IoT BASED SMART ENERGY METER FOR ADVANCED METERING INFRASTRUCTURE

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ABSTRACT

Due to lack of situational awareness, automated analysis, poor visibility, and mechanical switches, today's electric power grid has been aging and ill-suited to the demand for electricity, which has gradually increased, in the twenty-first century. Besides, the greenhouse gas emissions on the Earth caused by the electricity industries, the growing population, one-way communication, equipment failures, the capacity limitations of electricity generation, decrease in fossil fuels, and resilience problems put more stress on the existing power grid. Modernizing the electricity grid of a nation involves implementing an advanced metering infrastructure (AMI) and offers numerous advantages such as enhanced grid efficiency, optimized load balancing and shedding, lower cost of energy, preservation of resources and increased transparency for the consumers. An integral part of the AMI is the smart energy meter which can be installed for domestic and industrial purposes, automating the process of meter reading and assessment. Implementing two-way communication enabled meters will allow the electricity suppliers, users and technicians to remotely access and control the meters, enhancing convenience. IoT has led to the creation of advanced interconnected smart systems that were not possible in the past. In this article, an IoT based smart energy meter is proposed which is capable of two-way data communication over LPWAN technology. The system can measure the energy parameters in real time such as energy consumption (kWh/kVAh), current (I), voltage (V) and power. The meter also has theft and tamper detection capability which alerts users through notifications. The system can be remotely accessed through the head end system application software and meter data management system which allows multiple users to access the meter data securely. The proposed system is accurate, reliable, and less expensive, and offers advantages over existing smart energy meters.

Index Terms: Smart meters, energy meter, IoT, LoRaWAN, Advanced Metering Infrastructure (AMI), Automatic Meter Reading (AMR), smart grid, electricity, theft detection, tampering, LPWAN, automation

INTRODUCTION

The Internet of Things (IoT) is a network of physical objects (referred to as "things" or "objects") that are integrated with sensors, applications, and other technology for the purpose of communicating and sharing data with other devices and systems over the Internet. Because of the integration of various technologies, such as real-time analytics, artificial learning, commodity sensors, and embedded systems, things have changed. The IoT is enabled by traditional fields such as embedded systems, wireless sensor networks, control systems, automation (including home and building automation),
and others.

AMI (advanced metering infrastructure) refers to the entire infrastructure, which includes everything from smart meters to two-way communication networks, control centre facilities, and all the technologies that allow for the collection and transmission of energy consumption data in near real-time. AMI enables two-way connectivity with consumers and serves as the smart grid's backbone. Remote meter reading for error-free results, network issue detection, load profiling, energy audit, and partial load curtailment in lieu of load shedding are some of the goals of AMI. IoT based smart energy meters are being built to simplify meter reading, error identification, billing, theft/tampering detection, and load balancing, among other things. These integrated smart devices provide suppliers with more information about consumption habits, peak use hours, and peak usage areas, helping them to increase the quality and availability of these services.

In contrast to automated meter reading (AMR), advanced metering technology (AMI) allows for two-way communication between the meter and the retailer. Cellular communications, wireless ad hoc networks like low power long-range wide area network (LoRaWAN) with high radio penetration rate, free, using the frequency 865-867 MHz are wireless connectivity solutions.

Through this paper, we propose a IoT enabled smart energy meter which is capable of two-way communication over LoRaWAN and can display various parameters through its in-built display as well as through an web based Head-end-System application software. The meter measures energy usage, current, voltage, power and provides the bill amount in real-time. An additional feature of this meter is theft and tamper detection which alerts the user of theft or tampering through the application software. This meter eliminates the need for manual checks for collecting meter data and generating electricity bills. The IoT enabled meter can transmit this data over LoRaWAN to multiple devices at once, allowing various entities such as consumers, linemen, and the electricity distributors to view the required meter data. Additionally, the availability of real-time data to the electricity distributors will help improve grid efficiency and prevent energy wastage as it will allow the distributors to analyse consumption patterns of the users and execute techniques such as load balancing and shedding successfully. Further, the system will ensure transparency between the users and the suppliers, reducing dishonest behaviour and preventing the manipulation of electricity bills.

LITERATURE REVIEW

GSM (global system for mobile communications) based smart energy meter systems eliminate the need for manual meter reading collection and provide an alternative to traditional energy meters. They can form part of AMR systems and transmit data over the GSM network to mobile devices. The smart energy meter utilizes a relay to cut off electricity supply remotely which can be used by electricity distributors. Further, the meter displays the necessary information on its in-built LCD in addition to transmitting it through GSM communication. The energy meter is largely limited to one-way communication and only the line cut or connect-disconnect feature can be remotely carried out through two-way communication due to operation over GSM. The meter readings obtained are not in real-time as the data is transmitted to the user through short message service (SMS) which limits the frequency with which the data is updated. Additionally, the energy meter lacks crucial information such as current, voltage and power measurements. The process of adding more users or recipients of the energy meter data is also extremely cumbersome as it would require modifying the source code of the system due to the use of SMS for data transmission.

IoT based smart energy meters offer a better solution in comparison to GSM-based ones as they support fully functional two-way communication which forms an essential part of the AMI. The system proposed in utilizes LoRa LPWAN technology for transmitting data which provides a fast and reliable connection. The meter can provide real-time information to its users through a application software and can detect energy consumption as well as theft. However, the system developed does not utilize external sensors to detect tampering or theft but rather predicts the occurrence of theft using a current sensor which could sometimes lead to unreliable detection and false alarms. The data obtained by the meter is displayed on an in-built display which shows limited information due to its small size. The IoT based smart energy meter system created in allows real-time two-way communication and measures the energy consumption.

The GSM based smart energy meter designed is limited by the use of GSM for communication due to which the data is sent over SMS and hence the information obtained is not real-time, but rather, sent to the user at the end of every month. The smart meter has a warning system that sends SMS alerts to the user when they are about to reach a pre-defined energy consumption limit. The in-built LCD can display useful information during physical meter evaluation. However, the system does not measure numerous important parameters and lacks safety features such as theft detection leaving it susceptible to electricity theft.

Improving on IoT based smart energy meter designs, the smart energy meter proposed in can transmit data real-time through an web based application and support two-way communication. The smart meter lacks theft and tampering detection and is vulnerable to external manipulation. Additionally, the proposed system does not generate bills for the user and only reports the energy usage. Further, the meter measures various parameters such as power, energy, active power, reactive power and power factor but does not use external sensors to obtain accurate and reliable measurements for the current and voltage values.

For a robust two-way communication, the smart meter uses low power wide area network (LPWAN) technology in which the smart meter transmits data using the LoRaWAN protocol to an LPWAN gateway. The smart meter data is then sent to a network server and routed to an application server for processing. Afterward, the data is transmitted to the application software for viewing and monitoring the energy parameters.

OBJECTIVES

This project focuses on the development of a two-way communication system capable IoT based smart energy meter that can be implemented at a low cost. The main objectives of this project are:

- Measure energy parameters, current, voltage and power as per DLMS standards.
- Display real-time parameters in application software.
- Generate bill amount available to the user based on a set price for each unit of electricity consumed.
- Alert users in case of theft or tampering of the energy meter.

METHODOLOGY

A. Proposed System

The proposed system will remove the need to manually survey the energy meter to collect readings or to view the status of the meter. Additional functions can be added to the system by incorporating the necessary modules as per the needs of the user or electricity supplier. Fig. 1 shows a diagram of the proposed system.

Fig. 1. Block Diagram of the proposed system

The main components of the proposed system include:

Smart Electricity Meters

Smart meter is an a.c. static transformer operated watthour and Var-hour meter with time of use registers and two-way communication capabilities. It is designed to measure 'forwarded only' or 'import and export' energy, store and communicate the same along with other parameters defined in DLMS standards. It shall be remotely accessed for collecting data/events, programming for selected parameters. The smart meter support the following features/services:

- Smart meter association requirements
- Push services
- Advanced security profile
- Communication profile
- Firmware upgrade
- Connect/disconnect services
- Parameter list for smart meters

Date Exchange Protocol

The data exchange protocol for Smart Meter shall be as per IS 15959 (Part 3) including specific requirements for Smart Meters for the application layer. This application layer protocol which is primarily DLMS/COSEM shall work through the other layers.

LoRaWAN Communication Technology

LoRa is the wireless modulation technology utilized to create the long-range communication link. LoRa is based on chirp spread spectrum modulation, which maintains the same low power characteristics as FSK modulation but significantly increases the communication range. LoRaWAN defines the communication protocol and system architecture for the network. A single gateway or base station can cover entire cities or hundreds of square kilometres.

LoRaWAN Network Architecture

In LoRaWAN, network nodes are not associated with a specific gateway. Instead, data transmitted by a node is typically received by multiple gateways. Each gateway will forward the received packet from the end-node to the cloud-based network server via some backhaul (either cellular, Ethernet, satellite, or Wi-Fi). The intelligence and complexity is pushed to the network server, which manages the network and will filter redundant received packets, perform security checks, schedule acknowledgments through the optimal gateway, and perform adaptive data rate, etc.

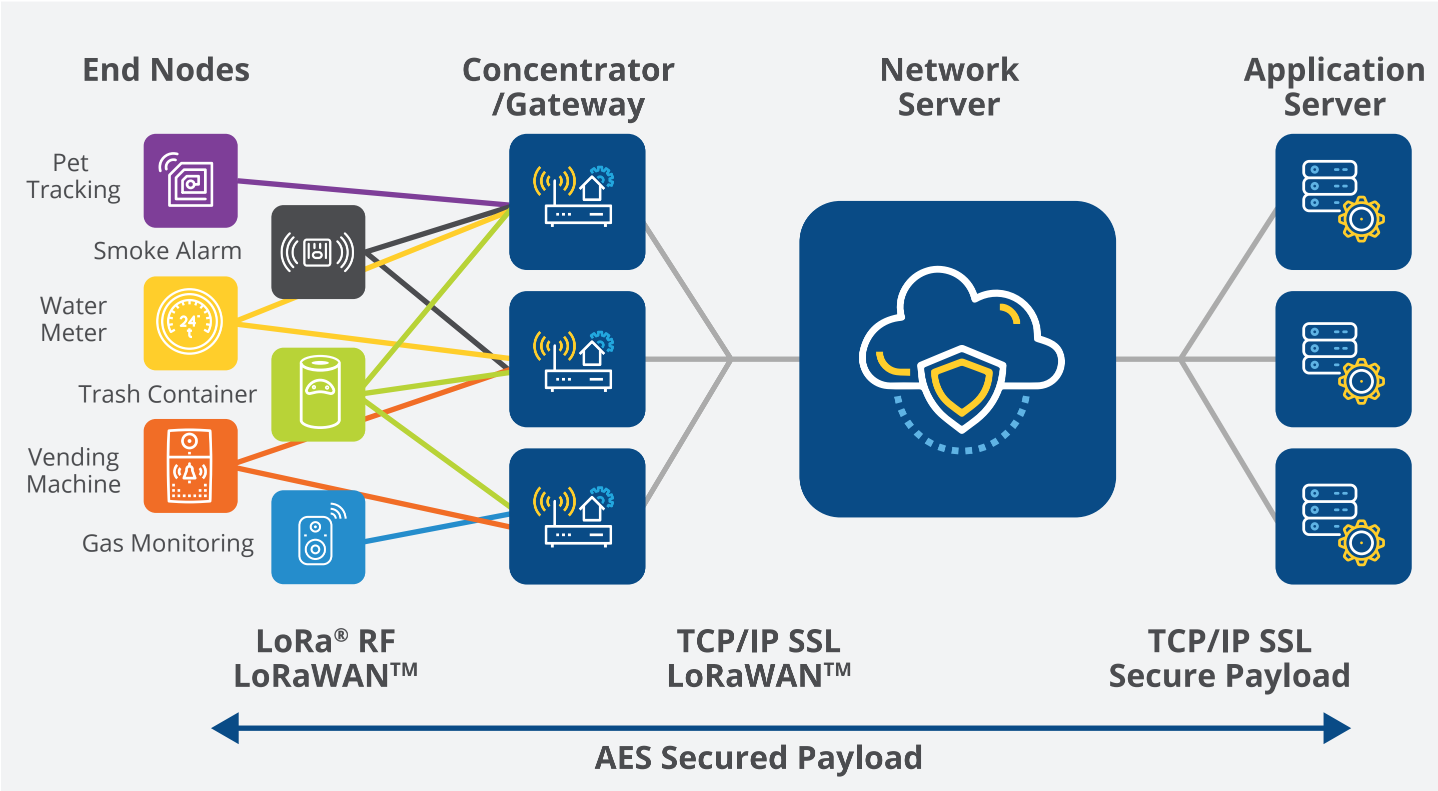


Fig. 2. Network Architecture of LoRaWAN

LoRaWAN Security

The LoRaWAN protocol's baseline authentication and security framework draw from the AES 128 encryption scheme as implemented by IEEE 802.15.4/2006 Annex B [IEEE802154]. In a typical smart deployment, separate keys are used for user data encryption and authentication/network integrity.

LoRaWAN Network Capacity

LoRaWAN support High network capacity. It is achieved by utilizing adaptive data rate and by using a multichannel multi-modem transceiver in the gateway so that simultaneous messages on multiple channels can be received. The critical factors effecting capacity are the number of concurrent channels, data rate (time on air), the payload length, and how often nodes transmit. Since LoRa is a spread spectrum-based modulation, the signals are practically orthogonal to each other when different spreading factors are utilized. As the spreading factor changes, the effective data rate also changes. The gateway takes advantage of this property by being able to receive multiple different data rates on the same channel at the same time.

Application Software

This entity is called Head end System (HES) and is situated at the top of AMI system and receives data and events over LoRaWAN. It is responsible for using these data and manage network components and smart meters. HES is also responsible for handling security keys, passwords intended for smart meter programmability and firmware upgrade and host applications such as remote connect/

disconnect, analytics, billing, and messaging. HES acquire meter data automatically, avoiding any human intervention, and monitor parameters acquired from meters. HES manage the connectivity and schedule the collection of data from the metering infrastructure including both the meter devices and communication. It also enables secure access to meters for configuration, software updates and ad-hoc requests.

B. Implementation

The diagram below showcases the data communication journey from smart electricity meter (IS16444, DLMS/COSEM Compliant) with pre-integrated LoRaWAN module to the head end system application software over LoRaWAN network communication technology.

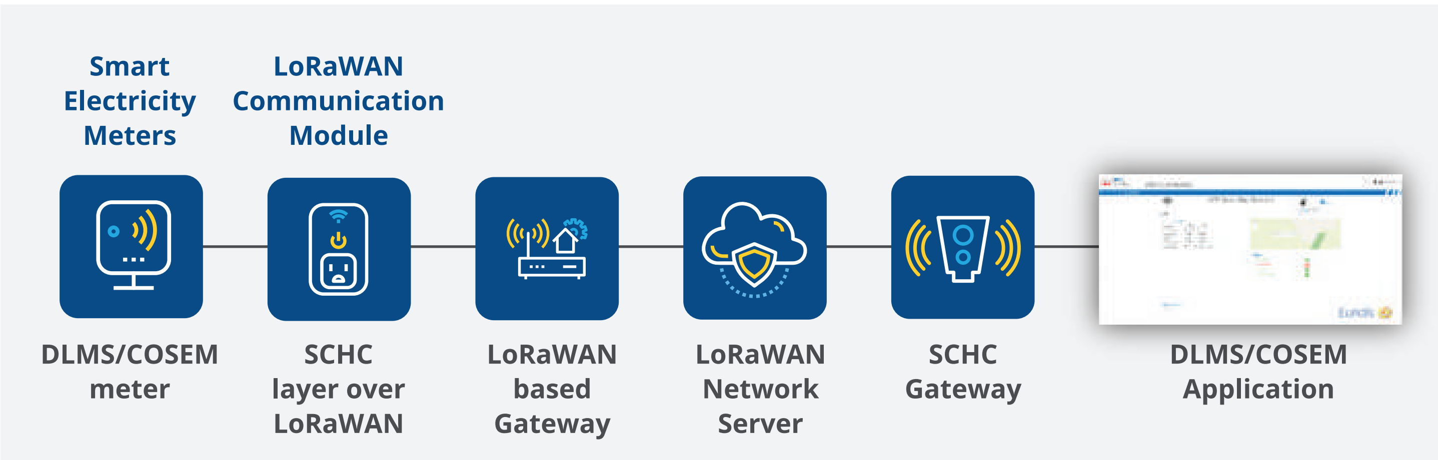


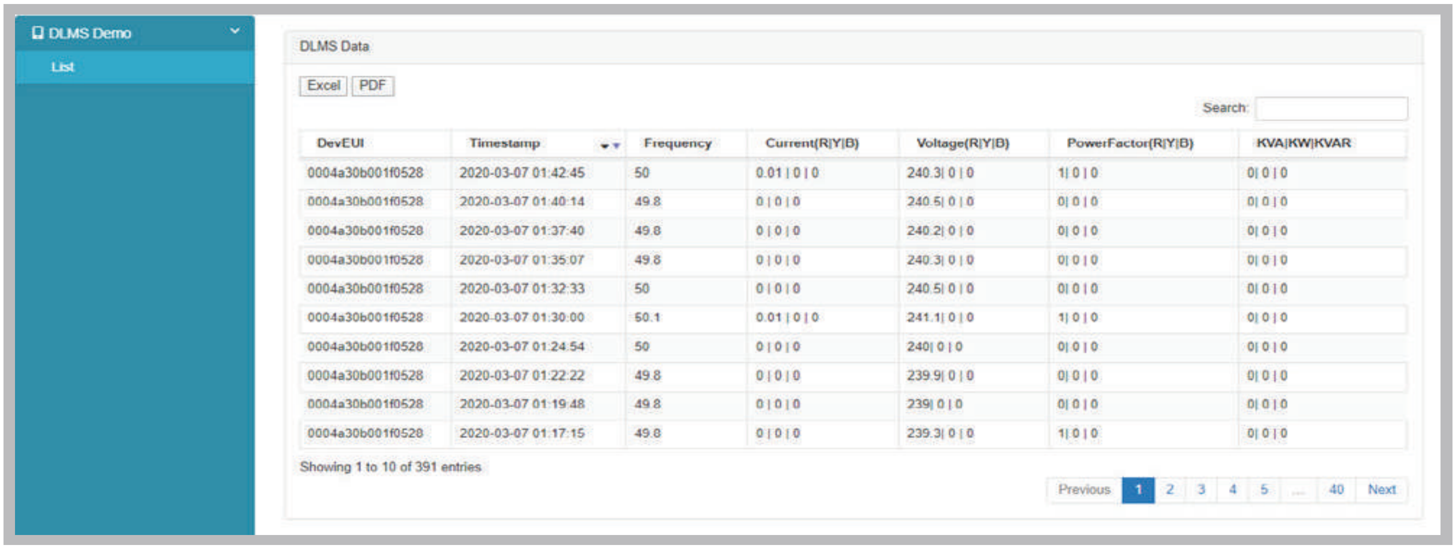
Fig. 3. Implementation diagram of AMI over LoRaWAN

As depicted from the diagram above the smart meter generate data packets for various DLMS parameters (Instantaneous, Load profile etc.,) in an given periodic interval. The data packets generated by the device are compressed and fragmented using SCHC technology – Static Context Header Technology at the LoRa module. The data packets are transported in IPV6/UDP packet format. The fragmented data packets are transmitted over LoRaWAN and relay the data into the centralized LoRa network server.

The fragmented data packets from the network server are pushed to the SCHC Gateway using API services. At SCHC gateway, every fragmented data packet is reconstructed to create the single complete DLMS parameter packet. The SCHC Gateway push the complete DLMS parameter data packet the Head End System Application software which in turn produce necessary dashboard, KPIs and reports as applicable.

RESULTS AND DISCUSSION

The IoT based smart energy meter system executed all the functions reliably and measured and displayed the parameters such as current, voltage, power and energy consumption successfully.



DevEUI	Timestamp	Frequency	Current(R|Y|B)	Voltage(R|Y|B)	PowerFactor(R|Y|B)	KVA|KW|KVAR
0004a30b001f0528	2020-03-07 01:42:45	50	0.01 | 0 | 0	240.3| 0 | 0	1| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:40:14	49.8	0 | 0 | 0	240.5| 0 | 0	0| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:37:40	49.8	0 | 0 | 0	240.2| 0 | 0	0| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:35:07	49.8	0 | 0 | 0	240.3| 0 | 0	0| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:32:33	50	0 | 0 | 0	240.5| 0 | 0	0| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:30:00	50.1	0.01 | 0 | 0	241.1| 0 | 0	1| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:24:54	50	0 | 0 | 0	240| 0 | 0	0| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:22:22	49.8	0 | 0 | 0	239.9| 0 | 0	0| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:19:48	49.8	0 | 0 | 0	239| 0 | 0	0| 0 | 0	0| 0 | 0
0004a30b001f0528	2020-03-07 01:17:15	49.8	0 | 0 | 0	239.3| 0 | 0	1| 0 | 0	0| 0 | 0

Fig. 4. Smart Meter data on Head End System

Table II concludes the comparison between existing smart energy meters and the smart energy meter proposed. It can be confirmed through an analysis of the table, that the proposed smart energy meter offers many advantages in comparison to existing smart meters while being less expensive and more accurate.

TABLE II: COMPARISON BETWEEN EXISTING SMART ENERGY METERS AND PROPOSED IoT BASED SMART ENERGY METER

Parameter	Existing Smart Energy Meters	Proposed IoT based Smart Energy Meter
Energy consumption reading and bill generation	YES	YES
Remote access and configuration	YES	YES
Measurement of parameters such as current, voltage, power and theft detection	NO	YES
Two-way communication support	YES	YES
User device notifications and app alerts	NO	YES
Accuracy	>99.0%	>99.5%
Cost	Rs. 4000 - Rs 8000	Approximately Rs. 3300

CONCLUSION

This project aims to create a cost-effective, accurate and reliable smart energy meter that can be integrated within the advanced metering infrastructure (AMI). The IoT based smart energy meter is capable of two-way communication through LoRaWAN with the data being available in real-time. The developed system measures numerous parameters such as current, voltage, power, and energy consumption, and generates a bill based on the energy consumption and price per unit of electricity. The smart meter ensures security through theft and tamper detection system that prevents manipulation, misuse and theft of electricity. The smart energy meter comes with a compact and secure design that can be enclosed with an external casing to enhance safety and aesthetics. The meter's robust and simple components ensure long-term durability and reliability which is essential for its real-life deployment.

To scale with long-term interoperability and benefit from the great disruption of the IoT, utilities are demanding open-standard connectivity technologies allowing the choice between several network models (public/private/hybrid). Utilities also need cost-effective, robust, reliable, perennial, secure, easy-to-install wireless technology to support their businesses' digital transformation, along with those of their partners and customers in the long term.

Embracing AMI and implementing smart energy meters throughout India's electricity grid will offer innumerable advantages and modernize India's grid. The implementation of smart meters will enhance transparency, prevent theft, increase grid efficiency and allow the electricity supplier to perform functions such as load balancing and shedding by analyzing the energy consumption patterns of the consumers. This would make energy more readily available, prevent wastage of energy and reduce costs for the consumers. One of the biggest advantages offered by smart energy meters is the elimination of manual meter reading and status check which will save time and resources.

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