



Power Consumption Analysis in Smart Home Using Data Acquisition

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ABSTRACT: One of the major attribute of the Smart home automation and energy management systems integrate IOT and renewable energy resources at the consumption premises. With advancement of Automation technology, today's world prefers Automatic systems over manual systems. This paper presents the design, implementation and testing of an embedded system using arduino that integrates solar energy resources and energy management to a smart home incorporated with IOT. The proposed system provides and manages a smart home energy requirement by installing renewable energy and scheduling the power flow during peak and off-peak period. IOT (Internet of things) is the latest and emerging internet technology. 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 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. This paper presents an Energy Management System (EMS) for smart homes. In this system, 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. Since air conditioning contributes to 60% of electricity consumption in Arab Gulf countries, HVAC (Heating, Ventilation and Air Conditioning) Units have been taken as a case study to validate the proposed system. A prototype was built and tested in the lab to mimic small residential area HVAC systems.

KEYWORDS: Business Intelligence, Big Data Analytics, Energy Management System, HVAC, Internet of Things, MQTT, System on Chip.

I. INTRODUCTION

The Internet of Things (IOT) is the recent advancement in tele-communication that is the future, in which the devices of everyday life will be equipped with microcontrollers, transceivers for digital communication, and suitable protocol that will make them able to communicate with one another and with the users, becoming an integral part of the Internet. The IOT concept, aims in making the Internet more reliable and pervasive. Thus by enabling easy access and interaction with a wide variety of devices such as, for instance, home appliances, surveillance cameras, monitoring sensors, actuators, displays, vehicles, and so on, the IOT will help in the development of various applications that make use of the potentially enormous amount and variety of data generated by such objects to provide new services to citizens, companies, and public administrations.

This paper presents the design of home energy management system that integrates the power resources from the traditional grid and renewable energy sources namely; solar energy and storage energy. A single chip microcontroller is used to multiplex the three power sources to supply the house with its required power based on a communication between the utility and the house owner. In this regard, Low Cost Automation is a technology that promises to be very useful for any kind of manufacturing organization. With the advent of liberalization and globalization, it is necessary that industries explore methods of enhancing automation and productivity to acquire greater competitiveness. Therefore, from a system perspective, the realization of an IOT network, together with the required backend network services and devices, still lacks an established best practice because of its novelty and complexity. In addition to the



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technical difficulties, the adoption of the IOT paradigm is also hindered by the lack of a clear and widely accepted business model that can attract investments to promote the deployment of these technologies.

1.1 Background

Data analytics on this data using business intelligence (BI) platform [2] 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. In order to have an effective cost saving system, it is important to monitor and control the operation of residential loads depending on the aggregate power consumption over desired period, the peak power consumption, the effect of weather/atmospheric conditions and consumption slab rates.

This is where the combination of IoT technology, Big Data analytics and BI comes into play for implementing energy management solutions on a local and national scale. 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 paper 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. Energy management in the context of smart homes spans the three areas namely; Smart devices, Wireless Sensor Networks (WSN), and Home Energy Management System (HEMS). A HEMS requires a reliable communication network using WSN that can transport the consumption details and consumer load behavior periodically. In [3, 4, 5], 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 [6] 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.

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 in [7, 8]. Various studies have been steered in the application of IoT environment for HVAC control and scheduling methods to optimize HVAC energy consumption [9, 10, 11]. A hierarchical, smart-home service architecture employed with multiple in-home displays for user interfaces is described in [12]. In this research [12], 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 [12]. 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.

Authors in [13] emphasize on IoT based DC powered homes to develop a DC distribution system encompassing all residential DC-based loads that interact with each other. However, the lack of standardized protocols and regulations were the main challenges in considering intelligent DC powered homes as suitable replacement to AC power systems.



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Challenges could be overcome with IoT that will provide an integrated platform for DC powered technologies in efficient energy distribution.

Multiple in-home display systems (IHDs) and automatic meter reading systems (AMR) were discussed in the context of providing energy management information in [14]. 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. A proposed architecture of HEMS utilizing power line communication was addressed in [5]. 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. In [6], a residential gateway controller was developed with a central management system that generated an operation plan for all the connected nodes in a home network depending on weather conditions. The devices status and power consumption details were transported to the web server through an extensible markup language (XML) interface. Since XML files tend to be heavy weight for data delivery between browser and servers, the architecture will face significant bandwidth challenges in sending these large files across the network [16].

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 [1]. Data analytics on this data using business intelligence (BI) platform [2] 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. In order to have an effective cost saving system, it is important to monitor and control the operation of residential loads depending on the aggregate power consumption over desired period, the peak power consumption, the effect of weather/atmospheric conditions and consumption slab rates. This is where the combination of IoT technology, Big Data analytics and BI comes into play for implementing energy management solutions on a local and national scale. 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.

1.2 Motivation

The figure (1) shows the various advantages of the internet of things like the different methods for connecting our devices and appliance to the internet from any place anywhere in this world and integrating this connectivity with our home and the devices connected. IOT technology is the connection of various networks in embedded devices used in the everyday life integrated into the Internet. It aims to automate the operation of different domains such as home appliances, health care systems, security and surveillance systems, industrial systems, transportation systems, military systems, electrical systems, and many others. In order to achieve a fully automated process, devices in the different domains must be equipped with micro-controllers, transceivers, and protocols to facilitate and standardize their communication with each other and with external entities. Sensors, Global Positioning Systems (GPS), cameras, and Radio Frequency Identification Devices (RFID) are examples of devices that exist at perception layer. IoT systems use a combination of Internet and short-range networks based on the communicated parties. Short-range communication



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technologies such as Bluetooth and ZigBee are used to carry the information from perception devices to a nearby gateway. Other technologies such as Wi-Fi, 2G, 3G and 4G carry the information for long distances based on the application. These systems and appliances include sensors and actuators that monitor the environment and send surveillance data to a control unit at home. The control unit enables the householders to continuously monitor and fully control the electrical appliances. It also uses the surveillance data to predict future activities to be prepared in advance for a more convenient, comfortable, secure, and efficient living environment. Other applications of the smart community concept are in health care, managing shared resources, and enabling support social networking. The concept of a smart community is extended to develop a smart city. This difficulty has led to the proliferation of different and, sometimes, incompatible proposals for the practical realization of IoT systems. Therefore, from a systems view, the visualization of an IoT network, together with the required backend network services and devices, still lacks an established best practice because of its novelty and complexity. In addition to the technical difficulties, the adoption of the IoT paradigm is also hindered by the lack of a clear and widely accepted business model that can attract investments to promote the deployment of these technologies. In this complex situation, the application of the IoT to an urban context is of particular interest, as it responds to the data of many national governments to adopt ICT solutions in the management of public affairs, thus realizing the so-called Smart City concept. Although there is not yet a formal and widely accepted definition of “Smart City,” the final aim is to make a better use of the public resources, increasing the quality of the services offered to the citizens, while reducing the operational costs of the public administrations. This purpose can be done by the implementation of an IoT that will give a simple, and easy access to multiple platforms of public services. A multi-level IoT, may bring a number of benefits to the management and optimize the traditional public services, such as transport and parking, lighting, surveillance and maintenance of public areas, preservation of cultural heritage, garbage collection, hospitals, and school. Furthermore, the availability of different types of data, collected by Arduino with IoT, may also be exploited to increase the transparency and promote the actions of the home owners enhance the awareness of people about the status of their home, stimulate the active participation in the management of energy consumption, and also stimulate the creation of new services upon those provided by the IoT.

II. LITERATURE REVIEW

The design and implementation of a home monitoring system based on hybrid sensor networks. The system follows a three-layer architecture which combines hybrid-node networking with web access. An enhanced sensor node has been designed and fabricated to add controlled mobility to wireless sensor networks. The mobile node is capable of simple planar motions and is easy to be controlled through different user interfaces. A test bed including the static nodes as well as the mobile node has also been created for validating the basic functions of the proposed hybrid sensor network system. Network repair and event tracking capabilities of the mobile sensor node were tested. Stability of the proposed system in longtime home monitoring tasks was also verified.[3]

Then a WSN-based intelligent light control system for indoor environments. Wireless sensors are responsible for measuring current illuminations. Two kinds of lighting devices, namely, whole lighting and local lighting devices, are used to provide background and concentrated illuminations, respectively. Users may have various illumination requirements according to their activities and profiles. An illumination requirement is as the combination of background and concentrated illumination demands and users locations. We consider two requirement models, namely, binary satisfaction and continuous satisfaction models, and propose two decision algorithms to determine the proper illuminations of devices and to achieve the desired optimization goals. Then, a closed-loop device control algorithm is applied to adjust the illumination levels of lighting devices. [5]

A ZigBee Based Home Automation System This technology offers new and exciting opportunities to increase the connectivity of devices within the home for the purpose of home automation. Moreover, with the rapid expansion of the Internet, there is the added potential for the remote control and monitoring of such network enabled devices. However, the adoption of home automation systems has been slow. This paper identifies the reasons for this slow adoption and Evaluates the potential of ZigBee for addressing these problems through the design and implementation of a flexible

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home automation architecture. A ZigBee based home automation system and Wi-Fi network are integrated through a common home gateway. The home gateway provides network interoperability, a simple and flexible user interface, and remote access to the system. A dedicated virtual home is implemented to cater for the system's security and safety needs. To demonstrate the feasibility and effectiveness of the proposed system, four devices, a light switch, radiator valve, safety sensor and ZigBee remote control have been developed and evaluated with the home automation system.[6]

The home energy control system design that provides intelligent services for users and demonstrate its implementation using a real testbed. This paper designs smart home device descriptions and standard practices for demand response and load management "Smart Energy" applications needed in a smart energy based residential or light commercial environment. The control application domains included in this initial version are sensing device control, pricing and demand response and load control applications. This paper introduces smart home interfaces and device definitions to allow interoperability among ZigBee devices produced by various manufacturers of electrical equipment, meters, and smart energy enabling products. [8]

A ZigBee-based wireless sensor network node for the ultraviolet (UV) detection of flame. The sensor node is composed of a ZnSSe UV photodetector, a current-sensitive front end including a high-gain current-to-voltage amplifier with 120 dB and a logarithm converter, and a transceiver operated at a 2.4-GHz industrial, scientific, and medical band. A passive photodetector is designed to have a cutoff at 360 nm and convert the UV emission of flame into picoamperes. Including mixed signal processing and ZigBee transmission, the speed of flame detection is as fast as 70 ms. The sensor node consumes only an average of 2.3 mW from a 3.3-V supply. The performance of a prototype sensor node was verified when the luminous flame was imaged onto the sensor node with different angles ranging from -30° to 30° and distances of 0.1, 0.2, and 0.3 m enabling effective fire safety applications. [17]

III. PROBLEM STATEMENT

In existing system each home device is not 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 so its create a less privacy and security Also in existing approach the data acquisition System on Chip (SoC) module is not able to collect energy consumption data from each device of each smart home and transmits the data to a centralized server for further processing and analysis that's why this information from all residential Areas is not accumulates in the utility's server as Big Data so it was gives a less optimal solution.

IV. REPORT OF THE PRESENT INVESTIGATION

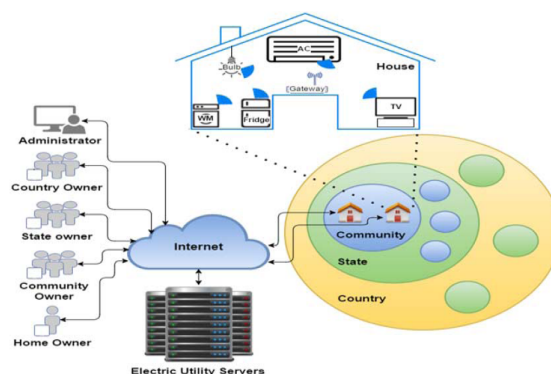


Fig. 1. Proposed System Architecture



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Explanation-

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.

2) High-end Microcontroller

A SoC high end microcontroller is used as edge device data acquisition module that manages the HVAC unit . 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.

3) Servers

In the proposed 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.

B. Software Architecture

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

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.

2) Middleware Module

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

i. 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. On the broker side access control was enforced to prevent unauthorized access to certain topics. Some topics such as consumption reporting topic and device state change reporting topic is configured as write only. Only those with required privilege can read what is being published. Topics like control command is configured as read only, so that unauthorized controlling of device is prevented.

ii. Storage Server

A highly scalable storage server is used as data warehouse for storing the edge devices' sensor data and user information [1]. It can handle the generated Big Data from residential units as well as scale up to more residential areas that can be added in future. A high performance and scalable database is required to store information related to users, user-house relations and house-device relations. Operational database that runs on top of existing scalable storage server was chosen .

iii. Analytics Engine server

An off-the-shelf business intelligence software tool was utilized to make smart decisions from the received big data [2]. 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. Moreover, benchmarking feature allows users to compare their consumption details with those with similar setups Accordingly, home owner can turn ON/OFF the device based on such information if needed. In addition to that, the tool can empower local utility and regional utility to see the energy consumption pattern according to their respective privileges. For example: a local residential utility center can view each individual houses' aggregate consumption within its geographical area. A state utility center can view the aggregated consumption of each residential area in the state. The centralized Utility center can view each state's consumption pattern. These reports and graphs will be rendered to the client application through the web server.

iv. Webservice



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The client application accesses the operational database through different web services implemented using JavaScript [4]. 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. HTTPS protocol is used to design web services to encrypt the traffic flow.

3) Client Application Module

A cross-platform IDE was used to develop the front end mobile user interface [5]. The advantage of using such an environment is that it utilizes standard web development languages. It also ensures the cross-platform feature for application which means that only one application is developed for different mobile phone platforms without the need for reimplementing. 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. 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. Based on the above system requirements, the proposed system's hardware and software architecture are as follows:

A. Hardware Architecture

As shown in Fig. 1, the hardware architecture of the system comprises of the following building blocks:

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

V. RESULTS & DISCUSSIONS

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:

A. 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 [26]. As mentioned in the previous section, the microcontroller [2] 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. The data is framed in a lightweight format [2] compatible with MQTT server. This framed data is attached with the user, house and device details as shown in Fig. 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. shows the prototype that was built in the lab to mimic the proposed system.

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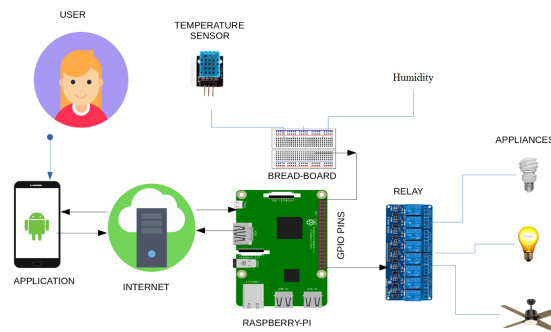


Fig. 2. Hardware Components

B. 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 setting optimal energy management goals and policies. The business intelligence software tool serves as an optimum platform for benchmarking real time data and generating user interactive charts and reports [2]. Different benchmarking scenarios are deemed for the four stakeholder levels as mentioned in the previous section. For example, a stakeholder like home owner in a residential area is 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. The home owners can use benchmarking service to compare their power consumption with other housing units that have a similar setup. 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. It's worth mentioning that the same chart can be obtained on a daily or monthly basis.

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. The Country stakeholders at a Centralized Utility Center are the highest level authority in the stakeholder hierarchy. These owners can view annual power consumption of each state in a country. The aggregated energy consumption can be compared to the overall energy generation from the central power generation station. This can assist the state to plan and implement data driven energy strategies and decisions. Additionally, the country owners can check online the temperature, humidity and power consumption variation across different states using the Geo-Map service. They can inspect power consumption of states based on consumption slab rates using an Energy map as shown in Fig.

2) Client Application

A cross-platform application is developed that gives 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. and second is remote

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control services (ON/OFF) for house devices as shown in Fig. For the bill tracking service, the user can view the monthly bill and pay the due amount online as shown in Fig.

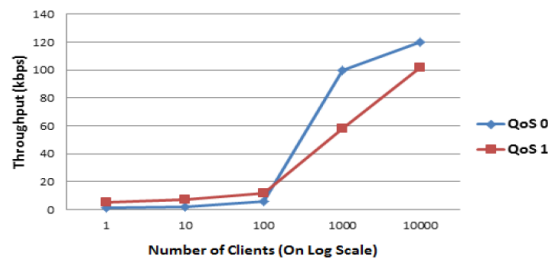


Fig. 3. Throughput (kbps) Vs. Number of clients' graph

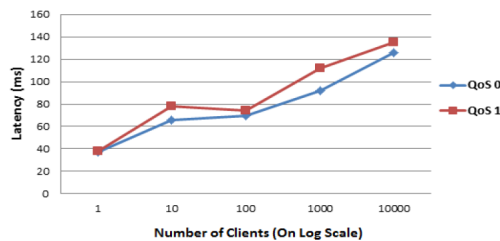


Fig. 4. Latency (ms) Vs. Number of clients' graph

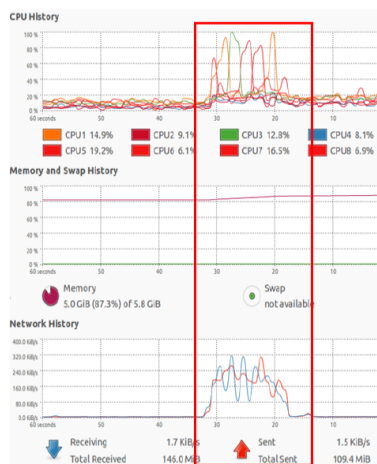


Fig. 5. Server performance during request phase

VI. 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.



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