IoT enabled Smart Meter Design for Demand Response Program

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***Abstract*—The smart grid is a new revolution in the energy sector in which information and communication system is integrated within the conventional electric power generation and distribution system. A key component of this system is the Advanced Metering Infrastructure (AMI), which enables two-way communication between consumer and utility company via a smart meter. In the smart home energy management system (SHEMS), the smart meter is commissioned to monitor, control, trade, and log the energy consumption. Due to the diversification of the appliances in SHEMS, manufactured by different vendors with uncommon standards and deregulation of the communication protocol, then applications and devices in SHEMS become difficult to interoperate. With IoT invention, the smart meter should be able to address the heterogeneity issues. This paper propose an IoT smart meter architecture that addresses the heterogeneity problem in SHEMS by making use of middleware platform which solves interoperability problem in any IoT scenarios. A prototype system using Raspberry Pi and Kaa IoT middleware is reported.**

***Index Terms*—Internet of Things; Smart grids; Middleware; AMI, SHEMS.**

I. Introduction

Smart grid uses Information and Communication Technologies (ICT) to collect data and take actions in an intelligent way. Using the modern technologies, smart grid enables electric power grid to improve reliability, quality and efficiency. However, one of the strategic ways toward achievement of smart grid, is implementation of Advanced Metering Infrastructure (AMI) [1]. Deployment of advanced metering infrastructure target to bring benefits to both sides, through different applications such as demand response, remote controls, outage detection system and others. In AMI,smart meter links the utility and consumers premises. For that reason, Smart meter play a key role in Smart home energy management system as it connects directly with consumer appliances and applications. However due to diversification of appliances, it becomes difficult to integrate appliances and applications [2]. Smart Meter was observed to be center of concentration to address the heterogeneity problem in SHEMS. Using common standards in developing IoT products such as smart meter and accossiated SHEMS in order to meet the interoperability requirement is one of the options. However, due to difficulties of enforcing universal standards on all IoT solutions, industry and literature proposed an introduction of an abstraction layer which is being referred as IoT middleware platform [3]–[6]. Being part of thesis work done by [7], this study proposed and developed an IoT enabled smart meter adapting one of existing IoT middleware platform and experiments were conducted to study its feasibility as a device specifically on power consumption and accuracy.

II. Related work

To fit all possible SHEMS applications in the current situation of having diverse IoT devices from different vendors without forgetting the penetration of IoT enabled appliances on consumer side, interoperability became one of the important requirement in AMI components specifically on smart meter [8] [9]. Number of approaches have been proposed to meet the requirement, hence introduced the IoT concept on metering system.

Work done by [10], [11] and [12] indicated that there is no smart metering platform carrying and meeting demands and requirements of IoT concepts, especially on interoperation and data management. Another very closely related solution was on water sector where by [13] proposed an architectural framework for smart water meter reading system in IoT environment. They used an ultrasonic flow measurement technology on water meter (STUF-280T) to sense water and temperature data. For interoperation and data storage, analysis, availability on the cloud, LinkIt ONE development board and Mediatek Cloud platform was used to bring the sense of IoT environment.

[10] proposed wireless IoT based metering system which argued to be less expensive about 25 percentage low compared to the ones in the market with 97 percentage accuracy and power consumption of meter itself has been reduced about 16

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percentage. The use of SQL databases in their design was a shortcoming due to limitation of centralized database systems such as scalability.

[11] developed a smart meter platform by integrating big data and IoT technologies offering electricity consumption data sensing, processing and virtualization. It was worth observing that the idea of the developed smart metering platform relates very closely with this study, however the point of deviation in kind of tools used, differentiated the design and performance at large. Interoperation in SHEMS cannot be achieved if heterogeneity due to appliances diversification has not been taken care of accordingly.

Moreover, Study by [14] demonstrated the features and implementation of interoperable low cost smart plug which enable realization of demand side management program in IoT environment. The study demonstrated on how to measure the key power parameters of AC based home appliances via smart plug based on Arduino controller and Zigbee communication protocol and obtained data on the smart meter side with accuracy of more than 78 percentage. With the same idea of having an interoperable smart plug, the smart meter was required to address the heteregiouty challenge on its other key platform especially when realizing that in any SHEMS and IoT environment, devices and applications will need to be integrated in a seamless manner.

With regards to technological and economical advantages, selection of middleware was based on number of previous works which suggested/proposed Kaa to fit the purpose [8], [15]–[18]. Moreover the technological capabilities of hardware platform, Pi4 promises to fit the industrial need even in the near future as compared to other processing unit [19]

Therefore, an IoT enabled smart meter architecture based on Raspberry Pi as a hardware platform and Kaa IoT middleware was proposed. The rest of the paper is organized as follows. Section III describes the technologies and tools of choice adopted to achieve the objectives of this work. Section IV discusses implementation of the system and depicts results obtained. Section VI concludes the paper, while highlighting possible future work.

III. Middleware for smart-meter

A. IoT Middleware

As a result of IoT emerging technologies, middleware is a platform in charge of masking the heterogeneity and distribution problems that we face when interacting with devices [20]. On creating an abstraction, IoT middleware is basically responsible for receiving data coming from diverse devices, process those data and provide them to corresponding connected applications or devices when needed. With such kind of platform, there is a need for making use of it, on designing interoperable smart metering solutions, capable of collecting and receive data from the wide range of consumer appliances and applications regardless of proprietary. Moreover, on addressing the IoT device or application's portfolio, there are already general defined functional requirements in which middleware are expected to meet. See Table I.

Table I
Middleware's Functional, Non-Functional and Architectural Requirements.

Functional	Non-functional	Architectural
Data management	Scalability	Interoperability
Resource management	Real-time or Timeliness	Programming abstraction
Resource discovery	Reliability	Service-based
Code management	Availability	Context aware
Event management	Security and privacy	Adaptivity

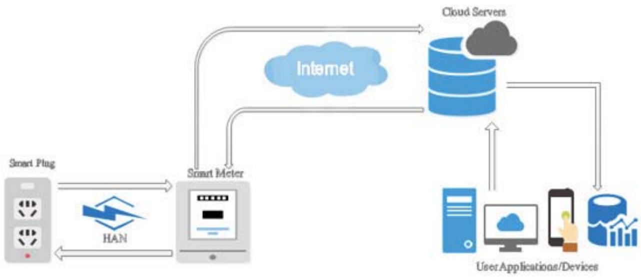


Figure 1. Overall System Architecture

In recent years, a number of IoT middleware solutions have been proposed. According to [3], there are more than 60 proposed middleware for IoT, some of which are open source and others are proprietary. Existing Middleware platforms meet IoT the mentioned demand and requirements differently [8]. Taking that into consideration, this study review and analyse these platforms in order to make best selection of appropriate middleware to adapt, see Table II. After review, Kaa was selected to proof the concept since it is a free platform,transparent, can work on both structured and unstructured data and its compatibility on any kind of hardware [21].

B. Proposed IoT Smart Meter Architecture

Requirements of IoT based smart meter were gathered and analyzed, observing critical functionalities of smart meter in achieving almost all related smart meter applications and SHEMS in order to propose appropriate tools. IoT smart meter should be nearly real time having about 1 sec sampling rate, providing two-way communication, and be able to capture all smart meter parameters. Parameters which acts as data sets are not limited to Interruptions, Voltage frequency, RMS voltage, Harmonic distortion, Voltage, current of each appliance to obtain the power consumption, Motion/Movement.

The proposed architecture in this paper introduces new hierarchical layer in the existing Smart Metering System. Fig.1 shows the overall system architecture of IoT smart meter that has been developed. The architecture depicts a typical IoT infrastructure comprising three layers;device, gateway and middleware platform server. Smart plug or smart appliance stands as a device layer which is a point of data source and command control. Current and voltage sensors sends the collected raw data via HAN based on Zigbee protocol to the raspberry pi. At the core of our solution is middleware

Table II
MIDDLEWARE'S FEATURES EVALUATION

IoT Middleware	Features of Middleware				
	Device Management	Interoperability	Portability	Context Awareness	Security and Privacy
HYDRA	√	√	√	√	√
ISMB	√	X	√	X	X
ASPIRE	√	X	√	X	X
UBIWARE	√	X	√	√	X
UBISOAP	√	√	√	X	X
UBIROAD	√	√	√	√	√
GSN	√	X	√	X	√
SMEPP	√	X	√	√	√
SOCRADES	√	√	√	X	√
SIRENA	√	√	√	X	√
WHEREX	√	√	√	X	X
KAA	√	√	√	√	√

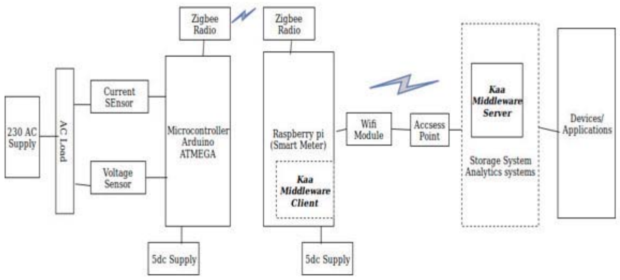


Figure 2. Block diagram of the smart meter

platform to be inserted on both sides such that endpoint can connect with the server/cloud. On successfully embedding of Kaa SD into the raspberry pi, it pre-processes the data before transferring it to the middleware server which has been integrated with CASSANDRA system for further analysis, storage and consumption by other applications and devices. The proposed architecture was detailed more using the block diagram on Fig. 2 showing all technologies and platforms incorporated. AC load, powered by 230 V, 50 HZ AC supply source, is measured its current and voltage at sampling rate of 1 second. Since the AC load are home based appliances, Current sensor is expected to have sensing range between 0-30 A, and sensor of choice was ACS712. ACS712 was connected to Arduino Uno R3 Micro controller having ATmega328 chip. A Zigbee communication protocol was configured using pair of XBEE S1C modules one at the arduino configured as end device and the other at meter configured as a coordinator. Smart meter involved raspberry p as its hardware platform and KAA middleware client application as software platform embedded in the pi. In order to send processed data from the smart meter system to the middleware server, ESP8266 wifi module was used to connect meter and server. Moreover, a computer with minimum of 8 Gigabytes of RAM was used as a sandbox to install and configure the middlewas server.

1) Kaa Middleware: Kaa is a ready-made middleware platform in IoT industry based on the fog computing paradigm, administered by KAA IoT Technologies and licensed under Apache 2.0. It was chosen on assurance of its support on interoperation as a standard feature With a default lightweight IoT protocols such as MQTT and CoAP and as well as support on other Protocols. Kaa creates a uniformity and standardization environment among IoT devices and applications which provide seamless communication, integration and to number of IoT devices and sensors. KAA offers better scalability as it can run in cluster format. KAA is perfect for large corporate solutions where performance, reliability and security are important factors [15]. KAA adds more advantage by being 100 percentage an open source technology, with end-to-end integration, supporting integration with analytics tools so it will be possible to treat well the huge amount of data generated from AMI including smart meter.

2) Raspberry pi: Raspberry pi (RPi) was used as a hardware platform for the smart meter. In spite of existing different models, Pi 3 model B was selected because of its advantageous features such as quad-core 64-bit ARM Cortex A53 clocked at 1.2 GHz making it faster than Pi 2. RAM is 1GB of LPDDR2-900 SDRAM, and it has the graphics capabilities, provided by the VideoCore IV GPU. In the proposed architecture, it was treated as gateway. It was strategically designed to receive data from current, voltage and environmental sensors via LoRa communication protocols, specificcally Zigbee network. The RPi stored and pre-processed the metering data at the edge before uploading via WiFi to an application running on a Cloud middleware platform. The platform made further elaborations of the data by means of algorithms for consumer profiling,demand response and appliance remote control, and so on.

IV. IMPLEMENTATION RESULTS

To prove the design concept, the system was implemented to collect power data after every 1 second from three home appliances,electric kettle, fan and light bulbs rated 2500W, 60W and 40W respectively connected on 230V AC supply. See Figure 3.

On the smart plug section which brought the concept of smart or IoT enabled appliance, the section comprised of current sensor ACS712, controller board, Arduino unoR3 with ATMEGA chip. According to [22] Zigbee communication

Figure 3. Prototyped smart meter

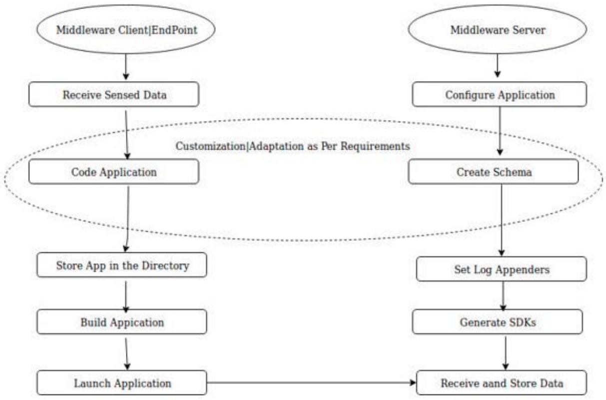


Figure 4. Client and Server/cloud operational process

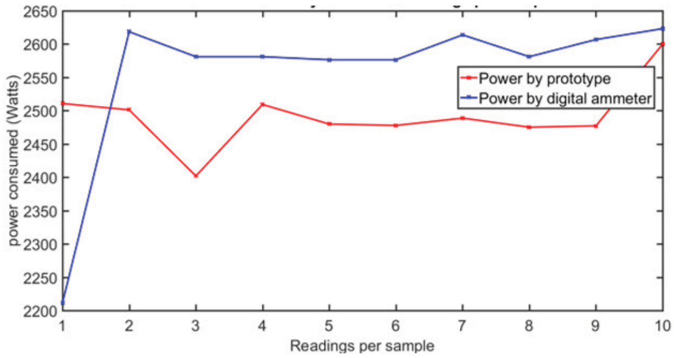


Figure 6. Real-time measurements of an electric kettle

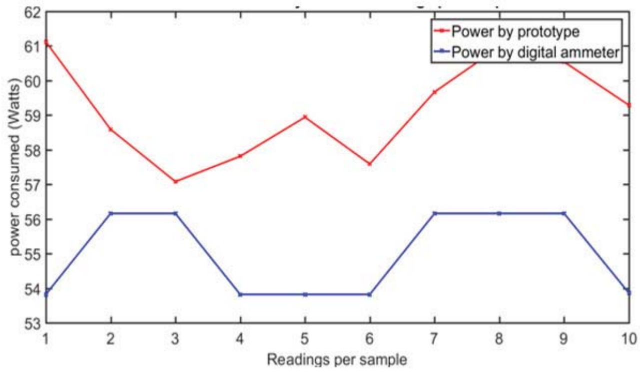
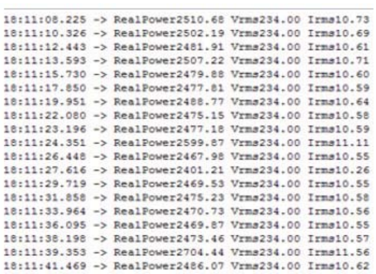


Figure 7. Real-time measurements of a light bulb.

protocol is proposed to be one of the good option of low range communication for SHEMS. simple HAN of Zigbee protocol was configured using S2C Xbee modules to take data from the smart plug to smart meter. Smart meter involved raspberry pi as its hardware platform, then a middleware endpoint application, Kaa SDK written in java was embbeded in it, and makes pi as a midddleware client and be able to implement real-time bi-directional data exchange with the middleware cloud server via internet. Data is appended to a Kaa node and analyzed using a defined log schema (See Kaa Customizationa and operation process on Figure 4). Fig.4. Therefore, the prototype can collect consumption data from the appliance to the middleware server, see Figure 5.

By comparing energy consumption readings of these appliances using industrial ammeter and readings of the prototype at the same time it was able to learn how realistic to obtain accurate power consumption pattern information of the appliances connected in the system. small deviation was observed as compared to the expected energy consumption ratings indicated in manufacture data sheets see Figure 6 and Figure 7. Having such kind of monitoring system involves constant data transfer and analytics, the experiment went further on finding out energy implication experienced by endpoint devices, raspberry pi after additional of new application on it.The setup was to measure the timing a fully charged power bank battery is using to power the pi until the power bank run completely out of charge using the formula below. This was done before and after embedding the application and see the consumption trend differences on this new adaption and repeated the exercise four times in both cases to have reasonably number of readings for comparison.Results are shown on Figure 12. From its data sheet, power bank has provided the rated cell capacity of 10000 mAh and output voltage of 5 V. The mathematical formula to obtain number of hours was as follows. Current in Ampere = (Rated cell Capacity in mAh) / (1000×Number of Hours). Power in Watts = Current Flowing in Amps × Rated Voltage. For example, when the client application was not running, the battery lasted for 14 hours, and 28 minutes, making consumption of 0.691 amps per hour hence the 3.455 Watt (0.691 amps * 5 V) average power was obtained. When the pi executed the application, then the battery lasted for 10 hours and 12 minutes, with the same mathematical formula the



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18:11:08.225 -> RealPower2510.68 Vrms234.00 Irms10.73
18:11:10.326 -> RealPower2502.19 Vrms234.00 Irms10.69
18:11:12.443 -> RealPower2481.91 Vrms234.00 Irms10.61
18:11:13.593 -> RealPower2507.22 Vrms234.00 Irms10.71
18:11:15.730 -> RealPower2479.88 Vrms234.00 Irms10.60
18:11:17.850 -> RealPower2477.81 Vrms234.00 Irms10.59
18:11:19.951 -> RealPower2488.77 Vrms234.00 Irms10.64
18:11:22.080 -> RealPower2475.15 Vrms234.00 Irms10.58
18:11:23.196 -> RealPower2477.18 Vrms234.00 Irms10.59
18:11:24.351 -> RealPower2599.87 Vrms234.00 Irms11.11
18:11:26.448 -> RealPower2467.98 Vrms234.00 Irms10.55
18:11:27.616 -> RealPower2401.21 Vrms234.00 Irms10.26
18:11:29.719 -> RealPower2469.53 Vrms234.00 Irms10.55
18:11:31.858 -> RealPower2475.23 Vrms234.00 Irms10.58
18:11:33.964 -> RealPower2470.73 Vrms234.00 Irms10.56
18:11:36.095 -> RealPower2469.87 Vrms234.00 Irms10.55
18:11:38.198 -> RealPower2473.46 Vrms234.00 Irms10.57
18:11:39.353 -> RealPower2704.44 Vrms234.00 Irms11.56
18:11:41.469 -> RealPower2486.07 Vrms234.00 Irms10.62
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Figure 5. Real-time measurements using our prototype smart meter

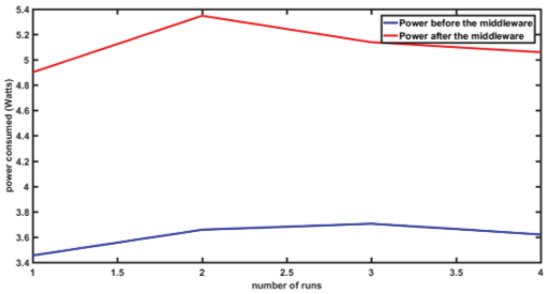

Figure 8. Raspbery pi Power Consumption before and after Adaption of middleware.

current consumption was 0.98 amps making average power of 4.902 Watt (0.98 amp $\times$ 5 V). All obtained results have been plotted as on Figure 8.

V. CONCLUSION

IoT middleware is capable of standardizing and provide uniformity to diverse consumer appliances and applications in SHEMS regardless of the manufacture proprietarity. Adapting a middleware platform Kaa to the system was proved to be cheap and fast. Moreverer, results showed that, if raspberry pi will be used as a hardware platform of the meter on merging the middleware, then power consumption of of the system will not exceed 35 percentage. Data received on the middleware server from the appliances were accurate enough by 98 percentage; and therefore they can be trusted to be used by other entities in the infrastructure, including smart meter applications such as demand response. Successfully implementation of the proposed architecture designed in this study ensured that any deployment of this smart meter to a real system will provide interoperation across the Advanced Metering Infrastructure and across SHEMS.However more studies need to be conducted in this area to evaluate the feasibility of newly proposed meter especially on security aspect to make sure consumer data are not exposed to security threats.

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