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Smart Home and Ambient Assisted Living Based on the Internet of Things

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ABSTRACT

This paper presents a Smart Home and Ambient Assisted Living (SHAAL) system that has been developed and tested in a real experimental home environment. SHAAL system is designed on wireless sensor network (WSN) linked to the cloud network on the Internet. The development of SHAAL is divided into two phases: the design of SHAAL network and the development of SHAAL applications. SHAAL network is made up of the home network which is the WSN, and the cloud network. The network is designed using TelG mote that operates under Zigbee technology and includes various sensor modules for SHAAL system. The cloud network consists of the gateway, the server and user devices running on third generation (3G) network. Using priority scheduling algorithm for data transmission, it is shown that the performance delay of this system on the test-bed experiment is 34.2 percent less compared to the theoretical study. The implementation of the experimental testbed has proven that SHAAL has been successfully designed and deployed in the real world.

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1. INTRODUCTION

The future Internet, designed as an Internet of Things (IoT) is foreseen to be a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols [1]. The IoT is derived from the idea of globally interconnected continuum of devices, objects and things including computers, sensors, or mobile phones that can dynamically join the network, collaborate and cooperate efficiently to achieve different tasks. IoT comprises of strong network elements such as computers and smart phones, as well as weak elements like sensors and RFID tags with different technologies and consideration. Due to this fact, the main challenge in IoT is networking where the concern is how to interconnect a large scale heterogeneous network elements and achieve efficient data transmission [2].

Wireless sensor networks (WSNs) that connect things and machines have vital roles to collect surrounding context and environment information. The sensor nodes communicate wirelessly through multi-hops network to a central gateway that connects the sensor network to the wired world where collecting, processing, analyzing, and presenting of the measured data are carried out. WSNs form the basis of smart home and ambient assisted living (SHAAL) applications, where sensor nodes are required to control the WSN configuration that covers different task. These tasks such as addressing administration to ensure scalable network constructions and ensuring self-healing capabilities by detecting and eliminating faulty nodes or managing their own configuration must be handled efficiently for better improvement. Thus, there is a need to design and develop a practical working SHAAL applications that are tested in a real environment.

Smart home is well known as an integrated system, which takes advantage of computers, communication network as well as synthesized connections of all indoor subsystems that are attached to home appliances and household electrical devices [3]. By using smart home techniques, the management and services in the house can be centralized effectively. Meanwhile, the concept of ambient assisted living is to support the daily activities of elderly people by using intelligent products and the provision of remote services including care services within their home environment. In general, SHAAL system is a residential setting equipped with a set of advanced electronics, sensors and automated devices specifically designed for care delivery, remote monitoring, early detection of problems or emergency cases and promotion of residential safety and automated living [4]. The SHAAL system requires the development of application specific design and protocols. It is also necessary for the system to have a reliable networking, trouble free operation in different geographical locations and minimal maintenance. Hence, the system design should be robust, reliable and provides immediate information to users when something occurs at home.

This paper presents the design and implementation of SHAAL system in a real test-bed using priority scheduling, which include the hardware design and software programming and configuration of WSN, the gateway and the server residing in the cloud network. The rest of the paper is organized as follows. The next section discusses the related works for sensor networks and SHAAL applications. Section 3 describes the system model for SHAAL and the development of SHAAL applications. Meanwhile, Section 4 presents the performance evaluation of the proposed system and finally this paper is concluded in Section 5.

2. RELATED WORKS

A typical WSN architecture consists of a base station, sensor node, event area and the user. Nevertheless, the specific architecture and function of WSN depend on its implementation in which application-specific protocols are also required. Some of the examples of WSNs applications are environmental monitoring [5], smart home and smart city applications [6]–[8], and health monitoring [9].

A distributed algorithm for the employment of sensor networks in firefighting application is proposed in [5]. The network model in this work includes obstacles which anticipates the danger of the area under coverage. It was designed to guide the firefighters step by step through a burning area by choosing the safest path. The simulations have shown that the network can adapt to the introduction of new obstacles quickly and robustly. Meanwhile, the work in [6] presented a low cost wireless controlled smart home system for controlling and monitoring the home environment. The system utilized the Arduino Ethernet for the micro-web server which is then used for accessing and controlling appliances through Android based application. The system was successfully implemented and tested where it is able to perform the smart home operations such as switching functionalities, automatic environmental control and intrusion detection.

A framework for the design of an urban IoT has been proposed in [7]. Based on the proposed framework, the authors reported its implementation in the “Padova Smart City” project. This project is a proof-of-concept deployment of an IoT island that is located in Italy, interconnected with the data network of the city municipality [7]. The proposed technical solutions that has been adopted is described in details in this paper. In addition, the measurements collected by this system is also reported. Another successful implementation of IoT is reported in [8] where an indoor architecture for smart museum was designed and validated. The authors have proposed a system that relies on location-aware wearable device equipped with image recognition to provide users with cultural contents related to the observed artworks. Using Bluetooth low energy (BLE) infrastructure, the device tracks the user and recognizes the artwork in front of the user via its localization information and processing capabilities. The proposed architecture has been deployed and evaluated in the MUST (Museo Storico) museum, Lecce Italy.

Authors in [9] proposed an ambient assisted living (AAL) application in Wireless Biomedical Sensor Network (WBSN) for measuring physiological signals in a home setting. The architecture of the proposed WBSN is the combination of biological sensors, wireless communication, embedded microcontroller and radio communication. The mote is integrated with biosensors such as electrocardiogram (ECG) and temperature that capture the physiological data. The data is then sent to a base station through multi-hop routing before being forwarded to a server of an authorized medical institution. A comprehensive review of the AAL area with an emphasis on healthcare frameworks, platforms, standards and quality attributed is provided in [10]. A literature survey was done and data from e-mail survey was collected to recognize the necessary aspects of AAL system and to study the issues from the design, technology, quality of service and user’s experience. It is found that the current AAL solutions lacks the required interoperability and integration properties that results in deployment complexity. The review also has shown that the end-users require significant technical support continuously for keeping the AAL systems operational for daily use. Hence, design methodologies play a vital role for evolving more robust and reliable AAL solutions.

3. SYSTEM MODEL

SHAAL network comprises of home network and cloud network connected through the Internet as shown in Figure 1. The main feature of SHAAL is the communication network that connects the various sensors nodes in the WSN to the servers in the cloud network using the Internet through the gateway. Major components in the proposed system are sensor nodes with sensors that measure data and form the sensor network in the home network. The sensors include temperature sensors, door lock sensor, camera, alarm and switches that control the lights. A gateway functions as the mediator that interworks WSN with the internet or Global System for Mobile Communication (GSM) network while server stores the data received from the sensor nodes.

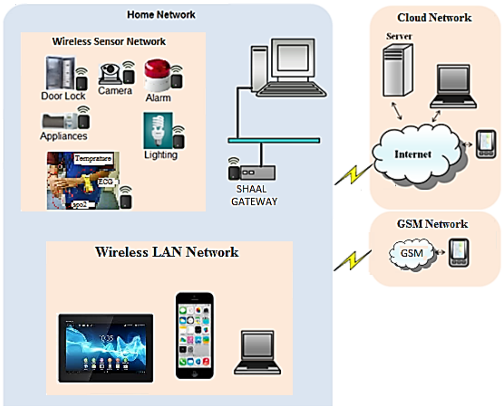

Figure 1. SHAAL system

3.1. SHAAL Network Framework

Figure 2 shows the SHAAL network architecture. The data from the sensor node is transferred into the home network and the cloud network and finally to the server based on layered approach. The home network comprises of WSN and WLAN. WSN sensor nodes communicate with each other and to the gateway. In this work TelG motes are used as the sensor nodes, with self-developed WiseOS as the operating system [11]. Several TelG motes may connect to each other to form multi-hop network. Meanwhile, a cloud network is formed by the Internet and the network may use 3G networks or the WLAN. Optionally, GSM network may be adapted to link to a mobile phone that acts as the control and monitoring end device. The Internet provides connection to the server and also to end users. The two major networks interwork with each other based on the layering concept to form SHAAL system and functions as IoT. Sensor data from sensor node is sent using IEEE 802.15.4 protocol. At the gateway the sensor data is relayed to the Internet and sent to the server using TCP/IP protocol.

The cloud network consists of servers which store the database for SHAAL system. Data and information from the home network is updated in the database. The information that is stored in the database can be accessed through web based devices such as computer, smart phone or tablet. Remote users can monitor and control the sensors at home through the internet connection. The SHAAL system can also be controlled by mobile phone, which has direct contact with the gateway.

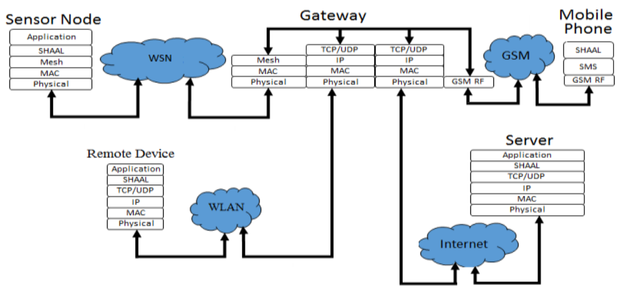

Figure 2. SHAAL network architecture

3.2. Communication of Sensors

SHAAL system includes sensor modules such as door lock, lighting, appliances, camera, alarm and AAL. Table 1 lists the specification of all sensor modules in SHAAL. The IEEE804.15.4 wireless standard has a workable transmission range of approximately 30m outdoor and 10m indoor. To overcome the limitation of wireless transmission range, the multi-hop design structure is deployed. This can extend the wireless transmission coverage area, reduces sensor nodes power used for communication when compared to single-hop, and overcomes signal deterioration due to long-distance wireless communication. The concept of multihop transmission in this work is illustrated in Figure 3.

The TelG mote as shown in Figure 4 is programmed to perform as source node or as intermediate node for multihop data transfer. If a TelG mote acts as a source node, it is programmed either to receive data from the passive sensors through input/output (I/O) interface or receive data from active sensors using the UART port. If the TelG mote operates as an intermediate node, it is programmed to receive data from the forwarding nodes and store them for transmission to the next forwarding node. A main program has been developed to execute and run in the TelG mote to receive, process and transmit data.

Table 1. Sensor modules specification

Sensor Module	Sensor	Specification
Door Lock	Gap sensor	RFID reader, magnetic lock
Lighting	PIR motion	Bulk lamp
Appliances	Switch	Socket 3 pin
Camera	Camera	C328R CMOS camera
Alarm	Alarm	Buzzer
AAL	ECG, SPO2, Temperature	CSN808 sensor board

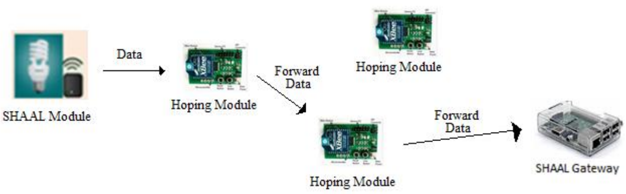

Figure 3. Multihop transmission between sensors

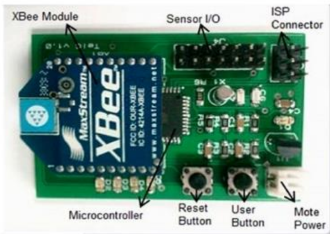

Figure 4. TelG mote with sensor I/O, Xbee and Atmel microcontroller as the control processing unit [4]

3.3. Development of SHAAL Application

SHAAL applications are categorized into two types; home applications and AAL applications. The home applications include smart door, smart lighting, smart appliances and smart surveillance while AAL applications include ECG, SPO2 and temperature monitoring. The home applications is based on client server mode where the person who is a user acts as the client and the server is in the cloud network. As shown in Figure 5, in this mode, the client has to request the server for accessing the information. Once the SHAAL system starts, it will go to listening state for user command. If a user makes a command instruction, the SHAAL application will send the command to the server state. The server will relay the command to targeted SHAAL gateway. Then, the gateway will send the command to specific sensor node. This sensor node will execute the command and reply the status to SHAAL gateway. The gateway will relay the status to server. Then, the server will reply the status of command operation to user.

In home applications, the proposed system controls alternating current power supply socket of smart appliances such as television, table fan, washing machine and refrigerators. The socket is monitored through ON and OFF operation using software programming. Meanwhile for smart lighting, lamp operation is monitored and controlled through light switch operation. Light switch module in SHAAL system is installed on the wall at home. The switch controls the operation of the lamp either to turn ON or OFF. There are two ways to control the operation of the lamp. The common method is for the user to manually switch ON/OFF or by using the software application. The second method is by using a passive infrared (PIR) sensor that is mounted on the module. The PIR works as a motion detector and can detect the presence of the user inside the house. The light will be automatically ON if the user is inside the house. Then, the light will be automatically OFF if the user leaves the house. For the application such as smart surveillance, alarm module and camera module are used. When the door lock module detects the opening of the door, the alarm is activated. The alarm message will be sent to the alarm module and the sound is triggered. After the alarm is activated, the module sends the status to the user.

The AAL application on the other hand monitors the health condition of needy or elderly people at home or nursing home. With SHAAL, nursing home can provide continuous medical monitoring of elderly or patient. Medical data can be accessed by the doctors or the caretaker even outside the home. Figure 6 shows the position of the medical sensor which is temperature sensor, ECG and SPO2; to measure the temperature of the body, the heart beat and the blood pressure of the body, respectively. All the data from these three sensors is forwarded using wired connection to the sensor nodes. Then, the data from sensor node is transmitted wirelessly to the SHAAL gateway.

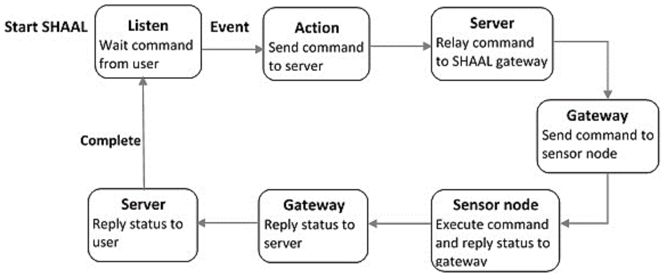

Figure 5. SHAAL operational state diagram

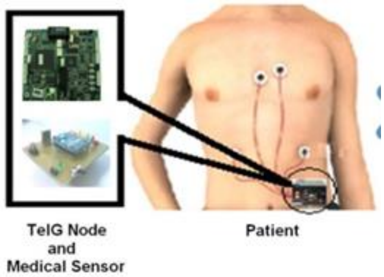

Figure 6. Data collection by sensor nodes in AAL application

3.4. Monitoring and Accessing SHAAL Application

Monitoring application at the gateway is developed to monitor three networks which are WSN, the Internet and GSM network. When handling the data from the sensor module, the received data will be delivered to a specific device module to perform a task. For instance, if there is a request to turn ON the lamp, this task will be invoked in term of instruction to lighting module. Then, the lighting module will notify the status of the operation and it will be updated in the database or to the user. For GSM network, after the network has been initialized, it waits until the GSM modem receives the instruction message that contains the request operation from the user. The instruction is transferred to the sensor module to perform WSN task. Then, the status is sent to the user using SMS messages. Meanwhile, the cloud network starts with the initialization of the connection to server. When the user receives request or want to send request, it will send command to the gateway to instruct the sensor node or retrieve information from the server. The sensor module and the sensor node are awakened and invoked and the database in the server is updated. For the purpose of monitoring, a graphical user interface (GUI) for gateway application was developed as shown in Figure 7. The GUI displays the gateway activities for administrator of the system to monitor. The status of the sensor modules can also be viewed from this GUI.

Accessing the database of sensor devices in SHAAL system can be made through any types of end user devices such as smartphone or laptop, and computer on three different platforms: Windows, Web-based and Android. Figure 8 shows the AAL application in Window platform. The data output from the ECG sensor, SPO2 sensor and temperature sensor are shown in this interface. The caregiver, physician, doctor or practitioners can monitor patient or the elderly at home and can be alerted if there is an abnormal condition that requires immediate attention.

Figure 7. Gateway GUI application

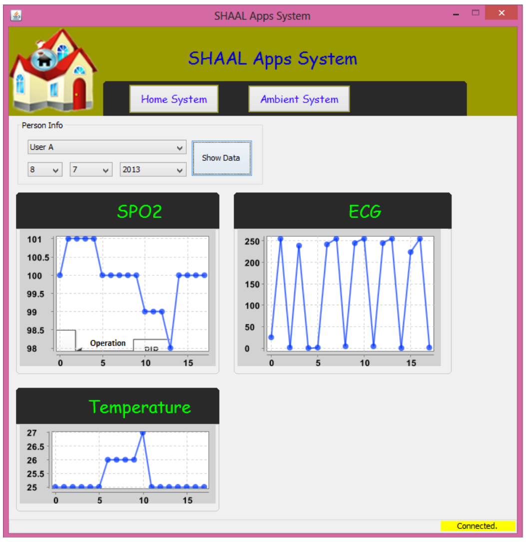

Figure 8. GUI for AAL system from Window platform

4. PERFORMANCE EVALUATION

A priority scheduling scheme is carried out in SHAAL system to ensure that the highest priority data is served first before the less priority data [12]. Consequently, the important data will be delivered with higher throughput and minimum delay. In SHAAL, the data are generated from home application and AAL system. The AAL data is given a higher priority compared to smart home data because it contains health information. Moreover, the data from an alarm module is also given a high priority compared to other data in the home application. The scheduling process is applied at the gateway that has a responsibility as an event logger. These functionalities provide the mechanism required for SHAAL system to facilitate notification of any event occurred to authorize personnel via remote terminal as well as receiving commands to be executed by SHAAL system.

The performance of SHAAL system when implementing priority scheduling is first measured in terms of packet delay, P_d as shown in (1), where P_{ts} is a packet time schedule of the data and P_{tr} is packet time received of the data.

$$P_d = P_{ts} - P_{tr} \tag{1}$$

Scheduling time is the time that is used to schedule the data in the buffer. It depends on the process that needs to be run. An experiment has been carried out to investigate the scheduling time of SHAAL priority scheduling. Figure 9 shows four different time schedules that were chosen for the experiment. The results show that the time schedule of 0.5 second produces the lowest delay. Based on this result, the time schedule for SHAAL priority scheduling is therefore chosen to be 0.5 second.

The packet delay performance for AAL system, smart appliances and smart lighting in home application is shown in Figure 10. It can be seen from the figure that the high priority data from AAL system has the lowest time delay. Meanwhile, for the packets with low priority, the packets will be served according to first in first out (FIFO) scheme. It means, the packet which comes first, will be served first. The implementation of priority scheduling requires the queue buffer. Although the delay of high priority data is better, the processing time will be affected when there are lots of packets arriving at the buffer. By using *M*/*M*/1 queuing mathematical analysis, the waiting time in the queue can be calculated using (2) [13].

$$E[W] = \rho/(\mu - \lambda) \tag{2}$$

where μ is a service rate of transmission which is equals to 625b/s [14], while λ is a packet load distribution and ρ is a ratio which is $\rho = \lambda/\mu$. Figure 11 shows the result of time delay in queue by using *M*/*M*/1 calculation and from SHAAL system. The time delay will increase with the increasing load to the queue system. It can be observed that the time delay introduced in SHAAL system is less than *M*/*M*/1 theoretical analysis by 34.2%. Although, the delay time is different for both, the pattern of graph is quite similar. It also proves that the queuing technique implemented is in compliance with the theory of *M*/*M*/1 system.

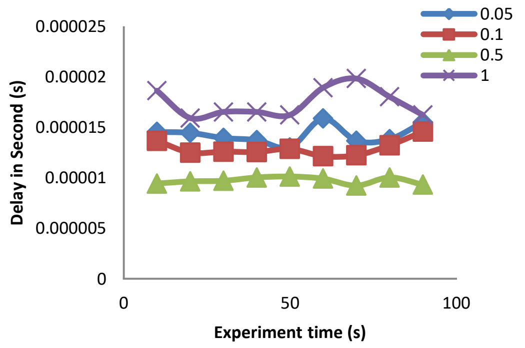

Figure 8. Packet delay with different time schedules

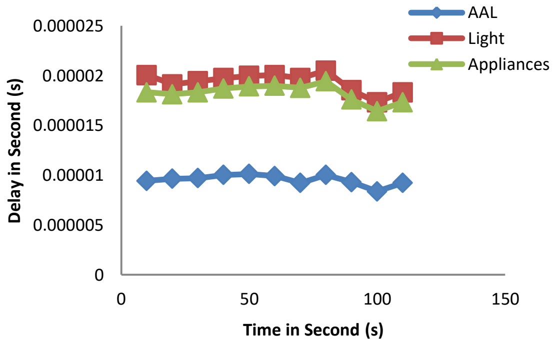

Figure 9. Packet delay with priority scheduling

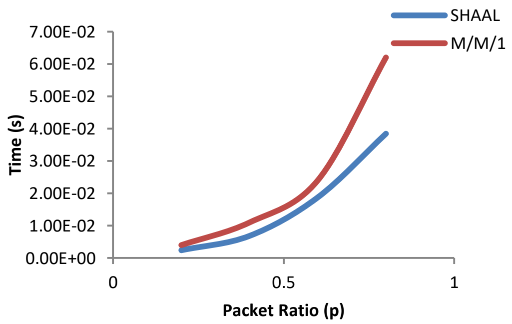

Figure 10. Delay in queue buffer

5. CONCLUSION

The research work on developed SHAAL system grants huge benefit to the comfort of living at home as well as facilitates the wellbeing of the elderly living at home. SHAAL is an example of IoT that allows things to be accessed anywhere, anytime and anyhow. The development of SHAAL began with the design of WSN as the home network and then was extended to link to the gateway and to the server in the cloud network. Finally, SHAAL applications were developed to run on the SHAAL network test-bed. Five applications that serve as smart home and ambient assisted living applications have been developed to support SHAAL. Priority scheduling is imposed to ensure more important packets from applications such as AAL and alarm applications are given higher priority to be served. The result shows the time delay incurred is less than $M/M/1$ network by 34.2%. SHAAL can be further furnished with more handy sensors that can be easily integrated into the network. The design concept of SHAAL that is intended for IoT can be straightforwardly enhanced for smart building application and can also be improved for smart city application.

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