A Smart Home Energy Management System Using IoT and Big Data Analytics Approach

SEMINAR REPORT

Submitted in the partial fulfilment of the award of the degree of

Bachelor of Technology

in

Computer Science & Engineering

of

APJ Abdul Kalam Technological University

by

S HEMANTH

November 2019

Department of Computer Engineering

College of Engineering, Chengannur, Kerala -689121

Phone: (0479) 2454125, 2451424; Fax: (0479) 2451424

COLLEGE OF ENGINEERING, CHENGANNUR
KERALA

Department of Computer Engineering

CERTIFICATE

This is to certify that the seminar entitled

A Smart Home Energy Management System Using IoT and Big Data Analytics Approach

Submitted by

S HEMANTH

is a bonafide record of the work done by him.

Co-ordinator **Guide** **Head of the Department**

ACKNOWLEDGEMENT

I am greatly indebted to **God Almighty** for being the guiding light throughout with his abundant grace and blessings that strengthened me to do this endeavour with confidence.

I express my heartfelt gratitude towards **Dr. Jacob Thomas V.**, Principal, College of Engineering Chengannur for extending all the facilities required for doing my seminar. I would also like to thank **Dr. Smitha Dharan**, Head, Department of Computer Engineering, for providing constant support and encouragement.

Now I extend my sincere thanks to my seminar co-ordinators **Mrs. Shiny B**, Assistant Professor in Computer Engineering for guiding me in my work and providing timely advices and valuable suggestions.

Last but not the least, I extend my heartfelt gratitude to my parents and friends for their support and assistance.

ABSTRACT

Increasing cost and demand of energy has led many organizations to find smart ways for monitoring, controlling and saving energy. A smart Energy Management System (EMS) can contribute towards cutting the costs while still meeting the energy demand. The emerging technologies of Internet of Things (IoT) and Big Data can be utilized to better manage energy consumption in residential, commercial, and industrial sectors.

An Energy Management System (EMS) for smart homes is considered in this work. In this, each home device is interfaced with a data acquisition module that is an IoT object with a unique IP address resulting in a large mesh wireless network of devices. The data acquisition System on Chip (SoC) module collects energy consumption data from each device of each smart home and transmits the data to a centralized server for further processing and analysis. This information from all residential areas accumulates in the utility's server as Big Data. The proposed EMS utilizes off-the-shelf Business Intelligence (BI) and Big Data analytics software packages to better manage energy consumption and to meet consumer demand.

Contents

List of Figures

1 INTRODUCTION

Effective management of Energy consumption in smart homes saves money, enhances sustainability and reduces carbon footprint at large. However, the lack of low cost, easy to deploy, and low maintenance technology has somewhat limited a large-scale deployment of such systems.

The sheer quantity of data collected throughout different cities of a country presents multiple challenges in data storage, organization, and analysis. Internet of Things (IoT) technology and Big Data are natural candidates to address these challenges. IoT technologies can provide a ubiquitous computing platform to sense, monitor and control the household appliances energy consumption on a large scale. This data is collected using many different wireless sensors installed in residential units. Similarly, Big Data technology can be utilized to collect and analyze large amounts of data[2]. Data analytics on this data using business intelligence (BI)[3] platform plays an essential role in energy management decisions for homeowners and the utility alike. The data can be monitored, collected and analyzed using predictive analysis and advanced methods to actionable information in the form of reports, graphs and charts. Thus, this analyzed data in real-time can aid home owners, utilities and utility eco-systems providers to gain significant insights on energy consumption of smart homes. The energy service providers can use the power consumption data available with analytics engine to provide flexible and on-demand supply with appropriate energy marketing strategies. The consumers, being aware of their consumption behavior and having a close interaction with the electricity utilities, can adjust and optimize their power consumption and reduce their electricity bills.

The literature review indicates that various communication protocols in a WSN have been utilized in EMS for smart homes. However, for a seamless integration of all residential devices, an open-source light weight communication protocol is required. This will foster interoperability leading to scalable systems. Installation of home EMS can help home owners to understand contribution of each device towards the overall electricity bill they receive. In addition, most previous work has primarily focused on individual smart homes and lack the energy management provisions for regional utility providers or national level utility centers. The technology to collect huge volumes of data from home sensor networks is available, however, managing the collected data efficiently and extracting deeper insights from it remains a challenge. The existing paradigms on EMS and cost saving models are implemented on discrete units while the proposed model can be built on top of the existing architectures to cater to a distributed EMS platform from consumer to community level stakeholders.

The design and implementation of an EMS that addresses these shortcomings is introduced and the proposed system utilizes an IoT based communication protocol based on well-established standards like MQTT which makes the system scalable. In addition to this, the proposed system is empowered with analytics and Business Intelligence (BI) that provides a meaningful perspective on the collected data through dashboard visualization and reporting. Moreover, using Big Data based data storage technology ensures the system scalability on a national level, thus catering energy management services to both home owners as well as utility providers.

Finally, as an additional advantage, the use of IoT also enables seamless remote access control of home devices where the customers get online access to the ON/OFF usage pattern of in home appliances via a personal computer or a mobile phone.

Rest of the report is organized as follows. Previous work in using Home Energy management System (HEMS) is presented next. This is followed by the proposed system requirements. The system architecture is presented next followed by a description of implementation details. Evaluation and testing is described and succeeded by the conclusion.

2 RELATED WORK

2.1 Home Energy Management System (HEMS) using a ZigBee Module

In [4,5,6], an implementation of a HEMS Unit in a Wireless Sensor Network using a ZigBee Module to communicate with sensor nodes, is presented. The system monitors the device consumption data and sends control signals to end nodes during peak load hours. However, the lifetime of a WSN network deteriorates with time due to the deployment of new sensors in the network. Additionally, Han et al. in [7] introduced a system for monitoring power consumption using ZigBee as the communication protocol in a WSN. However, in this system the data was collected and aggregated solely by the home server which could lead to data loss in case of a system failure. Moreover, a bridge between ZigBee and TCP/IP stack would be required to connect this system to a community of homes.

2.2 Extending the Previous Work

In [8,9], the above mentioned WSN networks have been extended to wider ranges in the IoT paradigm utilizing the GSM/GPRS networks to remotely control the end-devices.

2.3 An Integrated Cloud-based Smart Home Management System

In[13], a hierarchical, smart-home service architecture employed with multiple in-home displays for user interfaces is described by them. In this research, a home controller system interfaced with device sensors is responsible for aggregated energy reporting of all devices to home owners. For community representatives, a community broker server is integrated with different home network devices such as security cameras within a community. Furthermore, a comparative analysis between Message Queuing Telemetry Transport Protocol (MQTT) and Hypertext Transfer Protocol (HTTP) is also performed to determine which protocol was more efficient in providing home control services [13]. The design of the proposed architecture, however, lacks the incorporation of Big Data which is instrumental in processing and analyzing huge volume of data collected from several home sensor networks.

2.4 Developments of the in-home Display Systems for Residential Energy Monitoring

Multiple in-home display systems (IHDs) and automatic meter reading systems (AMR) were discussed in the context of providing energy management information in [15]. Depending on the ambient conditions, the smart home systems could choose the display devices such as TV, smartphone or tablet computers and accordingly select the appropriate user interface. The architecture, however, lacked a standardized user interface for all the home devices that could accomplish the requirement for multiple displays.

2.5 Home energy management system based on power line communication

This architecture of HEMS utilizing power line communication was addressed in [16]. Using smart meter data, this HEMS can monitor and provide real-time information on home energy consumption along with online access to devices status, thus allowing remote control of devices by customers. The proposed design is based on standard HTTP protocol and does not provide support for lighter-weight communication protocol like MQTT which is essential to scale up the system in order to accommodate multiple residential areas.

3 PROPOSED SYSTEM REQUIREMENTS

The functional requirements of the system are specified as general functional requirements and specific system requirements. The general requirements are the system's functionality and specific requirements are different business processes delivered. Non-functional requirements comprise of system's attributes such as scalability, security, privacy.

The proposed system's functional requirements are:

- The SoC should gather power consumption information and the ambient condition information periodically, and send it to a centralized server.
- The server should parse the information and transmit the readings to a central data storage system or database.
- The stored data should be used by analytics engine to process it and generate reports, graphs, and charts.
- Clients should be able to view the generated graphs through a cross-platform mobile application.
- Depending on the user privileges, the application should render different services to each user such as viewing reports, device status, and remote control of device or bill payment.

The proposed system's non-functional requirements are:

- Scalability

  The data is collected and analyzed on a national level accommodating four different levels of stakeholders: Home Owner, Community Representative, State Representative and Country Representative. Each stakeholder has its respective view of the data and services offered. The six business processes mentioned above should be applied to each stakeholder as required. To serve these levels of clients, the system should be based on an easily scalable architecture.

- Security

  Security of the system is important as a minor flaw in system design can lead to catastrophic disasters. Multiple levels of security such as secured web service calls using https must be implemented to ensure protected communication of the system.

- Privacy

  The communication between server and end devices should be private. Access control using two factor authentication and proper encryption techniques should be utilized to prevent illegitimate users from prying over the data.

4 SYSTEM ARCHITECTURE

Based on the above system requirements, the proposed system's hardware and software architecture are as follows:

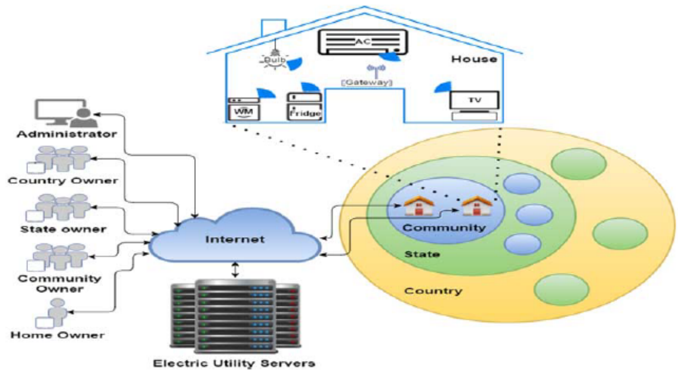

Figure 1. Systerm Architecture

4.1 Hardware Architecture

4.1.1 Sensors and Actuators

As the proposed system is to monitor and control the AC units, an integrated temperature and humidity sensor is interfaced with the microcontroller to measure the ambient conditions.[21] In addition, a solid state relay is controlled by the microcontroller to switch ON/OFF the devices accordingly. A current sensor is used to measure the AC current to calculate the power consumption.

4.1.2 High-end Microcontroller

A SoC high end microcontroller is used as edge device data acquisition module that manages the HVAC unit.[22] The compact sized, high speed and lightweight SoC is suitable for residential areas. Table I displays the specifications of the micro-controller used in this study.

4.1.3 Servers

In this architecture, the servers are high-end PCs which can also be deployed on Cloud for wide-scale accessibility. The installed servers are: MQTT Broker, highly scalable Storage Server, Analytics Engine server, and a Web server. The functionality of each server developed and utilized will be explained in the software architecture section.

Component	Description
Digital Ports	18 I/O ports
Analog Ports	8 ADC and 2 DAC
Memory	1MB Flash, 128 kB RAM

Table I. Micro-Controller Specifications

4.2 Software Architecture

Software architecture consists of three primary building modules; data acquisition module on the edge device, middleware module, and client application module:

4.2.1 Data Acquisition Module

The data acquisition module has two functions namely, monitoring function and controlling function. The monitoring function continuously reads the ambient temperature, humidity and the AC power consumption transmits the readings to the middleware module through MQTT protocol. These parameters are framed and reported to the middleware periodically in standard MQTT format. For example, the data frame has the user ID, house ID, device ID and the sensor values. The control function is used to receive the commands from the middleware module to turn ON/OFF the AC-Units accordingly.

4.2.2 Middleware Module

Middleware module consists of several software tools and servers that provide different services as explained below:

- MQTT Server
  MQTT server (Broker)[11], provides a medium for the communication between the edge device (home appliances such as AC-Unit) and the middleware.

- Storage Server
  A highly scalable storage server is used as data warehouse for storing the edge devices' sensor data and user information.Operational database that runs on top of existing scalable storage server was chosen [24].

- Analytics Engine server
  An off-the-shelf business intelligence software tool was utilized to make smart decisions

from the received big data.[3]

For example: the measured data is sorted and classified based on temperature, humidity and power consumption per house. This classification is used to generate reports, graphs, and charts that identify the consumption pattern of the houses in a residential area. This enables every house owner to see his/her own power consumption pattern based on the ambient conditions. Accordingly, home owner can turn ON/OFF the device based on such information if needed.

- Webserver

  The client application accesses the operational database through different web services implemented using JavaScript [24]. These services are used to transmit data to and from the database and send it back to the requester. Web services are used by the client application to authenticate monitor and control devices, view registered properties, and view registered devices, monthly bill viewing/paying and viewing graphs appropriate to the level of the user.

4.2.3 Client Application Module

A cross-platform IDE was used to develop the front end mobile user interface[26]. The application uses two types of authentication; the regular username-password combination is used to initiate connection. Once the user is authenticated a random generated string called API key is used to authenticate operations. This key can be changed anytime, API key changes per session. Once the user logs out, the API key is changed. Moreover, to make granting privilege like making a user a state-owner requires an additional parameter called secret key is used. This key changes daily, weekly or monthly and is only to be known by the top-level employees. Fig. 2 displays the overall sequence diagram showing the two-way data flow from home devices to end user application; one way is for monitoring device consumption details and other is for remote access control by the end user.

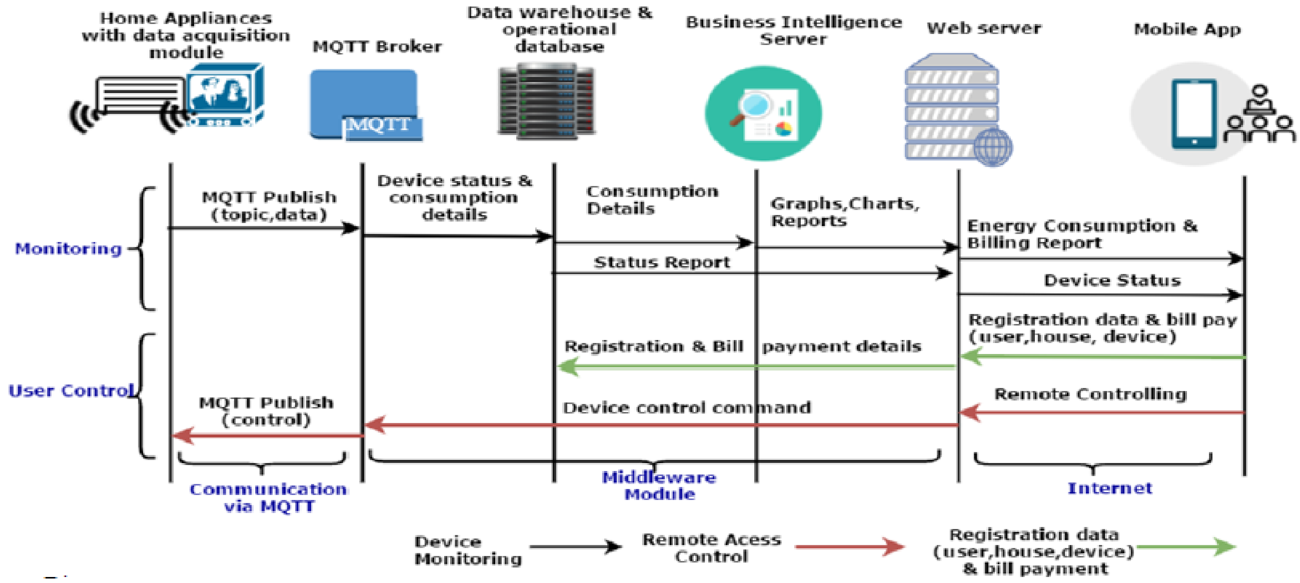

Figure 2. Sequence Diagram

5 IMPLEMENTATION

To validate the architecture of the proposed system, a prototype was designed, built and tested in the lab. The prototype architecture consists of various hardware and software modules. In this section the hardware and software components used in the system prototype are described in details as follows:

5.1 Hardware

The hardware consists of a sensor array, high-end microcontroller, and relay banks. The sensor array comprises of RFID reader, temperature, humidity and current sensors.These sensors collect the device status and report it to the microcontroller periodically. The RFID module consists of RFID tag and a reader for each home device which is used for the local control of the device by swiping the tag through the reader by the home owner.[27] As mentioned in the previous section[22], the microcontroller is a high end single SoC on the edge that collects the information from the sensors and forwards it to the servers for further processing via MQTT broker. Since the microcontroller cannot provide enough power, a solid state relays bank was used to provide a power driving circuit for the appliances. For the implementation in lab, 220 volts AC fans are used to mimic HVAC units. Depending on the different business processes, the microcontroller can be programmed to function differently for each scenario. For consumption analysis, the microcontroller is programmed to collect the temperature, humidity and power consumption data from the sensors.

User ID	House ID	Device ID	Power (kwH)
Humidity (%)	Temperature (C)	MQTT QoS	Message ID

Table II. Data Frame-Payload

The data is framed in to a lightweight format[28] compatible with MQTT server. This framed data is attached with the user, house and device details as shown in Table II. To implement remote controlling of devices through client application, the microcontroller reports the status of the device whenever the state of device is changed. To enable the billing utility process, the microcontroller transmits the total power consumption of the device every day to the servers via the MQTT protocol. Fig. 3 shows the prototype that was built in the lab to mimic the proposed system.

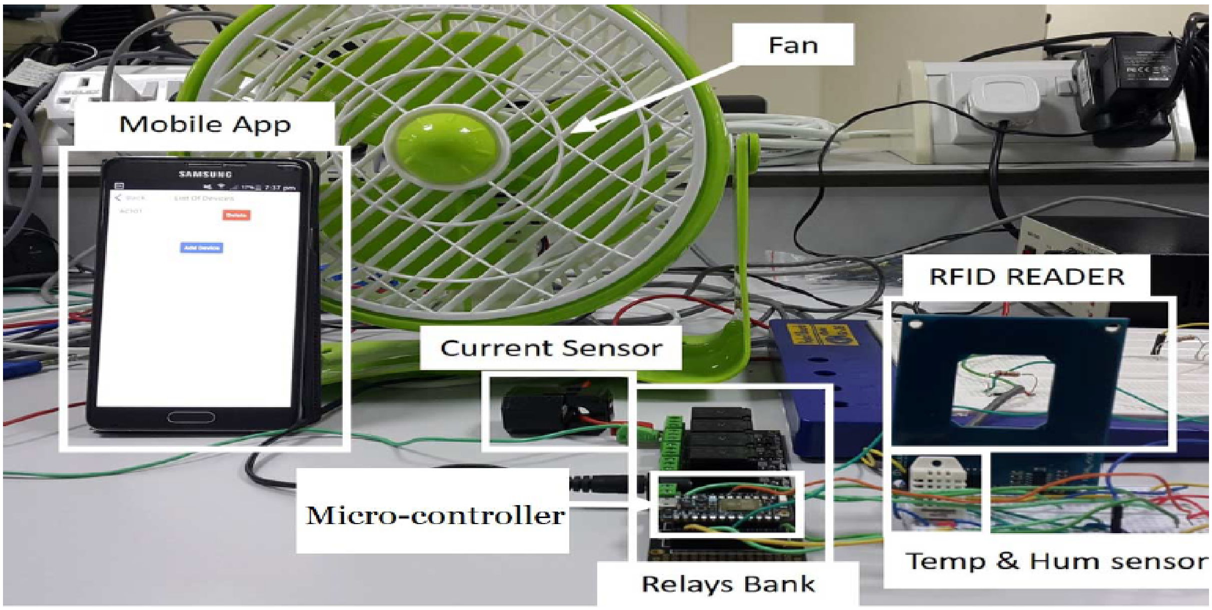

Figure 3. Hardware Components

5.2 Software

The software implementation involves benchmarking and data analysis techniques using Business Intelligence tool to generate graphs, charts and reports in real time. This was followed with the development of a mobile application to render the generated graphs, charts, and reports to end users. A description of these software modules is given as follows:

- **Benchmarking and data analysis using BI platform**
  One of the primary analysis techniques in data mining is benchmarking. Benchmarking the data sets can help identify which houses or residential areas should be focused on for setting optimal energy management goals and policies. The business intelligence software tool serves as an optimum platform for benchmarking real time data and generating userinteractive charts and reports. Different benchmarking scenarios are deemed for the four stakeholder levels as mentioned in the previous section.

For the stakeholder like a **home owner** in a residential area, they are entitled to view the graphs and charts for the total power consumption of his/her house on a daily, monthly, and annual basis. The user is prompted to enter his/her house ID and select the year for which he/she desires to view the power consumption of each device in the house as shown in Fig. 4. The home owners can use benchmarking service to compare their power consumption with other housing units that have a similar setup.

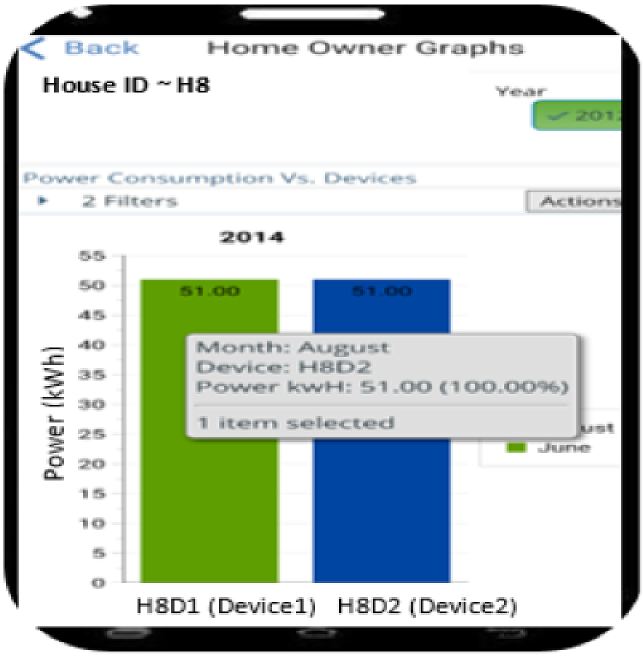

Figure 4. Home Owner Graph

For **community stakeholders**, they are entitled to monitor power consumption of all houses in their respective community. There are two types of settings involved; first, benchmarking annual power consumption of each house against per square feet power consumption. Second, categorizing each house depending on its annual power consumption with respect to the house-age. The community owner is prompted to enter his/her respective community ID in order to obtain the desired graph or chart. A screenshot of annual power consumption chart for several housing units with their respective house IDs in a community is shown in Fig. 5.

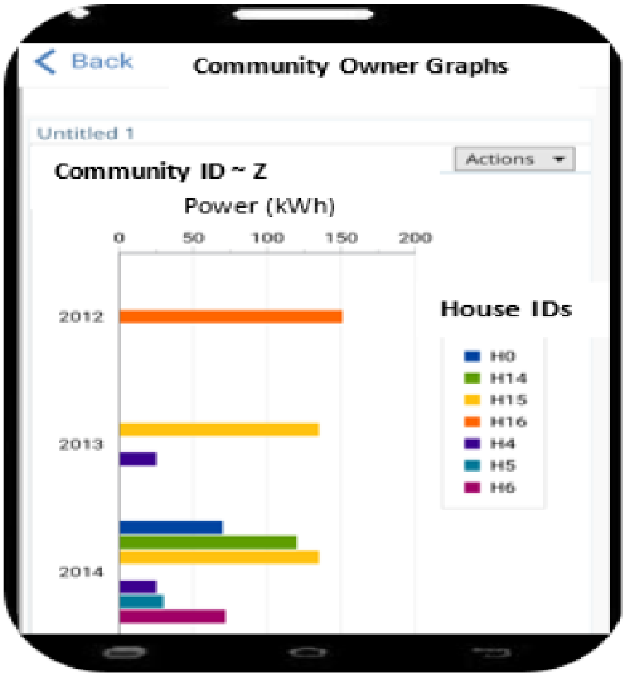

Figure 5. Community Owner Graph

The **state stakeholders** at a state utility center can view data set distribution across regional communities within the state. Also, they can view the average power consumption spread across different communities on a monthly and yearly basis. The graphical data will be used to create benchmarks based on past records for conducting root cause analysis which is one of the business processes as mentioned previously. The trend line graphs can help predict the nature of power consumption of the state with respect to weather conditions (temperature) in future as shown in Fig.6.

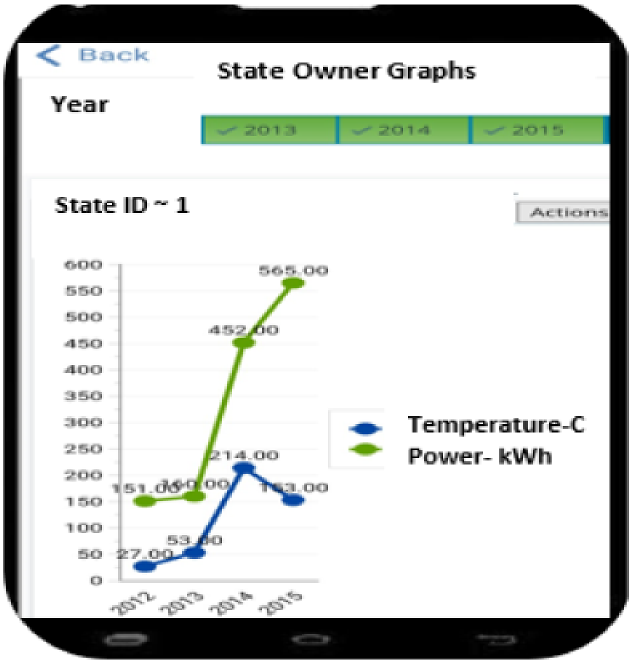

Figure 6. State Owner Graph

- **Client Application**

  A cross-platform application is developed which provides access to every stakeholder a different view to the data analytics according to his/her privileges. Once a user logs in, a service will run to get the user privileges and the user interface components that he/she will be able to see consequently.

  For example, for the home owner, there are two services available:

  First is monitoring power consumption data of each house device as shown in Fig. 6 and second is remote control services (ON/OFF) for house devices as shown in Fig. 7(a). For the bill tracking service, the user can view the monthly bill and pay the due amount online as shown in Fig. 7(b).

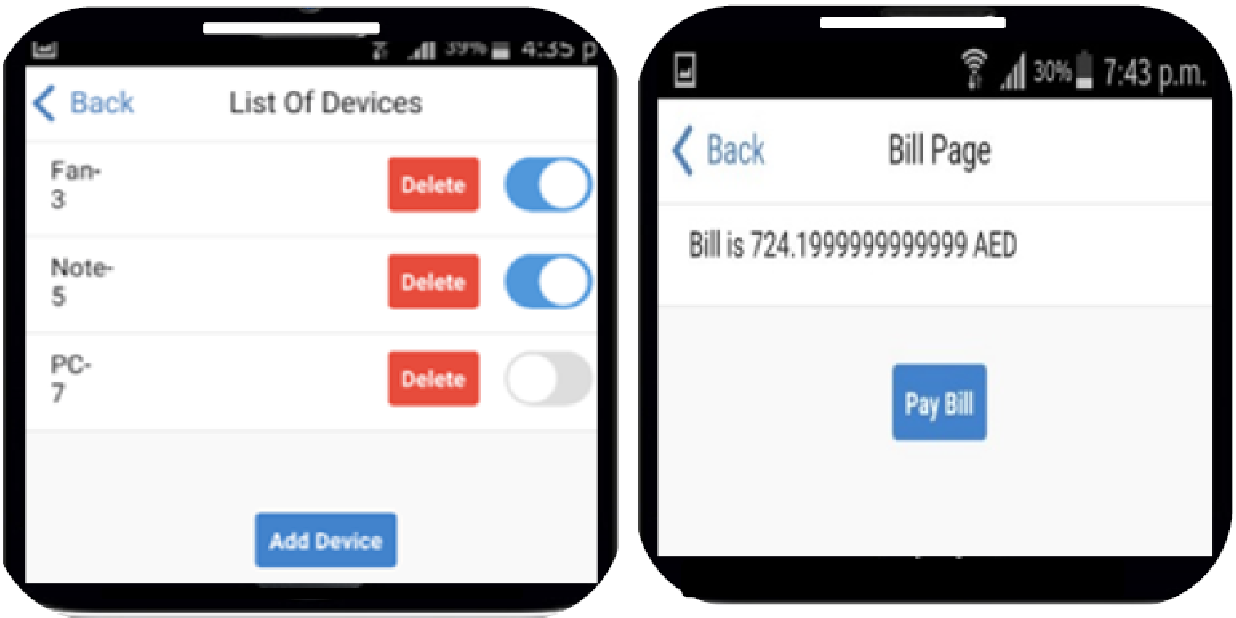

Figure 7. (a) Remote control of devices (b) Monthly Bill Management

6 EVALUATION AND TESTING

A set of criteria were developed to evaluate system performance for scalability, speed and security. Scalability is the main concern for the MQTT Server and Web server to accommodate all customers on national level. Speed was also important for querying to and from the storage server or operational database. It's worth mentioning that the security aspect of the proposed system is under development.

6.1 MQTT Server Scalability

A network analysis tool was used to measure the following metric: Throughput, Latency, and Packets dropped. For an experimental comparison, a logarithmic scale of clients was chosen to send 1, 10, 100, and 1000 consecutive messages with a reliability of Quality of Service: QoS-0 and QoS-1 in each case. QoS-2 was excluded in test cases due to its large overhead. Table III represents different test case scenarios indicating that the system was able to accept 1000 concurrent MQTT clients publishing messages to a subscribed topic of the MQTT server.

Number of Clients	Throughput (kbps)		Latency (ms)		Packets Dropped (%)	
	QoS-0	QoS-1	QoS-0	QoS-1	QoS-0	QoS-1
1	2.0	2.6	37	38	0	0
10	3.6	3.9	66	78	0	0
100	3.5	4.9	70	74	0	0
1000	105.5	57.9	92	112	2.9	2.6
10000	124.3	101.5	126	135	3.1	3.8

Table III. MQTT Test Cases and Results

From the results as shown in Table III, it is evident that the overall latency for QoS-0 is always lower than that for QoS-1 irrespective of the number of concurrent client requests. This difference is expected because in QoS-0 message delivery is not acknowledged whereas in QoS- 1 acknowledgment for confirmed message reception is sent, which adds to the latency of message transmission in QoS-1. Also, the throughput for QoS-1 was observed to be higher than that for QoS-0 for any number of clients since QoS-1 offers a reliable means of communication due to message acknowledgement and persistent session (Fig. 8).

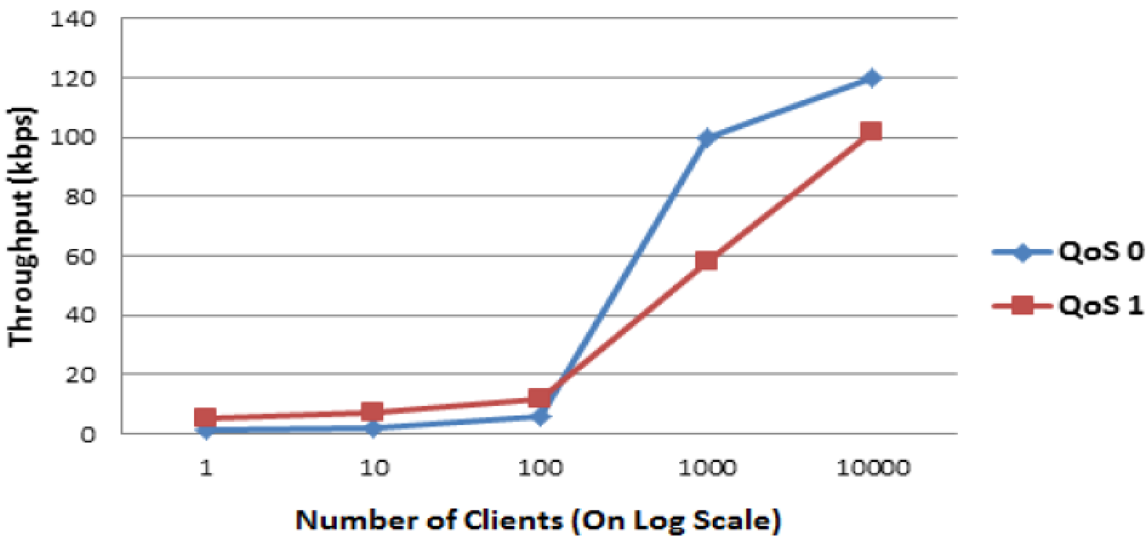

Figure 8. Throughput (kbps) Vs. Number of clients' graph

6.2 Scalability for Webserver

Many users were simulated concurrently using a Webserver Stress Tool. Each user in this test makes a request involving operational database. CPU and Network utilization were high when all requests started coming as shown in Fig. 9. Almost all requests were answered immediately up to 4000 users. Beyond 4000 users the communication was terminated due to data traffic congestion and testing tool limitation. Memory remained about 85database read and writes activity that runs asynchronously in the background.

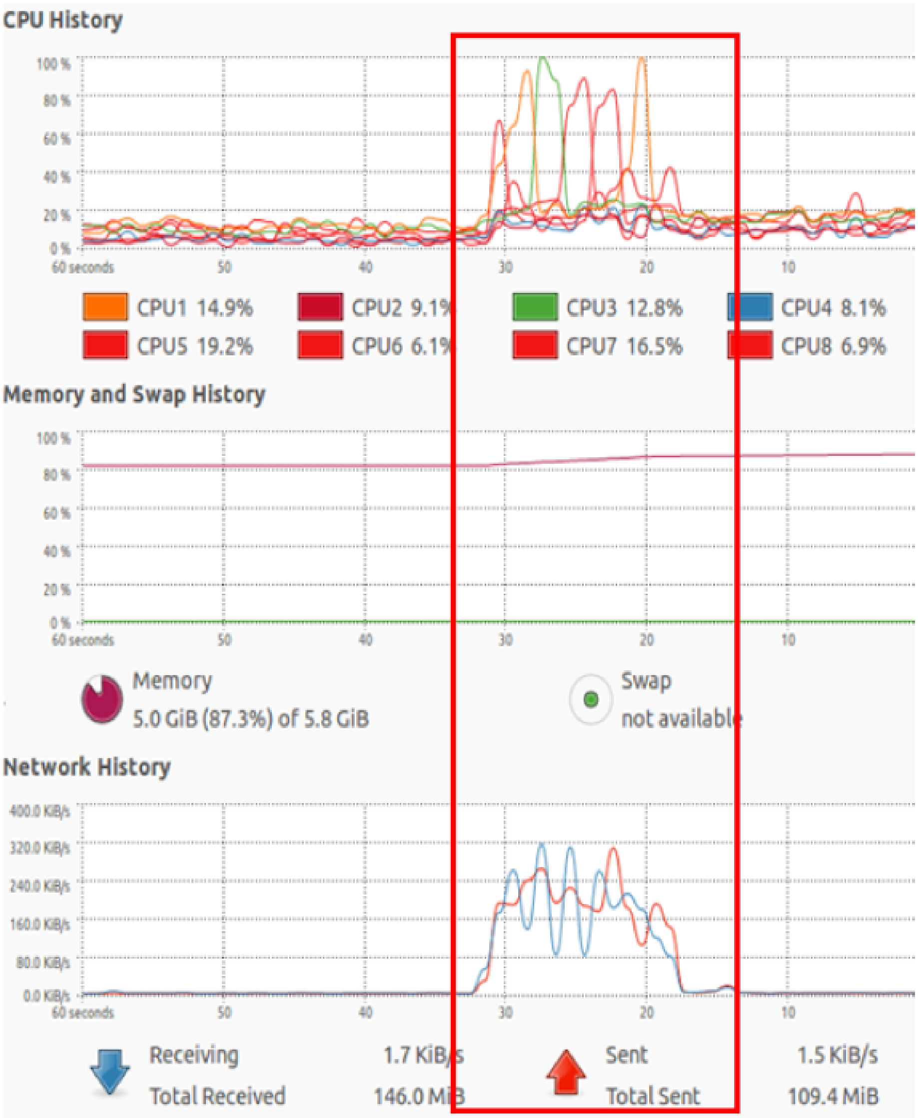

Figure 9. Server performance during request phase

6.3 Speed for Storage Server

The data server speed was acceptable up to 4000 concurrent users. This is again due to the data traffic congestion and testing tool limitation. The time lapse for querying up to 4000 concurrent requests involved storage server operations. Read operation was performed by the storage server using web services. Moreover, an ETL (Extract-Transform-Load) script was written to measure the time taken to read from storage server during peak time. 4000 files, each 62 Bytes in size, were extracted from the storage server for read operation. A summary of the response time to complete read and write operation by the storage server is shown in Table IV.

STORAGE SERVER READ AND WRITE
PERFORMANCE FOR 4000 CONCURRENT REQUESTS

Maximum response time	122.382	4.062
Average response time	065.925	3.771
Minimum response time	000.329	3.481

Table IV. Storage Server Performance

7 CONCLUSION

The proposed work is set to open new avenues for smart energy management on IoT and Big Data platform. The system design uses data analytics and scalable storage for building a smart EMS to aid different stakeholders with their respective privileges. The system empowers users to remotely monitor and control devices, and online bill generation via a friendly user interface mobile application

8 REFERENCES

[1] ”A.R. Al-Ali, I.A. Zualkernan, M. Rashid, R. Gupta, M. Alikarar, ”A smart home energy management system using IoT and big data analytics approach”,*IEEE Transactions on Consumer Electronics*, vol. 63, no. 4, pp. 426-434, 2017”

[2] “Design and implementation of building energy monitoring and management system based on wireless sensor networks,” *Tenth International Conference on Computer Engineering & Systems (ICCES)*, Cairo, 2015, pp. 230-233

[3] N. H. Nguyen, Q. T. Tran, J. M. Leger and T. P. Vuong, “A real-time control using wireless sensor network for intelligent energy management system in buildings,” *2010 IEEE Workshop on Environmental Energy and Structural Monitoring Systems, Taranto*, 2010, pp. 87-92.

[4] J. Byun, I. Hong, B. Kang and S. Park, “Implementation of an Adaptive Intelligent Home Energy Management System Using a Wireless Ad-Hoc and Sensor Network in Pervasive Environments,” *Proceedings of 20th International Conference on Computer Communications and Networks (ICCCN)*, Maui, HI, 2011, pp. 1-6.

[5] J. Han, C. s. Choi, W. k. Park, I. Lee and S. h. Kim, “Smart home energy management system including renewable energy based on ZigBee and PLC,” *IEEE Trans. Consumer Electron*, vol. 60, no. 2, pp. 198-202, May 2014.

[6] J. Wang, J. Huang, W. Chen, J. Liu and D. Xu, “Design of IoT-based energy efficiency management system for building ceramics production line,” *IEEE 11th Conference on Industrial Electronics and Applications (ICIEA)*, Hefei, 2016, pp. 912-917

[7] G. Mingming, S. Liangshan, H. Xiaowei and S. Qingwei, “The System of Wireless Smart House Based on GSM and ZigBee,” *International Conference on Intelligent Computation Technology and Automation*, Changsha, 2010, pp. 1017-1020.

[8] Serra, J., Pubill, D., Antonopoulos, A and Verikoukis, C. “Smart HVAC constraints”, *The Scientific World Journal*, 2014, pp 1-11.

[9] Fong, K. F., Hanby, V. I., and Chow, T. T. “HVAC system optimization for energy management by evolutionary programming,” Energy and Buildings, 38(3), 2006, 220-231.

[10] Tacklim Lee, Seonki Jeon, Dongjun Kang, Lee Won Park and Sehyun Park, "Design and implementation of intelligent HVAC system based on IoT and Bigdata platform," *IEEE International Conference on Consumer Electronics (ICCE)*, Las Vegas, NV, 2017, pp. 398-399.

[11] Y. T. Lee, W. H. Hsiao, C. M. Huang and S. C. T. Chou, "An integrated cloud-based smart home management system with community hierarchy," *IEEE Trans. Consumer Electron*, vol. 62, no. 1, pp. 1-9, Feb. 2016.

[12] E. Rodriguez-Diaz, J. C. Vasquez and J. M. Guerrero, "Intelligent DC Homes in Future Sustainable Energy Systems: When efficiency and intelligence work together," *IEEE Consumer Electron. Magazine*, vol. 5, no. 1, pp. 74-80, Jan. 2016.

[13] D. S. Kim, S. Y. Son and J. Lee, "Developments of the in-home display systems for residential energy monitoring," *IEEE Trans. Consumer Electron*, vol. 59, no. 3, pp. 492-498, August 2013.

[14] Y. S. Son, T. Pulkkinen, K. D. Moon and C. Kim, "Home energy management system based on power line communication," *IEEE Trans. Consumer Electron*, vol. 56, no. 3, pp. 1380-1386, Aug. 2010.

[15] N. Kushiro, S. Suzuki, M. Nakata, H. Takahara and M. Inoue, "Integrated residential gateway controller for home energy management system," in *IEEE Transactions on Consumer Electronics*, vol. 49, no. 3, pp. 629-636, Aug. 2003.

[16] M. Erol-Kantarci and H. T. Mouftah, "Wireless Sensor Networks for Cost-Efficient Residential Energy Management in the Smart Grid," in *IEEE Transactions on Smart Grid*, vol. 2, no. 2, pp. 314-325, June 2011.

[17] T. Fiedler and P. M. Mircea, "Energy management systems according to the ISO 50001 standard — Challenges and benefits," *International Conference on Applied and Theoretical Electricity (ICATE)*, Craiova, 2012, pp. 1-4.

[18] K. Dittawit and F. A. Aagesen, "Home energy management system for electricity cost savings and comfort preservation," *IEEE Fourth International Conference on Consumer Electronics Berlin (ICCEBerlin),* Berlin, 2014, pp. 309-313.