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A generic internet of things architecture for controlling electrical energy consumption in smart homes

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ABSTRACT

The Internet of Things (IoT) is progressively developing since it was first introduced at the beginning of the 21 st century. The IoT becomes more prominent due to the enormous data generated by the IoT devices called the Big Data. Further, the application of Big Data is widely adopted in many areas such as smart home and city planning, efficient system design, etc. However, during the developing stages of IoT, the researchers have many challenges that need to be addressed before standardizing IoT for general use. These challenges include co-existences of many communication technologies such as Bluetooth, ZigBee, WIFI, and so on. The effect of such technologies on the communication becomes more when these technologies exist in shot communication range. Similarly, other challenges include processing of huge amount of data generated by the IoT devices in real-time. Therefore, in order to address these challenges, we come up with a proposed scheme that enable a generic communication architecture among the IoT devices with less interference. Further, the proposed architecture consists of four main steps i.e. 1) a system to discover and identify electrical appliances in a smart home or smart building, 2) deployment of sensors, 3) applying proposed load balancing on appliances and sensors, and 4) processing the data obtained from these sensors for better usage of home and electrical appliances. The proposed scheme is tested on real electronic appliances and the energy consumption is recorded using the proposed Electronic Device Sleep Scheduling Algorithm (EDSA). Furthermore, the EDSA is responsible for controlling the activities of the sensors while it is active, sleep, and idle modes. The results show that the proposed architecture perform better in a heterogeneous environment compare to simple Wireless Sensor Network (WSN) based technologies. The data is also processed using Hadoop Ecosystem is to maximize the efficiency and minimize the time required to process the data in real-time.

1. Introduction

Internet of Things (IoT) notion has been revolutionized with the unceasing development of heterogeneous communication technologies. In late 2000, IoT term was initially coined by two students who worked on Radio Frequency Identifiers (RFID) at MIT. Thereafter, IoT concept has been widely used to connect various embedded devices. IoT environments incorporate both short and long-range communication technologies along with advanced protocols and algorithms. Real-time data processing facilitates data transmission between an end user and a sensor attached to an embedded device. With the maturation, IoT notion has been evolved and extended to various others fields such as Internet of Every Things (IoET), Internet of Social Things (IoST), Internet of Vehicle Things (IoVT), fog for everything etc. (Baccarelli, Naranjo, Scarpiniti, Shojafar, & Abawajy, 2017; Lin et al., 2017). These innovative concepts assist in identifying domain specific technologies, protocols, and privacy data of special purpose IoT environments. Moreover, classification of enormous amount of data incorporates many other fields such as cognitive radio networks, software-defined networking, etc. The utmost goal of IoT is to expedite services provision to

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end users via the connected network with minimal overhead and congestion. Such that, a simple and user friendly IoT environment can improve the Quality of Life (QoL) of human beings. For an instance, consider a scenario where the user wants to wash clothes with aid of IoT. Accordingly, the machine at home and the user are connected via internet and user could send control commands to the machine via the internet. Lighting control, other domestic appliance controlling is also facilitated through IoT applications. The IoT applications specifically designed for home management and appliance controlling are known as smart home applications. Smart smart parking, smart health management, smart traffic and vehicular communications, etc. are some other extended applications of IoT. Furthermore, novel technologies such Information-Centric Networking (ICN), Name Data Networks (NDN), and Wireless Sensor Network (WSN) based data dissemination, etc. were evolved consequent to IoT advancements (Bari, Chowdhury, Ahmed, Boutaba, & Mathieu, 2012; Bouk, Ahmed, Kim, & Song, 2017; Gou, Zhang, Bian, Zhang, & Xie, 2016; Shojafar, Cordeschi, & Baccarelli, 2016; Silva, Khan, & Han, 2017). Existing literature reports further describe many other technologies that incorporate IoT.

Nevertheless, according to state-of-the-art, IoT encounter with various issues and challenges. Real-time processing of colossal data amounts generated by innumerable IoT devices has been identified as a major issue for IoT applications (Jabbar, Khan, Silva, & Han, 2016; Xia, Wang, Bekele, & Liu, 2017). Efficient data acquisition, data dissemination, device controlling over existing networks are some other key concerns in IoT field of study (Barker, Irwin, & Shenoy, 2017; Daneels et al., 2017; Khan, Silva, & Han, 2017). In fact, current works related to IoT lack the credibility, which standardize that IoT based infrastructures i.e. smart homes, cities, grid, etc. are appropriately fulfilling the current demands, while fulfilling existing issues. Data transmission from IoT devices exploit an intermediate layer comprises o heterogeneous communication technologies that is further extended to connect with an application layer. Facilitating inter- communication among these layers is another issue yet to be addressed, in order to provide efficient data transfer. Hence, poor cross-layer communication facility, offline data processing, seamless data transfer among mobile devices can be identified as the key issues with current layered IoT architectures (Amadeo et al., 2016; Zhang, Duan, Sun, Cheng, & Chen, 2017). Battery operated short-range communication technologies is another common problem. In addition, the short-range communication technologies need much assistance as it is mainly operated on batteries. Thus, a communication overhead or other problem can consume much battery during peak hour time which can make it imperative to improve energy efficiency and increase the lifetime of an IoT device with limited battery capacity. Moreover, unique addressing space for IoT devices can further improve data transferring in a local IoT environment. For example, distinguishable names E.g. IoT enable device could be helpful to discriminate the specific sensor from other WSN based sensors. Standard naming can be promoted with standard IoT communication protocol designing, however standard bodies i.e. IEEE, ACM, and Microsoft should take the first step towards IoT standardization (Gazis, 2017; Kim, Lee, & Jeong, 2017).

Experts in both industry and academia have taken immense interest on addressing afore stated issues and challenges. The European Communication Council (ECC) presented an IoT technology standard in 2007 Nevertheless, stated standard is still under refining phase to amend and revise before releasing for public use. Many other technological firms and institutions came up with various methodologies to incorporate IoT in homes, cities, hospitals, grids, and many more fields. The US National Intelligence Council (NIC) claims that not only electronic devices, but also food items and furniture will be connected with IoT by 2025. IoT device data collection is extensively studied during the last decade and many approaches including clustering approach and service approach were proposed to enhance data gathering efficiency (Ju & Zhang, 2017; Luong et al., 2016; Maiti, Sahoo, Turuk, & Satpathy, 2017). Aforementioned protocols are capable gathering various data according to the site of deployment E.g. sensors placed on roadside count the number of cars passing by and immediately transfer gathered data to notify drivers about real-time road congestion level. Hadoop, SPARK, and GRAPHX are used to manage real-time processing of gathered Big Data. Nonetheless, real-time dissemination of reliable and accurate data to citizens is still being a major concern. Subsequently, new fields of study such as ICN and NDN were emerged to address the said problem, even though it has not favored fully for data distribution among heterogeneous networks (Trihinas, Pallis, & Dikaiakos, 2017). A home automation system optimizes real-time energy consumption, with aid of management station, which gathers data from home appliances has been proposed in (Liu, Liu, & Wang, 2014). The proposed work is designed for both single-user scenario and multi-user scenario. A game theory based scheduling mechanism addresses the electricity pricing and consumption with aid of dynamic programming. Another scheme similar to the previous work has further incorporated sunlight to optimize energy consumption of domestic light sources (Li & Lin, 2015). This work divides a room into certain areas corresponding to time of the day and maneuver the light source accordingly. Even though many works have been conducted on various IoT domains, they do not fully address the challenges in a generalizable manner.

Hence, here in we propose a scheme that addresses existing challenges in a generic manner by deploying sensors in an IoT setting, in order to share data in real-time. The proposed work incorporates sensor sensors networks, ICN, NDN, and big data analytics. This work is further evaluated with a smart home scenario and a smart city scenario that utilizes Hadoop, SPARK, and GRAPHX for data analysis. Authenticated data sources were tested for real-time data distribution that enforces betterment of service selection and service provision. The sensor deployment phase deploys sensors on specific locations and gathered data from heterogeneous IoT enabled devices. Subsequently, gathered data are passed towards the Hadoop eco system. Upon completion of data processing, processed data are transferred to the application layer, in order to be used by corresponding users and services. The proposed work tested results of smart homes, smart parking, and smart environmental management departments. As revealed by the results, the proposed work is capable of processing data in real-time in order to enhance the service efficiency offered to citizens.

The rest of the paper is further divided into following sections. Section 2 explains the current and existing literature about IoT based smart homes and cities. The proposed scheme is explained in Section 3 following by results and discussion in Section 4. Finally, the paper is concluded in Section 5.

2. Related work

In view of the fact that, M2M and IoT play a significant part in facilitating communication between different appliances in a smart home, thus a number of proposal have been given based on these technologies (Collotta & Pau, 2015). For instance, to resourcefully manage the home resources, resource-aware management systems are proposed for smart home (Liu et al., 2014; Rani et al., 2015). In these proposals, the authors proposed smart schedulers for energy consumption of appliances. In addition, particular algorithms are designed based on dynamic programming to control and manage smart home activities. However, the complexity is increased extensively by adding additional units to these systems. Therefore, it is better to stay focused on the WSN-based technologies for power consumption, instead of wasting on such smart home design that needs high changes in the existing architectures. Furthermore, integration of WSN and functionality of self-management extensively assist in dropping the needless voltage consumption of the appliances. Energy Communication Unit (ECU) is designed to keep record of the consumption measurements of the household devices (Han, Choi, Park, Lee, & Kim, 2014). Further, a ZigBee-based model is designed to transmit power, energy, current, and voltage used by devices. Similarly, Home Energy Management (HEM) system is designed for energy consumption using a particular TLV (threshold limit value) in peak hours. The HEM trail a consumer practice to attain high consumer comfort level. In (Shirazi, Zakariazadeh, & Jadid, 2015), scheduling technique is presented in which the energy of a variety of renewable energy sources is calculated. A number of organizations examining the smart home systems e.g., the Apple designed a home kit, and the Amazon gives a solution from scheming to operating a smart home (Apple, 2016; Room, 2016). Similarly, the Qualcomm presents different services of smart home to enhance the smart home communications architecture (Qualcomm, 2016).

Low power communication is a vital factor for any IoT system. In order to cater this demand, IEEE802.15.4 presents a complete physical layer architecture for short-range communication requirements. Accordingly, we can claim that IoT aims to enable direct communication between two objects deployed in a low coverage area. Network Interface Card (NIC) is liable for many tasks including the conversion from digital to analog or electromagnetic. Digital bytes are converted to analog streams using modulation techniques. Since analog signals are less powerful, NIC antenna cannot transfer them directly. Hence, analog signals are converted to high power signals for better air transmission. Signals from NIC are received at the amplifier and then forwarded towards the antenna. Throughout the process of converting and sending, signals are vulnerable for many challenges i.e., noise, riding, and volatizing. Currently, low noise amplifiers are used, in order to create strengthened signals that are manageable with demodulators. The radio interfaces receive weak signals ranging from 80 dB m to 90 dB m. Noise amplifier, demodulator, and modulator are the elements with highest energy consumption. Hence, designing an IoT infrastructure that enforce lowest energy for radio communication is essential. In order to overcome power consumption issues, schedulable automated radio facility was introduced for IoT enabled Devices (IoTED). While keeping in mind about the power consumption demands, scheduling mechanisms were integrated to IoTED. In the recent past, number of scheduling schemes and mechanisms were proposed to reduce the round trip of IoTEDs. Schemes incorporated priority queue model is claimed to have round trip lower than 1% as reported in (Leu, Chen, & Hsu, 2013). IoT agents were introduced to manage scheduling among IoT clients and devices, since determining the cyclic duration is tedious and depends on the device. M/M/1 queue method facilitates traffic flow without any noise among the participant devices. Moreover, traffic flow categorization was proposed considering messages. Further, this work described on how to use traffic methodologies to manage and process request time, as performance degradation due to queue congestion could be a potential challenge result from random device requests. A similar work based on the concept radio round-trip was proposed in (Palattella et al., 2013).

Global IoT device vendors should adhere with a universal standard, while designing and manufacturing light weight, energy constrained, and comparatively smaller devices. Accordingly, various IoT devices were designed considering constrained energy demands and dimensions, in order to facilitate future IoT service demands. In IEEE802.15.4, several states were defined for IoTED namely, idle, receiving, sleep, awake, transmitting, etc. Many research conducted on IEEE 802.15.4, aimed to serve betterment of energy consumption as well as energy conservation. When the node is in listening state, transceiver listens to available channels and notify them to the node, so that they can start transmission. Once the node is in the idle state, though the transceiver is in awake state the node interface is unable to process any data received or requested via the channel. Both data sending and data receiving take place in the active state. Accordingly, many works claimed that round trip can be minimized by idling the radio interface. Energy management of IoT devices and operational optimization has become an active research area during past few years. Reducing a node's duty cycle can be explained with an example as below. Assume a node contains 3000 mA h battery and an LTC5800 radio consumes 10 mA for data receiving When the radio is turned on permanently, battery life time will be 3000/10 = 300 h (roughly 12.5 days) with 100% duty cycle. However, if the duty cycle is reduced to 1%, battery lifetime will be extended up to 1217 days. Power consumption constraints of IEEE 802.15.4 have been elaborated in the upgraded IEEE 802.15.4e model by introducing MAC layer and direct communication protocol for the interface. The operation scenario of IEEE 802.15.4e can be simulated using Bluetooth v3.0 (master-slave communication) and Bluetooth v4.0 (node intercommunication). Owing to wireless network characteristics, stable and noise free connection cannot be guaranteed, since signals are prone to external noise, jitter, and acknowledgement delays. As a result, single channel performance degrades over the network. Synchronization ensures communication establishment among devices. Frame method and acknowledgment method are used to perform synchronization. The receiver computes the frame difference of sending and receiving frames in acknowledgement based synchronization. While in the case of frame synchronization process, the receiver calculates the time difference between arrival and actual arrival time. The upgraded IEEE 802.15.4e model does not require any hardware modifications. Exploiting the benefits of reduced duty cycle, IEEE 802.15.4e model reduce the energy consumption significantly. Incorporating time based synchronized channel hopping technique named TSCH plays a major role in duty cycle synchronization. The prior version used time synchronized mesh protocol (TSMP) until 2006. TSMP is adopted for Wireless HART (Zand & Shiva, 2008) because of its substantial success in varies products. The ultimate goal of IEEE 802.15.4e is to manage node's energy consumption by synchronizing the duty cycle with TCSH, while improving the reliability. As the synchronization process is ended, each node is labeled with time slots and channel offsets (Mehta, Kerkez, Glaser, & Pister, 2012). The same nodes information (slots and channel slots) are used to communicate with neighbors.

Enhanced scheduling methods are another significant feature of MAC layer in IEEE802.15.4e Scheduling should be handled with care, since if a node expect to communicate with another node, intended recipients should be in listening state. In order to serve scheduling, IEEE 802.15.4e provides centralized and distributed scheduling. A single node appointed as the manager is responsible for maintaining, controlling, and distributing schedules in centralized scheduling. In distributed scheduling, nodes are freely scheduled by considering link establishment among nodes. Another similar work based on link capacity has been proposed in (Tinka, Watteyne, & Pister, 2010). Moreover, the authors referred to Aloha-based scheduling model that utilize broadcasting advertisement to allocate nodes to channels. Moreover, the reservation-based scheduling is dedicatedly used to hold timeslots for target advertisement. Many QoS aware scheduling algorithms were proposed for IoT environments (Li, Li, & Zhao, 2014). However, a majority of these algorithms have considered generic network environment. For instance, in (Li et al., 2014), the author alters the existing layering structure with QoS-aware layering structure. Likewise, the authors introduced a scheduling algorithm in (Leu et al., 2013) while the mentioned proposed scheme is notably upgraded. When defining a generalizable scheduling mechanism afore stated constrained should be addressed, in order to upgrade the performance.

To conclude, the above literature exposes several vital challenges that require to be tackled. For instance, the majority of the energy management systems function in an explicit environment, co-existence of diverse technologies, the prescriptions in the accessible infrastructure, etc. Finally, we recognize the requirement for a well-organized, competent, and an efficient IoT-based smart homes communication model.

3. Proposed IoT architecture

The proposed scheme operates in two parts. In the first part, all the appliances currently available in the ON state or frequently remains in the ON state is dicovered. In the second phase, the proposed load balancing and switching mechansim is applied to efficiently balance the load among the appliances available in the ON state.

3.1. Overview of the proposed system

The IoT technologies enables multi-vendor, public and private firms, etc. to come up and design electronic and IoT enabled devices with a common standard and protocols. However, still there many challenges exist to come up with such standards and protocols such as different hardware architecture, communication technologies, and security concerns and so on. These issues can be somehow addressed and solve using a common sensor technologies, protocols, and standard. One of the reason of targeting and using a common sensor technologies and standards is that IoT mainly depending on WSN. However, using heterogeneous and an enormous number of sensor devices consumes high energy because the WSN devices are mainly battery operated. Therefore, we proposes a scheduling mechanism to schedule the sensor devices for better energy consumption. A sensor is kept in the sleep mode, whenever it is not performing any operation or the sensor is not functional. Similarly, the deployment of sensors in a smart home is designed in a way that the sensors far-away from the management station is attached to coordinator sensor node which collects the information from the sensors and send it to the management station. In addition to data processing, coordinators communicate with control server and send commands to sensors. The control server hosts a web service that performs automatic actions and records all the actions performed on each sensor. The sensor deployment, data collection, communication, data processing, and other similar activities in the proposed scheme is shown in Fig. 1.

3.2. Identification of switched-on appliances

In this phase, all the appliances in ON state is identified along with the monitoring of user presence and absence. Let assume a scenario, where a user is present in a one room and there is a television in ON state in the other room. Similarly, a user left for his workplace, however, he forget to switch-OFF the air-conditioning system of his room or house. Further, children always randomly switching-ON and OFF devices and sometimes they forget to switch-OFF a device which is running unnecessarily. Henceforth, we organized the electronic appliances in smart home environment based on user presence or absence. This organization and distribution of various appliances in a smart home scenario is shown in Table 1.

The electronic appliances mentioned in Table 1 is mostly available in the smart home environments. The proposed system is built based on these electronic devices, however, other common electronic appliances such as Refrigerator, Air-Conditioning system, etc. can be used handle with the proposed load balancing and scheduling scheme. In short, the proposed scheme is built for generic home appliances that can be used with heterogeneous devices.

Table 1
Appliances Categorization.

User Status	Usage Time	Appliances
High	User Choice	Television, light bulb, etc.
Medium	Partially user dependent	Hair Dryer, Scanner, etc.
Low	Automatic	Washing machine, rice cooker, etc.
Needless	Less dependent on User Actions	Street lights, microwave Owen, etc.

3.3. Sensor deployment

A smart and IoT environment is mainly dependent on the efficient deployment of the sensors nodes. However, uniform distribution of the sensors can be done with the help of statistical distribution models such as Poisson, etc. Therefore, we used Poisson distribution statistical model to deploy sensors in a smart home scenario. Moreover, the proposed system offers two type sensor nodes i.e. 1) One that are far away from the management station represented with F_R, 2) Relay nodes (R_S) that are used as bridge between F_R and Management Station (MS) Both of these two types of sensors are responsible for the communication between user, sensor and MS. The MS is the centralized system used to control different activities of sensors and the electronic appliances such switching a sensor into sleep mode, switch off an electronic appliance when the user is not available in the scenario, and so on. The MS is also connected with a web server where most of the activities of a smart home is presented in visualized and graphical format to the user. The use can also access an electronic appliance using the web services of the concerned location of an electronic appliance in a smart home. Further, the sensor are used to enable various commands on the electronic appliances such as switching OFF and ON a device, putting an electronic appliance into sleep mode and so on. The information from FN moves across various hops before reaching to the MS. Therefore, we adopted a multi-hop technology to enable the communication between F_N and MC. The working operation of R_S, F_N, and MC is illustrated in Fig. 2.

3.4. Event management and scheduling

As we know, a sensor consume much energy in transferring and receiving data. Thus, in the proposed scheme the R_N is always busy in receiving and transferring the data to and from the sensors. In order to address a similar scenario, a scheduling scheme called Electronic Device Sleep Scheduling Algorithm (EDSA) is proposed. The EDSA is

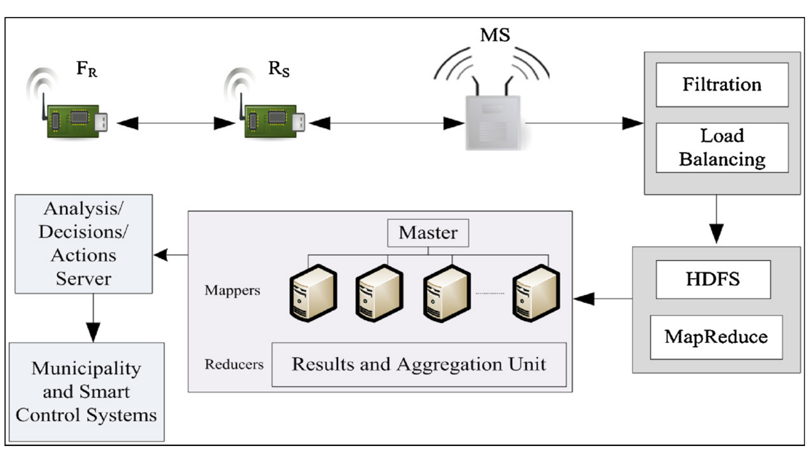

Fig. 1. Communication of F_R and R_S with MS.

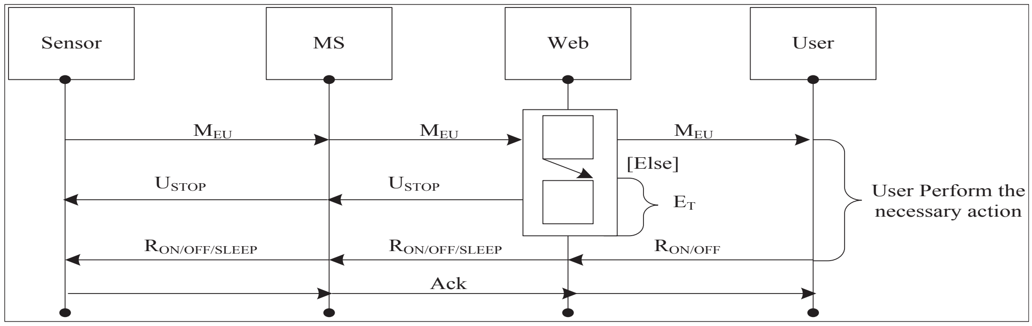

Fig. 2. Operation of EDSA algorithm.

responsible for controlling the activities of the sensors while it is active, sleep, and idle modes. The EDSA is used to combine various sensors based on the distance from the MC into various groups. For example, the sensors available in a room is grouped together to form an efficient network which further improves the life time of the sensors. The user can control the activities of an electronic appliance based on a proposed Event Management System (EMS). The EMS is responsible for providing a web interface to the users of a smart home to send a message (M_{EU}) to an electronic appliance to either switch OFF or ON a particular device. The M_{EU} contains the sensor ID (S_{ID}) and the electronic device ID (E_{ID}) and a command such as switched off or on the device. Similarly, the user can also schedule the activity of the operation of an appliance by using an ON Time (T_{ON}) variable to enable ($R_{ON/OFF}$) the device in that particular time.

The use can also perform a sleep operation (R_{SLEEP}) on a sensor which is currently in idle state for a long time. Similarly, an automatic message (A_R) is sent to a respective sensor whenever a sensor is unable to respond to the user action or it is getting late in taking an action from the user. However, if the message from the user arrives with delay, the MS sends a message called USTOP to the sensor to override the automatic message sent from the web interface. As the E_T expires, the corresponding sensor is switched-OFF or put into sleep mode by the A_R. Similarly, a confirmation message is distributed among the MS, user and web after performing a necessary action. The EDSA mechanism is illustrated in Fig. 2.

3.5. Data collection and processing

The sensors are programmed to collect two different type of information from each home appliance such as 1) the ID of the device called the E_{ID} and 2) the time the device is turned on T_{ON}. It is also programmed on the sensors to hold the information for a period of time represented with T_S. However, if the device is remained in turned ON state after T_S time, the sensor generates a message and send it to the MS. Similarly, the sensor waits for time W_T until it gets a response from a user or MS. Once the sensor gets the response message from the MS, it deletes the stored information and release the memory for the further information and data. It also perform necessary action based on the response message such as switching-OFF the respective sensor, etc.

The data collected at sensors is then transferred to a central data management system based on Hadoop Ecosystem alongside SPARK functionalities for real-time data processing. The data collected at sensors is first sent to the MC for initially processing and saving at local database and operations such as redundant data removal etc. Similarly, the refined data after MC is sent through intermediate system for further processing to the Hadoop ecosystem. The Hadoop ecosystem first divide the data into two forms i.e. 1) Real-time data and 2) offline data. This division of data is made based on the request from the user. If a user request to check the current consumption of electricity of the entire home, the user need to send a message requesting the electricity consumption of the home. Further, the Hadoop ecosystem shifts the task of real-time data to the SPARK system and the offline data is processed by the Hadoop ecosystem. The processing of the data using the Hadoop ecosystem is shown in Fig. 1. Hadoop by default handle a limited number of packets at once. However, we introduces the concept of data loading to the Hadoop Distributed File System (HDFS). The data is uniformly distributed among the HDFS system using a replica techniques. Moreover, the Hadoop system operates and process the data using multiple clusters. However, defining a fair number of jobs on Hadoop ecosystem is still a challenging job. The current literature consists of many schemes that distributes the jobs among the available clusters. However, there is still need of an efficient system to load the data to HDFS and then to Hadoop central processing system. Further, it is necessary to divide the incoming jobs to the Hadoop system into sub jobs in order to gain high efficiency. However, after a number of jobs loaded into Hadoop for processing cannot be changed at runtime. Therefore, we come up with a system to handle and divide new jobs among the available clusters at runtime is addressed using a dynamic scheduling mechanism. The job switching among the available clusters is handled in real-time based on the current load on a cluster, CPU utilization, and memory requirements. However, in a typical Hadoop architecture it is not possible to shift a job in real-time. Therefore, the Hadoop ecosystem becomes unstable due to high performance node remains in idle state most of the time and low performance node remains in busy state. This imbalance operation of low and high performance nodes greatly affect the performance of the Hadoop ecosystem. The proposed system monitors the Hadoop ecosystem in real-time and assign jobs at runtime to a cluster when its capacity drops below 70%. Considering this approach, the system greatly minimizes the effect on the Hadoop ecosystem and improving the efficiency. The results from Hadoop ecosystem is then transferred to the connected web server. Whenever, the energy consumption of a home, office, and building passes over the predefined threshold, a notification message is sent to the concern user.

4. Results and data analysis

A smart home architecture along with sensors, relay nodes, MS, and a web server is simulated. The MS is installed on Core i3 CPU 3.60 GHz computer. The RMS and web server is placed on a separate computer with windows server 2008 operating system. Similarly, the Hadoop ecosystem is installed on Ubuntu 16.04 system with multi-cluster support system. However, all these systems are integrated with each other by connecting the systems on the same lab. In order to check the devices/appliances discovery time, the sensors attached with each appliance is placed on separate LAN. The relay node is designed in a way that is based on a Full-Function Device (FFD) which serves as the relay of a personal area network. The rest of the nodes are following a Reduced-Function Devices (RFD) that requires as low resources and communication requirements. The proposed system follows a star topology architecture with one FDD node in each room and kitchen attached with multiple RFDs. The IEEE 802.15.4 does not have the capabilities

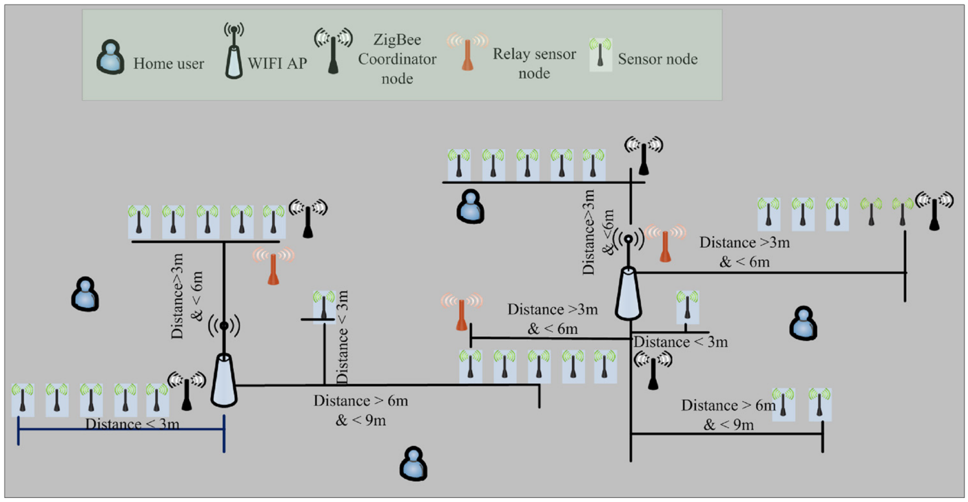

Fig. 3. Simulation scenario (tested in Real-time and Simulation).

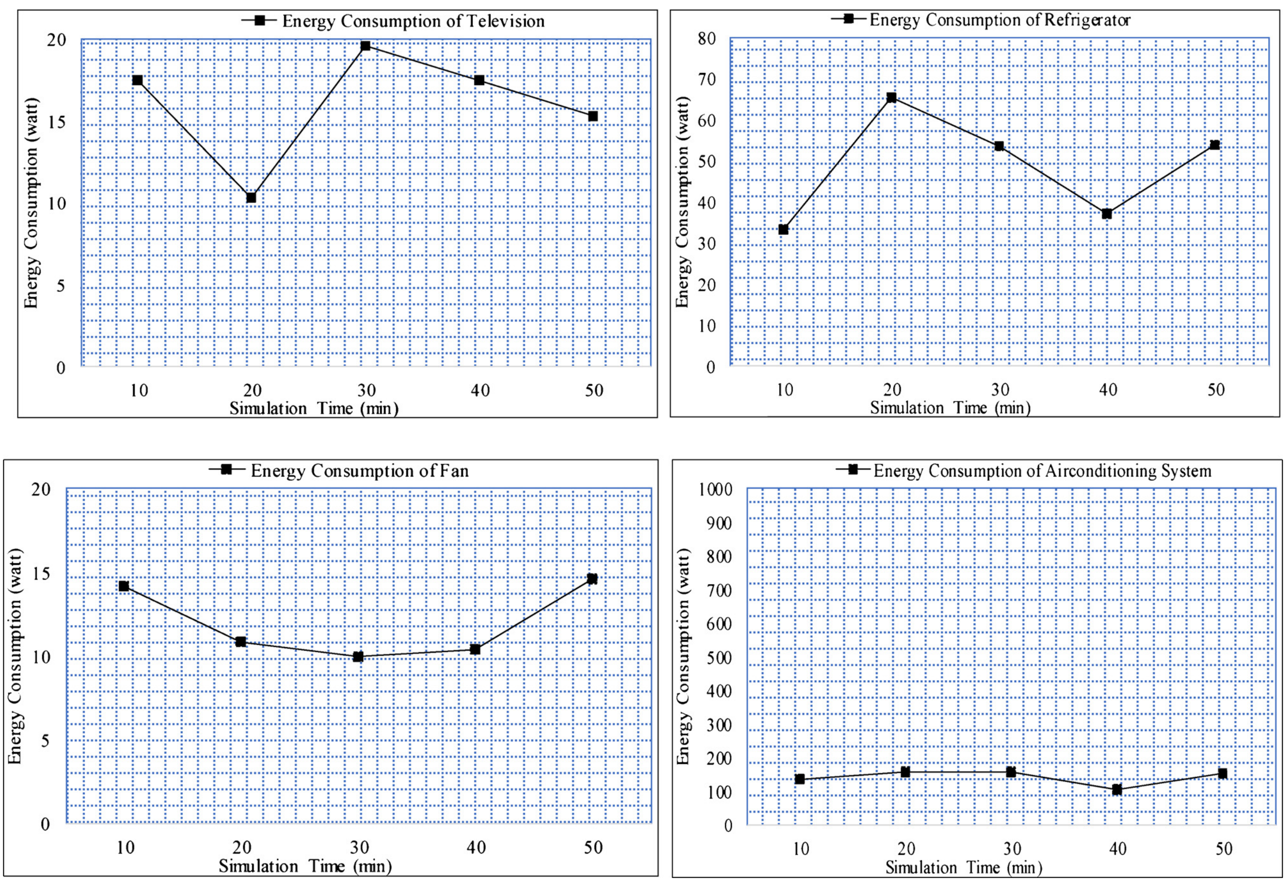

Fig. 4. Appliances energy consumption after testing and applying load balancing module.

and functionalities of network layer, therefore, to support the multi-hop concept, we made the addition for routing the data in a multi-hop environment.

In addition, the smart home in the proposed scenario is designed with fixed number of WIFI APs to check the interference level. Moreover, the consumers are doing two types of functions i.e. 1) continuously producing traffic with a specific range of size (1000–5000 bytes), and 2) arbitrarily switch off and on an appliance for duration of 6 h. The power utilization by sensors and electrical devices are calculated by considering the user functionality as a random variable i.e., 5 to 30 s apart from burner used in the kitchen. The room size is set to 3000 mm 3000 mm. The home user stays in one particular room for 5 to 10 min while randomly turning on and off the appliances available in the room. The simulation scenario is depicted in Fig. 3.

The power consumption of the appliances such as television, air-conditioning system, fan, and refrigerator is evaluated using the proposed scheme as shown in Fig. 4(A), (B), (C), and (D), respectively. The utilization of the machines is considerably decreased. The proposed architecture performs switching-OFF and ON a machine based on the consumer perspective. Therefore, unsuitable power utilization is saved using proposed scheme. Furthermore, the consumer is managing the appliances power utilization by checking records. Hence, a consumer is

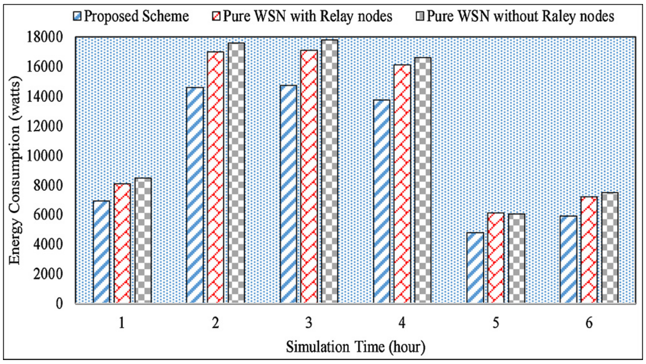

Fig. 5. Energy consumption of the entire smart home.

able to preserve the most favorable power utilization level of the machine. Moreover, the energy consumption data used in this scenario is obtained for 6 h, operating various electronic devices based on proposed scheme as shown in Fig. 3. Further, the energy of the entire home is computed comparing the proposed scheme, pure WSN technology without relay nodes and with relay nodes as shown in Fig. 5. The proposed scheme consumes less energy compared to the pure WSN technology without relay nodes and with relay nodes due to efficiently load balancing among the available home appliances.

The number of failed transmission to various sensors available in the smart home scenario is computed as shown in Fig. 6(a). The fail transmission increases due to high interference ratio among sensors available at shorter distance with each other i.e. available at same room etc. However, as the distance among the sensors increases, the interference ratio decreases resulting a decrease in number of fail transmission. Similarly, the response time increases with the increase in interference among the available sensors as shown in Fig. 6(b). The response time in the case of five sensors is more compare to ten and fifteen sensors because of the relative distance among the sensors. Thus, from this experiment, we conclude that the response time and the main cause of fail transmission is due to high interference available among the heterogeneous communication technologies available in the smart homes. In order to have a sustainable smart home with less interference, the relative distance among available sensors must be high enough to easily operate on 2.4 GHz ISM band.

`Further, the experiment is extended to identify and discover the available and new electronic appliances in less amount of time as shown in Fig. 7. For example, if the discovery time of appliance increases, the operation and controlling the current electronic appliances may be highly affected. Therefore, sensors deployment and its connection with the available appliances must be designed with proper care and each time a new device is added to the smart home.

The packet loss rate is calculated using different sensors in a smart home scenario with different rooms and a kitchen. The results are calculated in two different scenarios, i.e. pure WSN and WSN with relay nodes support. Both pure and relay based WSN follows the IEEE802.15.4e protocol for data exchange. Fig. 7(b) shows that the pure WSN requires more energy as the sensors are assumed in on-state most of the time. However, the relay support decreases the energy consumption because of transferring most of the data to the MS with the help of relay nodes. Similarly, we performed an experiment of grouping the sensors based on the distance from the MS. The sensors near MS is less affected by the congestion and, therefore, the packet failure rate of such sensors is less compared to the farthest sensors.

5. Conclusion and future directions

In this research work, an IoT based architecture is presented using the IEEE 802.15.4e protocol (ZigBee technologies) in a smart home scenario. Similarly, the electrical data is obtained from various appliances for a six hour time for evaluation and testing using Big Data analytics. The data obtained from the sensors is forwarded to central data processing system using a management station installed at each home or building. A Hadoop based system is used to process the data in real-time using a proposed dynamic Map Reduce system. In addition, thorough discussion is presented considering various aspects of an IoT environment such as MAC protocols, communication architectures, etc. Further, the entire proposed system is mainly comprised of four parts i.e. 1) a system to discover and identify electrical appliances in a smart home or smart building, 2) deployment of sensors, 3) applying proposed load balancing on appliances and sensors, and 4) processing the data obtained from these sensors for better usage of home and electrical appliances. Finally, the system is tested over real-time data obtain from a sample home hardware appliances for six hour time to check its integrity for better usage and low billing in future smart home.

Acknowledgments

Hide due Double Blind review process.

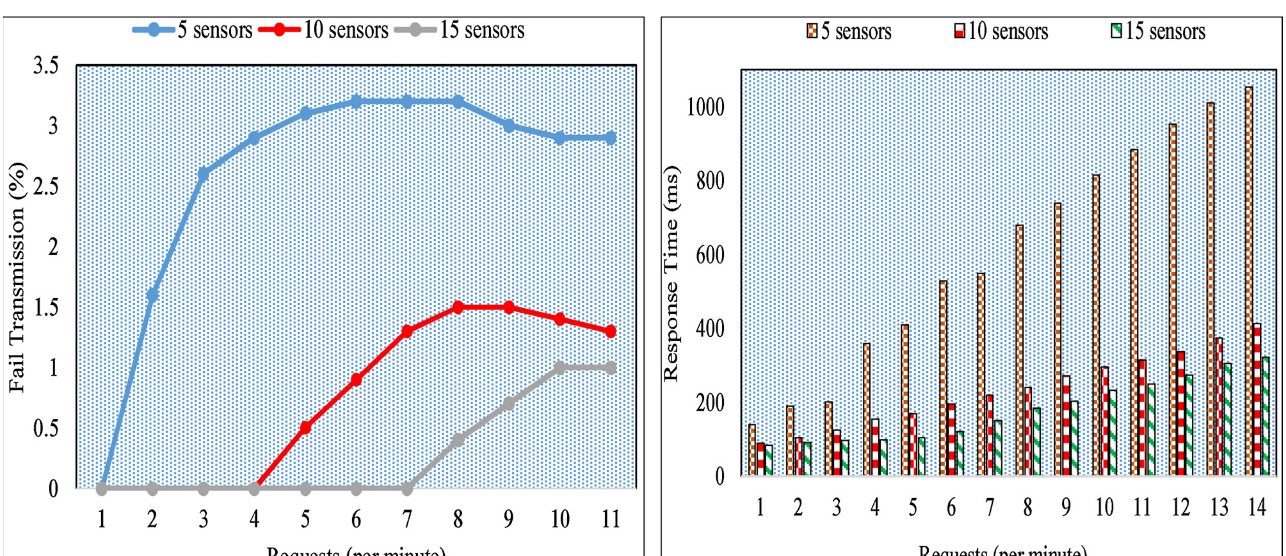

Fig. 6. a) Analysis of fail transmission and b) Response time of proposed scheme.

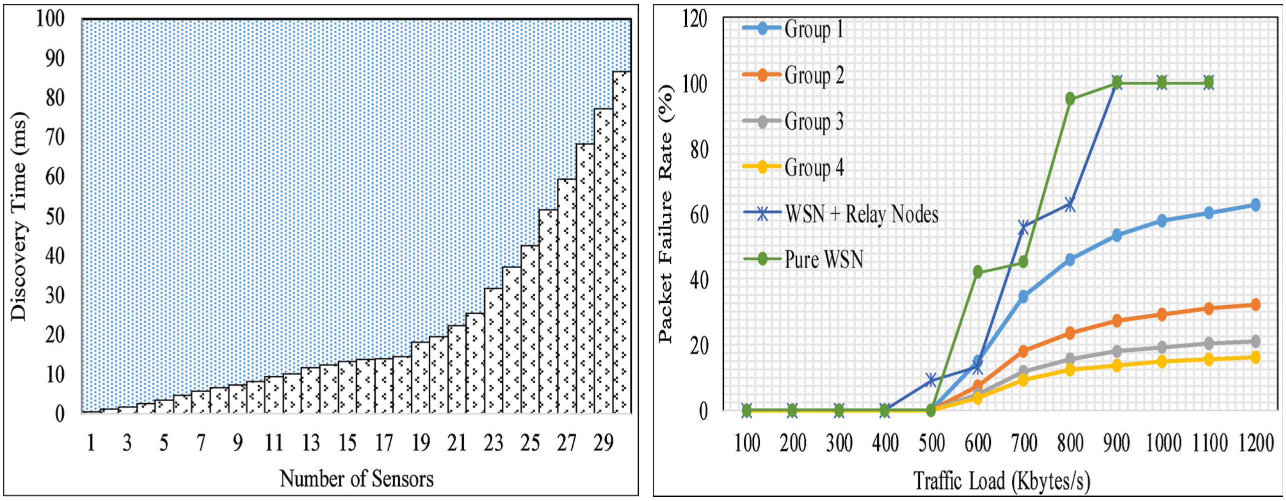

Fig. 7. a) Analysis of discovery/identification time of new and current home appliances and b) Packet Failure rate analysis of proposed scheme (group 1–4), relay based WSN and pure WSN.

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