Energy Monitoring Using LoRaWAN-based Smart Meters and oneM2M Platform

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***Abstract*—The Internet of Things (IoT) plays a key role in real-time monitoring at different stages of the power generation system, assisting to achieve better efficiency, minimize load on the grids by analysing usage patterns, provide faster resolutions to power outages, and so on. In this paper, we present a novel energy monitoring approach employing LoRaWAN-enabled smart energy meters and a oneM2M-based platform for collecting and analysing the data. The energy meters transmit data at 15-minutes intervals, i.e., 96 data points per day. A novel format has been developed for the LoRaWAN Protocol Data Unit (PDU) to transmit the values of phase currents and voltages, and data related to power and energy comsumption. This results in a high-resolution dataset containing more than 10,000 instances per meter, accumulated over the last four months. The data can be visualised in a live dashboard enabling the signal parameters such as Received Signal Strength Index (RSSI) and Signal to Noise Ratio (SNR) to be monitored in addition to the electrical parameters, to ensure proper data transmission. Finally, the trends in power and energy consumption of the load have been analysed, which can result in improved efficiency of building management, and early detection of electrical faults and failures.**

***Keywords*—Energy meters; Real-time Monitoring; oneM2M; LoRaWAN; IoT**

I. Introduction

Internet of Things (IoT) is pioneering a paradigm shift in global energy systems, imparting capabilities such as real-time monitoring, control, situational awareness and intelligence, and cybersecurity [1] at different stages of energy generation, transmission and distribution. Real-time monitoring, in particular, can assist in achieving better efficiency, minimizing load on the grids, providing faster resolutions to power outages, lowering the cost for consumers using demand-based dynamic pricing, and so on. Indeed, because of these advantages, multiple IoT-based energy monitoring solutions have been proposed in recent years. A comprehensive survey of smart electricity meters has been presented in [2] and [3], detailing aspects of the metering process, development and deployment, data analytics, existing technologies, and functions including data recording, alarming, and pricing. A Bluetooth Low Energy (BLE) based energy management method has been proposed in [4] using a BLE-enabled mobile device (basically any smartphone) to aggregate the energy consumption data. This was a modified architecture of their previous Zigbee and PLC based system [5], primarily aimed to reduce the energy consumption. Over the years, IoT devices have gradually steered away from traditional protocols such as Wi-Fi, BLE, and cellular, because low power and long range are favored in most IoT applications as opposed to higher bandwidth and data rate. Specifically, LoRaWAN is seen as a promising solution in sundry IoT applications [6] including smart cities [7], [8], localization [9], [10], utility metering [11], [12], etc., owing to its long range and low power capabilities. Extensive research on signal propagation [13], [14], path loss modelling [15], and range evaluation [16], has been carried out in the recent years and LoRaWAN-based energy monitoring systems have already been proposed in the literature [17]–[19]. In [20], class A LoRaWAN-based smart meters were used to monitor energy parameters and a detailed analysis of package delivery rate was presented. Energy monitoring using an Arduino-based sensor, Raspberry Pi-based gateway using LoRa for communication, and a NoSQL-based MongoDB database for data storage has been presented in [21].

One of the major disadvantages of the rapid integration of IoT is the limitation of meaningful data exchange between different verticals. To combat this, a global standard, oneM2M [22], has been devised. It acts as a horizontal layer between IoT end-nodes, communication networks, and applications by defining common service functions (CSFs), thus restoring the interoperability and scalability between different networks. In this paper, we propose an advanced metering architecture employing LoRaWAN-enabled smart meters for sensing the energy parameters, integrated with the oneM2M platform, for collecting and analysing the data. We deploy OM2M [23], which is an open-source service platform compliant with the oneM2M standards. The integration of oneM2M aids in realizing this energy monitoring vertical as part of a scalable smart city monitoring system, including verticals such as air pollution, crowd monitoring, security, and water quality.

II. Architecture and Implementation

Energy consumption data has been captured through LoRaWAN-enabled three-phase energy meters, compliant with the IS 16444 standard. This data is formatted in a specific PDU format and sent over a public LoRaWAN network (SenRa Co). The meter is first registered and activated on the SenRa network, following which, the meter starts transmitting an uplink message to the network server through the LoRaWAN gateways installed on campus. On the network server, the data is formatted into a JSON object with multiple key-value pairs

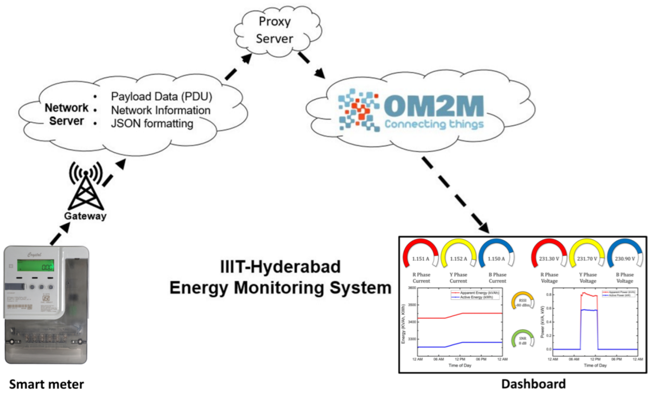

Fig. 1. Illustration of the energy monitoring system implemented at IIIT Hyderabad.

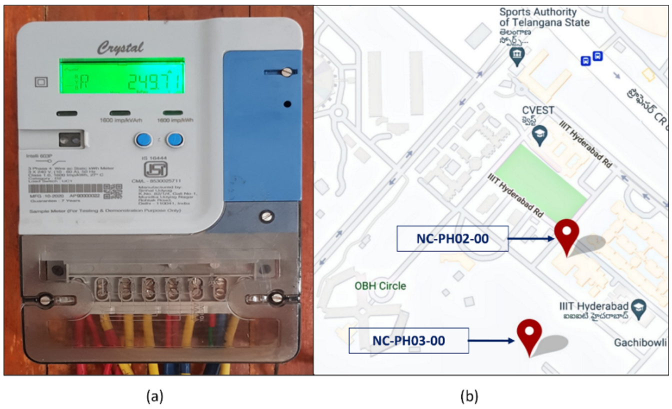

Fig. 2. (a) Photograph of the deployed LoRaWAN-enabled smart energy meter. (b) Geolocation information of the two meters deployed.

that hold the information including the payload, observation date and time, unique identifiers of the energy meters, transmit frequency, etc. The data packet with the best Signal to Noise Ratio (SNR) is then forwarded to the proxy server, where hexadecimal information of the PDU is converted into decimal values. The proxy server re-formats the JSON object to comply with the oneM2M standards, and forwards it to the OM2M platform. The data can then be accessed by cloud applications for analysis or visualization. A schematic of this architecture is illustrated in Fig. 1. As part of the pilot project, we deployed smart energy meters at two locations inside the campus of IIIT Hyderabad, India (Fig. 2). The system has been designed such that this number can be scaled up in the future without the need for additional infrastructure.

A novel format is used for the LoRaWAN Protocol Data Unit (PDU) to transmit electrical information. This includes instantaneous values of individual phase currents and voltages, average power factor (PF), average frequency, instantaneous values of apparent and real power, and cumulative values of reactive (kVARh), total (kVAh) and conventional (kWh or units) energy consumption. The payload consists of 46 bytes; each cluster of bytes representing an electrical parameter, as

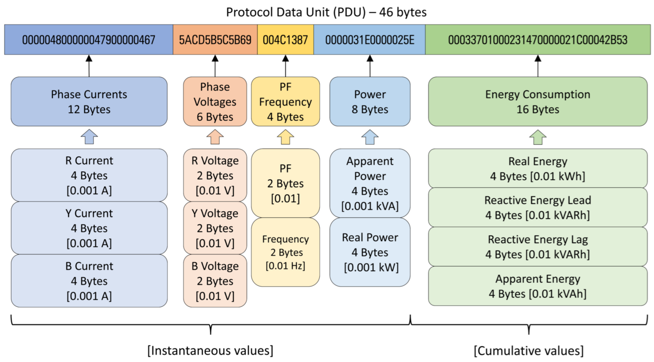

Fig. 3. The format followed for creating the LoRaWAN payload at the transmitter.

TABLE I
PDU DECODING PROCESS

Energy Parameters	*Hexadecimal to Decimal*		
	Hex value	*(Hex-to-Dec)/n*	*Final Value*
R Current (A)	00000480	1152/1000	1.152
Y Current (A)	00000479	1145/1000	1.145
B Current (A)	00000467	1127/1000	1.127
R Voltage (V)	5ACD	23245/100	232.45
Y Voltage (V)	5B5C	23388/100	233.88
B Voltage (V)	5B69	23401/100	234.01
Avg PF	004C	76/100	0.76
Avg Freq (Hz)	1387	4999/100	49.99
Power (kVA)	0000031E	798/1000	0.798
Power (kW)	0000025E	606/1000	0.606
Energy (kWh)	00033701	210689/100	2106.89
kVRh Lead (kVRh)	00023147	143687/100	1436.87
kVRh Lag (kVRh)	0000021C	540/100	5.4
Energy (kVAh)	00042B53	273235/100	2732.35

illustrated in Fig. 3. The conversion of the data bytes in the PDU to the values of corresponding electrical parameters is detailed in Table I. The payload data is broken into various segments according to the PDU format, and the hex value is converted into the equivalent decimal value and the decimal point is placed correctly. The final value thus obtained is stored in the OM2M platform in the appropriate data container. This data can be subsequently used for various IoT solutions including graphic visualization in the form of a dashboard, real-time monitoring of energy consumption, designing algorithms for predictive maintenance of electrical appliances to improve performance, early detection of potential problems preventing failures, hence reducing the maintenance costs of the system.

III. Results

The deployed meters have accumulated more than 10000 data points each, over a period of four months. The live data can be viewed in a dashboard illustrated in Fig. 4. The real-time values of phase currents and voltages can help in immediate fault detection in the loads. The live plots of instantaneous power and cumulative energy assist in estimating the time during which energy was actually consumed in a day. The RSSI and SNR values can be monitored to ensure proper data transmission. RSSI values above -120 dBm are considered

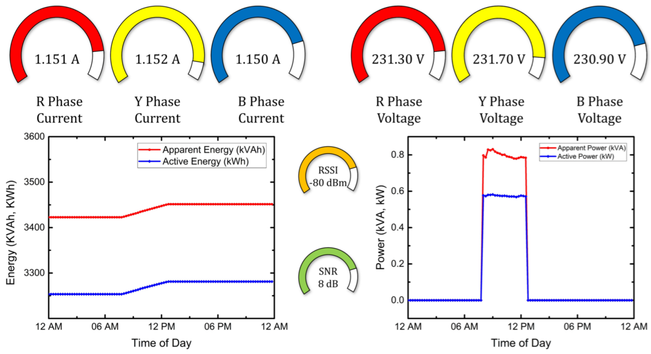

Fig. 4. A live dashboard can be used to monitor the electrical parameters and signal strength in real-time using a mobile application or a web portal.

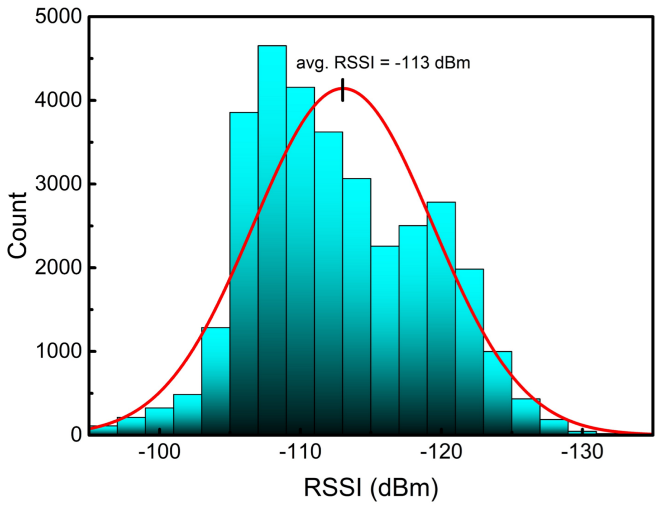

Fig. 5. A histogram of all the RSSI values from energy meter NC-PH02-00, over the 4 month period of deployment.

ideal in LoRaWAN, with values below -120 dBm indicating potential packet loss. The RSSI values of all the transmissions from meter NC-PH02-00 over the four months of deployment have been analysed to conclude that approximately 76% of them were in this ideal range, as illustrated in Fig. 5.

The access to daily energy consumption in both kWh and kVAh is one of the pivotal advantages of smart meters over traditional energy meters. This can help identify trends of energy consumption, particularly with changing weather, to optimize building energy consumption. The flexibility of tracking both kWh and kVAh usage along with real-time monitoring of PF values is also a key advantage in industrial deployments. The daily energy consumption data is as shown in Fig. 6. The line graphs indicate the 7-day moving average of energy consumption, which can provide interesting insights into the pattern of energy consumption in the campus. For example, we had a reduced student strength on campus because of the second wave of Covid-19 and the end of the Spring semester, starting 1st May. It can be clearly seen that the power consumption has reduced in the month of May. Further, the

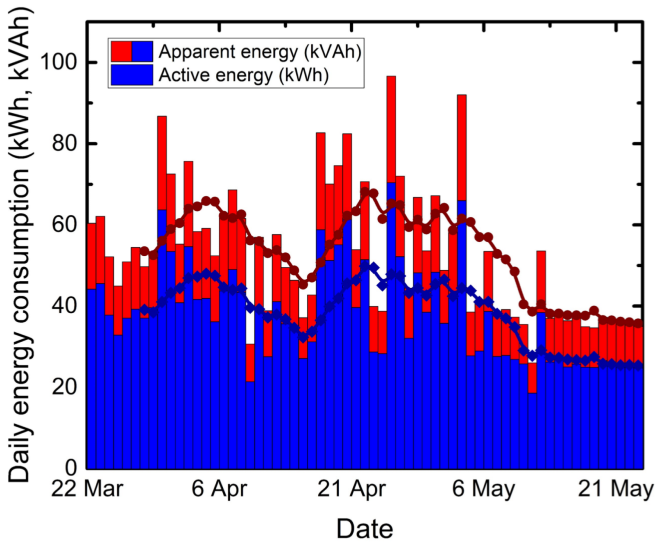

Fig. 6. Daily energy consumption from 23rd March to 23rd May, 2021. The line graphs indicate the 7-day moving average of active and apparent energy.

meter NC-PH02-00 was installed at one of the pump houses on campus, with a three-phase pump as its only load. We found that the values of currents in the three phases were either zero indicating that the pump was off, or a constant value indicating that the pump was on. The average non-zero value of red, yellow and blue phase currents was found to be 1.11 ± 0.03 A, 1.12 ± 0.03 A, 1.11 ± 0.02 A, respectively, thus giving a mean deviation of only 2.4% from their average values. This result can be used to determine if there is a fault in the pump by triggering an alarm if the non-zero values of currents are higher or lower than expected.

IV. Conclusion

In this paper, we have proposed a novel and scalable real-time energy monitoring system employing LoRaWAN-enabled smart meters and a oneM2M service platform. A novel format was used for the LoRaWAN PDU that contained 46 bytes of payload denoting values of phase currents and voltages, frequency, power factor, and power and energy consumption related information. The data accumulated over the four months of deployment can be analyzed to detect faults, minimize power loss and reduce energy consumption, and can be used for visualization purposes. This deployment can be scaled up to 100 energy meters in the future, without the need for additional infrastructure. Further, an Inter-working Proxy Entity (IPE) can be incorporated instead of a proxy server, to seamlessly transfer decoded packet information to the oneM2M platform.

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