Reimagining Energy Monitoring: A LoRa-Based Approach to Smart Metering

Rupali Sachin Patil[1], Anjali Ramesh Patil[2]
[1, 2] -DKTE's Textile and Engineering institute, Ichalkaranji, MAHARASHTRA 416115 India.

Abstract: The need for smart, energy-saving, and long-range systems that can monitor energy use is growing fast. This has led to the development of smart energy meters that use Internet of Things (IoT) communication methods. This paper introduces the design and ideas behind a smart energy meter that uses LoRa technology. It allows for real-time tracking of energy use, analysis of how much energy is being used, and sending data from a distance. LoRa is chosen because it is efficient in using energy and can cover a wide area, making it perfect for both rural and city areas. The system includes features like controlling how much electricity is used, detecting when energy is stolen, allowing users to pay in advance for electricity, and connecting to the cloud. The paper also looks at the benefits, challenges, and future opportunities of using LoRa in smart metering systems.

Keywords
LoRa, Smart Energy Meter, IoT, Remote Monitoring, Prepaid Meter, Load Management, Energy Efficiency, LPWAN.

I. INTRODUCTION:

Managing energy has become a key part of smart grid systems, with more demand for tools that can monitor energy use in real time, control it dynamically, and handle billing effectively. Older energy meters can't communicate, so they are not as useful or scalable. New wireless technologies, especially those in the LPWAN (Low Power Wide Area Network) category, have made it easier to create smart systems for metering. LoRa is one of the best options within LPWAN because it uses very little power, can transmit signals over long distances (up to 15 kilometers), and is cost-effective.
The smart energy meter using LoRa is built to collect, send, and analyze energy use data at regular times. It reduces the need for people to read meters manually, makes the data more accurate, allows users to get alerts, and helps energy providers manage the electricity grid better. This system can be used in many areas beyond homes, including projects to bring electricity to rural areas, smart city development, balancing energy use in small power grids, and managing energy in industries. The ability to pay for electricity in advance helps energy providers manage their income better and real-time alerts help users use energy more wisely.

II. LITERATURE REVIEW:

Using Low Power Wide Area Network (LPWAN) technologies in smart energy systems has made big progress in remote metering.Among the different LPWAN technologies, LoRa (Long Range) is special because it has a long range, uses very little power, and is easy to use with small devices. LoRa helps make smart meters that are both energy-efficient and affordable, which works well in both city and country areas.

Reynders et al. [1] looked closely at LoRa communication, including how far it can reach and how it works with other technologies.They found that LoRa gives a good balance between how far it can send signals and how much energy it uses, making it perfect for smart metering. Centenaro et al. [2] compared different LPWAN protocols and said LoRa is better because it is flexible and follows open standards, which is important for smart grid systems that are not centralized.Zainudin et al. [3] made a smart energy meter system using LoRa that can track energy use in real time.This system cuts down on the need for people to read meters manually and makes data sending more efficient by using LoRa's low-power features. Similarly, Surya and Sharma [4] created an advanced LoRa-enabled energy meter that also has features like controlling the load and detecting electricity theft. Their work shows how LoRa can do more than just measure energy—it can help with managing utilities and ensuring security.

Islam et al. [5] developed a low-cost smart meter using LoRa and an Arduino, which is useful for rural areas where traditional communication systems are not available.Their design focused on being simple and affordable, making it easy to scale in poorer regions. Zahid et al. [6] built a complete LoRa-based energy monitoring system for smart grids, proving that it works well in environments where the power network is spread out.

Adelantado et al. [7] looked at how well LoRa WAN can handle many devices in busy areas. While LoRa can cover a large distance and use little power, their research pointed out that it has limits in terms of how many devices it can support at once, which could affect its performance in large smart metering projects. Mishra et al. [8] countered this by making a LoRa-based prepaid energy meter that also sends messages to users. Their system helps users know about their usage and makes billing clearer.

Thakur and Yadav [9] compared Wi-Fi and LoRa for sending data from smart meters. Their results showed that LoRa is better in terms of how far it can reach and how much power it uses, making it more suitable for long-term smart metering systems. Islam et al. also worked on a low-cost smart meter using LoRa and an Arduino, making it useful for rural areas where traditional communication systems are not available. Their design focused on being simple and affordable, making it easy to scale in poorer regions.

Islam et al. [10] went a step further by creating a full smart meter that uses IoT and connects to the cloud, allowing users to view their energy usage data remotely through an easy-to-use dashboard. Azlina et al. [11] proposed a system that uses LoRa technology for automatic meter reading, which removes the need for people to read meters manually and reduces mistakes.Their system worked well even in different weather and environmental conditions.Kumar et al. [12] developed a billing and real-time monitoring system that uses LoRa.This system gives real-time data about energy use, helping utility companies be more accurate with their billing.Le et al. [13] introduced a smart home-friendly LoRa energy meter that can work with other IoT devices.This allowed for automated energy control inside homes, helping to manage energy use better and save energy.

Khan et al. [14] created a full Advanced Metering Infrastructure (AMI) system that uses LoRa.This system includes both the meters and data collectors, with data analysis done in the cloud. Their setup showed how scalable LoRa-based systems can be.Jain and Ghosh [15] came up with a new idea by combining LoRa-based metering with AI for predicting energy use.This helped in managing energy demand and making energy distribution more efficient, opening up possibilities for smarter grid systems in the future.Overall, the studies show that LoRa is becoming a popular choice for smart energy meters because it offers long-distance communication, is energy efficient, and is affordable.However, there are still some issues that need to be fixed. These include security risks, data protection, problems with too many devices in one area, and difficulty connecting with older systems. More real-world testing over a long time is also needed to check how reliable and easy to maintain these systems are in the long run. Future research should focus on making LoRa communication standards better for use in utilities and solving the challenges mentioned to help smart grids grow and become more widespread.

III.EXPERIMENTAL SETUP AND METHODOLOGY

The block diagram fig.1 illustrates the modular architecture of the LoRa-based Smart Energy Meter system. The system comprises designated sensing points where IR sensors are deployed for data acquisition. An ATmega328P microcontroller unit (MCU) is centrally positioned and serves as the core processing unit, interfacing with all peripheral components. The LoRa RA-01 module and the ESP-01 Wi-Fi module are interfaced with the ATmega328P at both the transmitter and receiver ends of the energy metering system to enable long-range and local wireless communication, respectively. The LCD module provides real-time visualization of the energy consumption data measured from the connected load via the energy meter. The system utilizes the LoRaWAN communication protocol to ensure reliable, low-power, and efficient data transmission, thereby enhancing overall system performance and scalability.

A) Hardware

i) Arduino ATmega328P:TheATmega328P is an advanced microcontroller based on the AVR architecture, which uses 8-bit data processing. It has 32 KB of internal flash memory to store programs and 1 KB of EEPROM for storing data that remains even when the power is turned off. This EEPROM allows information to be saved and accessed again once power is restored. The microcontroller also includes 2 KB of SRAM for handling data during operation. The ATmega328P is a 28-pin AVR microcontroller made by Microchip Technology, built with RISC architecture and uses flash memory for storing programs.

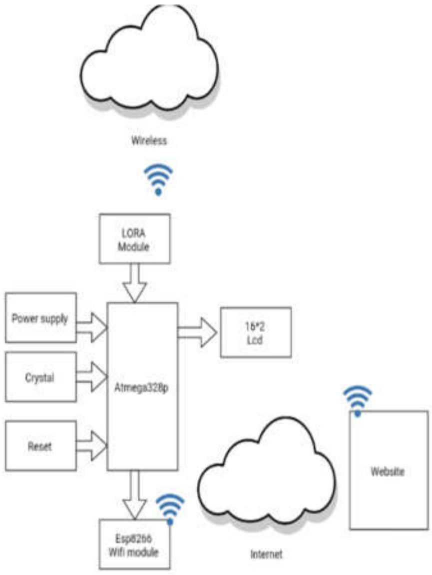

Fig.1 Block diagram of the lora based smart energy meter

*ii) ESP-01 Wi-Fi module:*The ESP-01 Fig.2is a commonly used Wi-Fi module made by Espressif Systems, a company known for its work in wireless communication and Internet of Things (IoT) technology.

It is one of the first modules in the ESP8266 family and still popular because it is small, inexpensive, and has many useful features. The module uses the ESP8266 system-on-chip (SoC), which combines a powerful microcontroller with built-in Wi-Fi capabilities.Because it is small and works well with Wi-Fi, the ESP-01 is great for projects like home automation, IoT devices, and DIY electronics. It supports Wi-Fi standards like IEEE 802.11 b/g/n, making it easy to connect to wireless networks. It also has a microcontroller unit (MCU) based on the Tensilica Xtensa LX106 architecture, which lets it run programs and handle tasks on its own.

Even though it is small, the ESP-01 has several General Purpose Input/Output (GPIO) pins that let it connect to sensors, switches, and other devices.It uses a Universal Asynchronous Receiver–Transmitter (UART) interface to talk to other systems. It is used in many IoT applications, like wearable gadgets, weather monitoring systems, smart home products,

Fig.2ESP-01 Wi-Fi module

and projects that need to log data, monitor remotely, or control devices over Wi-Fi.

iii) LoRa RA-01 transceiver module:The LoRa RA-01 module Fig.3is a wireless device that sends and receives signals using a special technique called LoRa, which allows for long-distance communication with very low power.

This module is made by Ai-Thinker and is used in many Internet of Things (IoT) projects where long-range communication, low power use, and affordability are important. It is easy to use, flexible, developers and hobbyists like to use it for different wireless tasks.

LoRa is a low-power wireless protocol that helps devices communicate over long distances with slow data speeds.This technology was created by a company called Semtech in 2012. It works well in unlicensed radio frequency bands such as 868 MHz, 915 MHz, and 433 MHz, which are commonly used for IoT applications requiring long-range communication.The LoRa RA-01 module is built for long-range communication with minimal power use, making it perfect for projects that need wireless connection over long distances.It can reach up to 15 kilometers, which is useful for tasks like tracking assets, monitoring the environment, and managing industrial equipment. It uses very little power, especially when it is not sending data. When it is idle, it uses only a few microamps, and when it is transmitting, it uses less than 120 mA. This low power usage means that devices using the module can run for a long time on a single battery.

The LoRa RA-01 module is a cost-effective choice for people who need long-range wireless communication.It works with many different microcontrollers and development boards, making it very versatile for various IoT projects. It has a simple serial communication interface that supports different data speeds and formats. This makes it easy to connect to a wide range of devices and use in different projects.

Fig.3 Lora RA-01 transceiver module

The 16×2 LCD can connect to microcontrollers and other digital systems in different ways. It can use a parallel connection with either 8-bit or 4-bit data lines, or it can use serial communication methods like I²C or SPI with the help of special adapters. This makes it versatile and easy to use in a variety of project integration with a variety of microcontrollers and communication architectures.

B) Software implementation

Flow chart:

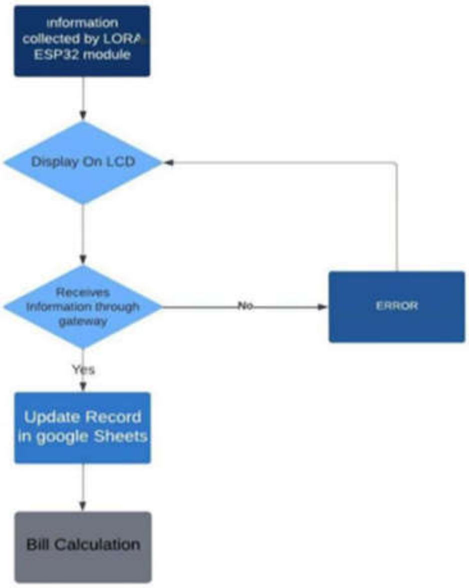

Fig.4 Flow chart of LoRa-based Smart Energy Meter system's data processing and billing

Algorithm:
1.Initialize input output ports
2. Initialize LCD, serial communication, LoRa Ra-01 trans
3. Wait for interrupt generated by energy meter
4.Transmit reading using LORA to receiver
5. Display units on LCD screen

1.Initialize input output ports
2. Initialize LCD, serial communication, receiver
3. Wait for data received from transmitter
4.Upload data to web site using wifi model
5.Display data received on LCD screen

The Fig.4 LoRa-based Smart Energy Meter system's data processing and billing workflow is depicted in the flowchart. The LoRa–ESP32 module starts the process by gathering data. Data on energy consumption is sent to this module via the LoRa communication network from the smart energy meter.
The data is first shown on the LCD for local monitoring after it has been gathered. This enables real-time energy consumption data to be viewed at the system level by users or technicians.
The system tries to send the data through the gateway after displaying it. At this point, a choice is made to confirm the success of the data transfer via the gateway. The system enters an error state, signifying a communication or gateway-related problem, if the transmission fails.
The system updates the recorded data in Google Sheets if the data transmission is successful. In order to facilitate further analysis, monitoring, and record-keeping, this step guarantees that energy consumption data is safely stored in a cloud-based platform.
Lastly, the system calculates bills using the updated data on energy consumption. The recorded energy usage values are used in the billing process to precisely calculate the electricity bill. The smart energy metering system's first operational cycle is now complete.

IV. RESULT AND DISCUSSION

The outcome that has been presented shows that the LoRa-based Energy Monitoring System was successfully implemented and operational. The picture depicts the system's actual hardware implementation, which consists of Fig.5 transmitter and Fig.6 receiver units covered in protective casings. The microcontroller, LoRa communication module, power supply circuitry, and LCD for real-time data visualization are all integrated into each unit. The system's active measurement and processing of energy consumption data is confirmed by the LCD's clear display.
The energy meter at the transmitter side keeps an eye on the connected load's electrical characteristics all the time. The microcontroller processes the measured energy consumption data before sending it wirelessly via the LoRa module. The system's capacity to carry out continuous energy monitoring is confirmed by the timestamp that appears in the monitoring interface, which shows that the data is being collected and sent in real time.
The transmitted data is successfully received by the LoRa module at the receiving end and sent to the processing unit. The received energy readings are

displayed locally and simultaneously uploaded to the cloud-based monitoring platform. The fig.7 Energy meter interface shown below the hardware images confirms that data from multiple meters (Meter 1, Meter 2, Meter 3, and Meter 4) can be monitored, highlighting the scalability and multi-node support of the proposed system. The successful update of energy consumption records in the centralized monitoring interface verifies reliable long-range communication and accurate data synchronization between transmitter and receiver nodes. This result demonstrates that the system effectively supports real-time energy monitoring, remote data access, and centralized data management. Overall, the outcome confirms the reliability, efficiency, and practical feasibility of using LoRa technology for smart energy metering and monitoring applications in both small-scale and large-scale deployments.

Fig.5Transmiter

Fig.6 Receiver

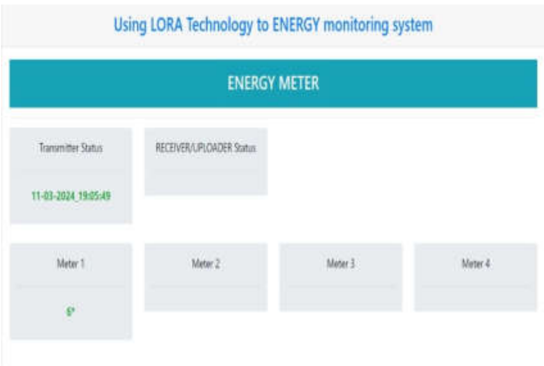

Fig.7 Energy meter

Long-range wireless communication is made possible by LoRa technology, which makes it ideal for smart energy metering applications in both urban and rural settings. Utility companies can deploy smart meters over large geographic areas without requiring a substantial physical communication infrastructure thanks to its ability to transmit data over several kilometres, which lowers installation and maintenance costs.

The low power consumption of LoRa-based smart energy meters is one of their main benefits. Because LoRa devices are made to use as little energy as possible, smart meters can run on batteries for extended periods of time. In remote or difficult-to-reach areas where a steady power source might not be easily accessible, this feature is especially helpful.
Another important advantage of LoRa-enabled smart metering systems is scalability. Utility companies can use a centralized data collection system to maintain dependable and stable communication while deploying and managing thousands of smart energy meters within a single network. Because of this, LoRa-based solutions are ideal for smart grid deployments and extensive energy monitoring.
Furthermore, real-time energy consumption monitoring is made possible by smart energy meters that are integrated with LoRa technology. Utilities can improve operational efficiency and resource utilisation by analysing usage patterns, identifying anomalies, and optimising energy distribution and management strategies thanks to continuous data transmission.

V. CONCLUSION AND FUTURE SCOPE

In summary, a LoRa-based smart energy metering system is a good way to modernize utility systems, improve energy management, and boost efficiency. Using LoRa, which has long-range, low-power, and scalable features, utilities can place meters widely, collect real-time data, and gain insights into how energy is being used. Even with its many benefits, LoRa has some limits, such as coverage issues, delays, limited data speed, and interference problems. To handle these, careful planning of the system design, smart placement of meters, and ongoing improvements are needed to ensure the system runs smoothly, securely, and efficiently.Overall, a well-planned LoRa-based smart metering system offers many advantages to utility providers, like being cost-effective, secure data sharing, following rules and regulations, and adapting to new energy needs.By overcoming its limitations and making the most of LoRa, utilities can fully benefit from smart metering, improve service, cut down costs, and support eco-friendly energy use.

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