SLASH: Self-Learning and Adaptive Smart Home Framework by Integrating IoT with Big Data Analytics

Mohamed Sultan, *Opencast Software, IEEE*, Khaled Nabil Ahmed, *King Abdulaziz University, SA*

***Abstract*—**

Over the last decades, smart home systems have failed to spread widely in every home and be a coherent part of our life like what smartphones did in half this period of time. However, the latest evolution of Internet of Things (IoT) and Big Data analysis gave new insights of smart platforms that can potentially lead to the new dream of 'smart cities'. The paper presented a survey such latest technologies that can lead to a new paradigm of a smart home, based on classifying the basic components of such systems and present the previous work in each component.

Moreover, SLASH framework is proposed for designing and implementing smart home systems that are both adaptive and self-learning. Our framework suggests integrating IoT across every home with a large network connected to Big Data analyser. Such an engine that supports analysing inhabitants' behaviours on a large-scale can enable a new type of home automation that depends on machine learning and develops on-going automation decision over time. Essentially, this approach holds some challenges that are considered throughout the framework or state for future enhancements.

***Index Terms*— Smart Homes, Human-Building Interaction, Embedded Systems, Ubiquitous Computing, Context-awareness, Big Data, Internet of Things.**

I. INTRODUCTION

Internet of Things (IoT) arguably represents the future mainstream and vision of 'smart cities' or 'smart environments' with significant interest among research communities of Ubiquitous Computing[1]. IoT have emerged from the conjunction of several conceptual and technological advances, in particular around wireless sensor networks, smart devices, embedded systems and data analytics. Thus IoT is changing business in different industries and playing vital roles in home automation (smart homes), supply chain-management (smart goods), agriculture (smart farming), IoT healthcare (smart health-monitoring wearables), manufacturing and education. Big data offers tremendous opportunities to IoT in terms of enabling smart living through its massive storage and analytics capabilities. For example, MongoDB, Hadoop and Humongous Data offer NoSQL databases with tools and techniques that can store, process and analyse large-scale distributed data from numerous sources that are too complex, unstructured and massive than ever.

So far, smart home systems are designed to serve a specific purpose such as surveillance, energy management, data collection for healthcare systems and the well-being of the inhabitants. Progressively, smart home, smart grids, smart museum, smart buildings, smart environments or smart cities are the main aim of many research covering (1)Environmental (home care, energy saving and control, green building) (2) Security (safety monitor) (3) Home entertainment (audio/video entertainment) (4) Domestic appliances (5) Information and communication (6) Health [2], [3]. However, it will be very useful if a background system analyses the collected (assimilated) data in order to recognise the inhabitant activity and consequently take the appropriate decision to support the inhabitant based on his recurring behaviour or based on his defined requirements. Systems that are utilising Big Data can be considered as the first wave that supports smart home data analytics. Others are related to user configuration (do it yourself - DIY) and make use of latest data communications technologies

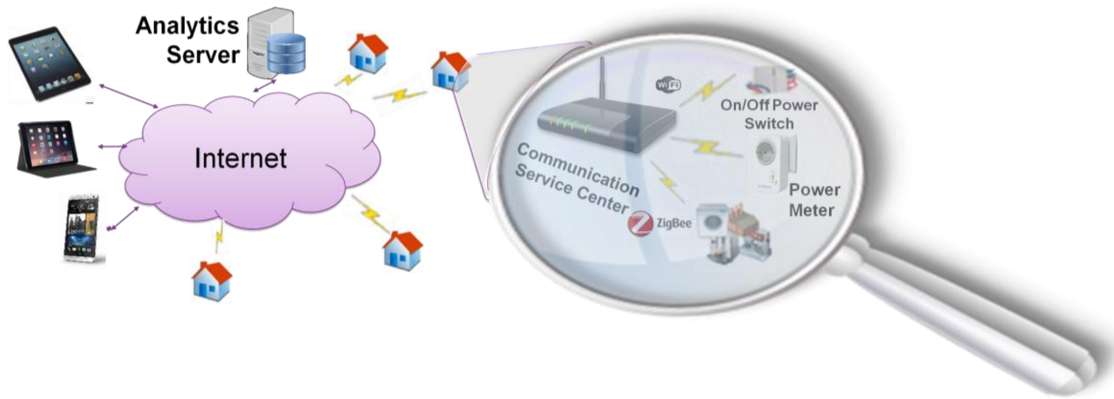

Figure 1. Diagram of SLASH framework in an IoT community

utilising Things to link between sensors/actuators and the control system. The only difference is how the system is implemented. The Internet of Things (IoT) can be described as connecting everyday objects (things) from smartphones to smart devices such as fridges or washing machines to the Internet [4]. Similarly, any other objects that can be potentially embedded with sensors and actuators can be a Thing. Consequently, all surrounding Things can be intelligently connected together enabling new forms of communication between Things and people, and between things themselves. Through wired or wireless communication interfaces, Things augmented with microcontrollers, embedded memory, power chips and various sensors and actuators that generate massive amount of data, all can communicate to interact with each other or with a central or an external hub that essentially processes all the collected data input and analyse them into an integrated decision-making system. Therefore, Things provide the flexibility for developers and service designers to build customer private network that can be operated as needed. Also, they support many communication types for integrations which can facilitate the service development. Finally, it is adaptive; Things can be customised for different purposes. It is expected that the most used daily tools and objects (Things) like clothes, brushes, keys, doors, etc. will be equipped with smart chips to be transformed into IoT as well for future activities. Therefore, it makes perfect sense to think of future smart homes as huge virtual networks of Things that collect and process the massive amount of sensor data and not just a few number of sensors like those introduced as individual products from IBM, Samsung and Intel.

In this paper, a survey for basic components of smart home systems state-of-the-art is presented, followed by a description of a framework for developing adaptive and self-learning home automation systems using both IoT and Big Data analytics. Such a framework mainly provides a better model for the architecture and integration of smart home systems, allowing easier scalability, maintainability, user friendliness and a combination of services. The next two sections describe the survey and framework respectively into details.

II. RELATED WORK

Previous work that tackled smart home systems usually focuses on a single aspect of the system's components. Figure 1 shows the five main components of a smart home system: Things (sensors), communication service centre (hub), user interface, integrated systems and data analytics. First, the Things that are the objects embedded with sensors and actuators that monitor the inhabitant and/ or the environment behaviour e.g. inhabitant movement or change of environment status (light change or heat change…). Then, translate the change digitally to the main control system. Hence, based on DIY or based on system decision, actuators translate the action to the real life e.g. opens doors, open/close curtains or turns on/off lights. Second, the communication media that compromises of different networking technologies such as ZigBee, RFID or WiFi. Third, the Communication Service Centre (CSC) that represents an internet gateway, access point, Internet protocol and ubiquitous/pervasive computing to create communication between devices as well as human user interface managements. CSC connects all Things together through the internet and thus decreases the deployment complexity of smart home systems [5]. Fourth, the user interface that is used for managing home actuators whether based on event/ situation, time schedule or manual intervention. The user interface can be implemented using a web interface, web or desktop application or mobile app [6]. Finally, the Fifth (optional) component is the data analytics service centre used for further data management and analysis. Such analysis is needed to support the inhabitant in ways that can potentially store reoccurring situations, predict next situation or monitor abnormal behaviour.

In the next sub-sections, more details are provided for each of these five components to elaborate the infrastructure of smart home systems state-of-the-art.

A. Things

A thing, in the context of the Internet of things (IoT), is an entity or physical object that has a unique identifier, an embedded system and the ability to transfer data over a network.

Things are the first and basic component of new smart home systems. IoT can be described as connecting things (objects) embedded with electronics, software, sensors, and network connectivity - as devices, vehicles or buildings - together through the internet if IoT is used instead. By bringing the internet to devices, new applications and services can be developed to support humans in their day to day activities. For instance, research proved the feasibility of integrating wireless sensor modules that are both low-cost and self-powered to be used to monitor temperature and light conditions [7]. An example of such short-range wireless technology is ZigBee [8] which is efficient in terms of power consumption and deployment scalability [9]. Most of the time, the sensor nodes in ZigBee network stay in the sleep state. When needed, nodes switch between the sleep state to the normal running state and vice versa. So the energy consumption is very low. Usually, a node can run continuously for 2 years relying on the general batteries [10].

It is expected that the overall number of devices connected to the internet will increase from 100.4 million in 2011 to 2.1 billion by the year 2021 with increase rate about 36% per year [11].Currently, most of 80% machine to machine (M2M) connections were made over mobile networks such as 3G, 4G and 5G.

Things and IoT are becoming the trend of network convergence. However, still facing challenges that need to be covered in such systems that use them. A few of these basic challenges that face Things in smart home research are:

1. Data Sharing: Things/IoT network still are an independent form. No interconnection or analytical data sharing between different homes. Hence this will make building smart systems or informational data fitting too complicated [12]
2. Technology Maturity: implementations of smart community buildings such as smart cities and housing complexes, are still in the pilot phase, and have not reached a level of maturity yet that allows special considerations required for embedding Things to be carried out during the construction phases. Similarly, system interfaces are still in the lab phase as well[13].
3. Energy Saving: High energy consumption is a hot topic to many of Things/IoT researchers providing suggestions for saving energy during the system operation.
4. Complex Network: Things networks consist of a large number of connected devices that extensively consumes network resources. This challenge increases even more as much as more capabilities and functionalities (i.e. more devices with sensors and/or actuators) are needed to be integrated with the network.

There have been different attempts at deploying Things networks with further capabilities than just sensing and actuating providing more benefits to users through autonomous behaviour and decision-making capabilities. An example for such a model is the decentralised and autonomous IoT ADEPT[14] concept which facilitates the purchasing decisions and procedures autonomously by the IoT themselves and maintains the security of these transactions as well. Conceptually, devices and home appliances are capable of sending operational problems and retrieving software updates on their own.

B. Communication

Different smart home research is focusing on how to use Things with different communication technologies (for example 5G, Wi-Fi, Bluetooth or RFID) plus a hub functionality (for example an Arduino device) to accomplish the most efficient home control using whether web services or mobile apps as an interface.

Although IoT can be connected directly to the internet, this model creates problems with security, scalability, and maintenance and data analysis. Therefore, an intermediate hub or Communication Service Centre (CSC) is recommended to solve such issues and further offers facilitating more functionalities and automation.

Research studies the communication between smart home devices (Things) in three directions: 1) communication between Things and the internet directly, 2) communication between Things and a CSC and 3) communication between the CSC and the internet. Small systems may not require a CSC acting as a local hub; however, large scale systems require such a model for efficient connectivity, management and control. Such large systems implementing concepts of ‘Smart Cites’ connect their CSC to the internet using communication platforms such as mobile networks [15] (3G, 4G and 5G), cloud-based services and Ad Hoc networking[16]. Other implementations include GSM-SMS [17] as a transmission media for IoT network. However, it should only be considered as backup network due to the high delivery latency which on average is equal to 3.5 seconds in test bed cases which is considered a major drawback to such systems, as in case of a high number of operating devices, the latency will increase accordingly.

As for communication between local sensor devices and the CSC, it can be simply implemented through RFID, Bluetooth, ZigBee or Wi-Fi with its wide bandwidth capabilities and power hungry requirements [18][19]. In [5] authors presented a full detailed design and implementation for a Things access point that supports different wireless protocols providing solutions for different challenges in the Things integrations such as solving the interferences between Wi-Fi and ZigBee. However, authors focused on only one type of communication technology (i.e. WiFi) leaving all others which raise issues regarding compatibility, scalability, cost and reliability to depend on one means of connectivity solely. Monitoring in Homes[20] is a simple system that studied low-cost ubiquitous sensing system using sensors and microcontrollers integrated with ZigBee Wireless Sensor Network. Smart community [19] built a network of smart homes using radio frequency. It used Wi-Fi (IEEE 802.11) and the third generation (3G) of mobile telephony.

Bluetooth is used for connecting low data rate devices using short range communication (less than 10m). Therefore, Bluetooth is suitable for devices such as healthcare wearables, key chain identifiers and so on. It is considered a low power consumption technology but is not considered the most suitable communication technology for smart home devices due to its range limitation that is too short. On the contrary, Wi-Fi provides a bigger range of data transfer which is more appropriate. However, Wi-Fi has a high rate of power consumption. In between is the ZigBee providing a wider range of data rate than which of Bluetooth and shorter than WiFi. It can connect devices in a range between Wi-Fi and Bluetooth as well. ZigBee is considered the lowest power consumption as it is only online when needed, thus might not need to change batteries for 2 or 3 years. Table 1 illustrates a comparison of these different communication technologies from different perspectives [21].

Table 1. Wireless Connectivity Techniques [21]

Protocol	**Bluetooth**	**ZigBee**	**WiFi 802.11**
Data Rate	1 Mb/s	20,40,250 Kb/s	11.54 Mb/s
Range	10m	10~100m	>100m
Networking Topology	Ad-hoc, small networks	Ad-hoc, peer to peer, start or mesh	Point to hub
Frequency	2.4GHz	2.4GHz	2.4GHz and 5GHz
Power consumption	Low	Very low	High
Typical Applications	Inter-device wireless connectivity	Industrial control and monitoring, sensor networks, building automation	WLAN connectivity

However, authors didn't provide a solution for system management or integration with central systems or how data will be extracted and managed from sensors.

In [3], the author is focusing on providing RESTful communication between the user and home devices through a developed gateway. The gateway consists of an Arduino server, router and firewall. However, it is not supporting iPhone and iPad which affects the customer experience and customer expectations. Smart Plug[21] which is a low-cost smart system that easily discovers the new device and provides Representational State Transfer (REST) interface that is flexible enough to be managed by the simple mobile application. Besides that, it also faces iOS compatibility problem, it uses ordinary RDBMS that needs a day to day monitoring to maintain the data feeds which is not realistic with the increase of devices.

C. User Interface

The third component is the User Interface (UI) which some research focuses on with the aim to study and enhance user interaction with the smart home management system. The user interface might be any way that allows the user to easily and efficiently remotely control and manipulate the physical IoT system. UI might not only be Graphical User Interface (GUI) but can also be implemented as a Tangible User Interface (TUI) [22]or an Organic User Interface (OUI) [23], both that provides physical manipulation as means of interaction instead of graphical representations.

Some smart home studies discussed user interaction with smart home interfaces such as Casalendar [24], Control Home Easily [25] and HBCI [1], while others focus on enhancing the application technology of the user interface using Software platforms, arguing how different technologies might affect the performance of the user interface and therefore users' engagement and embracement of their automation system.

Casalendar [24] uses the calendar as an interface to engage home inhabitants with their homes by presenting the status of each smart home device. Control Home Easily [25] is a mobile application that manipulates home devices using widgets. It automatically discovers and registers new devices within the system. It gives inhabitants the control of changing home rules which might not be accepted by other inhabitants within the home. The same for HBCI (Human-Building-Computer Interaction System) [1], which gives the inhabitant the luxury of controlling home devices using an android app implemented through RESTful architecture in addition to enabling the user to configure energy saving functionalities.

Research regarding the application layer of smart home UI utilises novel technologies such as REST or SOAP as the most flexible interfaces within large and complicated systems such as Smart Homes[26]. With the integration using Arduino Ethernet Server, it is applicable to develop an android user interface to easily manage sensors and actuators with low-cost implementation.

D. Integrated Systems

Some research presented complete systems that studied the integration of all components discussed earlier in the above sections. Examples are Home Automation system (HAS) using Intel Galileo [27], Ambient Assisted Living (AAL)[28] and Syndesi[29]. Home Automation system (HAS) using Intel Galileo [27] employs the integration of cloud networking and wireless communication. It is providing remote control management to lights and fans. Also, it is providing alarms based on temperature and humidity, motion detection, fire and smoke detection and finally light level. The system is very useful for data collection. However, is lacking the decision making experience. In other words, the system is lacking activating actuators based on dynamic sensor readings.

Ambient Assisted Living (AAL)[28] is used to support elderly people during their daily activities. It made use of RFID and NFC as communication technologies enabling the Things for building a smart system monitoring for elderly people. It mainly used to increase safety and wellbeing. It provides communications between (1) people and things, (2) Things and things and (3) people and people. It is very useful for relatives, physicians and elderly people themselves. Many features can be added if Big Data is used for fetching data to the concerned parties as with the increase of users, the system will face slow performance especially in a critical area that needs rapid actions based on sensor readings.

Syndesi[29] is a complete framework that consists of hardware and software unifying the heterogeneous devices (sensors, nodes and actuators) that are using different communication technologies (such as Near Field Communication (NFC), Bluetooth, ZigBee, and 6LoWPAN) personalising smart environment using Wireless Sensor Networks (WSN). Also, Syndesi is using REST API for data representation. It is a scalable framework that can be used in hospitals, schools and houses. Also, it is able to identify people and take the appropriate actuator action based on user needs. With providing a smart user interface to support the inhabitant, the system can be smart user-friendly system.

E. Data Analytics

Extensive researchers have been made to develop various smart home systems[30]. However, these studies are focusing on the home on individual bases. In order to be able to provide complete data analysis on user behaviour, it is needed to collect data from different home models to be able to cover all possible behaviours. Adding data analytics capabilities can be of great benefit to smart home research creating unpreceded potentials for understanding, implementing and deploying intelligent systems that can be both adaptable and self-learning.

However, current research utilising data analytics in smart home systems focuses on providing limited services such as audio and video entertainment, safety monitor, home care, energy saving and control, green building, or the wind and solar energy. Few researchers study analysing the huge amount of data provided by Things and sensors.

Latest breakthroughs in big data and cloud computing technologies offer great potentials for complex and large-scale systems that are context-aware and adaptive. Hadoop [31] and MongoDB[32] are Big Data solutions that are scalable in data processing and capable to analyse a large number of unstructured and unrelated data sources. With the increase of Smart Home appliances, cloud computing is needed as well. The principle of computing "in the cloud" can be described as sharing lot of data processing upon request. Cloud computing is a model for sharing a pool of configurable computing resources such as networks, servers, storage, applications, and services that can be easily controlled and managed. For comparison, researchers[32] have investigated the use of MongoDB versus one of the traditional RDBMS (i.e. MySQL) as data storages. MongoDB spent less time than MySQL with the increase of Insert queries which proves the capability of data processing in a large number of queries[33].

Related work includes a development of systems both in the lab and in the wild, utilising data analytics platforms for either data collection or further decision-making. The Safer@Home [34] project at the University of Stavanger includes twenty model homes for participating elderly, furnished with a network of sensors. Safer@Home provided analytics decision-making solution on behaviour and health of elderly people using Big Data. Aware House[35] is a living laboratory for ageing and life improvement. The system measured activities based on data collected from RFID tags, optical and pressure sensors. The Independent Lifestyle Assisting (ILSA) [36] and the MavHome project [37] introduce learning models based on patterns but they are lacking the use of updated technologies and data collection automation. However, the CASAS Smart Home Project[38] and the Smart Hospital Project[39] used several types of sensors to generate a complete dataset used to recognise activities in situations where inhabitants were performing different activities. The University of Washington Assistive Cognition (ACCESS) project [40] investigated machine learning and ubiquitous computing algorithms to support intelligent travel-patterns system that predicts likely destinations and detects unusual variations. MIT Home-of-the-Future [41] presented a predictive framework for location-aware resource optimisation in smart homes. The Neural Network House [42] from the University of Colorado based on neural nets, focused on providing adaptive control of home environments to anticipate needs of its inhabitants.

As for big data, AllJoyn Lambda[43] is a software solution integrating AllJoyn devices in a Lambda architecture used for Big Data analytics. AllJoyn is integrated with MongoDB and Apache Storm that used for data presentation. AllJoyn Lambda took the benefits of AllJoyn regarding the flexibility connecting of heterogeneous devices and overcome its disadvantage of managing the large-scale environment by integrating Big Data - Lambda architecture – to fulfil the framework scope. The system proved the capability of managing the system covering most of smart home use cases (1) Regular Pattern which is previously defined actions by the user (2) Event Based Pattern which is a set of defined actions based on defined event (3) Automated Pattern which is actions that is not configured by the user like moving the curtains based on the intensity of light. The framework successfully analysed the home clusters including kitchen and rooms. However, it is not proved for large scale data collected from different homes to analyse different situations from a different type of inhabitants.

III. FRAMEWORK

Many home automation systems were proposed during the last decade. However, the performances of these technologies still not mature enough due to the lack of rich datasets provided to complete the view of smart home environments. Numerous research is focusing on main smart home components like IoT devices, system communications or user interfaces. Less number of research focused on data analytics. However, it can be the missing point that prevented smart home systems from spreading as smartphones did [44].

Our proposed framework is to augment homes with machine-learning intelligence to automatically detect different situations, self-learn how the inhabitant acts and eventually reacts and controls the home autonomously. The proposed framework name is Self-Learning and Adaptive Smart Home system (SLASH). For example, the user turns on the entrance light when entering his home – without any change in other Thing devices statuses- then after a defined number of reoccurrences, the system will sense the user's entrance and automatically turn on the lights. The situation will be defined per each sensor status - within the home –and what change that led to that situation. With the increase in the number of situations and the complications, SLASH can learn and act to support the inhabitant's routine life.

To cover a mature number of situations and behaviours, a large number of sensor readings have to be provided from different inhabitants. This can be accomplished by providing home experiences to a centralised system that stores, analyse and acts upon. Hence, the decision taken by the system will be mature enough over time to take the correct actions based on data extracted per home. SLASH utilises big data analytics and smart machine learning mechanisms to collect, store and analyse situations, then provides decisions/actions in both rapid and accurate way at the same time.

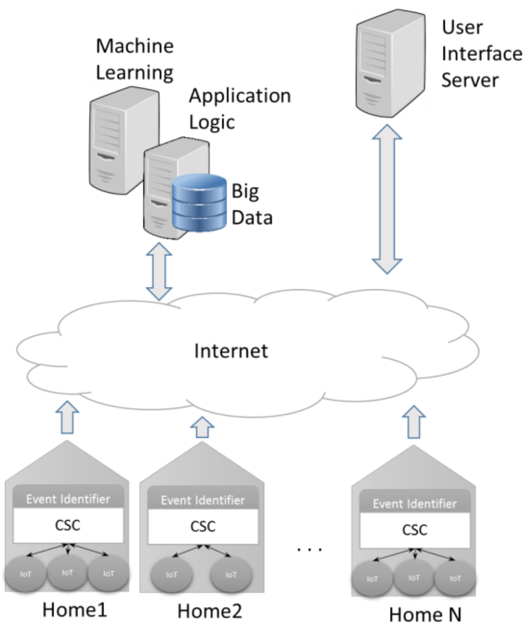

Figure 2. SLASH Framework architecture Components

To apply the SLASH framework, (1) complete and an auto-refreshed dataset is needed to analyse each situation (2) smart gateway responsible on dataset push/pull to the central server (3) big data storage (4) cloud computing to send/retrieve the inhabitant situation action. (5) Action actuator to taking place the decision requested by the situation action maker. The framework is responsible for enabling multiple applications including mobile apps, web interfaces and different types of data analytics. Figure 2 illustrates the different layers of the SLASH framework, from Things (sensors)/IoT, CSC (hub connectivity), Data Analytics to the UI. The following sub-sections describe each of these SLASH framework layers in more details.

A. Sensors and actuators Layer (Things):

This includes a network of different kinds of domestic Things and sensors spread throughout the home – temperature, motion, position, security and humidity. Two types of sensors, the basic one only senses the action taken by the inhabitant then translates it to the CSC. Data must be fetched periodically for data analytics. The advanced type senses the change of state and sends it back as an event to be collected by the data analytics and decision making.

Actuators receive the control signal from Application Logic (SLASH) to put in place the desired action. Actuators are acting as a listener at the gateway. Once actuators got a decision trigger from SLASH, the situation takes place at the dedicated actuator within the home network via the CSC. Many types of actuators can be used e.g. 1) electric motors for opening/closing curtains; also can be door shutters. 2) Valve actuator for heating control or gardening. 3) Switch actuators for light operations or light dimming.

B. Communication Layer (CSC):

Communication Service Centre (CSC) is responsible for managing connectivity for any sensor/actuator device within the WSN (Wireless sensor network) or within a wired one as well. It should support different communication ranges (1) Long range: 3G / GPRS / LoRaWAN / LoRa / Sigfox / 868 / 900MHz (2) Medium range: ZigBee / 802.15.4 / WiFi (3) Short range: RFID / NFC / Bluetooth 4.0. Also, it is responsible for new device discovery as well as providing the needed integration procedure within the network. Waspmotes by Libelium[45] can be used for this matter. Waspmites is a battery powered open source wireless sensor platform for developers. Battery lifetime of Waspmote sensor nodes may go from 1 to 5 years depending on the duty cycle and the radio used. CSC also supports gateway and proxy functionalities as it will be responsible for exchanging data between the home's network that includes Things and the external systems through the internet (i.e. User Interface and the Application Logic) using HTTP, CoAP (Constrained Application Protocol) and RESTful interfaces.

Event Identifier: The only straight forward of maintaining data collected from devices is by storing raw data. That means collecting data directly from devices having different sensing technologies. There are two advantages to this method. First, it is very simple to be implemented as it doesn't need any preceding data processing. Second, all information remains intact giving the chance of finding interesting information to provide new service(s). Despite these advantages, no prototype is found that claims storing raw data [46]; The main disadvantage of this method is that it needs storing huge amount of data which leads to waste of data storage and increase in connection bandwidth consumption as well. Moreover, storing raw data may lead to storing useless information and may be duplicated as well.

Hence, the main functionality of the Event Stream is to detect a change in the status of any sensor within home's network and sends only the change. By this way, saving more disk space and less bandwidth processing power is assured. Since events are tied to date and time, Event Stream adds supporting needed data like sensor type, event date & time and inhabitant ID. Then, Event Stream sends it to the external system using a gateway. Also, Event Stream should save more disk storage, removes unnecessary data and removes duplicates when needed. Hence, Event Stream makes it easy to understand situation logics. In addition, Event Stream includes another level of logging to be used for investigations and debugging.

C. Application Logic:

Application Logic can be considered as the brain of the Adaptive Smart Home Framework. It collects data extracted from different smart home gateways – after being staged by the Event Stream - into centralised cloud computing system that uses Big Data as well. Also, it performs data corrections, data correlation and data mining that are needed for machine learning. Finally, Application Logic supports situation extraction (activity recognition) for predicting inhabitant action.

1. Data Storage: In early years, sensor technology was more limited than nowadays. Now, sensors have more sampling rates providing more data than before which will lead indirectly to better service for the resident. If 30 sensor devices are used and data are collected every 200 ms which leads to 12,960,000 (30*24*60*60*5) entries per day per house. Thus, researchers must start thinking of Big Data to be able to analyse this huge amount of data in short time.
2. Data correction and Data Correlation: First, collect, store and clean dataset extracted from different sources (sensors, devices or any other data sources). Therefore, cleanup process is mandatory in this step as it removes any excess data that can be considered as noise or un-useful information. Second, prepare and reformat dataset in a format suitable for data mining algorithm. For example, bounding some numeric values, removing or adding/predicting some attributes caused by network disconnection, device faults, or software bugs.
3. Data Mining: which is a set of methods of discovering patterns within large data sets at the intersection of artificial intelligence, machine learning, statistics, and large database systems[47]. Data mining provides a new set of models (e.g. decision trees or set of rules). New models can be generated by one of two categories (supervised learning and unsupervised learning). A method can be considered as supervised when it is based on training dataset with labelled examples[46]. In this case, a method is to generate a function to map the inputs to outputs based on defined/trained datasets. Hence, it can be used to predict the output for previously unseen situations. The challenge in the supervised learning method is that it needs an expert to perform the situation mapping and labelling. In the contrary is the unsupervised learning method; it is based on unlabeled examples. It is harder to implement and extract the result from this method is often unexpected as the user normally don't know what he is looking for[46]. However, it gives the user new insight for the situation he is evaluating.
4. Situation Extractor: based on mined, corrected and correlated stored data, Situation Extractor extracts the situation based on the combination of Things states changes. Hence, Situation Extractor sends the situation to the machine learning module to add it to the situation collections used in predictions.

D. Machine Learning:

SLASH will start as empty situation actions and ready to adapt to the inhabitant routine. After a defined number of similar situation/routine reoccurrences, SLASH can start actuating based on the routine just like the inhabitant used for.

An example for a situation extraction: the inhabitant used to turn on the heater when he turns back home, switches on lights if the sunset is passed and makes sure that the curtains are closed.

As a condition to situation actuation activation, SLASH will request the inhabitant acceptance to automate the action as the inhabitant himself used to do.

With new situation change or discovering new unmonitored situation, SLASH will restart training again making sure that it follows the desired action. Therefore, SLASH can adapt on inhabitant routine and accordingly, cover most of the smart home applications (Environmental, security, home entertainment, domestic appliances, information and communication and finally Health.

E. User Interface Layer (UI):

Providing APIs, for different applications e.g. mobile app, web interfaces and OUI as well. It gives the user the flexibility to define home routines facilitating machine learning actions or let SLASH select the desired actions based on learning human behaviour. Also, UI will provide the functionality to deactivate a situation action the user found that it is not suitable or he doesn't want this action. Hence, it would be a good opportunity to enhance machine learning situation action. APIs is recommended to be RESTful APIs or similarities.

IV. Challenges

Privacy: The first challenge for such smart system is privacy. People don't like to expose their private life to the world. This can be solved by accepting the license. As many of other applications touching private data are ensuring that they will never expose user's data to anyone else. It will be needed only for data analysis. In addition, the smart system will provide very good service that is completely new for inhabitant giving very good life experience. Plus, no video cameras will be deployed saving inhabitant private life as many situation predictions can be assured using other sensor types.

Knowledge Sharing and Information Exchange (standardisation): Many systems would be deployed to satisfy customer needs whether are accomplished using Big Data or traditional RDBMS. Different organisations are racing to launch new products to dazzle users that perform unexpected actions. However, all these organisations are neither standardising data extracted from different homes nor sharing this information. This makes it very difficult to manage data or explore new idea between them. The Institute of Electrical and Electronics Engineers (IEEE), and the National Institute of Standards and Technology (NIST) have produced a list of standards that should be considered producing for example in smart grids [48], [49].

Incomplete dataset: Missing and the incomplete data set are one of the major challenges that such large systems could face. It could be due to network connections, un-authorization problems, limited disk space…

Data prediction based on previous experience can be one of the fastest solutions. However, it is not reliable, as it may lead to fake results. Data correlation would be another alternative for data prediction as missing data can be found in other datasets which can enhance the dataset mining and data extraction.

Data Quality: Each data extracted from different Things/IoT device may vary from each other. Things/IoT device may provide wrong readings which may affect the whole customer experience. SLASH would recommend compatible devices that it is assured of its accurate data provisioning or as per machine learning; the situation can be customised based on extracted readings. However, in case of changing the device or new device integration, situation prediction has to be reverted to comply with the new environment.

V. Conclusion

It is not science fiction anymore to believe that humans will have full control in automating their entire homes "smartly" by interacting with IoT through ubiquitous computing that can perform daily domestic tasks.

The paper provided details about the main components of smart home systems using IoT devices, communication, analytics and user interface. In addition, the paper provided the SLASH (Self-Learning and Adaptive Smart Home) framework as a conceptual architecture for designing adaptive and context-aware home systems. SLASH is different than all previous work in the smart home field in the sense that it starts without predefined configuration, but rather as a new born baby gaining experiences from different situations as it grows. SLASH framework utilises the relatively consistent behaviour of different users, captures and stores IoT/Things sensor data, and analyses through machine learning and big data analytics how the smart home should interact with the inhabitant. This framework allows a new paradigm of smart homes providing enhanced and customised experience according to the inhabitants' routines. Moreover, SLASH utilises data collections and analytical extractions from different homes to enhance the experience of all of them.

Finally, the paper stated the challenges in such a framework and smart home research topic in general opening areas that encounters issues and implications opposing the evolution of IoT/Things in our lives.

VI. Future work

The proposed framework and its components are not completely implemented. By integrating the system in a large scale with a relatively number of homes to assess the design and then true acquiring a large amount of data as an input source to both mature big data analytic big module and therefore evaluate accurately actual efficiency and performance of the SLASH formwork. This will enable the system to be in a position where authors can revisit the SLASH framework and propose the enhancement where necessary.

By the end, the system will prove its flexibility and its adaptively to different user personalities. Then, the system can be used widely in residential complexes providing user luxury and user excellence at the same time without touching inhabitant privacy in a reasonable cost.

References

[1] H. J., M. P., J. X., O. J., S. S., D.-H. S., and C. D., "HBCI: Human-Building-Computer Interaction," *2nd ACM Work. Embed. Sens. Syst. Energy-Efficiency Build. BuildSys'10*, pp. 55–60, 2010.

[2] R. Berger, "Home automation – The next big move in the utilities and telecom industries | Home automation solutions are becoming mature , with convincing products already being marketed | The smart home market is seen as a required strategic move for all players | Ut," *Think:Act*, p. 20, 2013.

[3] X. Ye, "A Framework for Cloud-based Smart Home," pp. 894–897, 2011.

[4] G. Kortuem, F. Kawsar, D. Fitton, and V. Sundramoorthy, "Smart objects as building blocks for the Internet of things," *Internet Comput. IEEE*, vol. 14, no. 1, pp. 44–51, 2010.

[5] C. Chang, C. Kuo, J. Chen, and T. Wang, "Design and Implementation of an IoT Access Point for Smart Home," pp. 1882–1903, 2015.

[6] C. Chen, S. Shih, and C. Hsu, "Proceedings of the 2nd International Conference on Intelligent Technologies and Engineering Systems (ICITES2013)," *Proc. 2nd Int. Conf. Intell. Technol. Eng. Syst.*, vol. 293, pp. 195–204, 2014.

[7] D. De Donno, L. Catarinucci, and L. Tarricone, "RAMSES: RFID augmented module for smart environmental sensing," *IEEE Trans. Instrum. Meas.*, vol. 63, no. 7, pp. 1701–1708, 2014.

[8] "ZigBee." [Online]. Available: http://www.zigbee.org/.

[9] "ZigBee and the Internet of Things." [Online]. Available: http://www.telegesis.com/our-markets/.

[10] D. Bruckner, T. Dillon, S. Hu, P. Palensky, and T. Wei, "Guest editorial special section on building automation, smart homes, and communities," *IEEE Trans. Ind. Informatics*, vol. 10, no. 1, pp. 676–679, 2014.

[11] S. Hilton., "Progression from M2M to the Internet of Things: an

introductory blog." [Online]. Available: http://blog.bosch-si.com/progression-from-m2m-to-internet-of-things-an-introductory-blog/.
[12] G. Chong, L. Zhihao, and Y. Yifeng, "The research and implement of smart home system based on Internet of Things," *2011 Int. Conf. Electron. Commun. Control*, pp. 2944–2947, 2011.
[13] T. Li, J. Ren, and X. Tang, "Secure wireless monitoring and control systems for smart grid and smart home," *IEEE Wirel. Commun.*, vol. 19, no. 3, pp. 66–73, 2012.
[14] S. Panikkar, S. Nair, P. Brody, and V. Pureswaran, "ADEPT : An IoT Practitioner Perspective," pp. 1–20, 2015.
[15] P. Lynggaard and K. E. Skouby, "Deploying 5G-Technologies in Smart City and Smart Home Wireless Sensor Networks with Interferences," *Wirel. Pers. Commun.*, pp. 1399–1413, 2015.
[16] E. A. D. G. Reina, S. L. Toral, F. Barrero, N. Bessis, "The role of ad hoc networks in the internet of things," *Internet Things Inter-Cooperative Comput. Technol. Collect. Intell.*, pp. 89–113, 2013.
[17] S. Pandikumar and R. S. Vetrivel, "Internet of Things Based Architecture of Web and Smart Home Interface Using GSM," *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 3, no. 3, pp. 1721–1727, 2014.
[18] M. Darianian and M. P. Michael, "Smart home mobile RFID-based internet-of-things systems and services," *Proc. - 2008 Int. Conf. Adv. Comput. Theory Eng. ICACTE 2008*, pp. 116–120, 2008.
[19] X. Li, R. Lu, X. Liang, X. Shen, J. Chen, and X. Lin, "Smart community: An internet of things application," *IEEE Commun. Mag.*, vol. 49, no. 11, pp. 68–75, 2011.
[20] S. D. T. Kelly, N. K. Suryadevara, and S. C. Mukhopadhyay, "Towards the implementation of IoT for environmental condition monitoring in homes," *IEEE Sens. J.*, vol. 13, no. 10, pp. 3846–3853, 2013.
[21] L. Zhi-Gang and H. Wei, "The design of smart home system based on Wi-Fi," *2012 Int. Conf. Comput. Probl.*, vol. 9, no. 6, pp. 454–456, 2012.
[22] J. T. K. Myung Eun Cho, Mi Jeong Kim, "Design Principles of User Interfaces for the Elderly in Health Smart Homes," pp. 2–4, 1987.
[23] S. Nabil and D. Kirk, "Future of Ubiquitous Home Interaction with OUI Interiors."
[24] S. Mennicken, J. Hofer, A. Dey, and E. M. Huang, "Casalendar," *Proc. Ext. Abstr. 32nd Annu. ACM Conf. Hum. factors Comput. Syst. - CHI EA '14*, pp. 2161–2166, 2014.
[25] S. Kartakis, M. Antona, and C. Stephanidis, "Control smart homes easily with simple touch," *Proc. 2011 Int. ACM Work. Ubiquitous meta user interfaces - Ubi-MUI '11*, p. 1, 2011.
[26] R. Piyare, "Internet of Things : Ubiquitous Home Control and Monitoring System using Android based Smart Phone," *Int. J. Internet Things*, vol. 2, no. 1, pp. 5–11, 2013.
[27] V. K. sagar N and K. S. M, "Home Automation Using Internet of Things," *Int. Res. J. Eng. Technol.*, pp. 2395–56, 2015.
[28] A. Dohr, R. Modre-Opsrian, M. Drobics, D. Hayn, and G. Schreier, "The Internet of Things for Ambient Assisted Living," *2010 Seventh Int. Conf. Inf. Technol. New Gener.*, pp. 804–809, 2010.
[29] O. Evangelatos, K. Samarasinghe, and J. Rolim, "Syndesi: A Framework for Creating Personalized Smart Environments Using Wireless Sensor Networks," *2013 IEEE Int. Conf. Distrib. Comput. Sens. Syst.*, pp. 325–330, 2013.
[30] S. Dixit and R. Prasad, *Technologies for Home Networking*. 2008.
[31] T. White, *Hadoop: the definitive guide*. O'Reilly, 2012.
[32] Z. Wei-Ping, L. Ming-Xin, and C. Huan, "Using MongoDB to implement textbook management system instead of MySQL," *2011 IEEE 3rd Int. Conf. Commun. Softw. Networks, ICCSN 2011*, pp. 303–305, 2011.
[33] Y. Jiang, X. Liu, and S. Lian, "Wireless Communications, Networking and Applications," vol. 348, 2016.
[34] A. Chakravorty, T. Wlodarczyk, and C. Rong, "Safer@home analytics: A big data analytical solution for smart homes," *Proc. Int. Conf. Cloud Comput. Technol. Sci. CloudCom*, vol. 1, pp. 705–710, 2013.
[35] G. D. Abowd, A. F. Bobick, I. a Essa, E. D. Mynatt, and W. a Rogers, "The aware home: A living laboratory for technologies for successful aging," *Proc. AAAI-02 Work. Autom.*, pp. 1–7, 2002.
[36] K. Z. Haigh, L. M. Kiff, J. Myers, V. Guralnik, K. Krichbaum, J. Phelps, T. Plocher, and D. Toms, "The Independent LifeStyle Assistant (I . L . S . A .): Lessons Learned," no. January, pp. 1–39, 2003.
[37] D. J. Cook, M. Youngblood, E. O. . I. Heierman, K. Gopalratnam, S. Rao, a. Litvin, and F. Khawaja, "MavHome: an agent-based smart home," *Proc. First IEEE Int. Conf. Pervasive Comput. Commun. 2003. (PerCom 2003).*, pp. 1–4, 2003.
[38] D. Cook, M. Schmitter-Edgecombe, A. Crandall, C. Sanders, and B. Thomas, "Collecting and disseminating smart home sensor data in the CASAS project," *CHI Work. Dev. Shar. Home Behav. Datasets to Adv. HCI Ubiquitous Comput. Res.*, no. November 2015, 2009.
[39] D. Sánchez, M. Tentori, and J. Favela, "Activity recognition for the smart hospital," *IEEE Intell. Syst.*, vol. 23, no. 2, pp. 50–57, 2008.
[40] P. Brown, D. Ed, M. Harniss, D. Ph, and A. Liu, "University of Washington ASSISTED COGNITION IN COMMUNITY , EMPLOYMENT , AND SUPPORT SETTINGS (PROJECT ACCESS) Project Members."
[41] S. S. Intille, "Designing a Home," 2002.
[42] A. Environment and M. C. Mozer, "The Neural Network House: An Environment that Adapts to its Inhabitants," pp. 0–4, 1998.
[43] M. Villari, A. Celesti, M. Fazio, and A. Puliafito, "AllJoyn Lambda: An architecture for the management of smart environments in IoT," *Proc. 2014 Int. Conf. Smart Comput. Work. SMARTCOMP Work. 2014*, pp. 9–14, 2015.
[44] M. Sultan and K. Nabil, "Smart to Smarter : Smart Home Systems History , Future and Challenges," in *Future of HBI: Human-Building Interaction Workshop, ACM CHI '16, San Jose, CA, USA*, 2016.
[45] "Waspmotes." [Online]. Available: http://www.libelium.com/products/waspmote/.
[46] K. Bouchard and C. Jh, "Smart Homes and the Challenges of Data," pp. 3–6.
[47] X. Wu, V. Kumar, Q. J. Ross, J. Ghosh, Q. Yang, H. Motoda, G. J. McLachlan, A. Ng, B. Liu, P. S. Yu, Z. H. Zhou, M. Steinbach, D. J. Hand, and D. Steinberg, *Top 10 algorithms in data mining*, vol. 14, no. 1. 2008.
[48] T. Basso and R. Deblasio, "Advancing Smart Grid Interoperability and Implementing NIST 's Interoperability Roadmap : IEEE P2030 Initiative and IEEE 1547 Interconnection Standards," *Proc. Grid Interoperability Conf.*, no. April, 2010.
[49] Nist, N. S. Publication, and National Institute of Standards and Technology, "NIST Special Publication 1108 NIST Framework and Roadmap for Smart Grid Interoperability Standards," *Nist Spec. Publ.*, vol. 0, pp. 1–90, 2010.