TikiriPower – Using TikiriDB abstraction on Smart Home systems

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Abstract — ***In the domain of Wireless Sensor Networks, Smart Home applications are becoming the newest trend. Such deployments face challenges of underlying complexity in programming of traditional wireless sensor networks as well as lack of collaboration within hardware components. To address these issues, a platform that considers sensors and actuators in a wireless sensor network as a database framework is presented. Monitoring electrical and environmental parameters and controlling electrical appliances in a Smart Home via SQL queries is suggested. A prototype system consists of monitoring and controlling capabilities was implemented to evaluate the framework. Usage of our platform makes Smart Home applications more efficient, reliable and maintainable. In return, reduction of domestic energy consumption and cost in monetary terms would be beneficial.***

Index Terms — Wireless Sensor Networks, Database Abstraction, Smart Home, Power Management, Multiple User Accessibility

I. INTRODUCTION

Wireless sensor networks (WSN) [1] is a well-established research domain in computer science with a wide variety of applications. It involves large number of small devices called "*motes*" which are networked through wireless communication. These motes are capable of sensing their deployed environment through various types of sensors attached to them. WSNs have been used in various applications including environment monitoring applications, military applications and so on [2].

Since sensor motes in a WSN are deployed in remote locations which are almost impossible to reach regularly for maintenance, these devices have to face many challenges on to survive until their intended task is completed. For example, sensor motes have to be powered by batteries and therefore efficient usage of power is a major requirement. To reduce power usage and deployment costs, sensor motes are designed with limited hardware resources such as memory capacity and CPU speed. Due to these limitations, conventional software applications cannot run on top of these hardware platforms. The programmers have to manage memory and device resources carefully to implement applications. Since it is not an easy task, different specialized software layers and operating systems like TinyOS [3] and Contiki [4] have been implemented to make developers life easier.

Domestic energy crisis has influenced emerging new applications of modern technologies and mechanisms to monitor and regulate power usage in houses. Smart Home concept is the result of the above requirement. In Smart Home applications, users are provided with facilities to monitor power usage of their houses and also if necessary, to regulate the power usage by controlling different electrical appliances.

Recently, there is a new trend of deploying wireless sensor networks in Smart Home applications [5]. There are many benefits of such applications. Since wireless sensor networks rely on radio frequencies for communication, there is no need to provide dedicated communication infrastructures for Smart Home application in a building. Another important aspect is the energy usage. Since the Smart Home applications task is to monitor and regulate power usage, the system itself should be energy efficient so that it would not add extra overhead to the power usage of the building. WSN hardware and software components are designed to run on low power mode and therefore it is applicable to Smart Home domain.

When applying wireless sensor networks to Smart Home, developers still face challenges in traditional wireless sensor network programming. Programming devices using specialized languages are difficult for programmers who are not domain specialists. Therefore building highly flexible and maintainable Smart Home application is still not an easy task if developers write applications from scratch. In this research we suggest a new platform for Smart Home applications based on a database abstraction implementation for WSNs. We evaluate the usability and performance of our platform using a prototype implementation.

Contribution

- New power monitoring and controlling drivers for Contiki.
- New power monitoring and controlling devices for the hardware platform.
- New power monitoring and controlling

queries for TikiriDB [6] .

- Combined and conditional queries for TikiriDB.
- Enhanced communication stack for TikiriDB.

II. BACKGROUND AND RELATED WORK

Currently, WSN field is live and emerging area of research which interacts comparatively much with physical world. Most of the traditional WSN specified components are limited to areas like medicine, military, manufacturing and communication etc. These days researchers are more deeply interested in embedding wireless sensor network related components into power monitoring and controlling devices on physical world.

When interacting with physical world scenarios, researchers attempt to reduce the hardware overhead of WSN programmers by introducing many hardware platforms. There are many hardware platforms for WSNs namely general purpose commodity based systems, sub-threshold systems, smart dust, Charm - Network stack acceleration ,Harvard Event – Driven Architecture and many more [7]. As for software in the domain of WSN, commonly using operating systems are Tiny OS and Contiki OS; which provide much simpler and easier way of programming WSN systems as well as customizations them to suit mentioned fields. Hardware and software customization and integration still result complexities and overheads for novel developers (new to WSN) though individual hardware and software have reduced the complexity. Eliminating these overheads, database abstractions such as TinyDB [8] , TikiriDB and file system abstractions such as TikiriDev [9] have been introduced. These abstractions give provisions to developers in order to think WSN as a database or file system leading them towards WSN specific hardware and software independent programming platform. But researchers have failed to integrate these WSN specific hardware platforms, software and abstractions into a single profound and worth application except for some applications related with wild life [10], transportation [11] and miscellaneous [12], [13] , [14] scenarios.

With the rapid development of technology, handling day to day chores have become complicated. In order to assure ease manageability of tasks at home, Smart Home concept came into being. Smart Home concept needs to entrust with care, security, reliability, scalability and portability. Smart Home environment needs to contain internal network and intelligent control with in appliances, and home automation. Further, wireless enabled Smart Home automation networks comprise varieties of embedded devices such as sensors and actuators. These are used to monitor and control home appliances with user comfort, reliability and efficient home manageability. This makes a sense of a Smart Wireless Sensor Network comprised of sensors and actuators making room to traditional WSN features in modern Smart Homes.

Applying WSN features to Smart Home application make great advantages such as device capability of settling and communication in low power mode, minimizing wiring cost, and ease of portability which makes wireless enabled Smart Home applications different from typical ordinary Smart Home applications.

Many researches are more interested in home digitization for human beings. WSN enabled Smart Home is more accomplished in the field of healthcare and medical. For disable people, it's really helpful to monitor and control home appliances by using a smartphone. Many researches are constrained into controlling procedures which are executed from a specific location. WSN feature are used in fields like home watering systems [15] but such system are in basic level of controlling and monitoring procedure since it cannot be operated remotely away from the specific location. Evans [16] has a concept of automating Smart Home using artificial intelligence. Fully automatic procedures are not totally reliable. System is not intelligent enough to understand human wishes and desires. Sensors in Smart Home may capable of act accordingly but controlling by human is really a necessity for day to day chores in a home. Simpler method is proposed by Das et al [17] to control home appliances by effective switching system using a GSM enabled mobile phone. Solution is gained by a verifying secure authentication code to home controlling system and mobile device through GSM technology. Prior research on WSN enabled Smart Home concept has used a different user communication protocol in XML with hard coded the functionalities [18]. Since user communication is achieved through fixed set of commands and instruction in XML language. Similar system for Smart Home automation was achieved by Jukka et al [19] using a wireless data exchanging interface. Other than Zigbee, some researches [20] have used EPIS network protocol for communication to develop middleware for Smart Home applications.

In many of previous researches on the process of home digitization, most of the applications are controlled by Bluetooth, EPIS, etc. Network protocols for above system communication are high power consuming, high cost, less secure and less reliable. Many systems are limited to a specific area with less efficiency. Fully automated controlling appliances are less practical and do not fulfill requirement of Smart Home owners completely. As for user communication protocol, XML hard coded functions are less user-friendly and modification is less efficient. With the advancements of the high technology, it is worth to use smartphone as a controlling source with GSM, or Wi-Fi mode rather than using GSM enabled mobile phones. Many of the previous implementations were restricted to ordinary GSM enabled mobile phone to handle Smart Home concept. It's really ideal phenomenon to use a smartphone to control Smart Home in order to collaborate with high advancements of new technologies.

In our research we provide SQL database abstraction based sensor network to a Smart Home which is a different

approach compared to all existing work. Declarative nature of structured query language (SQL) eases the task of application developers than conventional programming languages and application programming interfaces (API) do.

III. Theory and Methodology

Prominent feature of the platform is its' software core. A hardware prototype was developed to demonstrate the platform features and evaluated related parameters.

Developed System hardware prototype for programming can be mainly divided into three main categories namely power monitoring unit, power controlling unit and actuator unit.

Power monitoring unit and the power controlling unit compromise of required power monitoring and commanding circuitry attached to wireless sensor modules. Monitored power related parameters are transmitted to a server module and visualized through an Android Mobile Application (compatible for Android 2.1- Eclair or above versions). *Actuator unit* reacts according to the commands given by power controlling unit. It consists of all electronics that are necessary for reliable and safe power controlling. *A server module* serves as a home to system software components. It configured to function as a command distribution center for attached wireless base module. Base module analyses and redistribute commands to entire sensor network. Figure 1 illustrates the system communication and hardware connectivity in brief.

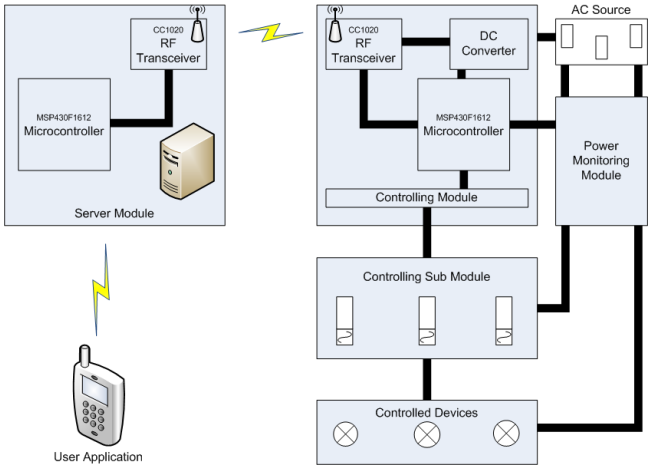

Fig. 1, System Overview

In the programming platform, core software consists of two main components. Contiki resides on the wireless sensor module provides operating system features for sensors. TikiriDB, portion of which resides on server module and the rest of it resides on sensor module, provides database abstraction feature for developers. Contiki core has been modified by developing and integrating monitoring hardware related drivers. Coniki communicates with power monitoring hardware through the driver which gives provisions for Contiki to access and modify power monitoring device registers. TikiriDB, being sensor network related abstraction for sensor related data collecting, incapability to provide Smart Home related functionalities to programmers. Communication stack was confined into limited character transfer. Further, forwarding modules only had the capability of forwarding simple grammar. Combining the software components, the new system executes power monitoring and controlling related queries. It eventually passes user commands to power controlling system on demand. Power controlling and monitoring can be view in Figure 3 and Figure 4. Comparing to existing systems, prominent advanced features is the core system software. Advanced features which were integrated into the existing software would be discussed in detail towards the later part of this section.

Communication between wireless modules is achieved by Zigbee wireless communication standard. Zigbee is well employed in this research due to its low cost, low power consumption, durability and ease of implementation. As can be seen by the diagram, a physical communication link (connected through controlling system GPIO) was used in between power controlling system and actuator system. Further, hardware consists of dedicated microcontrollers for respective intention of the system components. Following diagram (Figure 2) illustrates integrated (hardware and software) system flow.

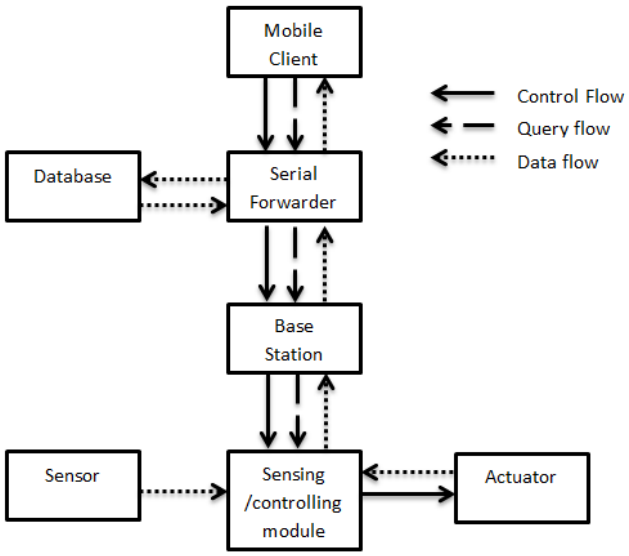

Fig. 2, System flow diagram

If an application developer for Smart Home needs to record data readings (parameters like nodeid, volt, current, frequency, power, temperature and humidity) to be displayed in the user application in every 2 seconds time periods for 20 seconds, he could send following SQL query from the preferred controlling device (in this research, a smartphone) to the sensor network.

SELECT nodeid, volt, current, frequency, power, and temp, humid FROM sensors SAMPLE PERIOD 2 FOR 20;

If an application developer in Smart Home needs to control devices attached to the network, following SQL can be used.

STORE STATUS=on SWITCHID=2;

STORE STATUS=off WHERE power>10;

Fig. 3, Control Layout

Fig. 4, Monitor Layout

Fig. 5, Sense Layout

Above implemented two queries, are switch on and conditionally off states of controlling devices. When a query is issued from user application, it sends to the server, where the gateway node is connected. Then TikiriDBs forwarding gateway software module directs it to gateway node which eventually broadcasted to the Smart Home network. Depending on the query type, platform returns the monitored data, system status or controlling query responses to controlling queries.

Conditional and Combined queries that are used in database applications to acquire cooperate results has been introduced by this platform for Smart Home application developers. This helps the developer to cultivate applications to control actuators attached to a Sensor modules based on status monitored through sensors, which are attached to the same sensor module. Following represents a conditional query.

STORE STATUS=off WHERE power>10;

Above has been used to control an actuator attached to a separate sensor module, based on power levels sensed through a sensor attached to the same sensor module. Cooperativeness of sensor and actuator can be achieved by presenting conditional queries. Mentoring the fluctuations of sensors can be view in the Figure 5.

The following query represents a combined query, where different types of sensors attached to different sensor modules cooperatively provide user required monitoring of temperature and humidity.

SELECT nodeid, temp, humid FROM sensors WHERE temp > 20 AND humid > 25;

IV. EVALUATION

Evaluation of this research work contains both qualitative and quantitative reviews. Platform features are available for developers would be qualitatively evaluated. Usability related parameters of each module would be quantitatively evaluated.

a. Qualitative Evaluation

The qualitative aspects were evaluated with an application developed to run on an Android smartphone that can be used to monitor and control the prototype hardware system. The application running on the Android device provides the functionality to the user for viewing power data and controlling power usage as shown in figure-4. We evaluate this work by going through a list of requirements that we found at initial stages and discuss whether they are addressed, if yes then how and if not then why.

- User should be able to monitor required parameters such as power level, temperature, humidity etc. regardless of the attached of the sensors to the wireless modules. That is to say that the sensors should cooperate to produce a common output at the user application.

This requirement is achieved by the platform by implementing combined queries that could ensure the cooperativeness of components.

- Users should be able to find out the amount of power usage of a building through their smartphone from any geographical location.

This is one of the main functionalities provided by the application program running in the Android mobile devices. Android application sends SQL queries to the Smart Home network and collects real time data. Platform provides the core functionality to the developer for this task.

- Users need to analyze power usage data in a building for a long time to track patterns. Therefore history data must be safely stored and retrieved when needed.

Serial forwarder of TikiriDB which is running on the server feeds all the data readings it take from the network to a database, while sending them to query, originated application running on the Android device. Therefore, the application developer can perform further analysis based on history data available on database.

- Users should be able to control power usage of a building by switching on and off the supply to different components and segments of the building using the application.

Users are provided with the capability to control the power supply of the building by turning switches on and off from the user interface of Android application. Application developer uses the implemented STORE query for the platform for this functionality. STORE query is a new branch to TikiriDBs query types which is specially developed for issuing control commands to the network.

- User should be able to conditionally control the power switches. In other words, the system should ensure the cooperativeness of sensors and actuators attached to separate wireless modules.

Conditional queries have been introduced in the platform for above task accomplishment.

- System should be able to detect unnecessary power usages and automatically control them according to some rules that users have set up

This functionality has been accomplished by implementing a STORE query for the platform in following manner which embeds into the Android application.

STORE STATUS=off WHERE power >10;

- A mechanism needs to provide for a proper security in data and functionality of the system so that unauthorized persons should not be able to read power data of Smart Home and control the power usage.

Security is a requirement that is still not addressed even in the core framework of this system which is TikiriDB. An access controlling mechanisms for TikiriDB have been proposed named as TikiriAC [21] which allows the administration of a TikiriDB based sensor network to define user privileges. It can be an ideal solution for security requirements of this Smart Home application. TikiriAC is under development and will be available in the near future as a plug-in to main TikiriDB system.

b. Quantitative Evaluation

Usability related parameters namely actuation time, actuation accuracy, monitoring time, and monitoring accuracy were tested and evaluated by directing around 200 data queries and control queries lead from smartphone to sensor network. Smartphone transfer data and instructions via Wi-Fi technology where sensor network wirelessly communicate to precede the command to handle. Following figures visualize the evaluation output for the above mentioned parameters.

Figure 6 depicts sensing time variation with respect to query frequency. Premium purpose of figure 7 is to measure variation time to retrieve sensor data and power results of Smart Home appliances gradually by increasing the number of queries directed the sensor motes.

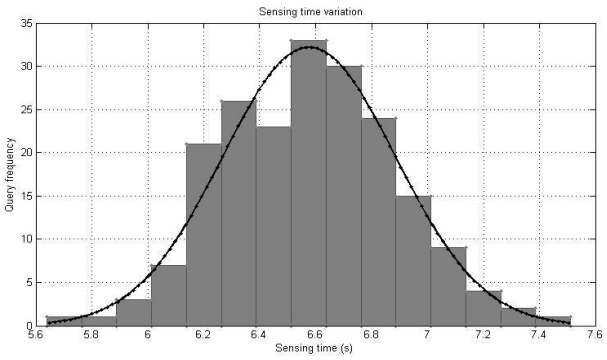

Fig. 6, Sensing time variation histogram

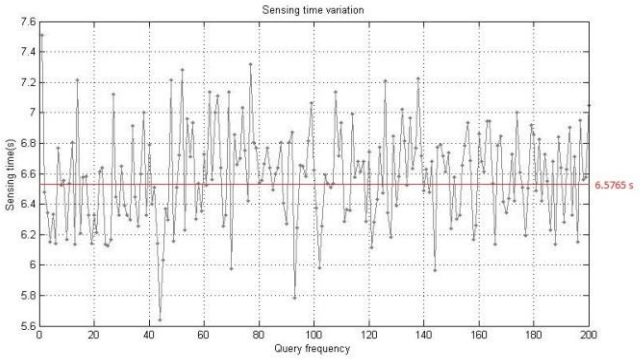

Fig. 7, Sensing time variation vs. number of queries

Averagely for the sensing procedure (Figure 7) it takes around 6.5765 s. Monitoring procedure of Smart Home appliances for 200 queries it give proper results for 97.5 % without data packet collisions and delays beyond the average time.

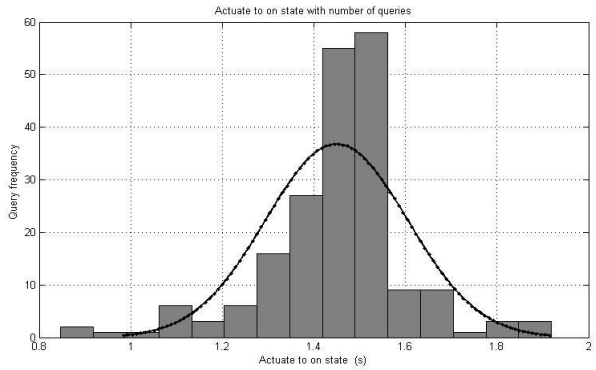

Fig. 8, Actuation histogram on "ON" state

It is a necessity to have a proper independent switching capability. Thus efficient and reliable switching procedure is a great advantage. We have tested TikiriPower to monitor the average time fluctuations in both "ON" (switch on) procedure and "OFF" (switch off) procedure. Figure 8 highlights time variations to switch on a device comparing with number of queries send to a specific device in order to switch on. According to Figure 9, average time taken to switch on a home appliance it takes about 1.4493 seconds.

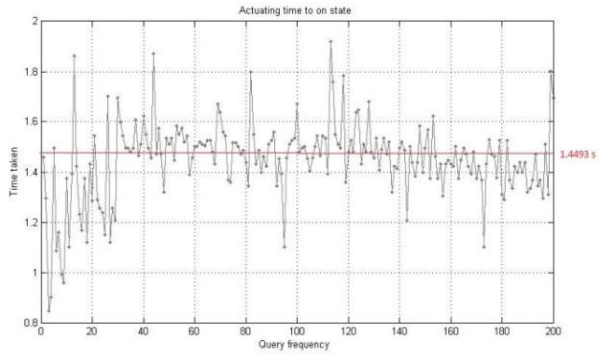

Fig. 9, Actuation time ("ON" state) vs. number of queries

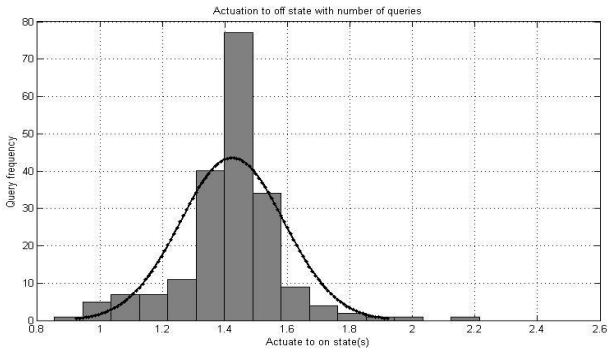

Fig. 10, Actuation histogram on "OFF" state

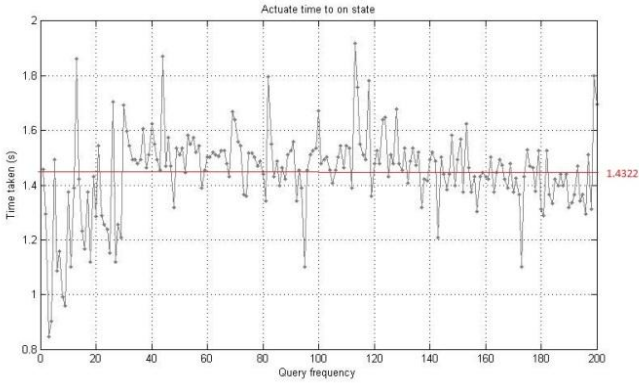

Fig. 11, Actuation time ("OFF" state) vs. number of queries

Actuation time taken to switch a device comparing with number of command queries are shown in Figure 10 and Figure 11. According to the experiments it takes averagely 1.4332 s. It gives 99 % accuracy to make the device from "ON" state to "OFF" state without query collisions or delays.

V. CONCLUSION

This research work presents a platform for novices in Smart Home applications who are less experienced in WSN programming. Thus it reduces time and effort that application developers have to dedicate for learning WSN programming or operating system related concepts in WSN. It provides an implementation for Smart Home application which is based on wireless sensor networks with database abstraction layer provided by TikiriDB. Monitoring and controlling the power usage of a house is acquired by a client application running on android mobile. Contiki and TikiriDB framework has been modified to have new type of queries to monitor and control. By implementing two types of queries namely combined and conditional, cooperativeness between sensors and sensors, sensors and actuators have been accomplished by the platform to make the development efficient together with monitoring accuracy of 97.5 % and controlling accuracy level as 99%.

Platform ensures scalability of the system by simple modifications. With the multi-hop routing protocol communication can ensure for long distance over a building without wiring. This prominent feature, platform helps the system to extend by adding new sensor nodes without changing previous deployments.

VI. ACKNOWLEDGMENT

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