

LORAWAN-Assisted Smart Meter For Real-Time Energy Insights

Mr. S. Thiyagarajan¹, Chandru A², Hari Preethan M P³, Pranesh S⁴

¹Assistant professor, Dept. of ECE, Sri Ramakrishna Institute of Technology., Coimbatore, India

^{2,3,4} UG Scholar, Dept. of ECE, Sri Ramakrishna Institute of Technology., Coimbatore, India

Emails: thiyagarajan.ece@sritcbe.ac.in¹, chandru.2204007@sritcbe.ac.in², haripreethan.2204015@sritcbe.ac.in³, pranesh.2204039@sritcbe.ac.in⁴

Abstract

This paper presents a LoRaWAN-assisted smart energy meter designed for real-time monitoring and efficient management of electrical energy consumption. The proposed system integrates voltage and current sensors with an ESP32 controller to continuously measure energy parameters such as voltage, current, and power. The collected data are transmitted securely over a LoRaWAN network to a cloud-based platform for real-time visualization and analysis, similar to the edge-enabled smart metering approach. The system provides automated alerts for abnormal energy usage, along with daily and monthly consumption reports and departmental energy comparison features. By enabling long-range, low-power communication and remote accessibility, the proposed solution reduces manual intervention, enhances operational safety, and supports scalable energy management for institutional and industrial environments

Keywords: Cloud monitoring, Energy Management, Internet of Things, LoRaWAN, Smart Energy Meter

1. Introduction

The rapid growth in electrical energy consumption has increased the need for efficient and reliable energy monitoring systems. Traditional energy meters require manual reading and lack real-time monitoring, data analytics, and remote accessibility. These limitations make energy management inefficient, especially in large institutions and industrial environments. Recent advancements in the Internet of Things (IoT) have enabled smart energy meters that provide automated data collection and monitoring [3]. However, many existing smart metering solutions rely on Wi-Fi or GSM communication technologies, which suffer from high power consumption, limited range, and scalability issues. To address these challenges, this paper proposes a LoRaWAN-assisted smart energy meter for real-time energy monitoring. The system integrates voltage and current sensors with an ESP32 controller and uses LoRaWAN technology for long-range, low-power data transmission [7]. Energy data are sent to a cloud-based platform for real-time visualization, automated alerts, and periodic reporting [12]. The proposed solution improves energy management efficiency, reduces manual

intervention, and is suitable for scalable institutional and industrial applications [1], [13].

2. Methodology

2.1. Conventional Energy Metering Systems

Conventional energy meters measure electricity consumption in kilowatt-hours (kWh) and display readings locally, requiring manual inspection. These systems do not support real-time monitoring, historical data analysis, or remote access, making energy management inefficient [3]. They also cannot monitor parameters like voltage, current, and instantaneous power, limiting the ability to detect load variations or abnormal conditions. Some semi-automated systems use GSM, Wi-Fi, or wired communication to transmit data, but these methods face issues such as high-power consumption, limited range, installation complexity, and operational costs [10]. Therefore, traditional systems lack scalability and efficiency for large-scale applications [7].

2.2. Limitations of Existing Systems

Existing energy metering systems often lack real-time monitoring, centralized cloud storage, and automated alert mechanisms. This restricts effective energy analysis, predictive maintenance, and de-

mand-side management [3]. Technologies like Wi-Fi and GSM also consume high power and have limited coverage, making them unsuitable for large deployments [7]. Additionally, the absence of advanced data analytics and edge computing increases network congestion and delays. These limitations prevent current systems from fully meeting the requirements of modern IoT-based smart grid environments.

2.3. System Overview (Proposed System)

2.3.1. System Overview

The proposed system is a LoRaWAN-assisted smart energy metering solution designed for real-time monitoring, efficient energy utilization, and remote access to electrical parameters. The system measures key electrical quantities such as voltage, current, instantaneous power, and total energy consumption using dedicated sensing modules. These parameters help analyze load behaviour and energy usage patterns [1]. An ESP32 microcontroller acts as the central processing unit, performing analog-to-digital conversion, processing sensor data, and calculating parameters such as power and energy consumption. The processed data are formatted into packets for wireless transmission [13].

visualized through dashboards, allowing users to monitor energy usage remotely [12]. The system also includes alert mechanisms to detect abnormal energy usage, overload conditions, and voltage irregularities, improving operational safety and reliability [14].

2.3.2. Hardware Components

The proposed smart energy meter consists of the following hardware modules:

Voltage Module

A voltage transformer (VT) steps down the supply voltage to a safe level for measurement. The signal is conditioned using a rectifier, voltage regulator, and resistors to produce a stable DC output proportional to the input voltage. This allows monitoring of voltage fluctuations and abnormal conditions.

Current Module

A current transformer (CT) measures load current in real time. The output current is converted to a measurable voltage using a burden resistor and conditioned with electronic components. Continuous current monitoring helps detect overloads and abnormal load variations.

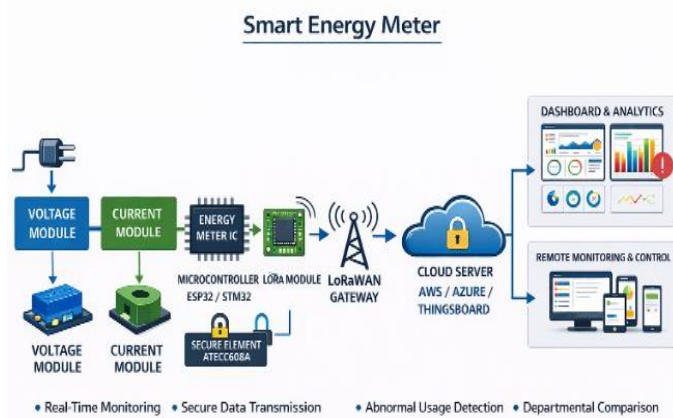


Figure 1 System Methodology

A LoRaWAN module enables long-range, low-power communication between the smart meter and a LoRaWAN gateway [8]. The gateway forwards the data to a cloud platform where it is stored and



Figure 2 Transformers

ESP32 Microcontroller

The ESP32 functions as the main processing unit, handling data acquisition, signal processing, power calculation, and communication control. Its processing capability and low power consumption make it suitable for IoT-based energy monitoring applications.

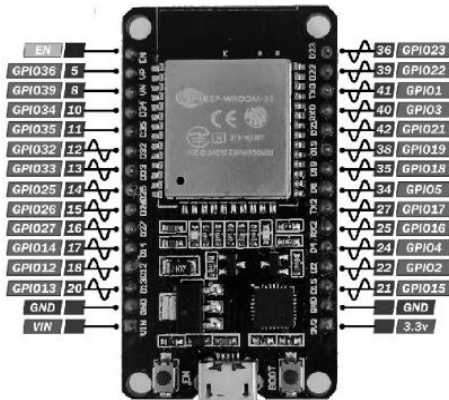


Figure 3 Microcontroller

LoRaWAN Module

The LoRaWAN module provides long-range, low-power wireless communication between the energy meter and the gateway, enabling reliable data transmission over large distances.

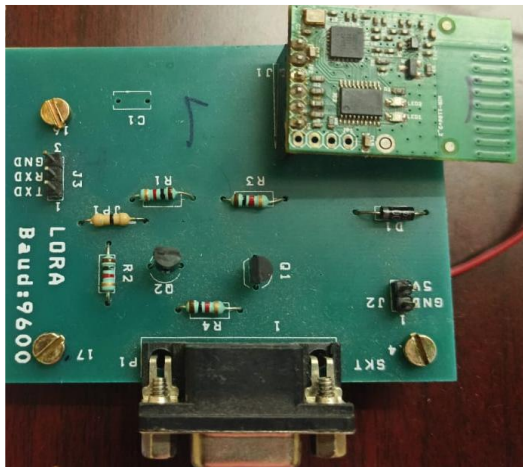


Figure 4 LORAWAN Module

Power Supply Unit

A regulated power supply provides stable voltage to the microcontroller, sensors, and communication modules, ensuring reliable system operation.

2.3.3. Communication Architecture (LoRaWAN)

LoRaWAN is used as the primary communication technology due to its long-range coverage and low power consumption [8]. In the proposed architecture, the smart energy meter acts as a LoRaWAN end device that periodically sends sensor data to a

nearby gateway.

The gateway collects data from multiple devices and forwards it to a network server through the internet. The server handles device authentication, data processing, and security management. The processed data are then stored in a cloud-based application server where users can view energy consumption through dashboards and reports [12].

The LoRaWAN architecture offers advantages such as long communication range, low energy consumption, high scalability, and secure data transmission, making it suitable for large campuses, industrial facilities, and smart grid applications [1].

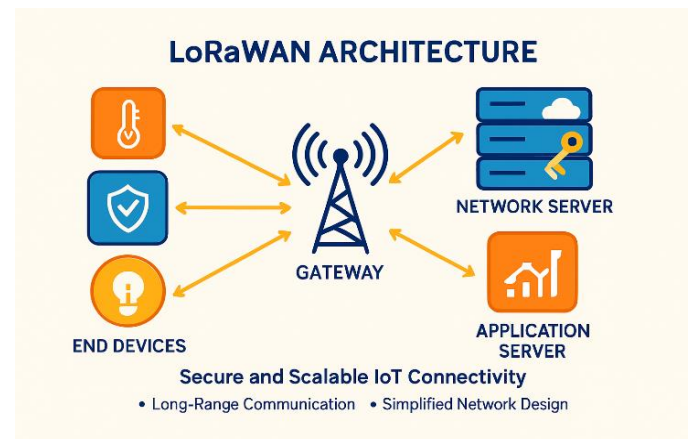


Figure 5 LoRaWAN Architecture

3. Results And Discussion

3.1. Results

The experiments were conducted to evaluate the performance of the proposed LoRaWAN-assisted smart energy metering system. The system was tested using different electrical loads while continuously measuring parameters such as voltage, current, power, and energy consumption through sensor modules connected to the ESP32 microcontroller. After acquisition and processing, the calculated energy parameters were formatted into structured data packets and transmitted through the LoRaWAN communication module to a nearby gateway using low-power, long-range wireless communication in the unlicensed ISM band [7]. FIGURE 6. Result The gateway forwarded the received data to a centralized network server through an internet connection,

where device authentication, packet verification, and data processing were performed [15]. The authenticated data were then stored in a cloud-based application server and also recorded locally in a CSV file to maintain historical records of volt-age, current, power, and energy consumption for further analysis. The experimental results demonstrated that the system successfully monitored electrical parameters in real time and displayed them on the cloud dashboard. The LoRaWAN communication provided stable data transmission between the device and the gateway with minimal packet loss, ensuring reliable system performance [7]. Compared to conventional Wi-Fi-based monitoring systems, the LoRaWAN approach offered extended communication range while maintaining lower power consumption. The cloud platform enabled graphical visualization of energy consumption patterns and load variations through an interactive dashboard, allowing users to observe real-time and historical data efficiently [12]. In addition, the system was capable of detecting abnormal conditions such as overload and volt-age fluctuations and generating alerts when pre-defined threshold limits were exceeded. These results confirm that the proposed system provides accurate energy monitoring, reliable long-range communication, and improved efficiency for real-time energy management applications [1].



Figure 7 Data Transmission

3.2. Discussion

The experimental results demonstrate that the proposed LoRaWAN-assisted smart energy metering system is effective for real-time energy monitoring and long-range communication. The reliable data transmission observed during testing indicates that LoRaWAN is a suitable communication technology for applications that require wide-area coverage with low power consumption. This makes the system particularly useful for large institutions, laboratories, and industrial environments where conventional short-range communication technologies may not provide sufficient coverage. The integration of sensing modules with the ESP32 microcontroller highlights the effectiveness of edge processing in energy monitoring systems. By performing data acquisition and basic computation at the device level, the system reduces communication overhead and improves overall efficiency. This architecture also enables continuous monitoring of electrical

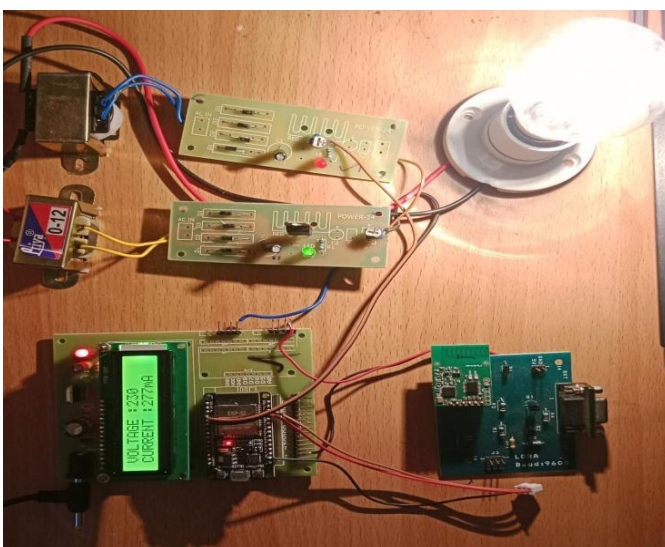


Figure 6 Result

parameters without affecting system stability. The cloud-based monitoring platform enhances the usability of the system by providing clear visualization of energy consumption patterns. This capability allows users to analyze load behaviour, identify peak usage periods, and implement energy-saving strategies [12]. Additionally, the alert mechanism improves operational safety by enabling early detection of abnormal conditions such as overload or voltage fluctuations [14].

FIGURE 8. LoRa-Based IoT Communication Architecture

Overall, the findings suggest that combining IoT-based sensing, edge processing, and LoRaWAN communication can significantly improve the performance and scalability of modern energy monitoring systems [7]. The proposed system therefore represents a practical and efficient solution for smart energy management in institutional and industrial applications.

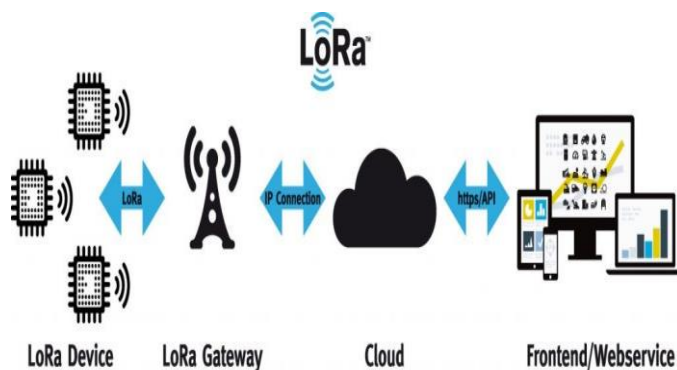


Figure 8 LoRa-Based IoT Communication Architecture

Advantages

The proposed smart energy meter improves conventional energy monitoring systems by providing higher efficiency, accuracy, and real-time monitoring capabilities. By integrating LoRaWAN (Long Range Wide Area Network) technology, the system enables long-range communication with low power consumption, making it suitable for deployment in large campuses, industrial facilities, and smart city environments [7]. This low-power connectivity allows devices to operate for extended periods with minimal maintenance, making the system reliable for

remote installations. The system supports real-time data acquisition and transmission, which is integrated with cloud-based visualization platforms. Users can monitor energy consumption remotely through web or mobile dashboards, enabling better transparency, decision-making, and energy optimization [12]. Detailed consumption analytics help users identify high-energy appliances and implement effective energy-saving strategies. Additionally, the smart meter includes automated alert mechanisms to detect overloads or abnormal energy usage. These alerts enable early fault detection, improving electrical safety and preventing equipment damage. The modular architecture of the system also allows easy integration of additional meters or sensors, making it scalable for large institutions, industries, and commercial facilities [13]. Overall, the proposed system reduces manual effort by eliminating the need for physical meter readings while ensuring reliable and cost-effective energy monitoring. This approach supports efficient energy management, enhanced safety, and sustainable energy usage.

Conclusion

This paper presented a LoRaWAN-assisted smart energy meter designed for real-time monitoring, efficient energy management, and improved electrical safety. The proposed system integrates voltage and current sensors with an ESP32 microcontroller and utilizes LoRaWAN technology to enable long-range, low-power, and reliable data transmission. The implementation of cloud-based visualization platforms, automated alerts, and periodic energy reporting allows users to monitor power consumption remotely and gain useful insights into energy usage patterns. The experimental results confirm that the system provides accurate and reliable energy measurements while effectively detecting abnormal conditions such as overloads and unusual energy consumption. The modular and scalable design of the system makes it suitable for deployment in institutional, industrial, and commercial environments. In addition, the system offers advantages such as low power consumption, minimal maintenance requirements, and cost-effectiveness, making it a practical solution for modern energy

monitoring applications. Overall, the proposed smart energy meter demonstrates an efficient, scalable, and reliable approach for improving energy monitoring and supporting smarter energy management systems.

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