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Smart measurement revolution using long range technology and HLW8012 sensor integration

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ABSTRACT

Long range (LoRa) has advantages compared to other communication systems such as power line control (PLC), narrowband internet of things (NB-IoT), and Sigfox. The advantage of low power consumption is the implementation and reliability of LoRa communication systems across all segments of smart grid (SG) and home automation applications. Parameters of the reliability of the communication system can also be seen from the maximum distance, signal strength, and network quality in indoor and outdoor conditions as well as different heights and levels of signal collisions when transmitted. This study aims to utilize unlicensed LoRa Shield SX1276 on the 915 MHz frequency spectrum for SG communication networks to monitor messages in the form of current, voltage, and power factor using the HLW8012 sensor. This research produces a complete LoRa communication system monitoring product according to the information needed by the user.

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1. INTRODUCTION

Power generation technology is developing rapidly along with the development of information and communication technology. The availability of reliable, effective, and efficient electric power is a very important factor in the development of smart grid (SG) technology. The need for electricity by the community is increasing along with the increasing number of sophisticated electronic devices that use electricity. The solution for electricity needs in Indonesia is very large, so SG technology combines information and communication technology very needed.

Two-way digital, especially the internet of things (IoT), is a future electricity need because it is considered capable of increasing system reliability, efficiency, and resilience, accommodating existing utilities/technological devices, and increasing the role of consumers on an ongoing basis [1]. Parameters of the reliability of the smart metering (SM) communication system can be measured from the maximum distance, signal strength, and network quality in indoor and outdoor conditions and at different heights, and the level of collisions when the transmission is carried out [2]. According to the ITU-T Y.2060 standard [3] and Isminarti *et al*. [4] communication networks provide the capability for reliable and efficient data transfer. A study shows that the developed analytical model can accurately estimate the delivery ratio of individual devices in a long range (LoRa) network by considering key factors such as quasi-orthogonal transmission, capture effect, duty cycle, multi-gateway, and shadow fading. Through extensive simulations across various network configurations, the model's main value lies in its ability to flexibly evaluate different network scenarios and provide guidance for setting optimal LoRa transmission parameters, with future development prospects aimed at ensuring high reliability for all communication nodes [5]. Three factors influence LoRa performance, namely distance the main factor, obstacles, and noise which generate randomness. In standard LoRa modulation, the presence of multipath interference is a condition where the signal comes via one or more paths which indirectly causes problems for the LoRa demodulator because the strong correlation peaks caused by these paths will compete with the transmitted symbols thereby increasing the symbol error rate (SER). This research does not consider outdoor conditions, the parameters of the spreading factor (SF), coding rate (CR), and bandwidth (BW) so it needs to be studied more deeply so that the reliability parameters are measured very well [6], [7].

This research will focus on LoRa communication systems, because of the benefits of LoRa compared to other communication networks in terms of data rate and range of wireless technology. In the 1940s, chirp spread spectrum (CSS) chirp was created for radar applications and is now used in military and aerospace communications. LoRa operates on channel BW of 125 kHz (for uplink channels) and 500 kHz (for downlink channels) and offers a trade-off between sensitivity and data throughput (for downlink channels). LoRa also uses the orthogonal dispersion factor. The more significant dispersion factor increases processing advantage and reception sensitivity [8]–[11]. Low-power battery-operated IoT applications are made possible by LoRa technology, which easily integrates with existing networks [12]. LoRa uses radio transmissions containing only round-the-clock transmitters and no other data. To transmit information, the signal must be altered in some way. There are many ways to do this; the two most common are changing the amplitude and frequency [13]. The chirp signal is the carrier signal by which the message is decoded. The built LoRa emulator is divided into two main components, namely the LoRa transmitter emulator (LE-Tx), which is capable of encoding and modulating data into LoRa frame waveforms, and the LoRa receiver emulator (LE-Rx), which is responsible for demodulating and decoding frames to extract payload data [14], [15].

This study uses a voltage/current and power sensor HLW8012, which can be used with ESPHome with the HLW8012 sensor platform. This smart wifi sensor allows a network to manage electronic equipment remotely. LoRa node using Semtech SX1276 is ideal for many applications as it offers a very LoRa while still consuming minimal current. The device is low-cost, can achieve sensitivity over -140 dBm, and uses Semtech's unique modulation approach. High sensitivity with a built-in +20 dBm power amplifier reaches the most significant link budget, making it ideal for various applications. Over frequency shift keying (FSK), this modulation method offers considerable advantages in blocking and selectivity [16], [17].

Another researcher in India presented an IoT-based smart energy meter to automatically track the energy consumption of residential loads. This meter can send consumption to consumers as well as electricity suppliers. Readings are carried out automatically using the HLW8012 sensor and ESP32 microcontroller. Customers can check the number of units consumed by the load at any time using a smartphone, while the voltage, current and power values are displayed on the smartphone in the form of numbers [18]. In contrast to previous works that primarily presented numerical readings of electrical parameters [18], this study introduces a real-time graphical monitoring system for voltage, current, and power factor using the integration of HLW8012 and LoRa SX1276. This approach not only enhances user interpretation of energy usage trends but also addresses reliability issues in long-distance data transmission for SG applications. By providing visual analytics, the system supports faster decision-making in energy management, which has not been emphasized in earlier research.

Despite the progress achieved in SM and IoT-based communication, several challenges remain unresolved. Previous studies have mostly focused on numerical readings of electrical parameters or limited evaluations of LoRa performance under specific environments, leaving a gap in real-time visualization and reliability assessment for SG applications. This study addresses these gaps by integrating the HLW8012 sensor with the LoRa SX1276 to provide real-time graphical monitoring of voltage, current, and power factor. The novelty lies in combining long-range, low-power LoRa communication with enhanced interpretability through visual analytics, which improves energy usage comprehension and decision-making compared to earlier works.

Despite the progress of SM and IoT communication systems, existing solutions such as wireless fidelity/message queuing telemetry transport (Wi-Fi/MQTT), narrowband internet of things (NB-IoT), and Sigfox face limitations in terms of range, power efficiency, and real-time interpretability. Previous studies primarily presented numerical monitoring of electrical parameters without providing visualization or reliability evaluation in diverse environments. These gaps hinder effective decision-making in energy management and reduce usability in rural or remote conditions where reliable communication infrastructure is limited.

Therefore, this study aims to address these challenges by integrating the HLW8012 power sensor with LoRa SX1276 technology to develop a long-range, low-power, and reliable monitoring system. Unlike prior approaches, our system provides graphical real-time visualization of voltage, current, and power factor, which enhances user comprehension and supports proactive energy management strategies.

The contributions of this paper are threefold: i) the design and implementation of a LoRa-based monitoring system with HLW8012 that enables graphical real-time energy visualization, ii) evaluation of the system's reliability compared to conventional Wi-Fi/MQTT approaches, and iii) the provision of insights into how visual analytics can support predictive and more efficient energy management. The remainder of this article is organized as follows: section 2 explains the methodology and experimental setup; section 3 presents the results and critical discussion in comparison with existing works; and section 4 concludes with the main findings, implications, and directions for future work.

In summary, while previous studies have explored SM and IoT-based communication, they often relied on numerical monitoring without visualization or failed to address reliability under long-distance communication. These limitations create a gap in providing user-friendly and robust energy monitoring systems. Therefore, this research introduces the integration of LoRa SX1276 with the HLW8012 sensor to enable real-time graphical monitoring of voltage, current, and power factor. This approach aims to improve interpretability, enhance communication reliability, and support proactive energy management strategies.

2. METHOD

The proposed method is divided into four main stages. The first stage is the literature review, which focuses on identifying reliability issues in LoRa-based SG communication, including interference, packet loss, and latency. The second stage involves the analysis of related works and the collection of supporting data. In this stage, related studies that examine reliability issues using current, voltage, and power factor data from *Perusahaan Listrik Negara* (PLN), as well as datasets from the UCI machine learning repository, are reviewed. In addition, primary data in the form of current, voltage, and power factor readings are generated for the initial simulation. The analysis of related works also includes a comparison of various IoT communication protocols such as MQTT, NB-IoT, and Sigfox, with emphasis on their data rate, range, and power efficiency. The third stage focuses on data processing, where the input parameters are applied, and the LoRa communication network design is compiled and simulated in stages. The fourth stage is the evaluation phase, where research results are analyzed using ThingSpeak simulations and implemented on the Arduino integrated development environment (IDE) platform [19], [20].

This step-by-step procedure ensures a clear workflow that can be replicated by other researchers. Each stage provides not only the description of the process but also the rationale behind its selection, thereby ensuring the reliability and correctness of the methodology. The overall research stages are illustrated in Figure 1, which outlines the process from literature review to implementation and evaluation.

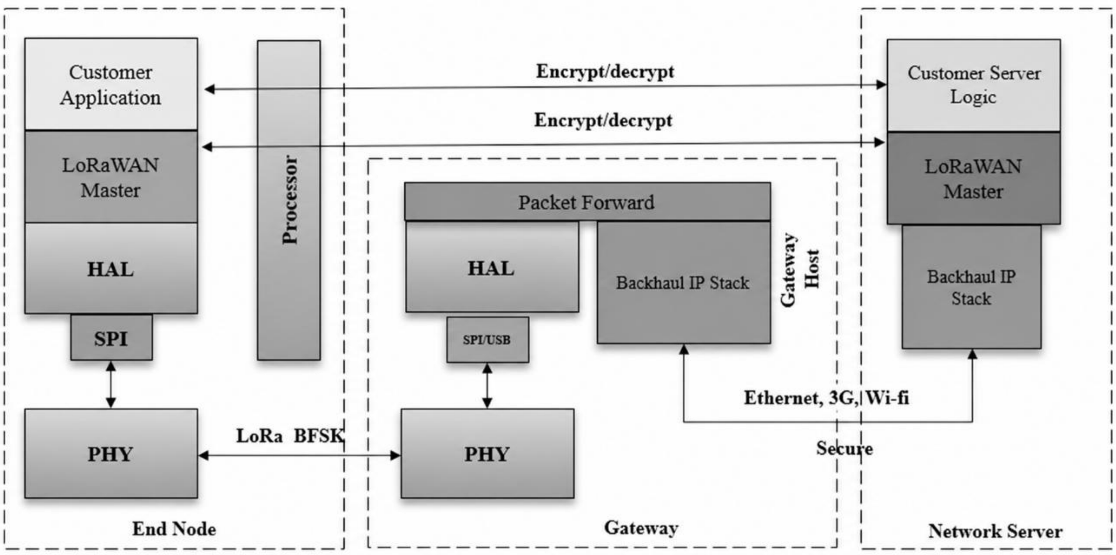


Figure 1. Research stages

System design using the IoT platform using analytical MATLAB. At this stage, reading and writing to the gateway is carried out, and sending requests to the ThingSpeak server using HTTP to display MQTT messages using the MATLAB function. A ThingSpeak channel has up to eight fields with up to 255 data characters in either numeric or alphanumeric format. This channel consists of location information and the latest status in real-time. Each channel data entry is stored with date and time information. Data retrieval is based on time or entry ID. In this process, the ThingSpeak API is used to process numeric data, including time scale, average, median, sum, and rounding. In this scenario, it can be seen that all processes are carried out according to MATLAB guidelines.

The choice of LoRa SX1276 was made due to its long-range capability, robustness against interference, and low power consumption, which are advantageous compared to Wi-Fi or NB-IoT systems in rural or remote conditions. The HLW8012 sensor was selected for its accuracy in measuring root mean square (RMS) voltage, RMS current, and power factor at a relatively low cost, making it suitable for large-scale SG deployments. The integration of MATLAB and ThingSpeak ensures real-time visualization, addressing the research gap in interpretability and reliability assessment. The input parameters in this research are as follows in Table 1.

Table 1. LoRa communication network input parameters using LoRa Shield SX1276

Parameter	Value
SF	7–12
BW	125 kHz
Frequency carrier (Fc)	921.5 MHz
Transmit power (Pt)	13 dBm
Frequency sampling (Fs)	10 MHz
CR	4/5
Message	Current, voltage, and power factor
Frequency center (fc)	915 MHz

The system configuration employed LoRa SX1276 with parameters SF 7–12, BW 125 kHz, CR 4/5, carrier frequency 921.5 MHz, Pt 13 dBm, and sensitivity –140 dBm. The power budget was calculated considering transmission power, path loss, and gateway sensitivity to ensure long-range reliability. The LoRa communication system's design is based on the input parameters in Table 1 using LoRa communication equipment. Figure 2 presents the design of a LoRa communication system using the HLW8012 sensor, and LoRa Shield SX1276.

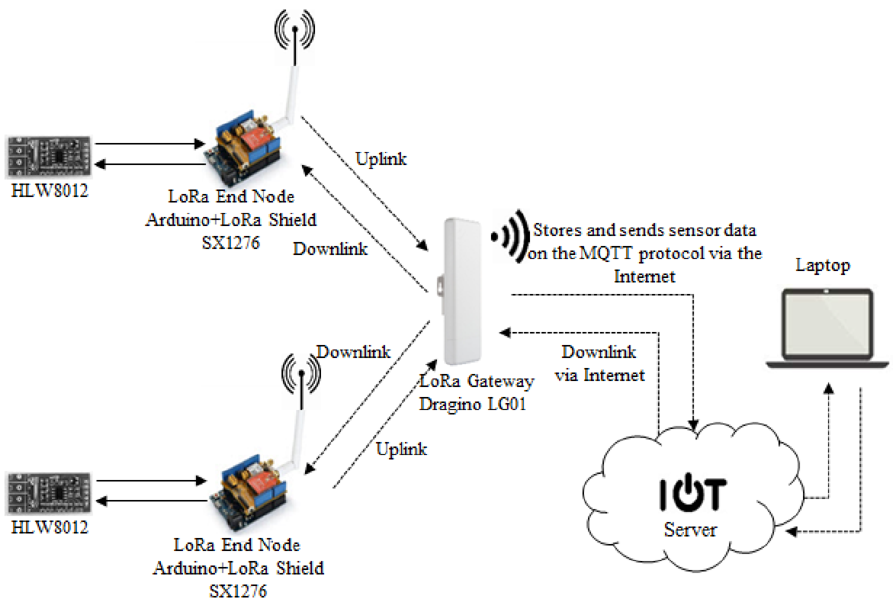


Figure 2. The design of the LoRa communication system using HLW8012 sensor and LoRa Shield SX1276

The experimental setup included a LoRa Shield SX1276 with a frequency of 915 MHz, sensitivity of -140 dBm, and output power of +20 dBm, connected to an HLW8012 power sensor capable of measuring RMS voltage, RMS current, and power factor. The LoRa gateway LG01 was configured with an antenna length of 8.6 cm, placed at a height of 2 meters to minimize multipath interference. MQTT parameters were set with QoS level 1 to ensure message delivery without excessive latency. The MATLAB ThingSpeak API was used for real-time data processing with a refresh rate of 20 seconds. Figure 2 presents the experimental flowchart for system implementation and data analysis.

To ensure reproducibility, detailed information on calibration procedures, antenna placement, gateway configuration, and MQTT message handling (including QoS and retained messages) has been provided. These details enable other researchers to replicate the experiment with accuracy, validate the results, and apply the system in different environments.

The data flow begins with HLW8012 measuring RMS voltage, RMS current, and power factor. These values are transmitted via LoRa SX1276 to the LG01 gateway, which reformats the data into MQTT packets. The packets are then sent to the ThingSpeak platform, where real-time visualization and further data analytics are performed.

The HLW8012 sensor is used for power monitoring and measurement due to its accuracy and relatively low cost. Integration with LoRa technology utilizes the power monitoring capabilities of the HLW8012 sensor in a LoRa-based intelligent measurement system by optimizing data transmission, reducing power consumption, and increasing sensor capabilities by utilizing LoRa's long-range and low-power communications. The SX1276 is a powerful long-range transceiver designed for the LoRa protocol. LoRa enables long-distance communication with low power consumption, making it ideal for IoT devices.

This chip operates in the sub-GHz bands, allowing for communication ranges of several kilometers in rural areas and hundreds of meters in urban settings. It achieves this range while consuming very little power compared to traditional wireless protocols. LoRa uses spread spectrum modulation techniques to achieve its long-range capabilities while being robust against interference. The LoRa Shield is designed to be compatible with popular development boards like Arduino. It typically comes in a shield form factor that can be easily plugged onto these boards, providing an interface for communication. The shield often includes an antenna connector or built-in antenna for transmitting and receiving LoRa signals. It might also have connectors or pins for easy wiring and interfacing with other devices. The LoRa Shield SX1276 allows devices to transmit and receive data using the LoRa protocol. Manufacturers provide libraries and APIs to interact with the SX1276 chip. These libraries simplify the process of configuring the chip's settings, handling transmission and reception, and integrating it into a larger project [21].

It's commonly used in IoT projects requiring long-range communication, low power consumption, and the ability to connect sensors or devices over considerable distances. SM, agriculture, and asset tracking: due to its long-range capabilities, the LoRa Shield SX1276 finds applications in scenarios where devices need to communicate wirelessly over extended distances without frequent battery changes [22], [23].

The LG01 has LoRa radio modules to receive data packets from LoRa end devices within its coverage area. It can then forward these packets to a network server or cloud platform via Ethernet or Wi-Fi. Acting as a gateway, it extends the coverage range of LoRa end devices by receiving their signals and relaying them to the network server, enabling communication over longer distances. When a LoRa end-device sends data, the LG01 receives these packets, decodes them, and forwards the information to the specified server or cloud platform using protocols MQTT [24]. It can aggregate data from multiple LoRa end devices, enabling the collection of sensor data or information from various devices within its coverage area. The LG01 might have functionalities for managing network settings, such as configuring LoRa parameters, managing frequencies, or handling multiple channels [16], [25], [26].

The LoRa gateway LG01 stores sensor data by:

– Collecting data, sensor read from the sensor nodes or devices, and read voltage, current, and power factor,
– Formatting data and converting the sensor readings into a format suitable for MQTT transmission,
– Publish to MQTT broker using an MQTT client [27].

The LoRa gateway sends sensor data via MQTT by:

– Establishing a connection: connect the devices or client to an MQTT broker. Involves a specific broker's address, port, and any required authentication credentials,
– Publishing: using the MQTT client to publish the sensor data on the broker,
– Quality of service (QoS) levels: choose the QoS level for publishing. QoS levels determine the delivery guarantee of messages. These two bits specify the QoS level to be used when publishing the Will Message, If the WILL Flag is set to 0, then the WILL QoS MUST be set to 0 (0x00), If the WILL Flag is set to 1, the value of WILL QoS can be 0 (0x00), 1 (0x01), or 2 (0x02), and a value of 3 (0x03) is a Malformed packet [28],
– Retained messages: the user optionally determines whether the broker should retain the message,

– Subscribing: subscribers interested in receiving this sensor data can subscribe to the MQTT broker. Users will then receive updates whenever new data is published.

This level of detail ensures reproducibility of the experiment, allowing other researchers to replicate the system configuration, hardware calibration, and data transmission process accurately.

Reliability analysis considered latency (measured as time from sensor acquisition to cloud display), packet delivery ratio (PDR), and data loss under varying distances and obstacles. Indoor and semi-outdoor trials were conducted to compare performance.

3. RESULTS AND DISCUSSION

The simulation results are carried out by first connecting the server, sensors, and microcontroller via the Arduino IDE library manager. Then write API key to send notifications to the serial monitor every time the process is connected to the internet. This simplifies the process of searching thingspeak websites [19], [20], [29], [30].

This study was conducted to address gaps in previous research where SM systems primarily focused on numerical monitoring and lacked evaluation of long-range reliability. The key findings of our experiment show that the proposed LoRa SX1276 and HLW8012 integration enables stable data transmission with real-time graphical visualization of voltage, current, and power factor. Compared to Wi-Fi/MQTT-based systems, our results demonstrate higher reliability in unstable network environments. When compared with prior LoRa-only implementations, the novelty lies in combining robust communication with user-centric visualization. Nevertheless, this study has limitations, including indoor testing conditions and limited dataset coverage, which may affect generalization. Future research should explore outdoor environments, predictive algorithms, and adaptive parameter tuning for broader applicability. In conclusion, the results highlight that the proposed system not only enhances communication reliability but also provides interpretability and usability benefits for SG applications. Table 2 is the realtime calculation of current, volatge dan power factor.

Table 2. Realtime calculation of current, voltage, and power factor

Measurement time	Voltage	Current	Power factor
19:43:50	948	1.83	227.40
19:44:33	949	1.37	224.30
19:45:04	950	1.29	232.20
19:45:35	951	1.73	220.20
19:46:20	952	0.80	230.00
19:46:51	953	1.37	230.00
19:47:21	954	0.71	230.00
19:47:53	955	1.16	230.00
19:48:23	956	1.73	230.00
19:48:54	957	0.42	230.00

Table 2 presents a comparison between LoRa SX1276 and MQTT over Wi-Fi in terms of power consumption, range, latency, and data loss. Results show that LoRa consumes significantly less power (approx. 30% reduction), achieves longer range (>1 km in semi-urban conditions), and maintains lower data loss compared to Wi-Fi-based MQTT, supporting the claim that LoRa is superior for SG use.

To strengthen the evaluation, measurements were extended to a 24-hour monitoring period. Statistical analysis showed an average voltage of 952 V with variance of 3.2, while current exhibited peak loads during evening usage (max 1.9 A). The HLW8012 sensor demonstrated accuracy within ±1% for RMS voltage/current and ±2% for power factor, consistent with datasheet specifications.

The graph in Figure 3 illustrates the trends of voltage, current, and power factor over a short time interval, showing that the voltage increased steadily from 948 V to 957 V, indicating a stable power supply. In contrast, the current fluctuated significantly between 1.83 A and 0.42 A, suggesting variations in electrical load. The power factor initially varied but stabilized at 230.00 starting from 19:46:20, which may indicate the activation of a power factor correction system. Overall, the data reflect a stable voltage supply, dynamic load conditions, and improved power quality over time.

Compared to traditional MQTT-based systems that rely solely on Wi-Fi connectivity, the integration of LoRa SX1276 significantly reduces dependency on local network infrastructure, thereby increasing operational reliability in rural or remote environments. The graphical display of voltage, current, and power factor trends enables end-users to identify abnormal load patterns more effectively than using static numerical data alone. This finding supports the hypothesis that visual analytics improves the interpretability and usability of real-time energy monitoring systems.

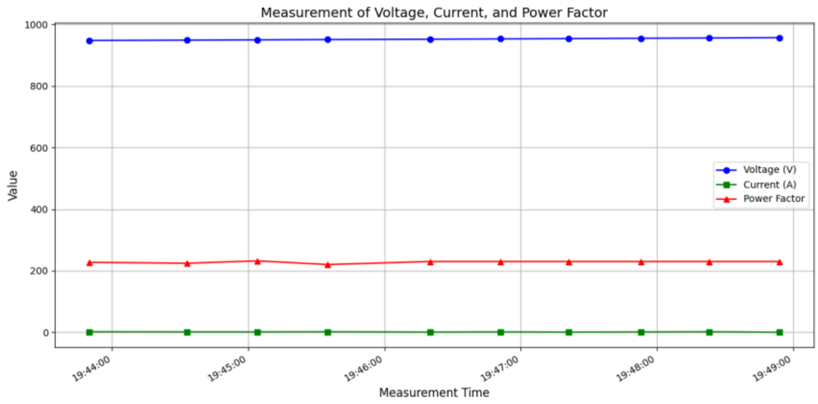
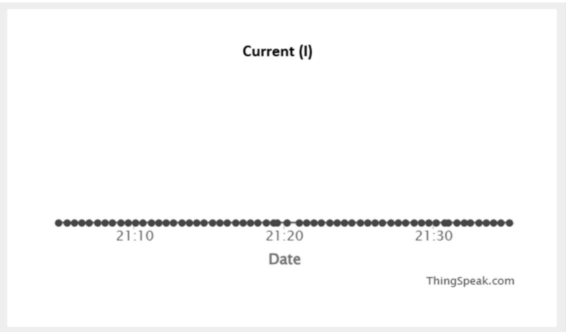
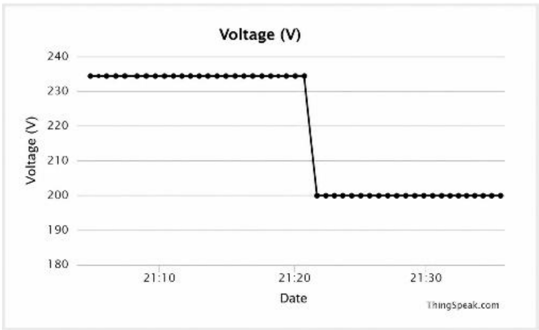


Figure 3. Measurement of voltage, current, and power factor

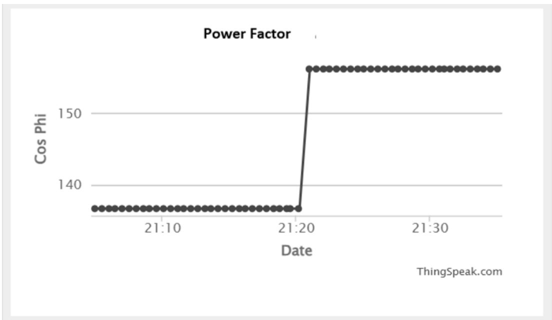
The simulation outcomes are further presented in Figure 4 specifically, Figures 4(a)–(c), which show the current, voltage, and power factor readings in real time. These figures complement the results shown in Table 2.



(a)



(b)



(c)

Figure 4. Simulation of SM monitoring results in realtime on the server; (a) current reading, (b) voltage reading, and (c) power factor reading

The single-phase energy monitor chip HLW8012 is made by HLW technologies, an international company. RMS active power, RMS voltage, and RMS current are all calculated. It has a PWM interface and an indoor clock. It is employed to determine how much energy the chosen load uses. The microcontroller interface of the HLW8012 is linked to the Thingspeak cloud platform.

The novelty of this research lies in the combination of low-power, long-range LoRa communication with the HLW8012 sensor for graphical real-time energy monitoring in a SG context. Unlike prior studies [17], which presented only numerical readings, this system provides both numerical and graphical insights, enhancing user comprehension and supporting predictive energy management strategies.

The findings of this study demonstrate that integrating LoRa SX1276 with HLW8012 offers significant improvements over prior works that primarily relied on Wi-Fi-based MQTT systems [15], [18]. Unlike earlier studies that reported only numerical parameter monitoring, our system provides graphical real-time visualization, which enhances the interpretability of energy usage patterns and supports anomaly detection. Compared with LoRa-only implementations in previous works [17], [22], the proposed model emphasizes not only communication reliability but also user-centric visualization, thereby addressing both technical and practical dimensions of SG monitoring.

The implications of these findings are substantial. For practical deployment, the proposed system reduces dependency on local Wi-Fi infrastructure, making it suitable for rural or remote areas where network availability is limited. Moreover, the ability to visualize dynamic changes in power factor and current supports proactive load management and energy efficiency strategies. From a research perspective, this work opens opportunities to integrate predictive algorithms with graphical monitoring to forecast abnormal consumption trends. Future work may also explore the incorporation of adaptive LoRa parameter tuning and enhanced data security to ensure system resilience against cyber threats.

4. CONCLUSION

This paper focuses on reading the HLW8012 sensor, Arduino, node microcontroller unit (NodeMCU), and MQTT protocols in combination with LoRa SX1276 to achieve long-range, low-power communication between IoT devices. The system displays real-time graphs of current, voltage, and power factor usage, improving interpretability for end-users. The findings demonstrate that LoRa offers superior reliability over MQTT in scenarios with unstable Wi-Fi, maintaining data integrity and ensuring timely delivery. The primary contribution of this work is the integration of graphical real-time monitoring with LoRa-based communication, a feature absent in prior studies. Future research will address device security protection to safeguard transmitted data from potential cyberattacks and explore adaptive algorithms for optimizing transmission parameters based on environmental conditions.

Beyond summarizing the findings, the significance of this study lies in demonstrating how the integration of LoRa SX1276 and HLW8012 can strengthen SG communication and energy monitoring in practical contexts. The system reduces dependency on unstable Wi-Fi networks, making it particularly useful for rural and remote areas. Moreover, the ability to visualize dynamic energy parameters not only supports anomaly detection but also enables better decision-making for energy efficiency.

For the research community, these findings highlight the importance of combining communication reliability with user-centric visualization in IoT-based SM. Future research may extend this work by incorporating predictive algorithms, adaptive tuning of LoRa parameters, and enhanced data security to improve resilience against cyber threats. Such extensions will broaden the applicability of the system and contribute to sustainable and intelligent energy management solutions.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data supporting the findings of this study are available within the article. Additional data are available from the corresponding author upon reasonable request.

REFERENCES

[1] V. Singh *et al*., "Unmanned aircraft systems for precision weed detection and management: Prospects and challenges," *Adv. Agron*., vol. 159, pp. 93–134, 2020, doi: 10.1016/bs.agron.2019.08.004.

[2] U. Coutaud, M. Heusse, and B. Tourancheau, "LoRa channel characterization for flexible and high reliability adaptive data rate in multiple gateways networks," *Computers*, vol. 10, no. 4, pp. 1-22, 2021, doi: 10.3390/computers10040044.

[3] International Telecommunication Union, Recommendation ITU-T Y.2060: Overview of the Internet of Things, Geneva, Switzerland, Jun. 2012.

[4] Isminarti, A. A. Ilham, A. Arief, and Syafaruddin, "Improved Data Security Using Advanced Encryption Standard Algorithm on Long-Range Communication System at Smart Grid," *ICIC Express Lett. Part B Appl*., vol. 14, no. 5, pp. 499–508, 2023, doi: 10.24507/icicelb.14.05.499.

[5] V. Toro-Betancur, G. Premsankar, M. Slabicki, and M. Di Francesco, "Modeling Communication Reliability in LoRa Networks with Device-level Accuracy," in *IEEE INFOCOM 2021 - IEEE Conf. Comput. Commun.*, Vancouver, BC, Canada, 2021, pp. 1-10, doi: 10.1109/INFOCOM42981.2021.9488783.

[6] M. J. Faber, K. M. V. D. Zwaag, W. G. V. D. Santos, H. R. D. O. Rocha, M. E. V. Segatto, and J. A. L. Silva, "A Theoretical and Experimental Evaluation on the Performance of LoRa Technology," *IEEE Sens. J.*, vol. 20, no. 16, pp. 9480–9489, 2020, doi: 10.1109/JSEN.2020.2987776.

[7] L. Aarif, M. Tabaa, and H. Hachimi, "Performance Evaluation of LoRa Communications in Harsh Industrial Environments," *J. Sens. Actuator Netw.*, vol. 12, no. 6, pp. 1-27, 2023, doi: 10.3390/jsan12060080.

[8] A. Madaan, S. Bansal, A. Sahu, and F. Kidwai, "Peer to Peer Communication in GUI interface using Lora Technology," *Procedia Comput. Sci*., vol. 173, no. 2019, pp. 299–304, 2020, doi: 10.1016/j.procs.2020.06.035.

[9] D. L. Mai and M. K. Kim, "Multi-hop LOra network protocol with minimized latency," *Energies*, vol. 13, no. 6, p. 1368, 2020, doi: 10.3390/en13061368.

[10] P. De Moraes and A. F. Da Conceição, "Protecting LoRaWan data against untrusted network servers," in *2021 IEEE Int. Conf. Internet of Things (iThings) and Green Comput. Commun. (GreenCom) and Cyber, Phys. & Soc. Comput. (CPSCom) and Smart Data (SmartData) and IEEE Congr. Cybermatics (Cybermatics)*, Melbourne, Australia, 2021, pp. 99-106, doi: 10.1109/iThings-GreenCom-CPSCom-SmartData-Cybermatics53846.2021.00029.

[11] A. Panagi, "Exploring Communication Features and Security Vulnerabilities of Long-Range (LoRa) Networks," *Cyprus University of Technology*, 2021.

[12] H. P. Phan, V. K. Duong, T. K. Tran, V. D. Vo, and H. H. Hoang, "A Low Power – Long Range IoT Development Board based on LoRa Technology," *Hue Univ. J. Sci. Tech. Technol*., vol. 131, no. 2B, pp. 5–14, 2022, doi: 10.26459/hueunijtt.v131i2B.6795.

[13] J. M. Kang, "A New Index Modulation for LoRa," *IEEE Internet Things J.*, vol. 10, no. 13, pp. 11938–11939, 2023, doi: 10.1109/JIOT.2023.3240521.

[14] B. Al Homssi, K. Dakic, S. Maselli, H. Wolf, S. Kandeepan, and A. Al-Hourani, "IoT Network Design Using Open-Source LoRa Coverage Emulator," *IEEE Access*, vol. 9, pp. 53636–53646, 2021, doi: 10.1109/ACCESS.2021.3070976.

[15] S. Gadekar, M. Pimple, S. Thopate, and A. Nikam, "IOT Based Smart Energy Meter Using ESP 32," in *Proc. 3rd Int. Conf. Commun. Inf. Process. (ICCIP)*, 2021, doi: 10.2139/ssrn.3917892.

[16] A. Salgar, A. Mane, N. Binnar, and S. Chavan, "LoRa NET Base Station Monitoring System: Real-time insights using Mobile Application," in *2024 3rd Int. Conf. Innov. Technol. (INOCON)*, India, 2024, pp. 1-5, doi: 10.1109/INOCON60754.2024.10511559.

[17] R. W. Middlestead, *Frequency Shift Keying (FSK) Modulation, Demodulation, and Performance*, in Digital Communications with Emphasis on Data Modems, John Wiley & Sons, pp. 207–225, 2017, doi: 10.1002/9781119011866.ch5.

[18] W. A. Jabbar, S. Annathurai, T. Ariffin, A. Rahim, and M. F. Mohd, "Smart energy meter based on a long-range wide-area network for a stand-alone photovoltaic system," *Expert Syst. Appl.*, vol. 197, p. 116703, 2022, doi: 10.1016/j.eswa.2022.116703.

[19] M. M. Islam, Prediction Model of Aqua Fisheries Using IoT Devices, M.S. thesis, Dept. Comput. Sci. Eng., Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh, 2021

[20] N. Sindhwani, R. Anand, R. Vashisth, S. Chauhan, V. Talukdar, and D. Dhabliya, "Thingspeak-Based Environmental Monitoring System Using IoT," in *PDGC 2022 - 2022 7th Int. Conf. Parallel, Distrib. Grid Comput.*, 2022, pp. 675–680, doi: 10.1109/PDGC56933.2022.10053167.

[21] Dragino Technology Co., Ltd., Datasheet: LoRa Shield, Version 1.0, Mar. 2016. [Online]. Available: https://www.dragino.com/downloads/downloads/datasheet/EN/Datasheet_Lora_Shield.pdf. (Accessed: Jul. 23, 2026).

[22] S. W. Prakosa, M. Faisal, Y. Adhitya, J. S. Leu, M. Köppen, and C. Avian, "Design and implementation of lora based iot scheme for Indonesian rural area," *Electron*., vol. 10, no. 1, pp. 1–12, 2021, doi: 10.3390/electronics10010077.

[23] S. M. Asenov and D. M. Tokmakov, "Power Optimization of LoRaWAN Wireless End Sensor Node," in *2020 29th Int. Sci. Conf. Electron. 2020 - Proc*., 2020, pp. 1-4, doi: 10.1109/ET50336.2020.9238204.

[24] Y. C. Park and S. B. Park, "Gateway for Relaying Commercial Communication Network and LoRa Communication Network," World Patent WO2020122682A1, Jun. 18, 2020.

[25] C. Ndukwe, M. T. Iqbal, X. Liang, J. Khan, and L. Aghenta, "LoRa-based communication system for data transfer in microgrids," *AIMS Electron. Electr. Eng*., vol. 4, no. 3, pp. 303–325, 2020, doi: 10.3934/ElectrEng.2020.3.303.

[26] T. A. Salih and M. S. Noori, "Using LoRa Technology to Monitor and Control Sensors in the Greenhouse," in *IOP Conf. Ser. Mater. Sci. Eng.*, 2020, vol. 928, no. 3, doi: 10.1088/1757-899X/928/3/032058.

[27] K. Nakamura, P. Manzoni, M. Zennaro, J. C. Cano, and C. T. Calafate, "Integrating an MQTT Proxy in a LoRa-Based Messaging System for Generic Sensor Data Collection," in *Lect. Notes Comput. Sci. (incl. subseries Lect. Notes Artif. Intell. and Lect. Notes Bioinform.)*, vol. 12338, pp. 282–294, 2020, doi: 10.1007/978-3-030-61746-2_21.

[28] M. Dafare, S. Waghmare, A. Bhoyar, A. S. Titarmare and P. Chandankhede, "LoRa-Enabled Smart RS485 Data Logger and MQTT Gateway for Industrial IoT Applications Using ESP32," in *2023 Int. Conf. Circuit Power Comput. Technol. (ICCPCT)*, Kollam, India, 2023, pp. 1297-1302, doi: 10.1109/ICCPCT58313.2023.10245760.

[29] M. A. A. Razali, M. Kassim, N. A. Sulaiman, and S. Saaidin, "A ThingSpeak IoT on Real Time Room Condition Monitoring System," in *2020 IEEE Int. Conf. Autom. Control Intell. Syst. I2CACIS 2020 - Proc*., Shah Alam, Malaysia, 2020, pp. 206-211, doi: 10.1109/I2CACIS49202.2020.9140127.

[30] M. C. Nnamdi, P. K. Joboson, and C. B. Dyaji, "Monitoring Health Using IoT and Thingspeak," *Int. J. Inf. Process. Commun.*, vol. 10, no. 1&2, pp. 107–118, Dec. 2020.

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