Development of an Embedded Smart Home Management Scheme

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Abstract

This paper describes the development of an embedded smart home management scheme over the Ethernet network. The platform of the smart home management system is built using bespoke embedded system design. An embedded control module developed by exploiting the Web Services mechanism, consist of 15 monitoring channels based on XML SOAP standards. Each channel is integrated to dedicated smart home management scheme and performs bi-directional real-time control. In the event of server unavailability, a mobile based communication module using GSM has been deployed as an alternate management mechanism. The proposed embedded-enabled solution offers bi-directional real-time management as well as optimized performance for smart home environment.

Keywords: *Embedded system; smart home; Web Services; interoperability*

1. Introduction

Recent advances in home technologies have fostered the rapid development of devices for smart home users. The Internet accelerated the availability of various appliances and devices in home that could automate and process information for specific services required in smart home environment. In particular, these devices are aimed to comprehend efficient interoperation and integrating the smart home with cyber environment, especially with the Internet. A smart home is defined as an intelligent environment that is able to acquire and apply knowledge about its inhabitants and their surroundings in order to adapt and meet the goals of comfort and efficiency [1]. The smart home also can be considered to be an augmented environment with the ability to offer home dwellers with the unprecedented level of access to information and assistance using cyber-physical systems. Recent expansion of services has been gradually transforming smart homes into a data cloud with many devices and appliances configured for specific domains. This alteration results in few problems, associated with administration and operation of devices in such environment. The first problem is associated with the existence of multiple devices in home environment that promote the growth of gateways. In typical home setting, different communication protocols and standards are deployed. These differences require number of gateways to be configured to support each device within home environment. A gateway plays significant role in converting a protocol to another protocol by mapping diversified data points [2]. With diversified protocols, considerable effort needed by the gateways to map the data points in a resourceful manner. This results into additional expenses for system developers. Gateways deployment

for legacy and new devices in home environment could slow down the performance of devices during protocol conversion. Another rising problem is the difference of resources, operating platform and programming languages accepted for home management systems. There are vast occupancies of new devices and appliances from different vendors that need certain degree of interoperability to perform their task accordingly. Heterogeneous services and devices need to be interoperable each other in order to perform joint execution of tasks. These heterogeneous services and devices contribute towards expanding the geometric range for smart home systems as well as driving new requirement that could fit the environment. For home systems, the main challenge is to provide interoperability between external environment and the home using common standard or solution. XML and Web Services technology are seen as potential answer in providing degree of interoperability for managing home systems. During the past years, XML and Web Services have been increasingly seen as a solution for larger distributed system. These criteria fit the home environment due to its diversification of services ranging from multimedia to home controls. The fundamental entities of Web Services are *publish, discover and invoke.* These fundamental entities are defined by Web Services standards known as Simple Object Access Protocol (SOAP), Web Services Description Language (WSDL) and Universal Description, Discovery and Integration (UDDI). Among these standards, SOAP act as *protocol glue* that lets users and service providers to 'talk' each other and exchange XML data to enable communication across the Web. SOAP defines an XML envelope to carry messages and invoke remote procedures between systems in a standard way that is operating systems, programming language and geographically independent. Using SOAP technology, Web Services can be invoked by turning a service invocation into XML message format. Recently, Web Services gained attention from developers when Open Building Information Xchange (OBiX) initiated by OASIS creates comprehensive standard for information exchange among various sub-systems that could facilitate home and building industries [3]. In this paper we will discuss the implementation of smart home management systems using SOAP technology. The system solution is built using embedded system. Embedded systems run custom software applications and provide generic features resembling PCs. These embedded systems are ideal for home environment due to their characteristics and desirable features like:

a) Extensibility: their smaller modular size enables extension to various home applications like access points and surveillance systems as well as wide range of digital and analog I/O modules.

b) Scalability: Embedded system units have wide spectrum of CPU types that allows easy scalability towards better performances for various home applications

c) Power management: The requirement of many embedded systems is low enough and could provide 24x7 uninterruptible supplies. This is an important criterion for home management systems especially for safety critical sub-systems like health monitoring that need to be in continuous operation.

d) Invisible computing: Embedded systems could realize the prospect of invisible computing in smart home environment to become more realistic.

The control and monitoring of the smart home management systems can be accomplished using either wired or wireless technology. We will also discuss on the use of alternate control mechanism using GSM in the event of server downtime. Implementation of SOAP assures smooth information exchange in the smart home management systems as well as effectively becoming distributed in nature to support appliances control and monitoring. In this paper, related works are discussed in Section 2, followed by system architecture in Section 3.

Section 4 dives into experimental work and evaluation. The paper is concluded in Section 5 with justification and future work.

2. Related Works

Several systems have been implemented to cater the functionalities of home management over the Web. One of the most common solution to solve the management issues are using network gateways (consisting hardware and software modules) between defined home networks that exist in smart home environment. These network gateways provide interface and translation mechanism between home networks for managing different systems in the smart home environment. An example is the interface between UPnP and LonWorks as highlighted by Cemishkian, *et al.*, [4] in their work. However, this solution lacks of scalability because the number of gateways grows up dramatically with respect to the number of systems to be connected. Here, home networks also follow the Metcalfe's Law wherein *n (n-1)/2* gateways would be necessary to support new services or devices in the smart home systems. There have been quite a number of proposed solutions using middleware's for smart home management systems [5-6]. Middleware standards like COBRA and DCOM are primarily for general Internet applications and they have some problems to be directly used for the smart home management systems. Problem like interoperability and network messages that hardly pass through firewalls makes them not preferable for smart home management systems. There is one important solution that comes from OSGi alliance [7]. OSGi is an open standard based software framework that represents gateway for home management systems. Work proposed by Charles Gouin-Vallerland, *et al.*, [8] focused on applications deployment is smart home using OSGi. Other similar work also highlighted the outcome of OSGi in smart home management systems [9]. Since OSGi is based on managed Java framework, home user may need to download Java Virtual Machine (JVM) into the external sub-systems or client terminal each time to perform operation and management. Another solution proposed by A.R Al-Ali, *et al.*, [10] demonstrated the potential of Java Server Pages in managing home appliances over heterogeneous environment. However, all the proposed design requires installation of Java Virtual Machine (JVM) in the remote systems. A similar solution that supports heterogeneity in smart home systems was presented by V.Kapsalis, *et al.*, [11] using web service for various service provisions. The emphasis was given towards e-services with dedicated application and lack of performance test. The works presented in [12-13] are some significant outcome on smart home management systems using Web technologies. A common feature of all these smart home management system is that they focus on a single platform implementation (device control) and does not work heterogeneously. These systems are designed in isolation and not meant for joint execution of tasks. If new systems needed to be integrated, a different architecture and software system has to be deployed. The legacy systems and the newly deployed could not 'talk' each other during integration. Another similarity is that all these systems are required to keep separate network connection for their operation in the home. Number of separate connection will consume up to number of gateways. In addition, each gateway will constitute as entry point of each network in the home and this takes up the bandwidth. Gateways also need to equip with better security enhancement or firewalls for full protection availability in home networks. Finally, each time new services introduced, configuration of the networks also changes and this lead to additional service or status update into the home dwellers databases.

3. System Architecture

This paper presents an integrated approach using SOAP protocol for effective web-service enabled smart home management systems. The proposed smart home management system able to support multiple services and devices integrated using embedded system. The embedded system is configured as residential gateway as well as interfacing with switching module and remote client. The residential gateway resides in the embedded system with a database module in the backend. The entire connectivity of the home management system takes place via Ethernet configuration. Ethernet is ideal for smart home environment due its performance in real-time as well as taking into consideration residential cabling of Cat5 that is readily available in homes. Ethernet has made its way to smart home environment due to its low cost implementation and wiring. The entire communication between devices and smart home management systems is based on SOAP messaging protocol. SOAP is chosen for its interoperability characteristic and defines a standard mechanism of message exchange using XML envelope as payload. The main advantage of SOAP usage is that it provides an open standard for end-to-end communication that is vendor independent as well as high degree of flexibility for disparate systems integration. Smart home environment are generally comprises of distributed entities with heterogeneous services and application. In such environment, interoperability requirement places a great importance to ensure interoperation among heterogeneous applications or services. SOAP as Web services technology would enable message exchange between two different sub-systems regardless of operating platform or language used. The whole system architecture is shown in Figure 1.

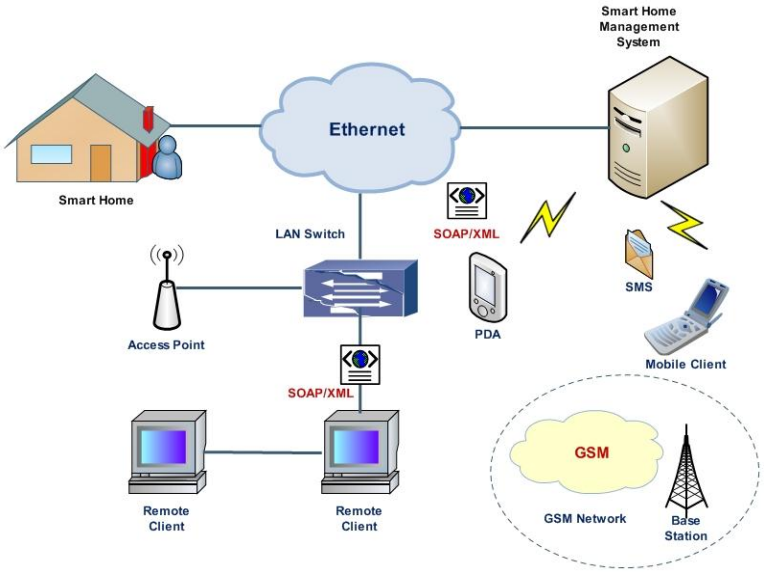

Figure 1. System Architecture for Smart Home Management System

3.1. Embedded System

The home management system is developed using embedded systems delivering both storage and gateway functionalities. For smart home management system the embedded systems forms the central module which hosts the server, drivers and software engine. Functions performed are to integrate the associated modules of home management systems and as gateway. The system is configured using Windows Server 2003 and Internet Information Services 6.0. .NET Framework 2.0 [14] is installed and configured together with

SQL Server as database in the backend. The software engine written for smart home management is stored using the 1GB Compact Flash™ storage available in the small for factor system. The system also supports 2 inputs and 2 outputs of Ethernet connectivity and system memory available up to 1024MB. Four USB 2.0 ports as well as two IDE ports are sufficient for external device configuration. Using RS-232 connection, the embedded system is integrated with the switching module interfacing the home devices and appliances. One of the characteristic of smart home management is to be operational 24 x 7. Home dwellers are also expected to access the appliances information all the time. Thus, embedded system seems to be an ideal platform for continuous operation with lesser downtime. Figure 2 shows the use case diagram for smart home management system:

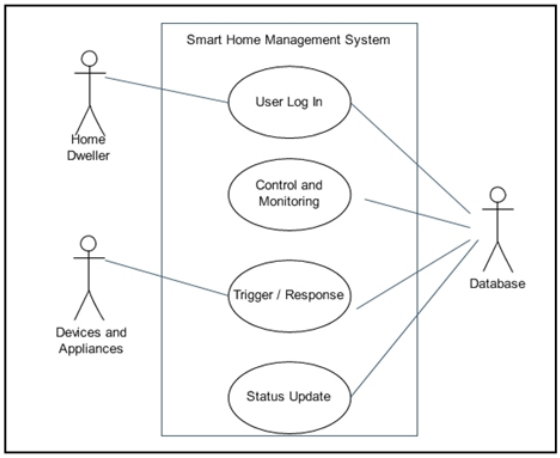

Figure 2. Use Case Diagram of the Management Consoles

The use case diagram in Figure 1 above depicts the purpose of smart home management system to perform four chronological tasks. The home user would be required to login to the system and configure their desired devices. Once the configuration takes place, the system will trigger the devices and update their status to the database. Status update provides home dwellers as a feedback reference of the operating devices or appliances controlled by the system.

3.2. Interfacing Module

Interfacing module comprises a web server chip with complete protocol stack installed on complete real-time operating system. This module provides all the necessary functionality needed for both Ethernet and Internet connections. Pre-configured functional stack for TCP, DHCP, HTTP and SNMP are included in this interfacing module. Using the software interface API, the entire interfacing module designed to cater the TCP to Serial conversion. The module is fully integrated with 10/100 Base T transceiver for Ethernet connectivity. The interface module manages and converts the network data from the home management system, to serial connection. This serial data resulting from the conversion will be routed to the switching device to perform the control mechanism of home systems. The entire process is vice-versa and provides feedback to the home dweller's client device or terminal. Figure 3 below shows the interfacing module.

Figure 3. Interfacing Module

3.3. Switching Module

One of the core modules for the home management system is the switching module that handles incoming signal for control and monitoring the home devices. The switching module is an expanded unit interfaced with the embedded system through the Ethernet connection. The functionalities of this module are listening to the incoming data, analyze, and perform triggering operation of the connected home devices via the smart home management system. A total of 15 feedback signals are produced based on the relay and switching module configuration. The format of a feedback signal is Little-Endean; and the status signals are interpreted in binary. The programmed codes for switching module on both ON and OFF mode are shown in Table 1 below:

Table 1. Switching Module Control Codes

Relay ID	Hex (ON)	Binary(ON)	Hex(OFF)	Binary (OFF)
R1	51	0101 0001	61	0110 0001
R2	52	0101 0010	62	0110 0010
R3	53	0101 0011	63	0110 0011

The switching module is designed using an 8-bit microcontroller that is programmed for performing fetching mechanism of the incoming data from interfacing module and generate corresponding output switching signal. 15 switching channel for remote activation signal are configured in switching module. These switching channels are interfaced with a group of relay set that receives and triggers the incoming signal. Home devices are connected to the digital output of the relays which provide sufficient voltage compatibility. Figure 4 below shows the prototype developed for switching module.

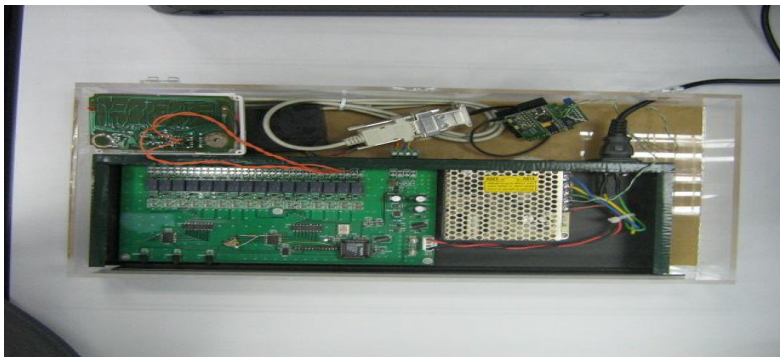

Figure 4. Switching Module

3.4. GSM Module

Realizing the potential of GSM communication in remote management systems, it has been also incorporated in this proposed smart home management system. Smart home management system has to be in continuous operational mode. In the event of server or network unavailability, the system performance would not be affected as alternate control mechanism using Short Message Service (SMS) is provided by GSM module to support the home devices operation. SMS can be seen as edge technology that is supported by mobile devices and hand-held devices. SMS also considered as most affordable solution with remote monitoring application. The purpose of incorporating GSM module as an alternate control mechanism in smart home management systems is due to the mobile device factor. Smart home users often prefer mobile devices as their remote terminal in managing their home systems due to several advantages. Home users prefer mobile devices due to its well-know interface and easier usage that often serve as primary user interface in smart home environment. These devices are also habitually carried around by home dwellers and they are most likely to be in the range of smart home environment when a physical interaction with it is about to take place. Other consideration are due to wireless network diversity, mobility as information stored on home management system remains accessible for home dwellers and personalization as mobile device belongs to certain person who uses the device exclusively. The control program, and communication protocol are stored in the embedded system while the GSM modem is connected to the system via serial interface to the switching module. The GSM module acts as an interface between the smart home management system and the GSM network, makes the system log on the network and performing data transfer and communication.

4. Experimental Work and Evaluation

The proposed smart home management system in this paper uses embedded system and client device that supports web browser, as remote terminal to access the software engine. Figure 5 shows an activity diagram of the smart home management system's operation:

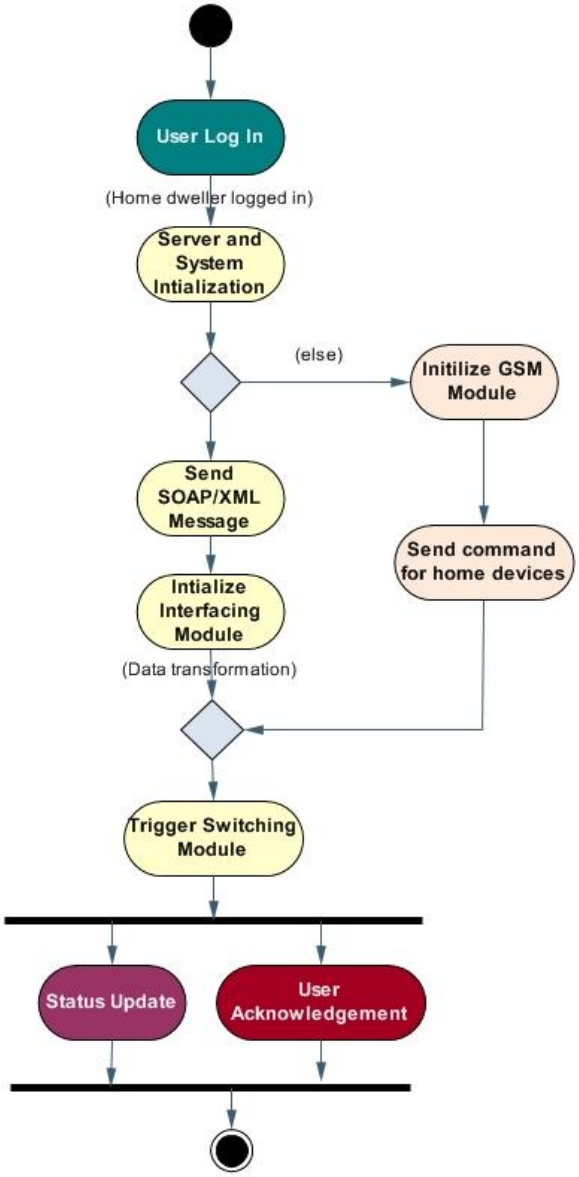

Figure 5. Activity Diagram of the Smart Home Management System

The smart home management system is activated through the establishment of Ethernet connection using pre-defined network configurations which automatically launch the network service in the small for factor systems. Once the server is initialized, the smart home management system will enable home dwellers to browse the SOAP software engine hosted in the server. Using their remote client, PC or mobile device, home dwellers will login to the system using unique user name and password. Once logged in, home dwellers could configure their desired devices to be turned ON or OFF. After the configuration performed, code transfer will begin and control data will be routed to the interfacing module. The received network data through TCP connection will be converted to serial data and will trigger the devices depending on the input ON or OFF given through XML-SOAP messages. Figure 6 below shows the body of SOAP Message carrying the control description.

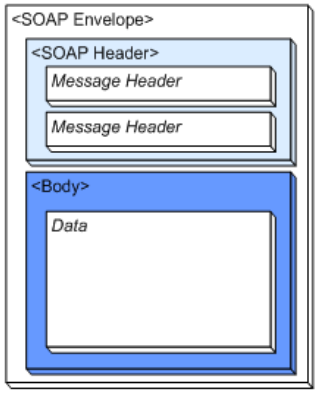

Figure 6. SOAP Message Structure

In the event of server or connection unavailability, the smart home management system could still be running and operational using an alternate control mechanism using GSM module. Using the GSM Module, home dweller could send the command in the form Short Message Service (SMS). Home devices connected to the smart home management system might not guarantee a successful operation of the system as there might be noise, defects or delay in receiving input signals. Therefore, to solve such defects, a feedback diagnostic unit has been incorporated within the switching module to provide indication of device status once control command received.

4.1. Performance Analysis

SOAP protocol is still in its infancy when comes to cross-platform communication for smart home systems [15-17]. SOAP is the ideal protocol for applications like smart home management system which run on a single platform and within Ethernet cloud (local area networks). Another obvious reason of using SOAP in smart home management system is because there is no requirement for inter-communication across firewalls as smart home applications are bespoke for each home dweller. For home management system, response time evaluation is important to ensure smooth functional of load intensity during concurrent request while operating. Figure 7 below shows the test result of response time for the SOAP messages.

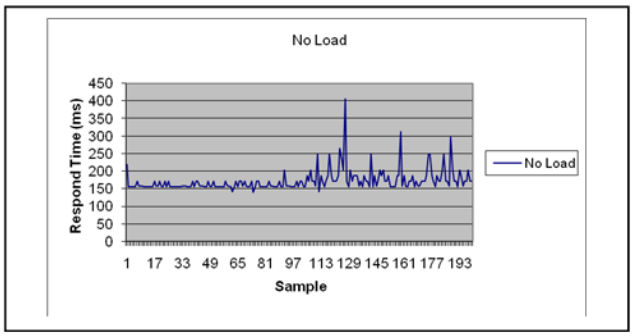

Figure 7. Response Time for Single Message Operation

From the Figure 7, the test result depicts the first response time at 219ms. During the system initialization, the smart home management system software engine is initialized at run-time by Just-In-Time compiler that is associated with .NET Framework. The compilation time produces a minimal delay in the initialization phase due to the JIT compiler execution. On overall, the test result indicates the SOAP performance (without load) with an average of 172.655ms. This average value obtained shows that the performance of SOAP in smart home management system is justified and met the requirement in managing heterogeneous devices. The test results are computed with 200 samples. The standard deviation is obtained at 30.25534622ms. No failure occurred during the testing phase.

5. Conclusion

This paper introduced the web-service enabled smart home management system, an integrated platform based on embedded system. The system is designed in such way that it caters the flexibility and interoperability of the XML based SOAP protocol in extending the functionalities of web-service enabled smart home management system. The proposed architecture provides an interoperability solution for managing home devices in an efficient manner. The developed system is based entirely of on SOAP/XML protocol which overcomes drawbacks CORBA and other proprietary standards and solution. SOAP provides scalability and flexibility in ensuring smart home systems to support existing legacy system as well as integrating new services or applications. SOAP and Web Services provides a viable framework for smart home management system taking into account of distributed nature of home environment with heterogeneous devices. SOAP implementation also would lead to transparent middleware approach bundled with universal connectivity. In near future, Web Services and SOAP protocol will have major impact in providing interoperability for smart home systems. An interesting challenge for future work would be developing a generic abstraction layer based on defined schema for managing heterogeneous systems with predefined rules extending to multimedia devices in home environment.

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