Interoperability Framework for Smart Home Systems

Thinagaran Perumal, *Member*, IEEE, A. R. Ramli, *Member*, IEEE, and Chui Yew Leong, *Member*, IEEE

Abstract — *Recent advancements in smart home systems have increased the utilization of consumer devices and appliances in home environment. However, many of these devices and appliances exhibit certain degree of heterogeneity and do not adapt towards joint execution of operation. Hence, it is rather difficult to perform interoperation especially to realize desired services preferred by home users. In this paper, we propose a new intelligent interoperability framework for smart home systems execution as well as coordinating them in a federated manner. The framework core is based on Simple Object Access Protocol (SOAP) technology that provides platform independent interoperation among heterogeneous systems. We have implemented the interoperability framework with several home devices to demonstrate their effectiveness for interoperation. The performance of the framework was tested in Local Area Network (LAN) environment and proves to be reliable in smart home setting*[1].

Index Terms — Interoperability, Smart Home, SOAP, Web Services.

I. INTRODUCTION

The large diffusion of smart home systems, together with their numerous services has led to a huge heterogeneity in the logic of interfacing and data acquisition from these systems. A smart home is an intelligent environment surrounded by disparate components that adjusts its function to home user's preferences according to the information acquired from computational system, context as well as the home user [1]. One of the main open issues in smart home systems is the integration of heterogeneous data from different devices and their ability to perform joint execution of tasks. Interoperability seems the main goal in smart home systems by providing a standard way for access as well as hiding the heterogeneity of different home devices. IEEE defines interoperability as the capability of two or more entities exchanging information and to use the information that has been acquired [2]. For smart home systems, interoperability is concerned with message exchange between two or more devices and performing interoperation in a federated manner without the need for external participation. A smart home system consist of subsystems and devices like home automation, CCTV cameras, fire alarms, audio streaming and infotainment, energy management appliances and so forth. Figure 1 below shows the components of smart home systems.

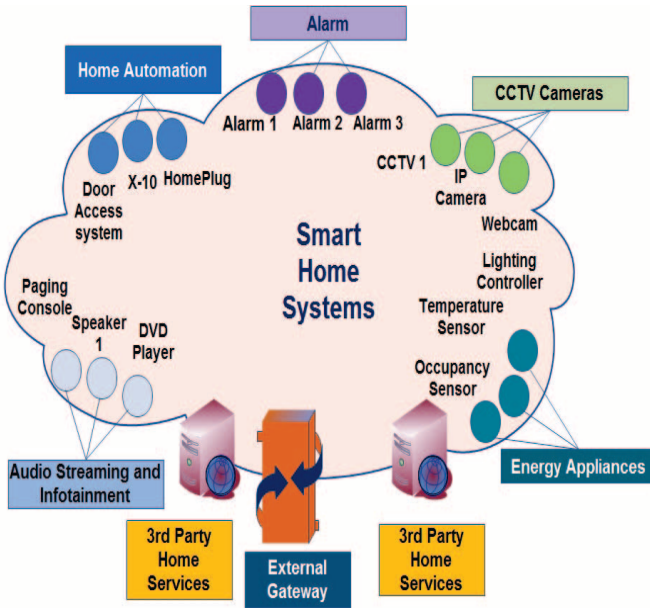

Fig.1: Components of smart home systems

Various devices and subsystems shown in Figure 1 generate heterogeneous data with respect to their functionalities and operation. Such scenario transforms the home environment into data-intensive entity that requires complex coordination and management that leads to significant interoperability requirement. In recent years, it is evident that the interoperability problem has become a major challenge for consumer electronics vendors to deploy various smart home services [3]. Lately, middleware approach has become a cornerstone in solving interoperability requirement for smart home systems project. Many interesting research works related to common exchange mechanism among different smart home systems exist, but very few architecture based on middleware have been proposed [4]. These solutions are often tightly coupled and subject to their proprietary protocols. Generally, smart home systems are developed in isolation and consist of different operating system and tier of services. There is need for a cross-platform interoperability that could make the smart home systems *'talk'* each other and operate in an interoperable fashion within home environment. Web Services seems to be the emerging technology that could lead

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Thinagaran Perumal is with the Institute of Advanced Technology, Universiti Putra Malaysia (e-mail: thina@ieee.org).

AR.Ramli is with Department of Computer and Communication Systems Engineering, Faculty of Engineering, Universiti Putra Malaysia (e-mail: arr@eng.upm.edu.my).

Chui Yew Leong is with the Institute of Advanced Technology, Universiti Putra Malaysia (e-mail: chuiyewleong@hotmail.com).

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the way in providing greater interoperability [5]. Based on Web Services paradigm, an intelligent interoperability framework technology for smart home systems is proposed. The framework is based on SOAP technology, with an effective means of representing, sharing and managing data in home environment. Simple Object Access Protocol (SOAP) is defined as a lightweight protocol intended for the exchange of structured information in a decentralized environment [6]. The strong advantage of SOAP and Web Services is to build message exchange mechanism by enabling the creation of applications and interoperable services without the knowledge of underlying systems. The outline of the paper is as follow. Section 2 presents the background and related work and Section 3 the system architecture. Section 4 describes the implementation and followed by experimental results and analysis in Section 5. Conclusions are drawn in Section 6.

II. BACKGROUND AND RELATED WORK

There have been several different initiatives in achieving interoperability for smart home systems. Several standard bodies proposed open standards like Open Building Information Xchange [7] as well as TAHI Interoperability framework [8] that addresses the importance of having common agreement for message exchange and understanding among systems in home environment. These consortiums agreed that interoperability would be the fundamental catalyst in catering the data-intensive systems in home environment. Other generic models of interoperability have been proposed by researchers [9], [10], mainly focused on syntactic, network and basic connectivity interoperability. One of the earliest work in smart home system's interoperability was a gateway integration proposed by Kapsalis et al., integrates various devices within a home environment [11].The outcome of the work was the implementation of gateway that allows dissimilar home services executed in unified manner. However the scalability couldn't be achieved due to point-to-point link implementation. Several efforts have been done in middleware technologies too. Rebeca et al. proposed the integration of various service composition using OSGi middleware [12]. Likewise, Haitao et al. implemented a skeleton based on OSGi that could provide agent based decision making in managing disparate services in home environment[13]. Their solution consist of home gateway based on hybrid OSGI middleware with UPnP technology and that works together in realizing home services. Though OSGI middleware presents a competing approach to heterogeneous subsystems management including support for interoperability in terms of joint execution of services and message exchange, they can only be implemented with the availability of Java Virtual Machine (JVM) in appliances or devices involved.

A common attribute of research works discussed in [12-13] reflects on a single scheme that focuses on specific domain of interest with isolated functionalities and only contributes in terms of unified integration. Different methods and techniques have been developed in order to assure the interoperability among several home devices and integration of heterogeneous data. They represent solutions for bespoke interoperability and/or integration problems and yet to solve total interoperability that can be easily integrated with other pre-existing platform. Besides that, these proposed solutions are not designed to support several diversified functionalities. If a new home device required to be installed, different structure would be needed, and to support it, new codes and accessibility commands has to be implemented. Modification of existing system would be expensive and difficult for home users especially when they need to add new services or home devices into their home network. In the next section, the system architecture of the proposed framework is described in depth.

III. SYSTEM ARCHITECTURE

To design and implement an intelligent interoperability framework that could manage unified device integration among smart home systems, we propose a SOAP based solution with Web Services technologies. The implementation of SOAP enables pervasive adoption for Web Services to reach interoperability. The developed framework offers several services and functionalities, which can be classified into three main categories: (a) services to elaborate data from heterogeneous sources; (b) services to manage all data sources (c) services to enable communication among heterogeneous systems. The main components of the framework consist of application interface, service stub, and database module. The framework was deployed using Ethernet configuration of home environment. Ethernet is the default connectivity in home environment with well defined structured wiring and broadband availability as well as considering its performance in real-time. The framework performs message exchange via SOAP messaging protocol. SOAP is best known for its interoperability nature and defines a standard mechanism of message exchange by 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 [14]. SOAP as Web services technology would enable message exchange between two different entities regardless of operating platform used. The components of the interoperability framework consist of application interface, service stub and database module are described in the following section.

A. Application Interface

The central component of the interoperability framework is the application interface. The application interface provides service software that locates the appropriate data ports of the respective heterogeneous devices and their integration within home environment. The application interface is also responsible to communicate with different products by means of various protocols from home devices / appliances or high-level smart home software. A driver configuration tool is provided to configure the drivers and data points for the interface, including the functions to modify the drivers and

data ports. This is useful to load data ports and drivers dynamically. The standard Web Services communication driver has been made as default driver in the implementation of the application interface, meanwhile other kinds of communication protocols can be developed for the framework according to device driver interface specification.

B. *Service Stub*

Adding new devices or appliances directly would be difficult during home service deployment. New dependencies of devices would always require major system modification to the underlying platform in smart home systems. To address such constraints, we proposed a separate module called service stub to enable new dependencies of subsystem into the framework. *Service Stub* contains built-in Structured Query Language (SQL) statements that correspond to the framework structure. Application developers could just deploy their application and subsystem dependencies based on the Application Programming Interfaces (APIs) provided in the *Service Stub*. The *Service Stub* generates the required SQL statements to allow dynamic manipulation of both rules and data in the database. An application developer would just need to call the appropriate API of preferred service, without knowing the details of the service structure; meaning that they can acquire the system information and restructure their own bespoke rules pro-actively to manage devices efficiently.

C. *Database module*

A database module is part of the proposed framework dedicated to handle the queries of SOAP messages of the devices and appliances configured in home environment. The database module consists of relational database which includes a number of methods for the storage as well as retrieval procedure of data management.

Database module accomplishes the home services function, operation logic and the access to local and remote databases. Various smart home systems often consist of remote databases provided by various providers with different technologies. The access to local and remote database is processed by database module. The database module component encompasses two distinct groups of classes called content components and data provider components. The data-provider components assist in data retrievals and updates. Developers can use the connection, command, and data reader objects to directly manipulate data. In more typical scenarios, developers use the *DataAdapter* class as the conduit to move data between the data store and the content components. In this module, all communication involves data exchange, and addressed the common data exchange limitation by using Extended Markup Language (XML) as its payload data format. XML syntax is text based and lightweight for parsing, therefore suitable for platform independent and transportable data format. In addition, employing XML as the data format on top of the HTTP network protocol minimized the firewall-related setbacks. With its XML format, the home users do not have to know device / service commands to de-serialize the packaged data. All they need is an XML parser, which is readily available in the Application Interface tier. The home device datasets are then serialized into XML and as the SOAP message is in text format, such serialization can rapidly reduce the bandwidth utilization for every interoperation task carried by the framework. The architecture of the interoperability framework is illustrated as in Figure 2 below:

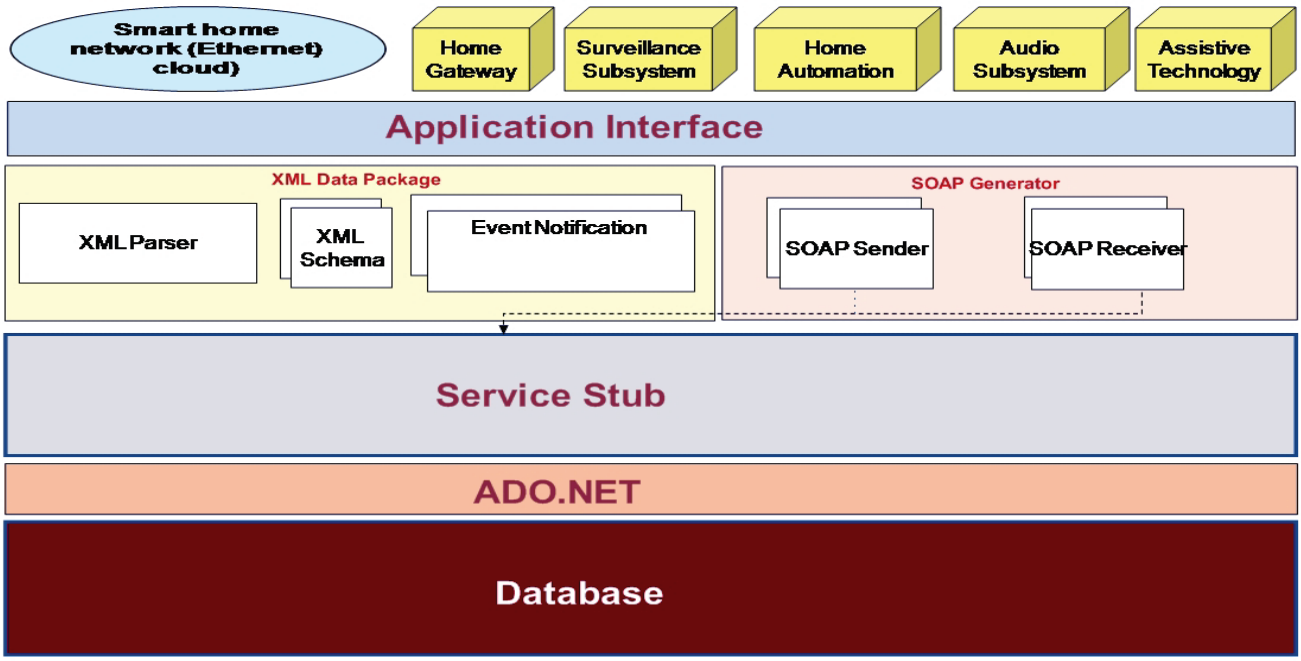

Fig.2: Architecture of the interoperability framework

IV. IMPLEMENTATION

The proposed interoperability framework in this paper uses SOAP technology for message exchange and interoperation between heterogeneous home devices and appliances. Figure 3 below shows the system implementation of the interoperability framework.

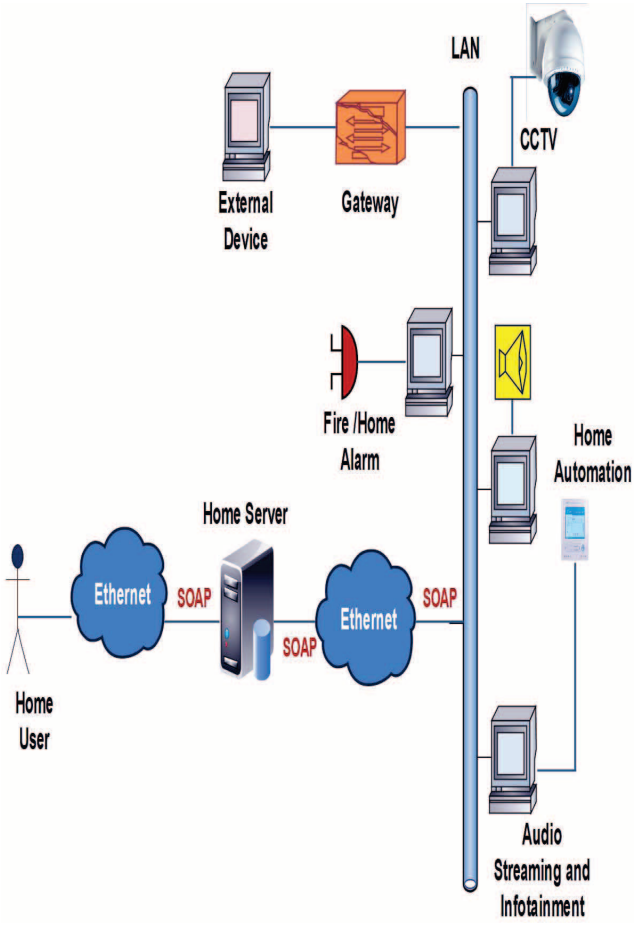

Fig.3: System implementation of interoperability framework

A home server using small form factor system is used as platform for the interoperability framework. For every event occurrences by respective devices will generate a SOAP message containing information about desired event. Once the SOAP message arrived to the home server, the SOAP contents which are in XML format will be interpreted by using XML parser. After the XML contents are being interpreted, the message is passed to the *Service Stub*. Here, the *Service Stub* will call the respective API's to communicate with database where those tables corresponding to device rules are stored. The sequence of the retrieval of tables represents the interoperation rules for smart home systems. In other words, the device rule mechanism is embedded in database as data in the form of table. The *Service Stub* will follow suitable sequences in fetching the appropriate data from the correct table of the database. From the database, SOAP packet need to be generated to notify other devices that interoperation has occurred. The notification code will go through the SOAP generator by generating SOAP packet based on the result computed by the framework.

V. EXPERIMENTAL RESULTS AND ANALYSIS

A. Experimental Setup

For experimental setup and testing purposes, three home devices have been tested together with the framework to demonstrate the framework ability in performing interoperation among them. Those subsystems are fire alarm systems, audio streaming infotainment module and home automation module integrated with 16 channels I/O. These subsystems are configured and tested through LAN (Ethernet). Two issues are critical to the performance testing that is the generation of heterogeneous subsystem's event and the use of Ethernet. One of the reasons is due to the nature of Ethernet that is non-deterministic and contributes towards non real-time performance. The need for performance testing also incurred because every subsystems would query the database to perform interoperation in smart home environment.

B. Performance Evaluation

Performance evaluation of the developed framework over network load is important to ensure smooth functional of load intensity during concurrent request of heterogeneous smart home systems that requires interoperation. The testing is conducted using 200 samples for each load condition. The results were computed in response time to evaluate the performance of the framework in each load requirement. The obtained results are then computed in standard deviation series to evaluate the entire performance of the framework. The testing was conducted with five phases; no load, 3200 Kbps, 6080 Kbps, 9600 Kbps, and 13120 Kbps loads. Figure 4 and 5 below shows response time between no load and 13120Kbps of the framework in LAN environment.

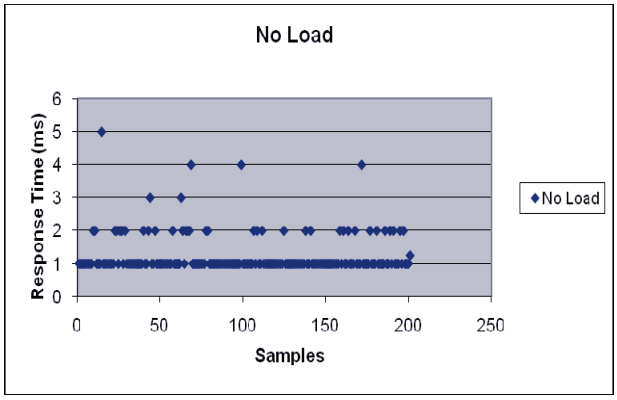

Fig.4: No load response times

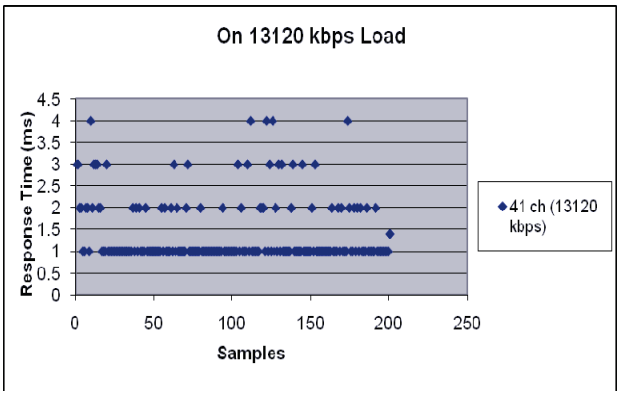

Fig.5: 13120 Kbps response times

From Figure 4and 5 above the performance analysis show that the response time for performance without load is 125.5ms. The standard deviation computer for no load requirement is 0.601484763. On the other hand, bandwidth 3200 Kbps load gives the value 137.5ms and 9600 Kbps load with 133ms. On other load testing, 9600Kbps and 13120 Kbps load resulting with 1.405ms respectively. The standard deviation value for 3200 Kbps is 0.645335019 and 0.658229695 for 6080 Kbps. The value computed for 9600 Kbps is 0.673231911 and finally for 13120 Kbps carrying increased value at 0.744139583. There is a gradual increase in the series of standard deviation for the entire tested network load. The testing results show that there are two significant performance drops with one at 10% and the other at 30% of the entire network load. Based on the outcome above, we could justify the performance of the framework are at the best performance criteria especially for the interoperation requirement among home devices.

VI. CONCLUSION

An intelligent interoperability framework for smart home systems is proposed in this paper. The SOAP based mechanism with Web Services is an ideal choice for managing diversified devices and appliances in home environment. The framework also allows new dependencies configured each time when a new home devices is added to the smart home systems without modification or external intervention. For future improvement, the framework functionality could be extended in semantic Web Services to achieve interoperability in higher tiers of home environment.

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BIOGRAPHIES

Thinagaran Perumal received his B.Eng. in 2003 at Department of Computer and Communication Systems Engineering, Universiti Putra Malaysia. He completed his M.Sc. degree in Intelligent Systems and currently pursuing Ph.D. in Smart Technology and Robotics at Institute of Advanced Technology, Universiti Putra Malaysia. His main interests are smart home systems, middleware technologies and embedded system design. He is a member of IEEE.

Abd Rahman Ramli received M.Sc. degree in Information Technology System from University of Strathclyde, United Kingdom in 1985 and Ph.D. in Image Processing from University of Bradford, United Kingdom in 1995. His main interests are imaging, image processing systems and intelligent systems. He is also involved in National Biometrics Working Groups since 2005 and actively providing consultation for government bodies.

Chui Yew Leong received his B.Eng. Electronics in 2000 from Universiti Malaysia Sabah and M.Sc. specializing in Computer Engineering in 2003 from Universiti Putra Malaysia He obtained his Ph.D. from same university. His main interests are embedded system design, network security and intelligent systems. Currently he is attached as postdoctoral fellow with Institute of Advanced Technology, Universiti Putra Malaysia. He is a member of IEEE.