WIRELESS SENSOR NETWORK FOR SMART HOME AND AMBIENT ASSISTED LIVING

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To my family.

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ABSTRACT

A smart home 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 quality of life. Smart home has been developed using different technology using wired and wireless network. In this project, Smart Home and Ambient Assisted Living (SHAAL) system has been developed and tested in 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 WSN has been designed using *TelG* mote as the sensor mote and various sensor modules which include door module, lighting module, appliance module, alarm module, camera module and the Ambient Assisted Living (AAL) module. TelG mote operates on Zigbee based network. The cloud network is made up of the gateway, the server and user devices running on third generation (3G) network. The development of SHAAL applications focuses on the smart door, smart lighting, smart appliances, smart surveillance and AAL applications. The various SHAAL applications run on different platforms which are Windows, Web-based and Android based smartphone. Since many applications may run on SHAAL network, a simple data scheduling scheme has been programmed to schedule data packets based on their application types and priorities. Results show packet reception rate is improved up to 22% using priority scheduling algorithm than the conventional First-In-First-Out method. Additionally, the performance delay of priority scheduling in the experimental test-bed is 34.2% less compared to the theoretical study. It is also shown that the proposed scheme can ensure higher throughput to the high priority data while gives sufficient access to low priority data. The implementation of the experimental testbed has proven that SHAAL has been successfully designed and deployed in the real world. SHAAL provides smart home automation and allows individuals to live independently in their preferred environment.

ABSTRAK

Rumah pintar merupakan tempat kediaman yang dilengkapi dengan peranti elektronik, penderia, peranti automatik yang direka khusus untuk pemantauan dan penjagaan dari jauh, turut juga mengesan sebarang masalah atau kes kecemasan dan juga meningkatkan tahap keselamatan dan kualilti hidup. Rumah pintar telah dibangunkan dengan menggunakan teknologi yang berbeza dengan menggunakan rangkaian berwayar dan tanpa wayar. Dalam projek ini, sistem Rumah Pintar dan Kehidupan Berbantu Ambien (SHAAL) telah dibangunkan dan diuji di dalam persekitaran rumah sebenar. Sistem SHAAL direka khusus pada rangkaian penderia tanpa wayar (WSN) yang dihubungkan dengan rangkaian awan di Internet. Pembangunan sistem SHAAL dibahagikan kepada dua fasa: mereka bentuk rangkaian SHAAL dan membangunkan aplikasi SHAAL. Rangkaian SHAAL terbina daripada rangkaian rumah yang terdiri daripada rangkaian WSN dan rangkaian awan. WSN ini telah dibina dengan menggunakan peranti TelG sebagai mod penderia dan juga melibatkan pelbagai modul penderia termasuk modul pintu, modul lampu, modul perkakas, modul penggera, modul kamera dan modul kehidupan berbantu ambien (AAL). Peranti TelG ini beroperasi pada rangkaian berasaskan ZigBee. Rangkaian awan pula terdiri daripada set laluan, pelayan dan peranti pada pengguna yang menggunakan rangkaian generasi ketiga (3G). Pembangunan aplikasi SHAAL memberi tumpuan kepada pintu pintar, lampu pintar, peralatan pintar, pengawasan pintar dan aplikasi AAL. Pelbagai aplikasi perisian untuk SHAAL dibina pada tiga platform yang berbeza iaitu Windows, berasaskan laman sesawang dan telefon pintar Android. Oleh kerana terdapat banyak aplikasi yang menggunakan rangkaian SHAAL, skim penjadualan data mudah telah diprogramkan untuk menjadualkan paket data berdasarkan jenis dan keutamaannya. Keputusan menunjukkan kadar penerimaan paket bertambah baik sehingga 22% dengan menggunakan algoritma penjadualan keutamaan berbanding kaedah konvensional Masuk-Dahulu-Keluar-Dahulu. Prestasi kelewatan skim penjadualan mengikut keutamaan di dalam eksperimen telah berkurangan sebanyak 34.3% berbanding dengan kajian teori. Hasil keputusan juga menunjukkan SHAAL boleh memastikan pemprosesan yang lebih tinggi kepada data utama sambil memberi akses yang mencukupi kepada data yang rendah keutamannya. Pelaksanaan ujikaji eksperimen telah membuktikan bahawa SHAAL telah berjaya direka dan digunakan dalam dunia sebenar. SHAAL menyediakan automasi rumah pintar dan membolehkan individu untuk hidup berdikari dalam persekitaran pilihan mereka.

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LIST OF ABBREVIATIONS

AAL	–	Ambient Assisted Living
ADC	–	Analog-to-Digital Converter
API	–	Application Programming Interface
CDMA	–	Code Division Multiple Access
ECG	–	Electrocardiography
FCFS	–	First Come First Serve
FIFO	–	First in First out
GHG	–	Green- House Gases
GSM	–	Global System for Mobile
GUI	–	Graphic user interface
HAN	–	Home area network
ICT	–	Information and Communication Technology
IoT	–	Internet of Things
ISM	–	Industrial, Scientific and Medical
LMDS	–	Local Multipoint Distribution Service
LTE	–	Long-Term Evaluation
M2M	–	Machine-to-Machine
MAC	–	Medium Access Control
MTU	–	Maximum Transmission Unit
OFDM	–	Orthogonal Frequency Division Multiplexing
OS	–	Operating System
OSI	–	Open Systems Interconnection
OTA	–	Over The Air
PAN	–	Personal Area Network
PHY	–	Physical Layer
PRR	–	Packet Reception Rate
QoS	–	Quality of Sevice
RAT	–	Radio Access Technologies

RF	–	Radio Frequency
RFID	–	Radio Frequency Identity
SCADA	–	Supervisory Control and Data Acquisition
SHAAL	–	Smart Home Ambient Assisted Living
SOA	–	Service Oriented Architecture
SPO2	–	Saturate Pulse and oxygen in blood
UMTS	–	Universal Mobile Telecommunications System
WAN	–	Wide Area Network
WiMAX	–	Worldwide Interoperability for Microwave Access
WLAN	–	Wireless Local Area Network
WMN	–	Wireless Mesh Networking
WPAN	–	Wireless Personal Area Network
WWAN	–	Wireless Wide Area Network
WSN	–	Wireless Sensor Network

LIST OF SYMBOLS

E	–	Packet Waiting time
λ	–	Packet Load
μ	–	Service rate transmission
ρ	–	Ratio λ over μ
P_d	–	Packet Delay
P_r	–	Packet Receive data per second
P_s	–	Packet Send data per second
P_t	–	Packet Throughput
P_{tr}	–	Packet Time Receive
P_{ts}	–	Packet Time scheduling
t_{dr}	–	Time delay response
t_{rs}	–	Time receive status
t_{sc}	–	Time send command

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CHAPTER 1

INTRODUCTION

1.1 Background

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, RFID tags or mobile phones that can dynamically join the network, collaborate and cooperate efficiently to achieve different tasks. IoT has infiltrated almost every aspect of modern living, from monitoring energy use in offices to tracking and assisting health improvements.

Wireless Sensor Networks (WSNs) that connect things and machines have vital roles to collect surrounding context and environment information. Sensors, devices, and machines, connect with each other in order to generate, analyze, and communicate intelligence data, and hence improve operational efficiencies. Wireless sensor network with spatially distributed autonomous devices uses sensors that are combined with a gateway to create a one communication system to monitor a phenomenon such as physical or environmental conditions [1]. 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. Routers can be used to gain an additional communication link and coverage and hence extending the reliability of the network [2].

Smart home is well known as an integrated system, which takes advantage of computers, network communication 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. In term of convenience, they help people in optimizing their living style, rearranging the day-to-day schedule, securing a high quality of living conditions and in turn enable people to reduce bills from a variety of energy consumptions.

Ambient intelligence is a vision of the future information society stemming from the convergence of ubiquitous computing, ubiquitous communication and intelligent user-friendly interfaces [4]. Ambient Assisted Living (AAL) aims at extending the possibility of elderly people living within their home environment by increasing their autonomy. The concept of AAL is to support the daily activities of elderly people by using intelligent products and the provision of remote services including care services. Most efforts towards building AAL systems for the elderly people are based on developing pervasive devices and use of ambient intelligence to integrate these devices together to construct a safe environment. Ambient intelligence refers to electronic systems that provide services in a sensitive and responsive way to the presence of people, and unobtrusively integrated into our daily environment [5].

In general, smart home and AAL 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 [6, 7, 8, 9, 10].

1.2 Problem Statement

The current life style demands an easy, fast, secure, ambient and comfortable style of living. This is especially true for elderly people, where there are needs to provide assisted independent living in order to increase the quality of life. In addition, there are increasing needs for system that supports green lifestyle, where it can reduce the electricity consumed and leads to optimized energy usage. Based on this, a smart system should be developed that can provide a better solution for human and green environment.

The home control and monitoring applications and ambient applications system require the development of application specific design and protocols. Meanwhile the ambient system necessitates embedding sensors in human or close to human organs,

requires safe and reliable networking, trouble free operation in different geographical locations and minimal maintenance. The design of smart home and ambient application system should be robust, reliable and provides immediate information to users when something occurs at home.

Since WSN forms the basis of the home and AAL applications, sensor nodes are required to control the WSN configuration. The configuration covers different 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. However, self-configuration of participating sensor mote is not a common feature in the WSN. Instead, the user is expected to reinstall applications and recover the system from crashes. In contrast, the unattended operation of autonomous sensor nodes requires novel means of network configuration and management. Thus, there is a need to allow flexible reprogrammable of sensor nodes should problem arises.

Other challenges include issues such as wireless networking protocols, power-efficient design architecture, security and performance problems that should be handled efficiently for better improvement. Thus, there is a need to design and develop a practical working smart home and AAL applications that are tested in real environment.

1.3 Research Objectives

The main goal of this research is to design and develop Smart Home Ambient Assisted Living (SHAAL) system for controlling and monitoring of home and the health of the elderly living in the house. In order to achieve the main goal of the work, the specific objectives of the research include:-

- To design and develop SHAAL network that provides interconnections and remote access through cloud network.
- To develop home and AAL applications running on SHAAL network on different hardware and software platforms.
- To evaluate the performance of SHAAL in real test bed implementation.

The proposed SHAAL system will be assessed based on the performance of the real experimental test-bed. The measure of effectiveness will be centered on the throughput in terms of packet reception rate (PRR) and packet time delay. The comparison of the performance of the test-bed with the theoretical study will be used as the confirmation of reliable network.

1.4 Scope of Work

The scope of this research is to design, develop and implement SHAAL system in a real experimental test-bed. The work includes the hardware design and software development of SHAAL system. SHAAL system consists of the SHAAL network and SHAAL applications. This work is based on the previous work on WSN network project at UTM-MIMOS center of Telecommunication Technology. In the previous work the sensor node defined as TelG mote and its operating system (OS) has been successfully developed and used discretely in Wireless Biomedical Sensor Network (WBSN) [11] project and Wireless Multimedia Sensor Network (WMSN) [12] project. SHAAL will be designed and developed based on these previous projects. The research work in this thesis is limited to:-

- Design and implementation of SHAAL network
  The design and implementation of SHAAL network is realized in a real experimental test-bed which include the hardware design and software programming and configuration of WSN, the gateway and the server residing in the cloud network. The development of WSN includes the design of sensor modules, the integration onto the TelG motes as the sensor nodes and the enhancements of the TelG motes. The sensor modules are restricted to home applications and health application which include door lock module, lighting module, appliances module, camera module, alarm module and AAL module. The gateway has been designed and configured on Raspberry Pi processor board. In this work the server is realized on free basic server.
- Interworking between home network and cloud network
  The function of the gateway is to interwork the WSN as the home network and the cloud network that holds the server. In this work, WiFi modules, 3G modules and GSM modules are used to link WSN to the outside world.
- Development of SHAAL Applications

The development of SHAAL applications is built on SHAAL network that relies on the relevant sensor module being addressed. SHAAL applications are accessed by end user connected to the cloud network. End user hardware device may vary from smartphone, laptop, tablets and personal computers. It is envisaged that users may want to access and retrieved information from the server using either one of the three different platforms; Windows, Web browsing and Android platforms. These will involve several programming language such as PHP for server, C for hardware and Java for GUI.

- Performance evaluation of SHAAL system
  The performance of SHAAL system will be evaluated on real experimental test-bed. The experiment scenario took place in real home-like situation, where the room is installed with SHAAL system. In the study of SHAAL system evaluation, it is assumed that data packets from only two different SHAAL applications are multiplexed at the same time with and without priority scheduling.

Since the entire work of the research involves the design and implementation of real experimental test-bed, the results of the research is in the form of system demonstration and experimental findings.

1.5 Research Approach

The design and development of SHAAL have been carried out in two phases. The first phase is the hardware design of embedded programming in SHAAL network. SHAAL network comprises of home network and cloud network. The main challenge is the design of WSN comprising of sensor nodes and the sensor modules. TelG motes are programmed to act as sensor nodes that drives the sensor modules. The hardware design of the sensor modules are based on the various sensors used for the specific applications. TelG mote has been enhanced with Over The Air (OTA) uploading and execution program for flexible reconfiguration of TelG mote operation. On the other hand the design of the cloud network is furnished with the gateway and the server. The gateway is programmed to allow internetworking between WSN and 3G and alternatively GSM network. Interconnections to the LAN and WLAN network can also be easily configured. The cloud network rides on the Internet network using 3G network

The second phase is the software development of SHAAL applications on the various hardware and application platforms. Five main applications have been developed including smart door, smart lighting, smart appliances, smart surveillance and AAL. The application software platforms considered in SHAAL are Windows, Web based and Android platform. The graphical user interface (GUI) is developed on the three different platforms for various end user devices such as smart phones, laptop, tablet and personal computers.

Finally, the performance evaluation on SHAAL system and the applications running on SHAAL is carried out. Figure 1.1 shows the research approach in resolving the design and implementation of SHAAL.

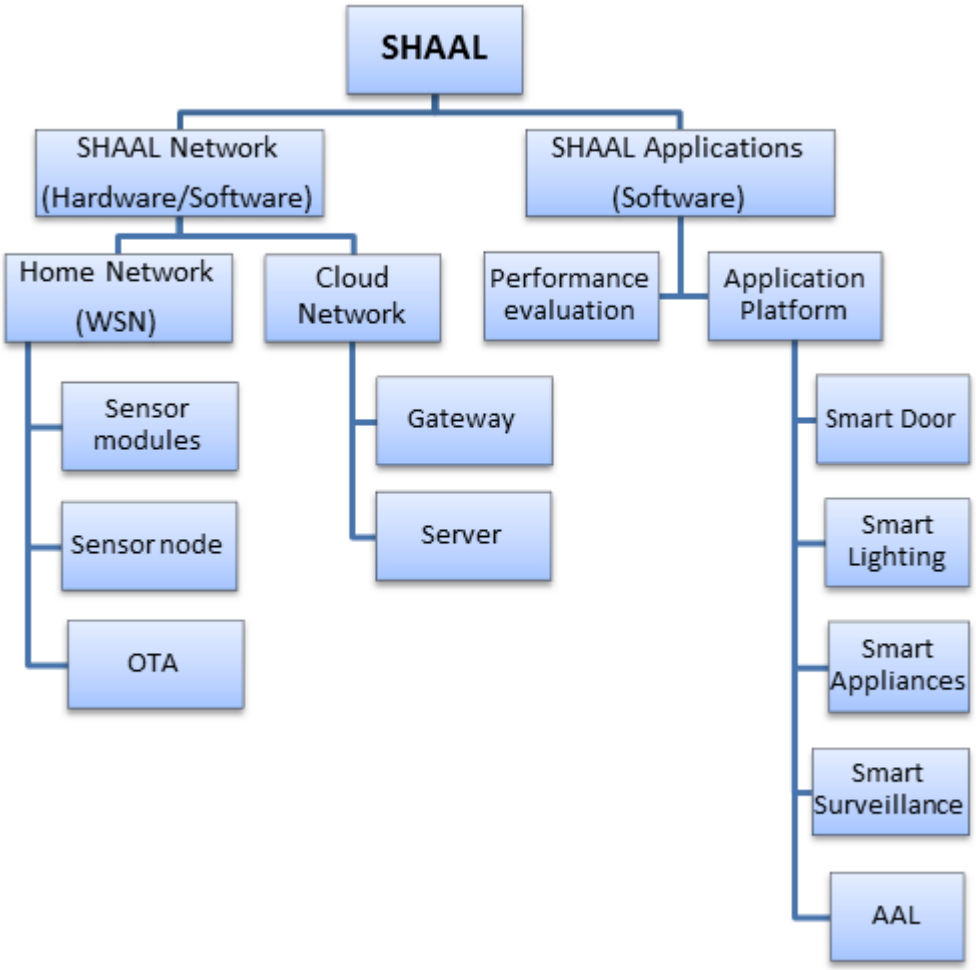

Figure 1.1 Phases of SHAAL development

1.6 Significance of Research Work

The achievement of developing and implementing SHAAL opens up more possible applications development for smart living. SHAAL provides services that satisfy the ever growing demand for comfort and pleasure, services related to e-Health, alarm systems, energy control, etc. that will invade future homes and change human daily life style.

The demonstration of SHAAL exemplifies how the smart home may function in the near future. It is envisaged that there will be more realistic vision with different sophisticated functions in a home environment. SHAAL lays down an open environment where the consumer and internet enabled devices interact through different kinds of services and functions. Future SHAAL related IoT applications may include smart building, smart transport, smart government and many more.

1.7 Thesis Organization

This thesis presents the research project on the design, development and implementation of SHAAL. Chapter 1 introduces the research topic, problem statement, and research objective, scope of work and the research approach of developing SHAAL system carried out in the thesis.

Chapter 2 elaborates the wireless technology such as WSN, WiFi and Wireless WAN. These wireless technologies will be used in development of SHAAL system. The function of smart home and its architecture is highlighted in this chapter. The structure of AAL system within the focus research area is also described. The final part of Chapter 2 discusses the existing related works for smart home application and AAL application which motivate the research work presented in this thesis.

Chapter 3 describes the design of SHAAL network. In the design, SHAAL network is composed of home network the cloud network. The design and implementation of WSN in the home network is elaborated and the development of the gateway and the server in the cloud network is explained. The bootloader program and OTA programing on TelG mote are also highlighted. A basic experimental testing of WSN network design is carried out to ensure remote communication in SHAAL.

Chapter 4 focuses on development on SHAAL applications such as smart door, smart lighting, smart appliances, smart surveillance and AAL running on SHAAL network. The various applications function on different end user software and hardware platforms. The end-user hardware platform includes smartphone, web browser based and Android platform.

Chapter 5 presents the performance of the SHAAL system with scheduling scheme. This scheme includes the priority scheduling for data from AAL module.

Chapter 6 concludes the outcomes of this research and proposes possible immediate and long term strategies for future works.

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