cases implementation. Every region also has its LoRaWAN network regulation, ruled by government policy. The Indonesian LoRaWAN network regulation is governed by the Ministry of Communication and Informatics [20], specifies a duty cycle of 1%, power usage not exceeding 20 dBm, and frequency in AS923-2 standard.

In addition to those standards and specifications, a power protection system is utilized to mitigate power issue risks, as illustrated in Fig. 6. The mitigation needs to be done because Musi Banyuasin, as a remote area, does not have a reliable and stable power source. Hence the electricity quality is poor. On top of that, the weather is quite extreme with rain and lightning. The power protection system consists of a solar panel, battery system, and surge protector, as seen in Fig. 7. The solar panel is located on the ground near the tower. The battery system is also located near the solar panel. As for the surge protector, the device is located on the tower near the LoRa gateway. This system is designed to take power from on-grid electricity as a default power source and can immediately change to a battery if the main source is unavailable.

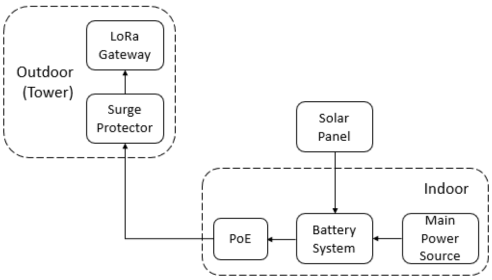

Fig. 6. Gateway protection system.

Fig. 7. Power protection installation.

4. RESULT AND ANALYSIS

This section verifies the accuracy and reliability of the proposed scheme through simulation and comparison of the performance with several well-known schemes. In this section, the result of the system implementation is shown. In addition, the analysis of the result is also described.

4.1 Monitoring and Controlling Dashboard

The electricity power usages are automatically monitored on the dashboard. Users can manage daily electricity consumption, last month recap electricity consumption, and recharge electrical energy. The monitoring feature for kWh usage and top-up kWh balance is important for the monitoring dashboard. The dashboard homepage is shown in Fig. 8.

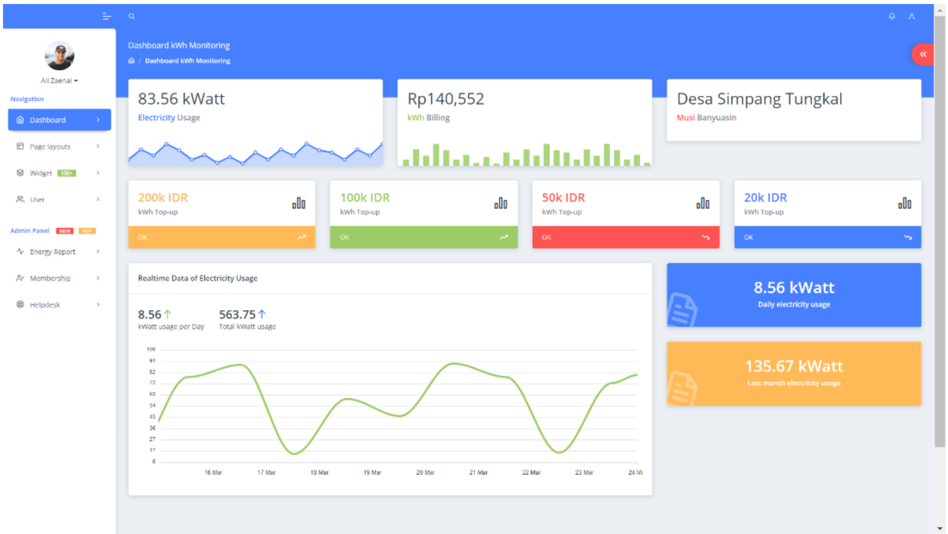

Fig. 8. Electricity usage monitoring dashboard.

4.2 LoRa Gateway Coverage

Eight LoRa gateways are deployed in the area around Musi Banyuasin, as illustrated in Fig. 5. However, the coverage in the simulation can be different from the coverage in actual implementation. Therefore, a driving test was conducted with a GPS LoRaWAN device to measure the exact gateway coverage, shown in Fig. 9. First, a field team was assigned to carry the device around the area, and then the result was mapped to see actual coverage with RSSI data.

This sensor functioned as a drive test device that sends longitude and latitude data to the gateway. The gateway then measured the RSSI data and sent the longitude, latitude, and RSSI, shown in Fig. 10. From Table 4, it can be concluded that the RSSI of our LoRa network is –99.40 dBm ±4.56 dBm with an interval of trust of 95%. This result is better than the target RSSI for LoRa, –110 dBm [21]. The longest distance between a gateway and an end-node device is 1.58km. The distance between the LoRa gateway and the end-node device somehow differs from the theoretical LoRa specification, and this can be happened due to the hilly contour and obstacles in Musi Banyuasin region. However, by implementing proper LoRa network planning, by utilizing eight LoRa gateways, 10,000 end-node devices can be connected.

Fig. 9. LoRa GPS sensor.

Data


```
{
  "batt": 31,
  "latitude": -6.237375,
  "longitude": 106.798725,
  "gpsFix": 0,
  "reportType": 0,
  "rssi": -107,
  "gateway": "b0fd0b7006cc0000",
  "time": "2021-02-24 02:11:45"
}
```


Fig. 10. GPS data from IoT platform.

Table 4. Uplink RSSI data.

Parameter	Value
Maximum RSSI	–80 dBm
Minimum RSSI	–117 dBm
Average RSSI	–99.40 dBm
RSSI Standard Deviation	4.56 dBm

4.3 LoRa Gateway Durability

We measure the LoRa gateway durability by using the uptime/power graph of the gateway. Fig. 11 is the graph that shows the uptime and power of the gateway. It shows uptime in duration and power in percentage. The green line shows the uptime, while the yellow line shows the power, as mentioned in the uptime/graph index in Table 5. If the uptime forms a ramp, the gateway never goes offline. If the uptime goes back to zero, it shows that the gateway experienced a power error resulting offline.

With the help of a protection system, a gateway availability of 100% can be achieved. Fig. 11 shows that even though slight time power is unavailable (indicated by the yellow line for power), the uptime (shown by the green line for uptime) is still untouched. The uptime graph and power graph can indicate some symptoms in the LoRa Gateway site, as mentioned in Table 6. When the power graph fades off implies that the gateway power source has been disconnected. Meanwhile, when the power graph shows a constant graph, the gateway is constantly getting the power supply. The uptime graph indicates gateway availability. If the uptime graph forms a ramp trendline, the gateway is always online, which means high availability. The opposite is when the uptime graph declines to zero, which means the gateway is offline, so the availability is low.

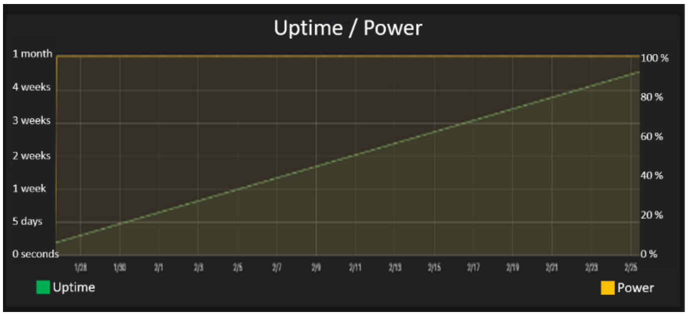

Fig. 11. LoRa gateway uptime/power graph.

Table 5. Uptime/power graph index.

Parameter	Unit	Index
Uptime	Duration (year, month, week, day, or minute)	Green
Power	Percentage	Yellow

Table 6. Uptime/power graph indication.

Indication	Meaning
Power fades off	Power cut from the source, the gateway does not have power
Power forms a full block	Gateway never have a power problem
Uptime forms a ramp	Gateway always turned on
Uptime goes back to zero	Gateway experienced a power error, and the gateway does not have power

5. CONCLUSIONS

The study has confirmed the availability of LoRaWAN-based smart electricity meters in rural areas. As one of the most reliable IoT connectivity schemes, LoRa has proven its effectiveness to be applied in rural areas with limited internet access. Furthermore, by leveraging LoRa gateways in specific areas for optimal coverage, smart electric meters are successfully implemented with high availability, optimal cost, and wide scalability for further implementation improvements.

The monitoring dashboard has also been implemented to monitor daily electricity power usage in each household in Musi Banyuasin. The dashboard enables the user to monitor the daily electricity usage and top-up kWh balance. Users can top-up kWh balance by selecting the button in the monitoring dashboard and completing the payment via any third-party payment.

Telkom LoRaWAN network can successfully cover 10,000 households with smart electric meters (kWh meter), consisting of the outdoor gateway covering up to 1.58 km in radius, with –99.40 dBm ±4.56 dBm RSSI. This result can be considered good as the target for LoRa RSSI is above –110 dBm. Moreover, its availability is improved to 100% after using a protection system. The protection system consists of a solar panel, a battery and battery charging module, and a surge protector to ensure the system is safely deployed.

The LoRaWAN-based smart electricity meter application in Musi Banyuasin has been successfully implemented as a pilot project for implementing IoT technology in rural areas. LoRaWAN technology is proven to be implemented in both urban and rural areas. LoRa connectivity has a great potential for implementing IoT in Indonesia's regions with its various benefits.

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