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SOA-Based Framework for Home and Building Automation Systems (HBAS)

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Abstract

Home and building automation systems (HBAS) today are categorized by plethora of data formats, communication platforms and software services accessible via heterogeneous embedded devices. These heterogeneous embedded devices characterized a building into a data intensive entity, generating numerous data and complex control information, brings a much heavy load to the HBAS. Consequently, this leads to interoperation difficulties among those devices for information exchange and operation management. In this paper, a Service Oriented Architecture (SOA) based framework that leveraged by services is proposed to manage HBAS efficiently by reducing their workload during joint execution of tasks. The proposed framework consists of several layers dedicated for services interwoven by Event-Condition-Action (ECA) oriented decision mechanism for managing heterogeneous embedded devices. The proposed framework is viable and highly efficient to be deployed for HBAS with limited computing resources.

Keywords: *Service-Oriented Architecture (SOA), Interoperability, Home and Building Automation (HBAS)*

1. Introduction

In recent times, the introductions of networking technologies together with consumer electronics appliances have fostered the increased growth of integrated heterogeneous embedded devices within Home and Building Automation Systems (HBAS). The complexity of HBAS, together with their broad services has led towards ambiguity in achieving interoperability among its configured heterogeneous embedded devices. Heterogeneous devices integration and interoperability are among the biggest challenges in the domain of home and building automation industry. A concrete reason on lack of interoperability deployment is because the industry has commonly been a moderate player when adopting prominent and emerging technologies. Another critical problem with HBAS is the dynamically changing environment, as such dealing with device integration and system is not a straightforward task. Hence, such conditions do not encourage consumer electronics vendors to adopt leading edge technology for HBAS. Twenty years ago, the majorities of HBAS were proprietary and considered mainly as standard requirement to manage a building. HBAS generally are more or less non-existent to the outside world. A typical HBAS topology is illustrated in Figure 1 below.

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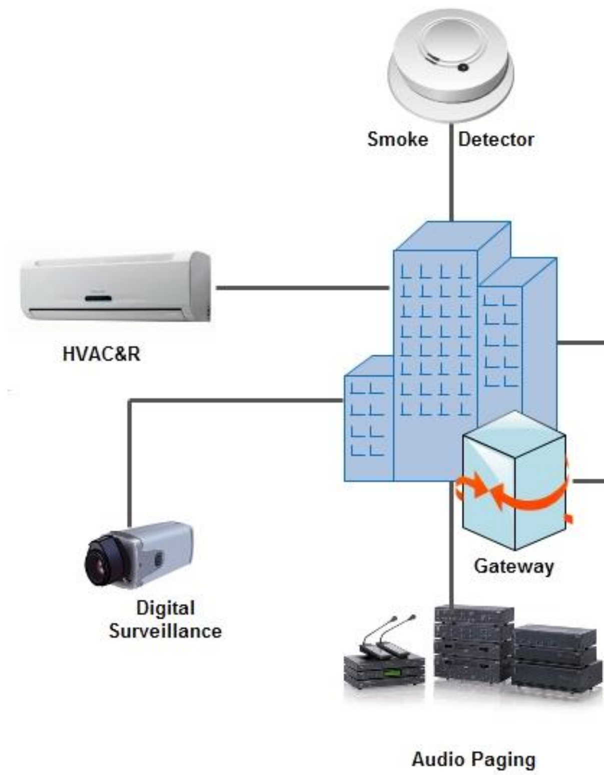

Figure 1. Heterogeneous Devices in HBAS

As shown in Figure 1 above, several systems like Heating, Ventilating and Air Conditioning (HVAC), audio paging distribution and digital surveillance are interconnected in HBAS. These heterogeneous embedded devices are managed by a specific communication protocol to realize an overall federated system management. In recent years, much advances in information, communication and automation technology fostered the need to create a unified HBAS, with common goal on achieving comfort and safety, ensuring easy management, reducing energy consumption as well as minimizing ecological impact. This advancement revolutionized HBAS towards heterogeneity in nature with wide range of protocols and products from different vendors. An overview of integration platforms in buildings are elaborated in [1]. The article also covers on diversified Web Services solutions as well as requirements for HBAS. Traditionally, HBAS are governed by protocols such as LonWorks [2] and Building Automation and Control Network (BACnet) [3]. However, with recent establishment of open system solution such as Web Services, HBAS has undergone tremendous transformation on the approach for data management and interoperation [4, 5]. Web Services enables independent and standardized component or services achieved in HBAS [6, 7]. As more HBAS services moves off-site, a glance into the consumer development suggest that the collaborative power of Service Oriented Architecture (SOA) might be the key solution to solve interoperation in HBAS. SOA is a paradigm that assists an entity to share their logic and data among diverse services [8]. SOA promises interoperability for HBAS by abstracting the interface that a service exposes to its environment, from the implementation of that service. In SOA, communicating components are loosely coupled with their respective service functionality exposed at its boundary via schemas and other formats. Using SOA, a user could focus on applying the function for their respective tasks by avoiding the operating cost of platform installation. SOA is seen as potential method to take advantage of real-time information in a resourceful manner. In this work, the focus is on the development of SOA-based framework for HBAS. The framework is based on service oriented, whereas the main goal is to share and manage heterogeneous services in HBAS. SOA and Web Services could complement each other for joint execution of tasks by enabling the formation of interoperating building services without knowing the details of underlying platform. Adopting SOA for HBAS could also ensure scalability of heterogeneous embedded devices in offering more services in future. Data demanding systems in HBAS could possibly be administered by deploying them in SOA environment that escalates decision making procedures in carrying out relevant services. SOA could also enable continuous commissioning and easy interdependencies among heterogeneous embedded devices configured in HBAS from time to time. Hence, the main motivation behind the efforts taken for this work is to expand the HBAS potential service oriented paradigm by leveraging on system scalability and managing diversified needs of HBAS related data. The presentation of this paper is organized as follow. Section 2 explores the related work and Section 3 elaborates further the framework architecture. Section 4 explains the implementation and results. Finally, conclusions are described in Section 5.

2. Related Work

In recent times, there have been several significant works related to the HBAS explored issues on interoperability [9-11]. However, open questions still remain elusive about heterogeneous devices data and their coordination in a federated manner. Many literatures highlighted the significance of services in managing heterogeneous embedded devices. A significant work on SOA was highlighted by Sleman et al. for managing embedded devices [12]. The mentioned work explored the need for SOA based distributed operating system to manage embedded devices in HBAS. The authors also proposed integration of those embedded devices via Internet and Smart Grid as the means to solve higher level interoperability. Another contribution made by Zeeb et al. mentioned about SOA implementation for embedded devices [13]. Their work depicted the approach of managing embedded systems using Device Profile for Web Services (DPWS), an important trend that integrates appliances in home environment. Similarly, a work demonstrated by Belimpasakis et al., proposed a REST based data integration in home environment [14]. Their system is centered on Web technologies that permit selective based building services accessible to remote users and partially trusted external services, favorable to the SOA type of environment. Other important works includes a conceptual model of smart services integration platform [15] as well as software design for smart home devices via cloud services that enables bespoke selection of device based on user requirement [16]. It is evident that several works have been proposed for deploying services in building environment. The related works discussed in [12–16] clearly shows the outcome trend is given to service based integration with isolated functionalities. Although common data exchange could be achieved for HBAS operation, service based data interoperation still seems to be in infancy stage. In a typical HBAS, the amount of data represented by periodic readings throughout the day, from heterogeneous devices are overwhelming. If these data arrives at a database hosted on the HBAS premise, it can overwhelm bandwidth into the premise as well as database storage resources. A good analogy on the amount of data consumed in HBAS systems with 1714 points deployed at Engineering Building 2, University of Tokyo is depicted in Table 1 below [17].

Table 1. HBAS Data [17]

SYSTEMS	NUMBER OF POINTS
ELECTRICITY DISTRIBUTION BOARDS	908
HVAC WORKING MODES	67
ELECTRICITY AT OUTLETS	639
MOTION DETECTION AND LIGHT STATUS	40
ROOM ENVIRONMENT	36
GAS AND WATER SUPPLY	17
WEATHER INFORMATION	7

As shown in Table 1 above, the frequency of data recording for each point varies and could be done each minute or at several intervals based on the systems configuration. Such total number of data elements in the HBAS storage could fetch approximately up to 400 million records for a year period. Such huge repository of HBAS data could possess greatest challenge for building administrators in ensuring sustainability of HBAS services all the time. SOA type of solution, therefore, is optimal for managing this massive data collection because the bandwidth and storage resources can scale better at a SOA based data repository. A potential solution to solve service integration is through Web Services combined with a decision framework. Web Services is proven to be the ideal integration approach among heterogeneous embedded devices in HBAS environment [18, 19]. Heterogeneous embedded devices from different vendors can be integrated without difficulty using Web Services. Hence, Web Services is expected to complement the SOA deployment for HBAS. The architecture of the SOA-based framework is elaborated in the next section.

3. SOA-Based HBAS Framework

In this paper, a SOA-based framework is proposed to enable federated joint execution of services among heterogeneous devices in HBAS. Figure 2 below shows the layered framework for service oriented architecture.

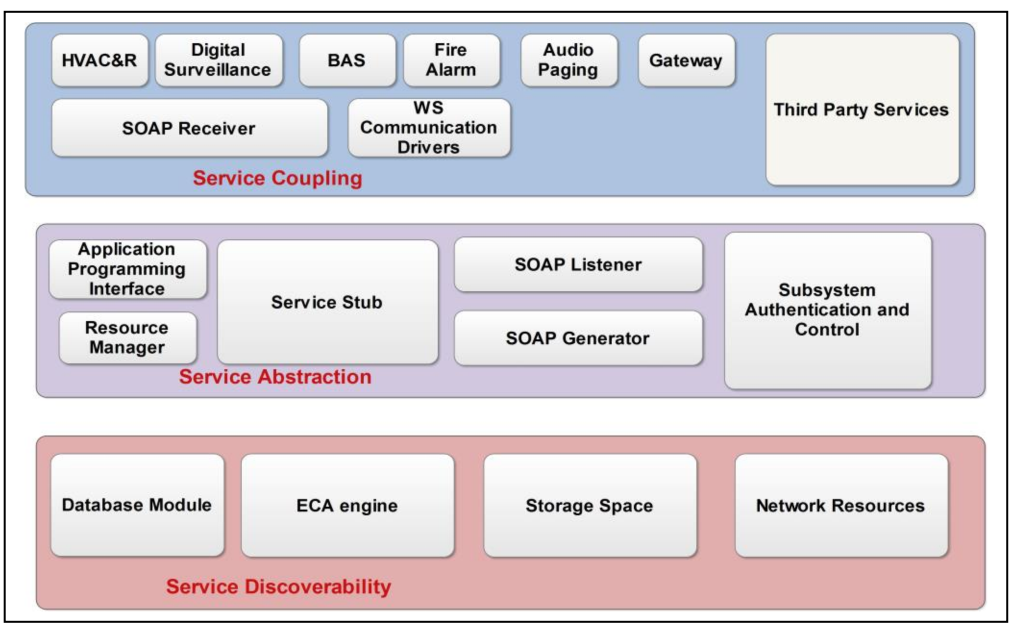

Figure 2. SOA-based Architecture

From Figure 2 above, there are three important layers for SOA-based framework; Service Coupling, Service Abstraction and Service Discoverability. Heterogeneous embedded devices are integrated with SOA-based framework seamlessly. In the next section, the functionalities of the layers are elaborated in depth. The service coupling layer resides at the top-most hierarchy of the framework. A single service in HBAS can increase its value by cooperating with other services. Hence, in HBAS, service coupling could be deployed to make a new service from more than one services cooperating with each other, which directly fits the building provision. The principle of service coupling in the framework is to promote the independent design and evolution of systems' service logic and their implementation. At same time, it guarantees HBAS connectivity for building occupants that have come to rely on the various services' capabilities. Such functionality enables reduced coupling within and between systems whereas their application increases independence as of their implementations and services from each other. This promotes an environment in which services and building residents can be adaptively evolved over time with minimal impact on each other. Another contributing factor is that loosely coupled services like in building environment usually require more runtime processing. Consequently, data exchange in general could consume more runtime resources, especially during simultaneous access and high usage events. Therefore, by deploying service coupling, runtime resources can be minimized by isolating the respective systems' data during particular operation. As such, this layer is responsible to advocate service coupling among heterogeneous devices. By default, Web Services based communication modules are also packaged together in this layer.

Alternatively, other kinds of communication protocols could also be supported by the layer based on third party system's specification. The secondary layer, Service Abstraction has taken on greater significance in managing heterogeneous devices in HBAS where operational logic is regularly decomposed into standalone units, each of which abstracts a portion of the greater whole. The layer is meant for abstracting specific information about know-how, logic, and function away from the building residents. Often, home and building occupants are not technically trained, therefore there is need to hide complexities through several level of abstraction in order to simplify user interaction in HBAS. By performing abstraction, it can be beneficial to hide details of the technology used to interoperate the heterogeneous devices so that the freedom to make technical changes is retained without affecting existing configured systems. In this layer, the system resources used by the program are hidden. Service abstraction for SOA-based framework is achieved using a bespoke component of an Application Programming Interfaces (API). In this SOA- based framework, the API covers generic functions that will be useful for application developers to develop functions based on heterogeneous embedded devices. This is followed by another type of abstraction called programmatic logic abstraction. Programmatic logic abstraction refers to internal details about a program that are deliberately hidden from the outside world. These include details like low-level design, algorithms, exception handling and logging routines. The abstraction process can be defined in few steps. The first step is called as systems individualization. In this step, the abstraction process assigns an individual address to front-end devices. If several types of the similar building front-end devices are present in the HBAS, systems individualization could solve by distinguishing the instances, such as by assigning a significant name to them. In a single HBAS system, there could be as many front-end devices configured. Hence, each device is assigned a hierarchical name based on integer. An example of assigned names for a series of building front-end devices will be SEN001, SEN002 and so forth. To manage the abstraction process, three classes are defined for the respective front-end devices; *BuildSysID*, *BuildDeviceID* and *BuildDeviceStatus*. The abstraction process via the class diagram is shown in Figure 3 below.

4. System Implementation

The framework encloses different layers of service functionalities for heterogeneous embedded devices interoperation. The developed framework is implemented as Web Services with SOAP as message transporter such that any user side request could simply call the desired functions, bypassing the complexities of the underlying infrastructure. SOAP messages are used to send the relevant information among heterogeneous devices via the framework. To compress the SOAP messages, a module called *SOAP Extension* is implemented as interception mechanism that can be used to manipulate SOAP request/responses before they are transmitted. Using *SOAP Extensions*, the size of SOAP messages transmitted using the framework can be greatly reduced especially when a system invokes a method from a Web Service. Application developers could write codes that executes before and after the serialization or de-serialization of messages. A database module included within the SOA-based framework to handle message queries of systems configured via HBAS. The data feed from the systems are stored in CSV format for further periodic analysis. The database serves the purpose as repository as well as data retrieval for building services via ECA mechanism. Figure 5 below depicts the system implementation of the SOA-based framework.

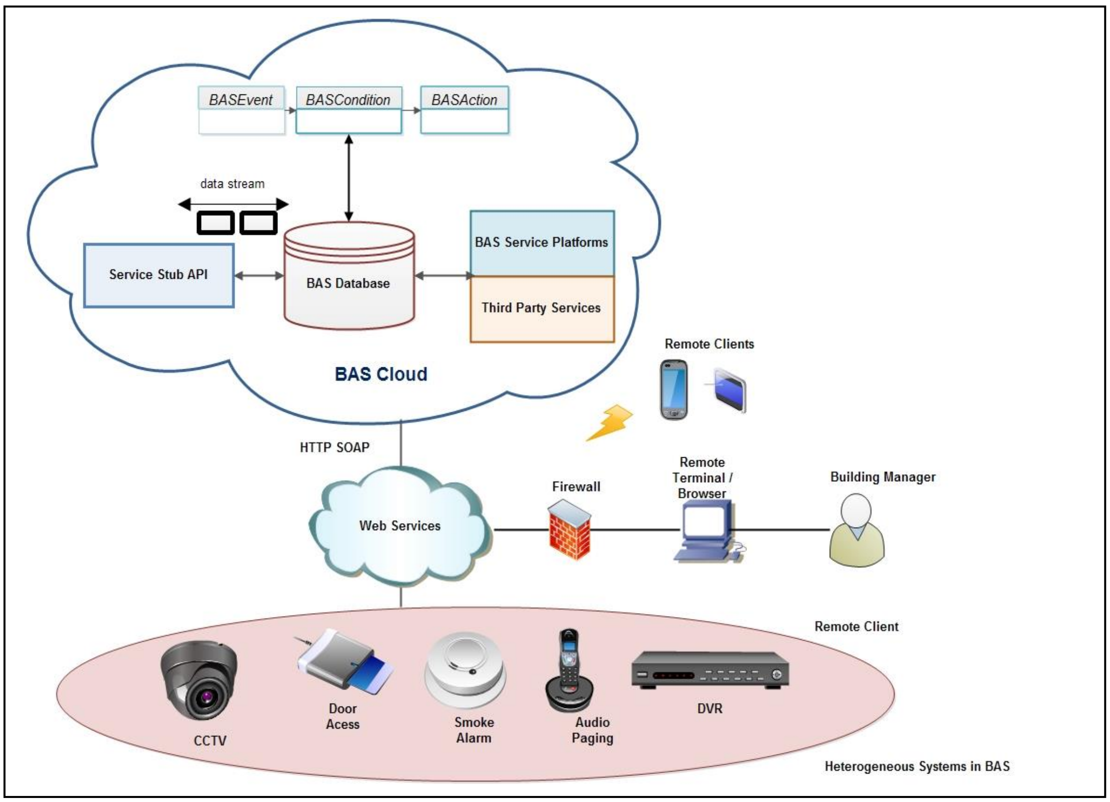

Figure 5. System Implementation

For experimental setup, three types of systems; digital public address system, CCTV camera and smoke alarm is configured within the SOA – based framework. The flow of operation is illustrated via sequence diagram in Figure 6 below. The sequence diagram clearly depicts the implementation of the SOA framework based on the declared classes. In this paper, the conformance testing based on response time metric is taken into account for performance evaluation of the SOA based framework [23]. A single interoperation task among these heterogeneous devices takes 125ms of response time using the SOA-based framework. To verify further, a framework conformance testing is performed to validate the building occupants' performance prospects as well as the correctness of the framework's design and functionalities. Conformance testing is important to analyze the behavior of heterogeneous embedded devices adapting with the developed SOA based framework specification. In building environment, the coexistence of the legacy systems – embedded in entirety or partially in the new dependencies or configured at backend environment is the biggest challenge for HBAS systems. For instance, new devices added into HBAS must integrate the old logic encapsulated in the new functions and also assures the requirements of the old data channels in place. The overall necessity is to ensure accessibility, which considers the capability of the SOA-based framework to trigger a service and guarantee provisioning even in the case of heavy traffic scenarios. The framework conformance testing will validate on how data access services are affected by the increasing number of events and devices that depend on them. The conformance testing is also performed to validate whether a triggered service delivers the function expected from the SOA-based framework. Since the invocation of a framework service can been seen as black box, specifically given certain rules, produce certain outputs for interoperation, therefore this testing approach is essential in ensuring the viability of the developed SOA based framework. It is evident that the framework functionalized towards orchestrating the hodgepodge of system's services deployed using SOAP technology. SOAP doesn't mandate its underlying transport mechanism, however HTTP has emerged as the most widely used one for SOAP. In the case of SOA based framework, HTTP provides the capability to carry the SOAP messages across heterogeneous platforms. It is worth mentioning that SOAP messages transmitted from the same server to various systems contain some similarity. In addition, SOAP messages deployed by similar implementation types commonly contain similar byte representation. In this case, the SOA-based framework ensures that message structures for each interoperation are well defined by the Service Stub using the pre-defined ECA mechanism rules. In particular, a SOAP message is bounded by a large amount of XML-based non-domain related data such as namespaces, encoding patterns, as well as other related transmission data. Consequently, partial of the information contained in SOAP messages is often acknowledged in advance by both receiving node and transmitting nodes. To further justify the conformance testing, standard deviation series were computed based on 16 sets of SOAP response messages, with each sets contain 32 samples of response messages for each incremental load of 10%; from no load to 80% load. Figure 6 below shows the outcome of the performance testing.

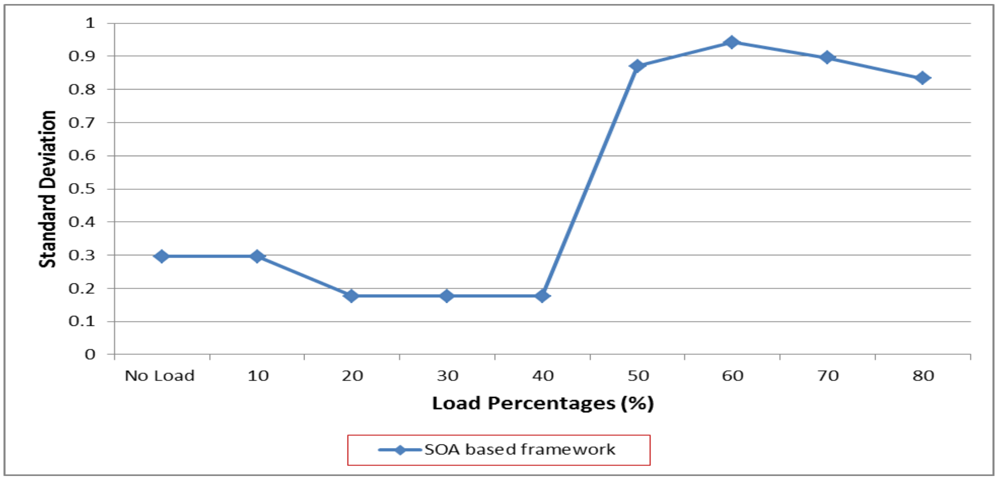

Figure 6. SOA - based Framework Testing

From Figure 7, the standard deviation series shows the value 0.2961 for No Load and 10% of the network load. Consequently the value 0.1767 obtained for 20%, 30% and 40% of the network load. This signifies the conformance of the framework is quite evident gradually as the traffic increases. The standard deviation value for 50% of the network load computed at 0.8700 and increased at 60% with 0.9418. In addition, once the traffic increased at 70%, the value obtained shows 0.8957. At 80% of the network load, the standard deviation series settled at 0.8327 signifying the drop at the maximum traffic load of the conformance testing.

5. Conclusion

This paper presented an implementation of SOA based framework for HBAS. SOA gives the flexibility to expand HBAS as well as makes it easier to compute sophisticated decision algorithms. SOA benefits will be further evident when service trend data becomes part of HBAS operational requirement. As the amount of the data and the requirement for algorithm increase, SOA for HBAS will be able to expand itself to accommodate the needs of continuous commissioning and scalable systems. The developed framework is tested using three types of heterogeneous embedded devices in order to measure their effectiveness in SOA environment. An early performance evaluation has been deployed to verify the framework's conformance for HBAS configuration. It is evident that SOA promises great potential HBAS industry to seamlessly integrate building services in an efficient manner as well transparent of the underlying technology. The trends in SOA implementation for HBAS seems to be focused on utilizing and sharing HBAS requirements with evolving services as well as utilizing protocols defined by IT enterprises. The SOA framework could benefit HBAS vendors and facility managers in facilitating building data and commands via SOA services that could solve HBAS requirements. In future, the SOA based framework could be enhanced with additional security modules to ensure secured interoperation among heterogeneous embedded devices. Standardization of SOA service for HBAS would have a long way to go but it is likely that the final outcome will be a manageable number of service options available. Finally, a precise utilization of the SOA based framework for optimizing HBAS energy utilization and their quality of service is a potential target for future direction.

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