Interoperability among Heterogeneous Systems in Smart Home Environment

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Abstract

The smart home environment is highly characterized by heterogeneity with many systems that need to interoperate and perform their tasks efficiently. With rapid growth of services, applications and devices in smart home environment, the interoperability factor seems still elusive. This is due to the nature of smart home as distributed architecture that needs certain degree of interoperability and interoperation for managing heterogeneous systems comprising of different platforms. These heterogeneous systems are developed in isolation and consist of different operating systems, different programming platform and different tier of services. There is need for a mechanism that could make the heterogeneous systems 'talk' each other and interoperate in an efficient manner regardless of operating platform. Web Services seems to be state-of-the art technology that could be one potential solution in providing greater interoperability. In this paper we describe interoperability issues that need to be considered and we present a solution based on Simple Object Access Protocol(SOAP) technology to solve the interoperability problem in smart home environment.

1. Introduction

Recent advances in computing and communication paved the way for emerging research and development in smart home systems research. Smart home environment is defined as an entity that could adjust its function to the home dwellers requirement according to the information it collects from the inhabitants [1]. For the past decade, research and development in smart homes moved towards ubiquitous computing, focusing on heterogeneous systems management and interoperability issues.

Heterogeneous systems in smart home environment consist of:

a) Home Entertainment
b) Surveillance and Access Control
c) Energy Management
d) Home Automation
e) Assistive Computing and Healthcare

There are many standards and middleware equipped with different communication protocols which is computationally enabled by heterogeneous systems in smart home environment. For examples, there are middleware such as Jini [2], HAVi [3], and UPnP [4] for connecting home entertainment systems while X10 technology [5] and LonWorks [6] suitable for home automation and surveillance systems. Heterogeneous systems with different specifications and middleware are characterizing smart homes towards data-intensive environment, resulting in few operational problems. The first problem is that a great number of heterogeneous systems exist covering the whole functionalities of smart home environment. Managing these systems has been difficult and contributes towards rapid growth of residential gateways with respect to the number of systems to be connected. The second problem is the interoperability issue, due to differences in operating systems, programming language and hardware for heterogeneous systems. Interoperability among heterogeneous systems involves not only by providing system interconnectivity with multiple entities but also in achieving join execution of tasks or interoperation. One of main difficulty in achieving

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interoperability among heterogeneous systems is that those systems are developed in isolation and independently without considering requirement for interoperation. Therefore, systems developed for smart home tasks consist of different operating systems, different host languages and different architectures. A mechanism needed to achieve the interoperability goal among the heterogeneous smart home systems. In order to overcome the problems mentioned above, we have explored the technologies required for interoperability among heterogeneous home systems. Figure 1 shows the required interoperability for heterogeneous systems in smart home environment.

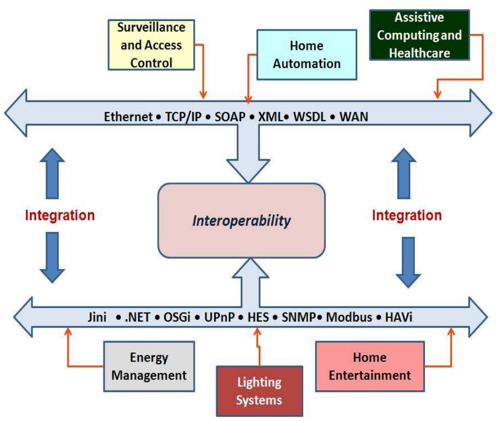

Figure 1. Interoperability among Heterogeneous Systems

The work presented in this paper is associated with the mechanism devised for integration and interoperability of heterogeneous home systems regardless of their level. This paper makes reference to the technologies associated with the proposed architecture and shows the results of deployment in addressing the interoperability for smart home systems. The rest of this paper is organized as follows. Section 2 discusses the interoperability levels in smart home environment, and Section 3 overviews related work and technologies. Section 4 describes the overall system architecture whereas Section 5 will address the system and performance evaluation. Conclusion and suggestion for future works are included in Section 6.

2. Interoperability Levels

Interoperability is defined as the ability of two or more systems exchange information and use the information that has been exchanged [7] [8]. Researcher has proposed some model of interoperability [9] [10] which have been sub-divided into syntactic interoperability, protocol interoperability and basic connectivity interoperability. These sub-divided interoperability tiers are derived from the seven layer OSI model [11]. These tiers are seems to be the foundation in achieving complete interoperability in smart home environment. A general interoperability tiers for smart home environment is depicted in the Figure 2 below:

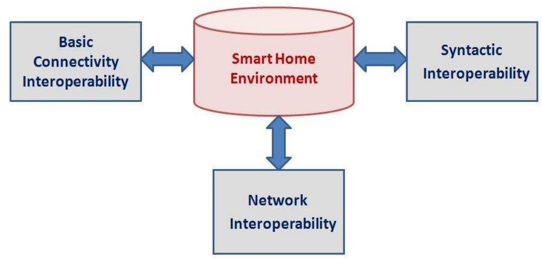

Figure 2. Interoperability Tiers for Smart Home Environment

Each of the tiers describes concerns on interoperability especially during interoperation of two or more heterogeneous systems in smart home environment. The descriptions of these three tiers are presented below:

2.1 Basic Connectivity Interoperability

Basic connectivity interoperability tier provides path for data exchange between two heterogeneous systems and established communication link. The basic connectivity interoperability can be achieved by common agreement of data transmission medium, low-level data encoding and rules of accessing the medium. Basic connectivity tier is represented by the physical and data link layers of the seven layer OSI model. Ethernet [12], Wi-Fi [13] and PPP [14] are examples of common standards for basic connectivity.

2.2 Network Interoperability

Network interoperability tier enables message exchange between systems across a variety of networks in smart home environment. It defines on agreement of addressing the issues rising from information transfer between heterogeneous systems across multiple communication links. Network interoperability is represented by the network, transport, session and application layers of the OSI model. Examples of common network interoperability standards are Transport Control Protocol (TCP), User Datagram Protocol (UDP), File

Transfer Protocol (FTP), Address Resolution Protocol (ARP) and Internet Protocol (IP/IPv6).

2.3 Syntactic interoperability

Syntactic interoperability tier refers to agreement of rules that manage the format as well as the structure on encoding information exchanges between heterogeneous systems. It provides mechanism to understand the data structure in messages exchanged between two entities in smart home environment. Syntactic interoperability is represented by the application and presentation layers of the OSI model. Some of the functions provided by this tier are message content structure, such as Simple Object Access Protocol (SOAP) encoding [15], message exchange patterns such as Asynchronous Publish/Subscribe and translation of one character data from one format to another.

3. Related Work

In addressing interoperability issues in smart home environment, a number of technologies and languages claim to provide support in managing heterogeneous systems. The common selected approaches that drives interoperability in smart home environment are Common Object Request Broker Architecture (CORBA)[16], Microsoft Component Object Model (COM) [17],.NET Framework[18], Sun's Java 2 Enterprise Edition (J2EE)[19] and World Wide Web Consortium's (W3C)[20] extensible Markup Language (XML) based Web Services. In the following section, we evaluate the interoperability approach using mentioned technologies.

3.1 Common Object Request Broker Architecture (CORBA)

Common Object Request Broker Architecture (CORBA) is an architectural framework established by The Object Management Group (OMG) [21] as part of standard in Object Management Architecture (OMA). The OMA set of standards consists of Object Services, Object Request Broker (ORB) function, common facilities, application objects and domain interfaces. The aim of the CORBA is to provide a common framework based on object-oriented applications with diverse interface specifications. In terms of interoperability, CORBA provides a mechanism to define interfaces between components, and specifies standard services such as persistent object services, directory and naming services and transaction services which is applicable for CORBA compliant applications [22]. CORBA also allow disparate systems to 'talk' each other regardless of platform used. The solution developed at University of Texas at Arlington proposed a smart home architecture called MavHome [23]. MavHome architecture was developed using CORBA interface catering the software components and power line control for managing systems in smart home environment. Although CORBA interface could resolve interoperability issues by providing heterogeneity interoperation feature for managing disparate systems, it also has some drawbacks which may not be ideal for implementation in smart home environment. Some of the drawbacks are 1) it requires information of the client system of a server's method name to utilize the functionality; 2) modification needed to enable system interoperation among heterogeneous systems, especially if the systems are not in compliant with CORBA specifications. Modification of legacy systems in smart home environment could be costly and time consuming. Therefore a framework that will enable interoperability in managing heterogeneous systems without requiring modification to the existing systems is highly needed.

3.2 Component Object Model (COM)

Component Object Model or widely known as COM was introduced by Microsoft which enables applications built from binary components defined by software vendors [24]. COM's successors are Distributed COM (DCOM) and COM+. These technologies are aimed to provide generic mechanism in integrating the components on Windows based platforms. In terms of interoperability, Component Object Model (COM) technologies provide similar features as CORBA. The difference is that COM address interoperability among binary software components while CORBA tackles at the source code level. However, the drawback of COM in providing interoperability is that it requires information of the remote systems before functioning and eventually leads into modifying the legacy systems that are not complied with COM standards. Similar to the CORBA's outcome, modification of legacy systems in smart home is not desirable for developers and home dwellers.

3.3 Microsoft .NET Framework

Microsoft .NET Framework is a technology designed by to enhance and solve problems of Internet based applications. Common Language Runtime (CLR), being the core of the framework is the successor of the Microsoft COM technology.

CLR relies on Microsoft Intermediate Language (MSIL) in providing an independent CPU instruction that can be converted to native code. MSIL implements a Common Type System (CTS) which defined the supported types in the CLR and indicates code written in one language could 'talk' to code written in a different language. The MSIL code produced by the development tool is then compiled by a Just-in-Time Compiler (JIT Compiler) to convert into machine code suiting the targeted platform.

In terms of interoperability, Microsoft.NET Framework seems one of the ideal platforms as it enables integration of .NET programs and legacy code. In specific, the .NET enables applications that are part of the managed code provided by the CLR to access unmanaged Dynamic Link Library (DLL) functions. Using .NET, an instance of a class could be passed to a method of another class written in different programming language. This means that the CLR enables .NET with an environment that supports cross-language interoperability where classes and objects of one particular programming language can be used in another programming language. This cross-language capability ideally suits the smart home environment especially with heterogeneous systems running on different programming platform and operating systems. Developers and vendors may prefer to develop their customized systems and application with preferred programming language. With .NET, it could allow systems and application developed by developers to be integrated into one single environment. Figure 3 shows the potential integration of heterogeneous systems using .NET.

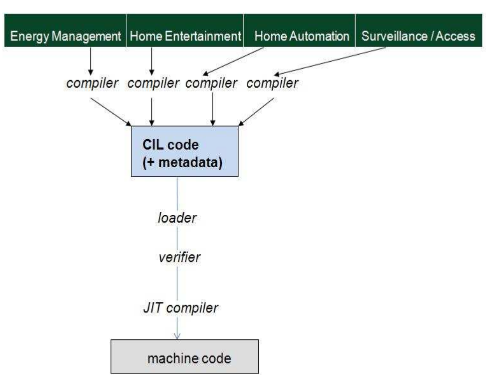

Figure 3. Integration using .NET

The main contribution of .NET framework is that a number of heterogeneities among systems could be removed using MSIL as a Common Intermediate Language. In addition, with recent development of Mono Framework, it ports the .NET features into broad-based interoperability solution by supporting open source based operating systems. [25]

3.4 Java Middleware Technologies

Sun Microsystems's Java middleware technologies defines Java platform for heterogeneous environment. Java Middleware technologies support interoperability by providing distributed protocols and APIs that can be used to create an interoperable system. In Java based platform, remote invocation or messaging is the key to achieve interoperability. Java middleware offers Remote Method Invocation (RMI) mechanism that is similar to CORBA-like object oriented middleware layer as distribution protocol. RMI enables objects to be called remotely from other applications in a heterogeneous environment. This feature also extends for interoperation execution between systems and information exchange. As part of the Java 2 Enterprise Edition, Sun also developed Java Message Service (JMS) API which acts as message-oriented middleware. In addition, there is also Java Web Services Developer Pack (Java WSDP) targeted to facilitate web services integration into Java applications. One of the implementation of Java Middleware in smart home environment is the OSGi framework [26]. The OSGi Alliance introduced the Open Service Gateway Initiative (OSGI) specification defines a standardized, component oriented, computing environment for networked services.

Work by Rebeca *et.al* [27] focused on service composition using OSGi framework for home environment. On the other hand, another feature called Java Server Pages (JSP) and Java Servlet technologies extends web server functionality to provide web service based applications. Work by A.R Al-Ali *et.al* [28] demonstrated the potential of Java Server Pages in managing home appliances over heterogeneous environment. However, the proposed design requires installation of Java Virtual Machine (JVM) in the remote systems. Java Middleware presents a competing approach to heterogeneous systems management similar to the one offered by CORBA and COM family. The core advantage of using Java Middleware technologies include its support for interoperability in terms of interoperation execution and information exchange, and full support for modification of existing systems. However, Java Middleware can only be implemented with the presence and requirement of Java Virtual Machine (JVM) in remote and local component of the system involved.

3.5 Web Services

Web Services are collected set of protocols and standards provides common method for programmatic interaction among applications, services and devices [29]. It describes the standardized concept of function invocation relying on web protocols, independent of any platform (operating system, application server, programming language, data base and component model). Web Services consist of three entities:

a) Service Provider – Create Web Services and publish to the external environment by registering through Service Registry
b) Service Registry- Registers and categorizes published services
c) Service Requester - uses Service Registry to find a needed service and bind them accordingly to Service Provider

Figure 4 below shows the three entities of Web Services.

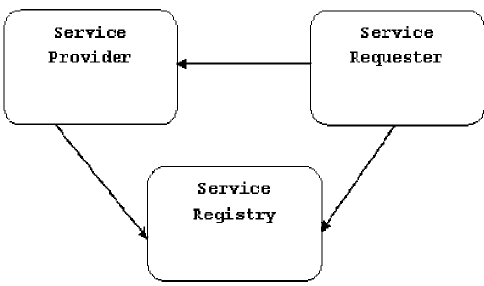

Figure 4. Three entities of Web Services

These three entities of Web Services founded upon three major standard technologies: Simple Object Access Protocol (SOAP), Web Services Description Language (WDSL) and Universal Description Discovery Integration (UDDI). All these standards are based on XML as defined mechanism for data definition, initiated by the World Wide Web Consortium (W3C). In smart home environment, Web Services are identified as potential solution for solving interoperability dimension in managing disparate systems. It is also worth highlighting about Open Building Information Exchange Group (OBIX), working towards developing comprehensive standards using XML and Web Services to facilitate the home and building information exchanges between heterogeneous systems [30]. Figure 5 shows how Web services could facilitate interoperability in managing heterogeneous systems in smart home environment.

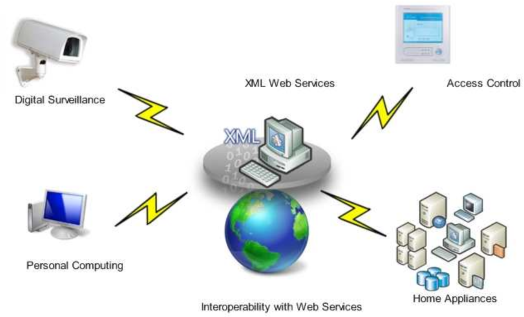

Figure 5. Interoperability with Web Services

3.5.1 The Simple Object Access Protocol (SOAP)

Simple Object Access Protocol (SOAP) is a lightweight protocol targeted for exchanging structured information in a distributed environment. SOAP exchanges information using *messages*. In the specification developed by World Wide Web Consortium (W3C), it is also included a method for encapsulating Remote Procedure Calls (RPCs) within SOAP messages.

Ideally, SOAP is created to support loosely-coupled application that could exchange one-way asynchronous messages. SOAP comprises the following elements: an envelope describing the content of the message and the way to process it, a set of encoding rules to express instances, application defined data types and a convention for the representation of remote procedure calls and responses. Figure 6 shows the structure of a SOAP message

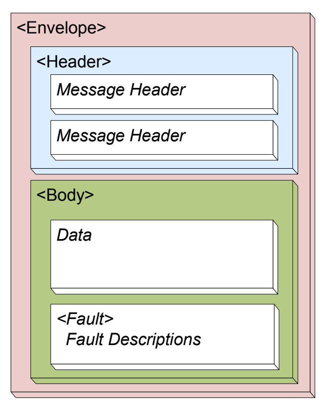

Figure 6. Structure of a SOAP Message

Each envelope consists of a *header* and a *body.* The information intended to be transported will reside in the *body* of the message*.* Any additional information or value added services will be included in the *header.* SOAP protocol can be used in two different style called document-style and RPC-style. In document style, interaction happens between two applications agreeing upon the structure of documents exchanged among them. While in RPC-style, a SOAP message encapsulate request while another message encapsulate the response. In this paper, we will demonstrate the ability of SOAP in providing generic interoperability mechanism.

3.5.2 Web Services Description Language (WDSL)

Web Services Description Language (WDSL) was created by IBM, Microsoft and Ariba for describing Web Services, and in particular describing service interfaces. It provides a model along with XML based format in describing the Web services [31]. A WSDL description is done with two levels of stages. One is the abstract stages consist the messages that it sends and receives. On the concrete stage, a binding determines the transport and wire format details for one or more interfaces. Ports or known as *EndPoint* combine the interface bindings information with a network address. Finally a service groups all the Endpoints that implement a common interface.

3.5.3 UDDI: Universal Description Discovery and Integration

Universal Description Discovery and Integration (UDDI) are the last element needed in providing Web Services implementation. The main goal of UDDI is the specification of a framework for describing and discovering Web Services. UDDI defines data structures and APIs for publishing service descriptions in the registry and querying the registry to look for published descriptions. UDDI is expected to be a service repository of business organization near future towards extending their business information and value added service for smart home environment.

Table 1 below shows the comparison of technologies in providing interoperability for smart home environment, depicting various features.

Table 1. Comparison of Technologies for Interoperability

	Java RMI	.NET	CORBA	Web Services
Programming language	Java	.NET languages (C#, VB.NET, ..)	independent	independent
Interface definition	Java Interfaces	.NET Interfaces	CORBA IDL	WSDL (XML-based)
Data structures	Java objects	.NET objects	IDL-specified objects	XML data
Transport protocol	RMI-IIOP	binary or OAP	GIOP/IIOP	HTTP, HTTPS, SMTP, FTP
Packaging	Java object serialisation	.NET object serialisation	ORB/CDR	SOAP
Infrastructure	Java RMI infrastructure	.NET remoting infrastructure	ORBs	Web, Mail, FTP server

4. System Architecture

Heterogeneous systems in smart home environment comprise a number of tasks that are associated with the sequential use of different systems and applications. The need for interoperability in managing heterogeneous systems has led towards a transition of vendor independence and open systems, taking into account of middleware and Internet technologies [32]. In this paper we propose an architecture that builds upon the general trend towards interoperability for smart home environment. Figure 7 shows the proposed system architecture.

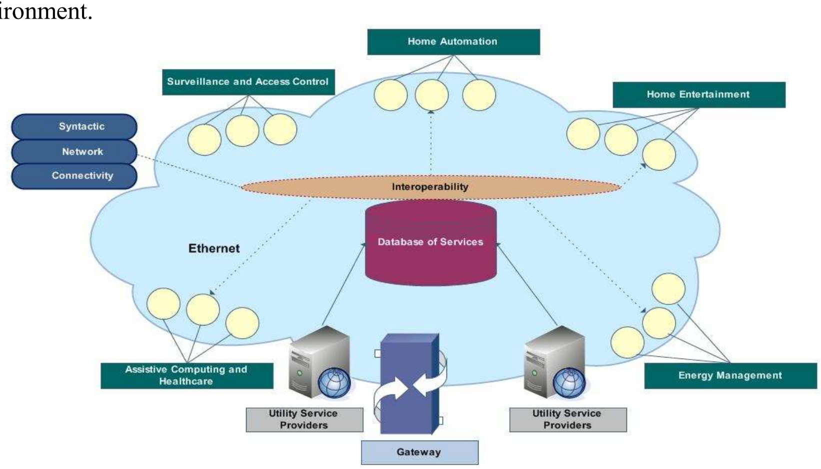

Figure 7. System Architecture

Each tier that defined interoperability has to be fulfilled in order to achieve full interoperability aspect in smart home environment. We propose the utilization of Ethernet cloud as basic connectivity interoperability in smart home environment. Ethernet also seems an ideal solution due to its performance oriented in real-time and also considering the existence of Cat 5 structured cabling in smart home systems. On the aspect of network interoperability, TCP is utilized to perform message exchanges between heterogeneous systems in smart home environment. TCP hides the details of actual interactions between communicating heterogeneous systems from users. The use of TCP here is justified as there is always one distinct approach in the field of smart home environment; to incorporate TCP based networking into embedded consumer devices as well as appliances. On the syntactic interoperability, it is evident that SOAP could be ideal solution as defined structure for message exchanges. We choose XML and SOAP technology as the enabler since both are prime candidates in playing their role as *lingua franca* for interoperability. In our opinion, SOAP is very well suited for providing interoperability among heterogeneous systems due to the standard way of data representation and the format is extensible to deal with changing requirements.

A database of services is configured to handle the queries of SOAP messages of the heterogeneous systems configured in smart home environment. Microsoft SQL Server [33] together with an application gateway is used as an intermediary for the storage and ordering of the messages between systems. An example scenario of interoperation could be explained with operation of two systems. This scenario involves an access control system and surveillance systems that provides security monitoring services for home dwellers. When an intrusion is detected, a triggering signal will be sent to the database of services using SOAP message by the access system. Upon acceptance of the condition, the interoperability tier would need to initialize the associated action by sending commands to other systems. Here, the interoperability tier residing in the core of smart home environment will ensure that message exchange takes place in timely manner. Upon the acceptance of the query, the interoperability tier will send a respond message using SOAP protocol to the surveillance systems or other systems that need to interoperate in order to acknowledge security status to home dwellers. This kind of scenario clearly requires heterogeneous systems to work and integrate together in an interoperable fashion. Figure 8 shows the interoperation of heterogeneous systems using SOAP messages.

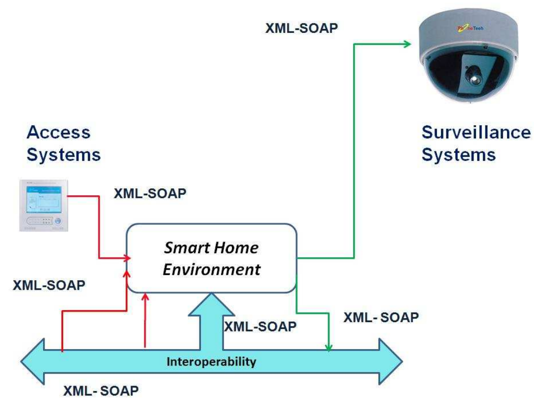

Figure 8. Interoperation of heterogeneous systems

5. System Evaluation

The present section of this paper depicts the system evaluation in order to further elaborate the system architecture. We first describe the system elements to address significant features of the software engine and then present the prototype implementation as well as the performance evaluation.

5.1. System Elements

Taking into consideration of interoperability and scalability features of .NET Framework, C# language and SOAP service classes with .NET Framework 2.0 are used to operate and manage the system operation of heterogeneous systems in smart home environment. The software engine stored in the application gateway is developed using C# language. The software engine provides the functionality in managing the service requirement using SOAP technology. .NET Framework provides cross-platform execution by enabling the use of multiple clients (i.e. cellular phones, desktop PC and personal digital assistants) to manage the systems by taking advantage of one single software engine stored in application gateway, accessible for home dwellers all the time. The XML-SOAP web services is developed using C# language in managed code using Visual Studio 2005. The implementation of the XML-SOAP Web services resides in a code-behind file and associated with the *.asmx* file using the *Codebehind* attribute of .NET. The heterogeneous systems in smart home must be secure in terms of interoperation and reliability while changing states between multiple applications. This implies as the .NET framework is defined as a runtime virtual machine using managed code. Hence, the security factor such as buffer mal-operation (overflow) is avoidable.

5.2 Prototype Implementation

A prototype designed consisting of an embedded CPU and application gateway, which also cater as storage unit for the entire system. The software engine using SOAP technology, written using C# language is stored in the application gateway. For this gateway design, the embedded CPU is installed with Windows Server 2003 and configured with Internet Information Service 6.0 environment. Microsoft SQL Server is configured in embedded CPU for services repository. In addition, .NET Framework 2.0 is installed and configured. The embedded CPU supports 4 inputs and 4 outputs of Ethernet connectivity and system memory available up to 1GB. In smart home environment, managing heterogeneous systems means 24 x 7 and information are meant to be exchanged all the time. Therefore, an embedded CPU configured as application gateway will be an ideal platform for continuous operation and increased application availability. Figure 9 below shows the developed prototype to test the interoperability services in smart home environment.

Figure 9. Application Gateway

5.3 Performance Evaluation

The performance of the system was tested in a dedicated LAN (Ethernet connectivity) and measured in terms of response time. For effective interoperation of heterogeneous systems in smart home environment, response time is significant and crucial for real-time application. The response time has considerable impact towards performance of SOAP protocol in managing those heterogeneous systems. Response time indicates the maximum time of systems tasks would take by execution without any interrupts or loads, between those heterogeneous systems. Figure 10 below shows the comparison of response time of the application gateway during each control event mechanism using XML-SOAP messages. Total of 200 samples (testing) was performed.

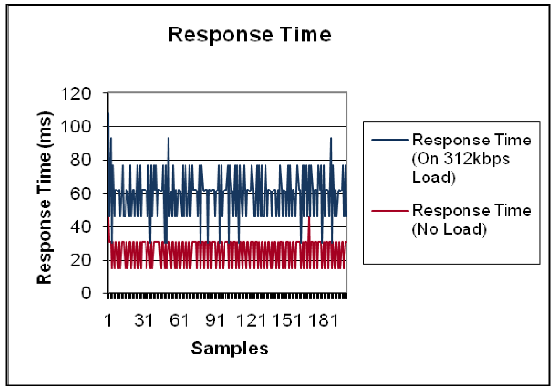

Figure 10. Comparison of Response Time

From the Figure 10, the first peak of response time (no load) obtained at 46ms. The first peak is due to the compilation time of Just-In-Time Compiler (JIT) in .NET Framework for initialization of the software engine at the beginning. The average time consumption for single interoperation of the system is 25.87ms. This value is justified for response time requirement especially for interoperation among heterogeneous systems. Standard deviation obtained at 7.8ms. In comparison, the whole response time evaluation with load (312kbps) indicates 110ms for the first launch. The average response time with load is 33.94ms and with a standard deviation of 11.08ms.

6. Conclusion and Future Works

The work presented in this paper elaborates the interoperability requirement for smart home environment. The architecture proposed specifies the Simple Object Access Protocol (SOAP) with Web Services ability in providing interoperability and scalability for managing heterogeneous systems. In providing interoperability among heterogeneous systems, data representation must be independent regardless of operating platform. Our work indicates that SOAP protocol maximizes the interoperability and performance of heterogeneous systems. Future research holds a lot of promises especially in extending the interoperability dimension towards semantic and business tiers. A universal schema definition could be defined towards developing a generic abstraction tiers for managing heterogeneous systems in smart home environment.

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