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State of the Art: Embedded Middleware Platform for A Smart Home

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Abstract

Paradigms and techniques that have bloomed in the area of the pervasive computing are general and pertinent. Environments with loosely coupled computational hosts, running heterogeneous hardware and software, associating one another in a just-in-time manner are characteristic of pervasive computing. Pervasive computational environments, such as our future homes are a prominent example of this tendency. In this paper, we present a review of the state of the art of pervasive middleware platforms for enabling a smart home. There are numerous projects carried out by industry and academic research groups to examine embedded middleware platforms for smart homes. There are projects that consider problems ranging from software to hardware issues of smart home technology and associated issues of privacy, security, and social concerns. These projects emphasize numerous functional and non-functional requirements of a smart house. We discuss stimulating and valuable projects in the literature that addressed some of the concerns that are at the basis of the middleware platform proposal. We consider two aspects during the overview of the state of the art. First, we review a number of existing and recently funded research projects that focus on pervasive embedded middleware platforms. Second, we look at pervasive methodologies and technologies that are relevant to the middleware platform.

1 Introduction

Smart homes constitute an environment where appliances inter-work with each other and coordinate to proactively support the user in his/her daily activities and in case of special home events. Home appliances, sensors and actuators are highly heterogeneous in a number of ways. They come from many vendors, have hardware and software resources that go from minimal to being as powerful as a desktop computer, and have the ability to change the physical space around them or just to sense it. This high heterogeneity needs to be reconciled to lay the foundations for a smart home, where devices are aware of each other existence and interaction interface. The reconciliation goes through the use of common ontologies, standardized protocols and unified techniques for discovering and messaging.

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2 Pervasive Middleware Platform

Home appliances are no longer isolated devices. They are interacting and communicating with each other at home. This brings many challenges to integrate various devices and to make them *smarter* for the users. This kind of smart home can help disabled or elderly people to live life with more independence and comfort. Home automation and assistive living are possibly the eminent cases of context-aware pervasive systems [41]. A home with these types of appliances and smart intelligence to combine the devices' services in smart ways is either called a smart home or house with home automation [52]. Home automation can comprise centralized control of lighting, heating, ventilation, and air conditioning (HVAC), home security, and other systems. The typical purpose of these systems is to deliver better convenience, ease, energy efficiency, and security. Further, it can provide increased quality of life for persons who might otherwise require caregivers and institutional care. In following, We describe the advantage and disadvantage of recently developed different middleware platforms.

2.1 Smart Home Projects

There are several smart homes and living labs under development around the world. Several projects related to middleware for networked embedded systems exist. Below, we review some of the earliest and most important ones. We highlight the main areas of particular projects. A list of functional and non-functional requirements are taken into consideration. Platform-independence, interoperability, adaptability, heterogeneity, scalability, service composition, fault-tolerance, and security are certain instances of non-functional requirements that should be considered, while implementing a middleware platform that can suit the requirements of diverse home network applications. We will use these requirements to classify and evaluate the current smart home middleware platforms, identify the main differences between them, and determine how well specific middleware meet each requirement.

2.1.1 HYDRA

The Networked Embedded System Middleware for Heterogeneous Physical Devices in a Distributed Architecture (HYDRA) project aim was to develop a middleware for intelligent networked embedded systems based on a service-oriented architecture, deployable on both new and existing networks of distributed wireless and wired heterogeneous devices that operate with limited resources in terms of energy, computing power, and memory usage [63]. The HYDRA architecture is based on three layers: the physical layer, the middleware layer, and the application layer [21]. The HYDRA middleware is tested in three user domains, such as building automation, health care, and agriculture [33]. The user can access the services offered by the HYDRA through a smart mobile interface.

It supports true ambient intelligence for ubiquitous networked devices and provides interoperable access to data, information, and knowledge across heterogeneous platforms, including Web services [33]. The middleware supports centralized and distributed architectures, security and trust, and model driven development of applications. This project particularly addresses the communication issues in terms of scalability, reliability, and security [33]. The current HYDRA middleware is only investigating the networking problem of devices in the industrial applications. The layered architecture of HYDRA middleware is developed by different programming languages that provoke heavier communications.

2.1.2 SOCRADES

The Service-Oriented Cross-layer infrastructures for Distributed smart Embedded devices (SOCRADES) project is similar to HYDRA and explores a service-oriented middleware approach to integrating device-level information into business processes. The SOCRADE project's aim was to have a design, execution and management platform for next-generation industrial automation systems, exploiting the Service-Oriented Architecture (SOA) paradigm, both at the device and application level [12]. The SOCRADES architecture focuses on existing promising technologies and integrates them through the use of Device Profile Web Services (DPWS). This project also examines the use of Web services in the area of home automation. Ultimately, this project creates an effective relationship between the device-level SOA and the services and applications that establish the enterprise back-end support [34]. However, the project primarily emphases the design and development of innovative technologies in the challenging context of smart buildings for users with different abilities and needs. The service discovery component is distributed and replicated at each physical site. The discovered devices' services are placed in a central repository as a single access point that is called device manager and monitor.

It also provides features like eventing, management, and service discovery. SOCRADES introduced new methodologies, technologies, and tools for the modeling, design, implementation, and operation of networked systems made up of smart embedded devices [12]. The developed middleware focused on coupling web service enabled devices with enterprise applications and satisfying the non-functional requirements, such as fault management, platform-independence, interoperability, security, adaptability, heterogeneity, and service composition [34]. SOCRADES' essential paradigm is the SOA common infrastructure for seamless integration from enterprise level to device level applications. A SOCRADES service is a software component encapsulating device-specific functionality. This functionality is advertised to the outside world, so as to be located and invoked by other networked devices and/or applications without the latter being aware of how the functionality is implemented. The drawback of this product is that every device has to communicate to the system using a driver that is tailored to the database connectivity. In this way, SAP xMII limits itself to devices or gateway solutions that support database connectivity.

2.1.3 Oxygen

MIT's project Oxygen [4, 36] enables pervasive, human-centered computing through a combination of specific user and system technologies. Speech and vision technologies are used to interact with the Oxygen system to address the end-user needs. These cooperating technologies help users to live in a comfortable world using the ambient intelligence embedded system, where they can do daily activities easily [36]. The Oxygen project focuses on merging speech recognition with recognition of facial expressions, and lip's movement to support it [4]. The Oxygen middleware supports resources and user mobility, and provides speech and vision interfaces to the user while satisfying security, adaptation non-functional requirements with a decentralized networks approach [51]. The Oxygen project addresses several non-functional requirements. Adaptability is provided within the network and the operating system, while openness is provided by allowing the addition of new software and performance of software upgrades in the operating system. The Oxygen platform uses the TCP/IP protocol for communication. Ultimately, it does not communicate through an SOA approach. Further, the system requires manual installation of new devices into the system. So, it does not support plug-and-play for new devices.

2.1.4 AMIGO

The Ambient Intelligence for the networked home environment (AMIGO) project aim was to develop an open, standardized, interoperable service-oriented middleware and ambient intelligence within the networked home environment through seamless integration of networked devices and related application services within the home system [7,23]. These devices belong to the consumer electronics, home automation, mobile, and PC domains. The available devices and services discover and communicate with each other through semantics in the home network. The AMIGO language and vocabulary was developed for semantic service description. The AMIGO project focused on digital home research, and throughout the development, a user-centric approach was used [23].

The AMIGO interoperable middleware operates across different application domains and across different homes and environments. This flexibility of the architecture ensures that the system can grow, as and when new devices and applications are added. Further, the Amigo software is open source, which encourages further development of the system. It also supports context information and intelligent user services that facilitate the users with smart intelligence to control the devices at home [45]. The AMIGO middleware does not support platform-independence, heterogeneity, or fault tolerance.

2.1.5 RUNES

The Reconfigurable Ubiquitous Networked Embedded System (RUNES) provides an adaptive middleware framework, which is completely component-based and offers functionality through well-defined interfaces. The proposed framework consists of a layered architecture, such as radio, network, and middleware layers, and simulation and verification tools are developed [55]. The RUNES project is mainly centered around the design of a general middleware architecture, which covers applications related to emergency scenarios. The RUNES middleware framework is highly scalable, widely distributed, and supports heterogeneous networked embedded systems that interoperate and adapt to their environments. RUNES investigates and develops solutions for supporting applications and services running on heterogeneous architectures of networked embedded systems. The RUNES middleware is not a fault-tolerant framework.

2.1.6 ANGEL

The Advanced Networked embedded platform as Gateway to Enhance quality of Life (ANGEL) project's primary objective is to develop methods and tools to make complex heterogeneous systems based on Wireless Sensor Networks (WSNs). It allows interoperability among well-known communication networks to monitor and improve the quality of life in smart environments (e.g., home, car, and city smart environments) [75]. The ANGEL gateway supports the concept of ambient intelligence for different WSN application domains, such as the medical domain [10]. Security services (e.g., confidentiality and authentication) are important requirements for ANGEL to confirm the safety and privacy of the users [22]. It provides dynamic access to the available devices' services at distributed gateways. The proposed middleware is reliable, timeliness and supports mobility, security, and privacy. However, the ANEGL embedded platform does not support middleware non-functional requirements, such as adaptability, heterogeneity, extendability, and fault tolerance.

2.1.7 SENSE

The main goal of the Smart Embedded Network of Sensing Entities (SENSE) project was to develop methods, tools, and a test platform for the design, implementation, and operation for smart home networks of embedded sensing components [58]. The developed home network is intelligent enough to sense the environment of heterogeneous devices and delivers reliable information between devices and the user. SENSE intends to overcome problems with current centralized networks. The wireless communication module is based on a Nanotron transceiver on which the TCP/IP protocol suite is used [8]. This project targeted the domain of security monitoring [58]. The final end-users can control the system through a standard web interface.

SENSE uses a completely decentralized approach. A newly added device can automatically better adapt itself to the environment and can communicate with the rest of the network devices [58]. It provides dynamic addition and removal of devices from the network without disturbing the rest of the network [8]. Newly added nodes automatically calibrate themselves to the environment, and share knowledge with neighbors. The network is scalable because of local information processing and sharing, and self-organizes based on the physical placement of nodes. Further, SENSE challenged the problems of scalability and complexity through decentralization of both processing and knowledge, relying upon the fusion of information at a high semantic level to allow computation [8]. However, the SENSE middleware is not a platform-independent framework. Furhter, it does not support adaptability, heterogeneity, and fault tolerance.

2.1.8 Microsoft EasyLiving

EasyLiving's goal was the development of a scalable architecture and technologies for intelligent environments that allowed the dynamic aggregation of diverse I/O devices into a coherent user experience [9]. The important components of the developed framework include middleware to enable distributed computing, location-based context-awareness, and service description. The EasyLiving project can currently handle a single room and tens of devices with dynamic changes to their configuration. It is an Extensible Markup Language (XML) based distributed agent system that uses computer vision techniques for person tracking and provides visual user interaction. It supports applications related to the child care and building automation [9].

The middleware supports location-based context-awareness, and service description. EasyLiving architecture is scaleable because of plug and play support, new devices should be intelligently and automatically integrated [9]. However, it does not support other functional requirements, such as interoperability, platform independency, adaptability and fault tolerance.

2.1.9 Gator Tech Smart House

The main goal of the Gator Tech smart house project was to develop a platform-independent middleware architecture for a smart home. It is based on layers such as physical (sensor and actuator platform), service and context management, and application layers [68]. The

Project	Interoperability	Adaptability	Scalability	Extensibility	Fault Tolerance
HYDRA	√		√		√
SOCRADES		√	√	√	√
Oxygen		√			
AMIGO	√				
RUNES	√	√	√		
ANGEL	√		√		
SENSE	√		√		
Microsoft EasyLiving			√		
Gator Tech Smart House	√	√	√	√	
inContext				√	

Table 1: Non-Functional Requirements of Embedded Middleware Platform for Smart Homes

proposed architecture service layer is based on the OSGi framework. It registers a device's services as a bundle. A component called composite services was proposed and aims to have coordination among different existing bundles by using service discovery protocol [68]. Smart plugs are used together with RFID to sense the incoming devices in the home network. Then OSGi-based solution downloads the corresponding device OSGi bundle and registers the devices' services in the local repository [68].

The Gator Tech Smart House features include a smart mailbox that senses and notifies the arrival of mail, a smart bed that monitors sleeping patterns, a smart front door that identifies residents, a smart mirror that displays important messages or reminders, such as when to take medication, and a smart bathroom that includes a flush detector, a toilet paper dispenser, and a water temperature regulating shower [44]. The Gator Tech Smart House middleware is highly scalable, adaptable to the diverse domains and supports interoperability and heterogeneity, and also provides service composition but it does not support fault tolerance.

2.1.10 inContext

The Interaction and Context Based Technologies for Collaborative Teams (inContext) project's goal was to have a software service with a distributed middleware architecture, which addresses the problems of context management, context modeling, and context-aware platforms for pervasive systems. The context modeling is based on several core ontologies, such as location, team, activity, resource, and context information of the end-user. The context modeling and management also play significant roles in the middleware architecture to execute complex goals to satisfy user interests [16].

The developed context-aware service middleware is platform independent. It enables powerful and flexible ways of interaction for the knowledge worker by proactively aggregating software services (using message-oriented middleware and Web services as well as P2P systems) and utilizing wireless network technologies such as WLAN, Bluetooth, WiMax, and 3G/UMTS, on several types of personal devices (Personal Digital Assistants, SmartPhones, Tablet PCs, Notebooks, etc.) over high-speed Session Initiation Protocol (SIP) based broadband networks. The distributed context management architecture does not support reasoning and dynamic planning. Further, it does not provide any support to address additional non-functional requirements, such as interoperability, scalability, adaptability, heterogeneity, and fault tolerance.

Summary: We presented a number of projects focused on novel middleware platforms targeting applications in various areas, such as home, industry, health, and structural monitoring. As shown in Table 2, a majority of middleware platforms have focused on home automation. Table 1 indicates, for each of the middleware presented, non-functional re-

Project	Application Domain
HYDRA	Home Automation, Health Care, Agriculture
SOCRADES	Industrial Automation
Oxygen	Home Automation
AMIGO	Home Automation
RUNES	Emergency Scenarios
ANGEL	Health Care
SENSE	Security Monitoring
Microsoft EasyLiving	Home Automation
Gator Tech Smart House	Home security, Energy Management, Home Care
inContext	Home Automation

Table 2: Project Application Domains

quirements addressed by the middleware. As we can see from Table 1, most of the efforts have focused on the requirements of platform-independency, interoperability, heterogeneity, and scalability in the networked embedded systems. Only HYDRA and SOCRADES embedded middleware architectures support fault tolerance. Extendability is also an important requirement of the embedded middleware platforms because these systems are growing very fast with the rapid development of technology. We find that only SOCRADES, Gator Tech Smart House, and inContext architectures support extendability. Table 1 shows that almost 50% of the studied embedded middleware platforms support adaptability. Based on the lessons we learned during the study of different middleware platforms, we developed a middleware solution for networked embedded system which fulfills the identified requirements and solves the problems we have found in existing approaches.

2.2 Pervasive Middleware Technologies

Smart home systems provide automation capabilities that allow home owners to have more complete control over their homes. These systems integrate many devices having different capabilities, such as TV, doors, lights, oven, windows, and multimedia players. Smart home systems also include sensors and actuators for different complex systems, such as intrusion detection, video surveillance, fire detection, patient health monitoring, and entertainment. These sensors and actuators use different communication protocols that are mostly incompatible with each other. Usually, current homes are equipped with smart devices with wired and wireless technologies.

In our reviewing of the literature, we found a number of networking protocols to interconnect devices in a smart home. These include Java intelligent network infrastructure (Jini), UPnP, and Device Profile Web Services (DPWS). Technologies based on service orientation are not new for pervasive systems. UPnP and Jini [19] have been proposed as protocols and architectures for dynamic device and functionality discovery, based on describing services in terms of WSDL and Java interfaces respectively. These are excellent starting points for our study, as they provide support for basic interoperation, but to realize genuinely smart homes, more aspects need to be designed in terms of home sensing and composition. There is some standard protocols for exchanging the information between the devices and the components of a middleware platform, such as Simple Object Access Protocol (SOAP), REpresentational State Transfer (REST) and Web Services Description Language (WSDL).

We will present the most prominent protocols and transmission styles that are important for home networking and service application. A central workstation (home gateway), such as a PC or a tablet with a smart interface, provides users with access to the device services using technologies and protocols, as discussed below.

Wireless Networking Standards	Embedded Middleware Platforms
ZigBee	[67], [84], [6], [82], [61], [20], [63], [33], [21], [40], [22], [73]
Bluetooth	[40], [59], [57], [70], [63], [61], [33], [21]
RFID	[74], [79], [30], [61], [78], [18], [63], [33], [21]

Table 3: Prominent Smart Home Wireless Networking Standards

2.2.1 Wireless Networking Standards

The home network needs technologies at the physical layer and middleware to provide control of devices to the application layer. Typically, physical communication media among devices is based on three different groups; structured wiring, existing wiring, and wireless [52]. In most cases, devices are interfaced with wireless communication because the wireless technology standards are everywhere. The wide spread of wireless networks in our daily life is enabled by the communication standards, such as Bluetooth, Zigbee, Radio Frequency Identification (RFID), and cellular technologies. A combination of these standards is envisaged to be used to construct the smart home. Effectively, all wireless technologies that can support some form of remote data transfer, sensing, and control are candidates for inclusion in the smart home portfolio.

ZigBee
ZigBee is a global wireless networking standard designed specifically for control and monitoring applications. Recently, it has become one of the most promising technologies for home networks because the energy consumption is very low; so, the batteries can last a long time. ZigBee has a low rate of data transmission but enough for the scenarios in which it should find application. ZigBee is a specification for a suite of networking, security, and application software layers based on the IEEE 802.15.4 standard for personal area networks [67]. ZigBee is especially appropriate for sensor applications including building automation, wireless light switches, electrical meters with in-home-displays, and traffic management systems. In general, it is indicated for any home automation situation in which high data transfers are not required and in which elements are dormant most of the time.

ZigBee technology implementation issues from hardware to software of home gateway and device nodes are presented by Zhang [84]. For instance, network topology and protocol stack layers. Similarly, hardware design issues are discussed for various home devices, such as wireless communications transceiver modules base, and control switches for electrical appliances in a room [6]. An architecture for dynamic integration of ad-hoc ZigBee home network devices into OSGi-based home gateways is presented in [82]. An ad-hoc ZigBee home network device is represented by a device proxy service in the proposed architecture so that it can be dynamically registered, discovered, accessed and unregistered just like a common OSGi service [82]. A ZigBee technology based system design concept and implementation approach of a smart home is described in [20].

Bluetooth
Bluetooth is a wireless technology standard for exchanging data over short distances from fixed and mobile devices. Bluetooth is also especially appropriate for sensor applications including health care, home automation, traffic management systems, and wireless light switches. The huge network of Bluetooth's devices includes phones, tablets, PCs, and TVs in use today worldwide. These devices cannot only talk to each other, but also communicate

with Bluetooth enabled appliances, heating, and cooling systems, and other devices in the smart home. Over the past decade, it has evolved to address all of the key requirements of the smart home market, including security, reliability, and wireless range [59].

In [59], a smart home system is developed for disabled people by using Bluetooth. The smart home system for disabled people is focused on making it possible for disabled people to carry out their daily activities safely and comfortably. The design and implementation of a low cost yet flexible and secure cell phone based home automation system is presented in [57]. The design is based on an individual Arduino Bluetooth board, and the home devices are connected to the board via relays. The communication between the cell phone and the Arduino Bluetooth board is wireless. A novel home network system is designed and developed for creating new network and service architecture by connecting home appliances that are networked using Bluetooth's technology with the Internet [70].

RFID

RFID describes a system that transmits the identity of an object wirelessly using radio waves [74]. It defines an RFID tag holding information about the object carrying the tag and an RFID reader. RFID systems can be used in smart homes where every single object can be connected to the home area network through a virtual wireless address and unique identifier. This can be used to keep an updated database holding information about objects' locations. The smart home can be asked to provide information about a specific object that the user is looking for, such as the user's car keys or the user's remote control. Further, the RFID system can be used to track smart home occupants; a number of studies have been reported in the literature that used the RFID concept to track smart home occupants [79].

In [30], RFID and wireless sensor networks were used together in a smart home to identify a caregiver who enters the home. A ubiquitous computing based smart home safety management for digital life was designed in [78]. The proposed scheme integrated RFID and context awareness technologies in ubiquitous environments to increase the efficiency of mobile commerce and improve the life quality. They designed the secure and automatic control service using an RFID-tagged ID card and context-based light and temperature management using sensor and RFID tag [78]. A smart home service system that benefits in terms of cost, energy consumption, and complexity is presented in [18], which proposed a novel read-out method for a hierarchical wireless master slave RFID reader architecture of multi standard technologies.

Summary Table 3 summarizes research on the smart home based on wireless standards. It shows that ZigBee is the most commonly used wireless protocols in home networking products because it is easily deployable, has low-cost and low- power consumption protocols, and provides more reliability and security than Bluetooth and RFID. Further, a large number of home devices supported by ZigBee technology are available on the market. ZigBee is especially appropriate for sensors, safety systems, remote monitoring applications, and so on. Table 4 shows the key characteristics of four wireless protocols. Each protocol is based on an IEEE standard. In general, the Bluetooth and ZigBee are intended for communication (about 10m) in smart home because these are short-range technologies. Further, a large number of devices are available on the market. However, ZigBee can also reach 100m in some applications. The RFID is most commonly used to track the location of the person in smart homes.

Protocols	**Range**	**Bandwidth**	**Energy Consumption**	**Topology**	**Operating Frequency**	**Security**
ZigBee	10-100 meters	20-250 Kbps	Very low	Ad-hoc, peer to peer, star, or mesh	868 MHz (Europe), 900-928 MHz (North America), 2.4 GHz (world)	128 AES plus application layer security
Bluetooth	10-100 meters	1 MHz	Medium	Ad-hoc, very small networks	2.4 GHz	64 and 128 bit encryption
RFID	1-100 m		Low	Application dependent	860-960 MHz	Application dependent

Table 4: Key Characteristics of Zigbee, Bluetooth and RFID

Protocols	**Modulation Scheme**	**Filtering**	**Access Protocol**	**Address Range**	**Speed (bit/sec)**	**Interoperability**	**Security**
KNX	BFSK	easy	time divided	32768	1200	Yes	Yes
X10	short 120 kHz pulses	easy	CSMA/CA	256	60	Yes	No

Table 5: Key Characteristics of KNX and X10

2.2.2 Networking Communication Protocols

Existing devices differ significantly from each other and from one household to another with respect to models, brand, type and quantity. Their purposes range from washing clothes to controlling room humidity. A home network must allow all such appliances to communicate with each other. Thus, it needs a technology that can seamlessly integrate various devices into a uniform communication network. A variety of service discovery protocols are available. The most well known so far are: KNX, X10, Jini, UPnP and DPWS.

KNX
KNX is a standardized network communications protocol for intelligent buildings [2]. It transfers control data to all building management components, and all components communicate via one common language. It can use a variety of means of transmission and defines several, including twisted pair, power supply, radio, infrared, and Ethernet [2]. It was designed to be independent from the hardware platforms which controlled it. A distributed multi-agent framework is developed for home and building automation, based on a semantic enhancement of EIB/KNX standard exploiting knowledge representation and reasoning technologies [25].

X10
X10 is a protocol for communication between electronic devices used for home automation. It allows compatible products to connect to each other using the existing electrical writing in the home. It primarily uses power line wiring for signaling and control. X10 technology is simple and inexpensive, requires no special wiring and is easily extendable [62]. On the other

Protocols	**Addressing**	**Discovery**	**Service Description**	**Control**	**Eventing**	**Presentation**	**Security**
Jini	DHCP, AutoIP	Lookup Service	Unspecified (JRMP, Jeri, IIOP, etc)	RPC or Remote Method Invocation	Distributed		Yes
UPnP	DHCP, AutoIP	SSDP	UDA Schema	SOAP 0.9, 1.1	GENA	HTTP, HTML	Yes
DPWS	DHCP, AutoIP	WS-Discovery	WSDL	SOAP 1.2	WS-Eventing	HTTP, HTML	Yes

Table 6: Key Characteristics of Jini, UPnP and DPWS

hand, X10 can support maximum 256 devices and does not provide any means by which information about the type of device can be conveyed [56]. X10 also does not provide any means for automated discovery of devices. In these instances, the home gateway must derive all information about the device via user input [37]. As mentioned earlier, X10 provides no provision for device discovery. This eliminates the possibility of developing any device discovery and service discovery applications in a computer controlled X10 environment.

Jini

Jini is a network architecture for the construction of distributed systems in the form of modular co-operating services. It is a Java-based distributed platform and concentrate on interoperability like other technologies, such as UPnP [52]. It is a middleware for networking technology that provides a set of application programming interfaces as well as network protocols that can meet home network requirements. Since Jini is tied heavily to the Java platform, its use is restricted to devices powerful enough to host a Java Virtual Machine (JVM). It supports service discovery, description, invocation and presentation, all implemented using standard Java facilities [27].

Jini provides a distributed environment for devices to communicate with each other [28]. Each device publishes its own interfaces, which other devices can use to communicate with it and thereby access its particular service. This approach ensures compatibility and standardized access among all devices [28]. The interoperability problem can be solved via standards-based connectivity and communications protocols. However, in the case of Jini, the static and runtime storage requirements of typical implementations are too great to be considered for the embedded systems in appliances [66]. A distributed security mechanism for home environment is developed in [5] using Jini technology, which is dynamic and active environment.

UPnP

UPnP is a technology which supports networking, and automatic discovery for various kind of device from different vendors. With UPnP, a device can dynamically join a network, obtain an IP address, convey its capabilities, and learn about the presence and capabilities of other devices automatically [48]. UPnP is a popular technology for home networking and control. However, constructing UPnP-based home networks is not easy. How to connect different devices to the home network is a significant issue because most existing devices have no UPnP interface. Therefore, a common solution is to UPnP control point is embedded in a residential gateway to solve this problem [42]. An appliance interface is added into

Middleware Networking and Communication Protocols	Embedded Middleware Platforms
KNX	[25], [2]
X10	[56], [37], [62]
Jini	[28], [66], [5], [40], [52], [41], [19], [27]
UPnP	[48], [42], [31], [71], [17], [24], [49], [40], [52], [35]
DPWS	[50], [56], [32], [14], [12], [43], [34], [26]

Table 7: Smart Home Networking and Communication Protocols

an UPnP adapter to translate the UPnP control messages into the private protocol of the appliance. On the other hand, the residential gateway acts as a UPnP control point and any control terminal can be used to control the appliance [42]. The UPnP residential gateway has an interface translating the UPnP control messages into the private protocol of the appliance [42].

An approach for content sharing among UPnP devices in different home networks is proposed in [31]. In this approach, a module is designed and developed that extends the home gateway with an UPnP-compatible protocol by using simple service discovery protocol (SSDP) messages used in the UPnP device architecture. Further, a method is presented by [71], to implement a UPnP application program interface, which helps to build UPnP applications on top of it. Another, middleware platform is proposed in [17] for a home network to extend the UPnP operations, which is originally restricted by a broadcast message. Moreover, a solution is proposed in [24] to integrate the networking and communication technologies in the smart homes for disable people. The developed prototype is based on the UPnP protocol to discover and control devices indoor. It uses wireless technologies to enhance mobility. Its importance resides in managing different protocol and ensuring networking and communication between environment's devices [24].

DPWS

DPWS is a Web Services profile that enables plug-and-play for networked devices. It defines a minimal set of implementation constraints to enable secure Web Service messaging, discovery, description, and eventing on resource-constrained devices [1]. Its objectives are similar to those of UPnP but, in addition, DPWS is fully aligned with Web Services technology and includes numerous extension points allowing for seamless integration of device-provided services in enterprise-wide application scenarios [26].

A secure service infrastructure for home networks that allows the secure access to DPWS services from within one network as well as from remote home network is presented in [50]. A Peer-to-peer (P2P) scheme is proposed for a flexible smart home architecture and analyzed the possibility of distributing the required application work flow logic to individual peers [56]. It is observed that the tools and techniques provided by DPWS, more specifically, its discovery and eventing mechanisms, are suitable to realize such a proposed architecture [56]. A Smart Home system is developed in [32], which interacts with the smart home, made by web-service driven smart appliances. Smart home appliances are implemented based on DPWS [32]. An event-driven SOA using DPWS is proposed in [14]. DPWS inherits the advantages of the traditional web services in achieving interoperability without dependence on platform, while improving service discovery and security as well as being optimized for deploying on resource constrained devices [14].

Summary: Having considered each communication protocol, we summarize the main differences between KNX and X10 protocols, shown in Table 5. The KNX powernet standard uses BFSK, a rather simple method, as a modulation scheme. Table 6 shows the differences between three home networking protocols based on using different protocols and standards for various requirements of the system, such as addressing, device discovery, service description, control, eventing, presentation, and security. These system requirements are explained in Section 6.

Table 7 summarizes the middleware networking and communication protocols used in different smart home systems. One notices that UPnP is the most widely used networking protocol because it is an open networking platform that leverages existing and greatly deployed the Internet protocols like TCP/IP, HTTP, and UDP. It uses the standardized XML scheme and SOAP to transfer data between networked devices. Additionally, UPnP supports plug-and-play networking with automatic device discovery. The DPWS protocol is also widely used in home networking. The objectives of DPWS are similar to the objectives of UPnP but DPWS aims to use Web Service standards, such as WSDL 1.1, XML Schema and SOAP 1.2 to archive these goals. This approach certainly has advantages, especially for interoperability with other systems based on Web service standards. There are, however, also some disadvantages. Unfortunately, the tooling support for most of the WS extensions used by DPWS is highly insufficient. DPWS is also a logical choice in smart home embedded middleware platforms because it offers easy interoperability with Web services. The main advantage of DPWS over UPnP is that it is completely built of WS standards and extensions where UPnP uses some non WS standards. On the other hand, UPnP is also accepted widely because it is supported by the OSGi framework.

2.2.3 Messaging and Interfacing Protocols

SOAP

SOAP is a simple and open XML-based protocol for exchanging information between computers. It is a communication protocol which is designed to communicate via the Internet and can extend Hypertext Transfer Protocol (HTTP) for XML messaging [47]. SOAP provides data transport for Web services and can also exchange complete documents or call a remote procedure. SOAP is the basic protocol for binding two services and is widely used on the Web. The most common messaging pattern of using SOAP is Remote Procedure Call (RPC), but SOAP can also be used in XML document style [72]. SOAP messages are written entirely in XML and are therefore, uniquely platform- and language-independent [47].

SOAP is a platform-independent messaging protocol, which means that as long as the applications are using Web service interfaces, they can communicate with SOAP. Usually, SOAP is based on HTTP, so that it is easy to be deployed on different networks and different devices. Further, the scalability of SOAP is related to SOAP encoding styles. Generally, document style coding has better performance than RPC. Additionally, SOAP has a simple message-level fault tolerance mechanism, by using the fault element in messages. There are a lot of non-standard fault-tolerance extensions designed for SOAP [65].

WSDL

WSDL is an XML based protocol for information exchange in decentralized and distributed environments. It is the standard format for describing a Web service and a language for describing how to interface with XML-based services, and what operations it will perform [15].

Protocols	Embedded Middleware Platforms
SOAP	[35], [47], [72], [65]
WSDL	[21], [85]
REST	[39], [80], [64]
OSGi	[40], [53], [83], [81], [29], [54], [68], [49], [69], [38], [76], [46], [14], [77], [19], [11], [13], [60], [82]

Table 8: Messaging and Interfacing Protocols

WSDL is frequently used in combination with SOAP and XML schema to provide Web services over the Internet. A client program connecting to a Web service can read the WSDL to determine what functions are available on the server. The client can then use SOAP to actually call one of the functions listed in the WSDL. In [85], a smart home gateway describes its services in WSDL and registers them to the cloud service directory so that other homes can search and consume the service.

REST

REST is an architecture style for designing networked applications. The idea is that, rather than using complex mechanisms, such as CORBA, RPC or SOAP to connect between machines; simple HTTP is used to make calls between machines [3]. REST is mainly used for interaction with embedded devices because it is an architectural style that defines how to use HTTP as an application protocol. Resources can only be manipulated by the methods specified in the HTTP standard (e.g., GET, POST, PUT, DELETE) under a uniform interface. The REST is more appropriate for resource-constrained, ad-hoc environments as it is a lightweight protocol that guarantees loose-coupling and a smooth transition from the Web to the embedded environment of physical devices [39]. Recent approaches suggest REST as the architectural style used in constrained environments [39, 64, 80]. In [64, 80], an IP-based sensor network system is implemented, where nodes communicate their information using RESTful Web services.

2.2.4 OSGi

OSGi is an open specification for the delivery of managed services to networked environments, such as homes and automobiles [14, 40, 53]. The OSGi service platform consists of the OSGi framework and a set of standard service definitions. The OSGi framework is the execution environment for services, which is based on Java Virtual Machine (JVM). It can accommodate many heterogeneous frameworks in a generic environment. The OSGi framework is able to integrate heterogeneous devices and services, which appear as local entities.

An OSGi-based smart home architecture is presented by [40], which uses the OSGi gateway as a central coordination point for managing the home network and covers numerous heterogeneous communication technologies. Smart homes usually require the integration of many heterogeneous devices and service applications in deployment so it is hard and expensive to implement system tests. [83] develop a OSGI-based smart home simulator, which is called SHSim. An OSGi based context-aware framework is developed to provide dynamically appropriate information and services for users in a smart home environment [81]. The developed middleware integrates services through a reasoning system. Further, a OSGi-based MyHome system is presented in [29], which provides integrated user interface and an event-driven, multi-threaded service development platform thorough adopting message oriented middleware and OSGi technologies. It offers reliable automatic operations, fault tolerant and configurable home automation, high extensibility and large scalability [29]. Several proposals for extending the OSGi description with appropriate semantics have been made in the literature, with the purpose to facilitate the discovery process [54] or for supporting their automatic parsing by software agents.

Summary: Table 8 shows a number of protocols used in smart home networking to exchange information in decentralized and distributed environments between different machines such as SOAP, WSDL and REST. There are two styles that are widely used on the modern web to communicate with the outside worlds, such as REST and RPC styles. REST style is very useful because the operations are easily mapped to HTTP verbs. Two RPC style technologies are SOAP and XML-RPC. The advantage of XML-RPC is that it is simpler than SOAP. A disadvantage of XML-RPC is that it lacks a service description language, where SOAP has WSDL as a service description language. SOAP protocol is extensively used because it provides interoperability between homogeneous or heterogeneous distributed applications and platform independence. Further, SOAP provides scalability because it uses HTTP protocol for transport due to which it becomes scalable. A large number of smart home middleware frameworks are based on OSGi as shown in the Table 8 because it provides interoperability and dynamic integration of many types of drivers and devices and seems as local entities in OSGi framework. OSGi is a platform- and device-independent framework that can be a good choice to develop the service gateway, which manages the services in the local network.

3 Summary

In this paper, we have illustrated the state of the art in the area of the middleware platform of a smart home. First, we reviewed a number of existing pervasive middleware solutions about smart homes. Second, we looked at various standard protocols and technologies, which are relevant for the middleware of a smart home and their existing implementation in different home networking solutions.

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References

[1] Devices Profile for Web Services, http://en.wikipedia.org/wiki/Devices_Profile_for_Web_Services

[2] Konnex official web page, http://www.knx.org/es/

[3] Representational state transfer (rest), http://en.wikipedia.org/wiki/Representational_state_transfer

[4] Pervasive Human-Centered Computing, MIT Project Oxygen (2004), http://oxygen.lcs.mit.edu/

[5] Al-Muhtadi, J., Anand, M., Mickunas, M., Campbell, R.: Secure smart homes using jini and uiuc sesame. In: 16th Annual conf. Computer Security Applications, ACSAC. pp. 77–85 (2000)

[6] Anan, F., Xiaoling, X., Wenling, Y., Li, Z.: The Realization of Intelligent Home by ZigBee Wireless Network Technology. In: Pacific-Asia conf. on Circuits, Communications and Systems. pp. 81–84 (2009)

[7] Bromberg, Y.D., Issarny, V.: INDISS: Interoperable Discovery System for Networked Services. In: Middleware. pp. 164–183. Lecture Notes in Computer Science, Springer, Grenoble, France (2005)

[8] Bruckner, D., Velik, R., Zucker, G.: Network of cooperating smart sensors for global-view generation in surveillance applications. In: 6th IEEE Inter. conf. on Industrial Informatics, INDIN 2008. pp. 1092–1096 (2008)

[9] Brumitt, B., Meyers, B., Krumm, J., Kern, A., Shafer, S.A.: EasyLiving: Technologies for Intelligent Environments. In: Inter. symposium on Handheld and Ubiquitous Computing. pp. 12–29. HUC '00, Springer-Verlag, London, UK (2000)

[10] Bruynen, J., Garino, P., Nalin, M., Decandia, M.: Angel System Platform Architecture. In: IEEE Inter. conf. on Electronics, Circuits and Systems. pp. 625–628 (2007)

[11] Bushmitch, D., Lin, W., Bieszczad, A., Kaplan, A., Papageorgiou, V., Pakstas, A.: A SIP-based device communication service for OSGi framework. In: First IEEE Consumer Communications and Networking conf. pp. 453–458 (2004)

[12] Cannata, A., Gerosa, M., Taisch, M.: SOCRADES: A framework for developing intelligent systems in manufacturing. In: IEEE Inter. conf. on Industrial Engineering and Engineering Management. pp. 1904–1908 (2008)

[13] Chang, G., Zhu, C., Ma, M., Zhu, W., Zhu, J.: Implementing a sip-based device communication middleware for osgi framework with extension to wireless networks. In: First Inter. Multi-Symposiums on Computer and Computational Sciences (IMSCCS). vol. 2, pp. 310–311 (june 2006)

[14] Chen, P., Zhi, X.l.: Smart home architecture based on event-driven DPWS. Journal of Shanghai University (English Edition) 15(5), 386–390 (Oct 2011)

[15] Chinnici, R., Gudgin, M., Moreau, J., Weerawarana, S.: Web Services Description Language (WSDL) (July 2002), `http://www.w3.org/TR/wsdl12/`

[16] Christian, M., Stephan, R.M., Hong, Y., Daniel, S., Schahram, D.: InContext - Interaction and Context-based Technologies for Collaborative Teams. In: Information and Communication Technologies and the Knowledge Economy (2008)

[17] Chuan-Feng, C., Steen, J.H., Sen-Ren, J.: An Intel. Home Environment based on Service Planning over Peer-to-Peer Overlay Network. Journal of Software pp. 3–10 (2008)

[18] Darianian, M., Michael, M.: Smart Home Mobile RFID-Based Internet-of-Things Systems and Services. In: Inter. conf. on Advanced Computer Theory and Engineering. pp. 116–120 (2008)

[19] Dobrev, P., Famolari, D., Kurzke, C., Miller, B.: Device and service discovery in home networks with OSGi. Communications Magazine, IEEE 40(8), 86–92 (aug 2002)

[20] Dongmei, Y., Zhiguang, D.: ZigBee-based Smart Home system design. In: Inter. conf.

on Advanced Computer Theory and Engineering. vol. 2, pp. 650–653 (2010)

[21] Eisenhauer, M., Rosengren, P., Antolin, P.: A Development Platform for Integrating Wireless Devices and Sensors into Ambient Intelligence Systems. In: 6th Annual IEEE Communications Society conf. on Sensor, Mesh and Ad Hoc Communications and Networks Workshops, SECON Workshops. pp. 1–3 (2009)

[22] Garcia-Morchon, O., Baldus, H.: The ANGEL WSN Security Architecture. In: Third Inter. conf. on Sensor Technologies and Applications. pp. 430–435 (2009)

[23] Georgantas, N., Issarny, V., Mokhtar, S., Bromberg, Y.D., Bianco, S., Thomson, G., Raverdy, P.G., Urbieta, A., Cardoso, R.: Middleware Architecture for Ambient Intelligence in the Networked Home. In: Handbook of Ambient Intelligence and Smart Environments, pp. 1139–1169. Springer US (2010)

[24] Ghorbel, M., Segarra, M.T., Kerdreux, J., Keryell, R., Thepaut, A., Mokhtari, M.: Networking and Communication in Smart Home for People with Disabilities. In: Computers Helping People with Special Needs, Lecture Notes in Computer Science, vol. 3118, pp. 937–944 (2004)

[25] Giuseppe, L., Floriano, S., Michele, R., Eugenio, D.S.: Semantic-based Smart Homes: a Multi-Agent Approach. In: 13th Workshop on Objects and Agents (WOA 2012). vol. 892, pp. 49–55 (sep-2012)

[26] Guinard, D., Trifa, V., Karnouskos, S., Spiess, P., Savio, D.: Interacting with the SOA-Based Internet of Things: Discovery, Query, Selection, and On-Demand provisioning of Web Services. IEEE Trans. on Services Computing 3(3), 223–235 (2010)

[27] Gunter, O.: Automatic configuration and service discovery for networked smart devices. In Electronic Embedded conf. Munich (2006)

[28] Gupta, R., Talwar, S., Agrawal, D.: Jini home networking: a step toward pervasive computing. Journal Computer 35(8), 34–40 (2002)

[29] Hsuan-Yu, H., Wei-Chung, T., Sheng-Luen, C.: Smart home at a finger tip: OSGi-based MyHome. In: Inter. conf. on Systems, Man and Cybernetics. pp. 4467–4472 (2009)

[30] Hussain, S., Schaffner, S., Moseychuck, D.: Applications of Wireless Sensor Networks and RFID in a Smart Home Environment. In: Seventh Annual Communication Networks and Services Research conf. pp. 153–157 (2009)

[31] Hyunyong, L., Jong Won, K.: An Approach for content sharing among UPnP Devices in different Home Networks. IEEE Trans. on Consumer Electronics 53(4), 1419–1426 (2007)

[32] Igorevich, R., Park, P., Jongchan, C., Dugki, M.: iVision based Context-Aware Smart Home System. In: 1st Global conf. on Consumer Electronics. pp. 542–546 (2012)

[33] Jahn, M., Jentsch, M., Prause, C., Pramudianto, F., Al-Akkad, A., Reiners, R.: The Energy Aware Smart Home. In: Future Information Technology (FutureTech), 2010 5th Inter. conf. on. pp. 1–8 (2010)

[34] Jammes, F., Mensch, A., Smit, H.: Service-Oriented Device Communications Using the Devices Profile for Web services. In: Inter. Conf. Advanced Information Networking and Applications Workshops. vol. 1, pp. 947–955 (2007)

[35] Janse, M., Vink, P., Georgantas, N.: Amigo Architecture: Service Oriented Architec-

ture for Intelligent Future In-Home Networks. In: Constructing Ambient Intelligence, Communications in Computer and Information Science, vol. 11, pp. 371–378 (2008)

[36] Jhing-Fa, W.: Advanced ubiquitous media for creative cyberspace. In: Inter. conf. on Advanced Information Networking and Applications. vol. 2, p. 520 vol.2 (2005)

[37] Ji Eun, K., Boulos, G., Yackovich, J., Barth, T., Beckel, C., Mosse, D.: Seamless integration of heterogeneous devices and access control in Smart Homes. In: 8th Inter. conf. on Intelligent Environments (IE). pp. 206–213 (2012)

[38] Jiankun, W., Linpeng, H., Dejun, W., Fei, S.: R-OSGi-based architecture of distributed smart home system. IEEE Trans. on Consumer Electronics 54(3), 1166–1172 (2008)

[39] Kamilaris, A., Pitsillides, A.: Social networking of the Smart Home. In: IEEE 21st Inter. Symposium on Personal Indoor and Mobile Radio Communications (PIMRC). pp. 2632–2637 (2010)

[40] Lin, R.T., Chin-Shun, H., Tee Yuen, C., Sheng-Tzong, C.: OSGi-Based Smart Home Architecture for Heterogeneous network. In: 3rd Inter. conf. on Sensing Technology. pp. 527–532 (2008)

[41] Lorcan, C., Steve, N., Graeme, S., Mark, S., Simon, D., Paddy, N.: Sensor Fusion-Based Middleware for Smart Homes. Inter. Journal of Assistive Robotics and Mechatronics (IJARM) 8(2), 53–60 (2007)

[42] Lu, Y., Fang, F., Liu, W.: Home Networking and Control Based on UPnP: An Implementation. In: Second Inter. Workshop on Computer Science and Engineering, WCSE. vol. 2, pp. 385–389 (2009)

[43] Luciana, D.S., Spiess, P., Guinard, D., Köhler, M., Karnouskos, S., Savio, D.: SOCRADES: A Web Service based shop floor integration infrastructure. In: Inter. conf. on The internet of things. vol. 4952, pp. 50–67 (2008)

[44] Machiko R. Tomita, Linda S. Russ, R.S., M., B.J.N.: Smart Home with Healthcare Technologies for Community-Dwelling Older Adults. In: Smart Home Systems. pp. 139–158 (2010)

[45] Magerkurth, C., Etter, R., Janse, M., Kela, J., Kocsis, O., Ramparany, F.: An intelligent user service architecture for networiked home environments. In: 2nd IET Inter. conf. on Intelligent Environments. vol. 1, pp. 361–370 (2006)

[46] Marples, D., Kriens, P.: The Open Services Gateway initiative: an introductory overview. Communications Magazine, IEEE 39(12), 110–114 (2002)

[47] Martin, G., Marc, H., Noah, M., Jean-Jacques, M., Yves, L.: Simple Object Access Protocol (2007), `http://www.w3.org/TR/soap/`

[48] Miller, B., Nixon, T., Tai, C., Wood, M.: Home networking with universal plug and play. Communications Magazine, IEEE 39(12), 104–109 (2001)

[49] Min-Xiou, C., Tze-Chin, T.: Heterogeneous service location service architecture based on OSGi technology. In: 11th Inter. conf. on Advanced Communication Technology, ICACT. vol. 03, pp. 1838–1843 (2009)

[50] Muller, A., Kinkelin, H., Ghai, S.K., Carle, G.: A secure service infrastructure for interconnecting future home networks based on DPWS and XACML. In: ACM SIGCOMM workshop on Home networks. pp. 31–36 (2010)

[51] Neal, C., Kevin, W.: Person tracking using audio-video sensor fusion. MIT Artificial

Intelligence Laboratory 1-2 (2001)

[52] Ngo, L.: Service-oriented architecture for home networks. In: Seminar on Internet working. pp. 1 – 6 (2007)

[53] OSGi service platform core specification v.4 (2010), www.osgi.org, www.osgi.org

[54] Panagiotis, G., Thanasis, B., Gregoris, M.: An OSGi-Based Semantic Service-Oriented Device Architecture. pp. 773 – 782 (2007)

[55] Paolo, C., Geoff, C., Cecilia, M., Luca, M., Gian, P.P., Stefanos, Z.: A Reconfigurable Component-based Middleware for networked Embedded Systems. Journal of Wireless Information Networks pp. 149–162 (2007)

[56] Parra, J., Hossain, M.A., Uribarren, A., Jacob, E., Saddik, A.E.: Flexible Smart Home Architecture using Device Profile for Web Services: a Peer-to-Peer Approach. Inter. Journal of Smart Home 3, 39–55 (Apr 2009)

[57] Piyare, R., Tazil, M.: Bluetooth based home automation system using cell phone. In: IEEE 15th Inter. Symposium on Consumer Electronics (ISCE). pp. 192–195 (2011)

[58] Pratl, G., Frangu, L.: Smart Nodes for Semantic Analysis of Visual and Aural Data. In: 5th IEEE Inter. conf. on Industrial Informatics. vol. 2, pp. 1001–1006 (2007)

[59] Ramlee, R., Tang, D., Ismail, M.: Smart home system for Disabled People via Wireless Bluetooth. In: Inter. conf. on System Engineering and Technology. pp. 1–4 (2012)

[60] Redondo, R.P.D., Vilas, A.F., Cabrer, M.R., Arias, J.J.P., Duque, J.G., Solla, A.G.: Enhancing Residential Gateways: A Semantic OSGi Platform. IEEE Intelligent Systems 23(1), 32–40 (2008)

[61] Reiners, R., Zimmermann, A., Jentsch, M., Zhang, Y.: Automizing home environments and supervising patients at home with the HYDRA middleware: application scenarios using the hydra middleware for embedded systems. In: Inter. workshop on Context-aware software technology and applications. pp. 9–12 (2009)

[62] Rosslin John, R., Tai-hoon, K.: Applications, Systems and Methods in Smart Home Technology: A Review. Inter. Journal of Advanced Science and Technology 15, 37–48 (Feb 2010)

[63] Sarnovsky, M., Butka, P., Kostelnik, P., Lackova, D.: HYDRA - Network Embedded System Middleware for Ambient Intelligent Devices. In: ICCC'2007: International Carpathian Control conf. (2007)

[64] Schor, L., Sommer, P., Wattenhofer, R.: Towards a zero-configuration wireless sensor network architecture for smart buildings. In: ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings. pp. 31–36 (2009)

[65] Shiping, C., Bo, Y., Zic, J., Ren, L., Ng, A.: Evaluation and modeling of Web Services performance. In: Inter. conf. on Web Services. pp. 437–444 (2006)

[66] Smith, L., Roe, C., Knudsen, K.: A JiniTM lookup service for resource-constrained devices. In: Inter. Workshop on Networked Appliances. pp. 135–144 (2002)

[67] Soyoung, H., Donghui, Y.: Remote Monitoring and Controlling System based on ZigBee Networks 6, 35–42 (July, 2012)

[68] Sumi, H., William, M., Hicham, E.Z., Jeffrey, K., Youssef, K., Erwin, J.: The gator tech smart house: A programmable pervasive space. Computer 38, 50–60 (2005)

[69] Szu-Chi, W., Kai-Peng, C., Tung-Yen, L., Chi-Yi, L.: Toward an OSGi-Based Infras-

tructure for Smart Home Applications. In: Symposia and Workshops on Ubiquitous, Autonomic and Trusted Computing, UIC-ATC '09. pp. 184–188 (2009)

[70] Tajika, Y., Saito, T., Teramoto, K., Oosaka, N., Isshiki, M.: Networked home appliance system using Bluetooth technology integrating appliance control/monitoring with Internet service. In: IEEE Inter. Conf. on Consumer Electronics. pp. 142–143 (2003)

[71] Tranmanh, T., Feijs, L.M., Lukkien, J.J.: Implementation and validation of UPnP for Embedded Systems in a home networking environment. In: Inter. Conf. on Communications, Internet, and Information Technology. pp. 279–284 (2002)

[72] Tsalgatidou, A., Pilioura, T.: An Overview of Standards and Related Technology in Web Services. Distributed Parallel Databases 12(2-3), 135–162 (Sep 2002)

[73] Ventylees, R.S.: Implementation of pervasive computing based high-secure smart home system. Inter. Journal of Engineering Science and Technology 4(11), 4663–4668 (2012)

[74] Want, R.: An introduction to RFID technology. Pervasive Computing, IEEE 5(1), 25–33 (2006)

[75] Willig, A., Hauer, J., Karowski, N., Baldus, H., Huebner, A.: The ANGEL WSN Architecture. In: Inter. conf. on Electronics, Circuits and Systems. pp. 633–636 (2007)

[76] Wu, C.L., Liao, C.F., Fu, L.C.: Service-Oriented Smart-Home Architecture Based on OSGi and Mobile-Agent Technology. IEEE Trans. on Systems, Man, and Cybernetics, Part C: Applications and Reviews 37(2), 193–205 (march 2007)

[77] Xie, L., Wenjun, Z.: The design and implementation of home network system using OSGi compliant middleware. IEEE Trans. on Consumer Electronics 50(2), 528 – 534 (may 2004)

[78] Xuemei, L., Gang, X., Li, L.: RFID based smart home architecture for improving lives. In: Inter. conf. on Anti-counterfeiting, Security and Identification. pp. 440–443 (2008)

[79] Yamazaki, T.: Ubiquitous home: real-life testbed for home context-aware service. In: First Inter. conf. on Testbeds and Research Infrastructures for the Development of Networks and Communities. pp. 54–59 (2005)

[80] Yazar, D., Dunkels, A.: Efficient application integration in IP-based sensor networks. In: ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings. pp. 43–48. BuildSys '09, ACM, New York, NY, USA (2009)

[81] Yeong-Sheng, C., I-Cheng, C., Wen-Hsuan, C.: Context-aware services based on OSGi for smart homes. In: Ubi-media Computing (U-Media), 2010 3rd IEEE Inter. conf. on. pp. 38–43 (2010)

[82] Young-Guk, H.: Dynamic integration of Zigbee home networks into home gateways using OSGi service registry. IEEE Trans. on Consumer Electronics 55(2), 470–476 (2009)

[83] Zhang, L., Suo, Y., Chen, Y., Shi, Y.: SHSim: An OSGi-based smart home simulator. In: 3rd IEEE Inter. conf. on Ubi-media Computing (U-Media). pp. 87–90 (2010)

[84] Zhang, S., Xu, D., Jiang, Y., Wang, R.: Realization of Home Remote Control Network Based on ZigBee. In: 8th Inter. conf. on Electronic Measurement and Instruments. pp. 344–348 (2007)

[85] Zhiqiang, W., Shuwei, Q., Dongning, J., Yongquan, Y.: Research and design of cloud architecture for smart home. In: IEEE Inter. conf. on Software Engineering and Service Sciences (ICSESS). pp. 86–89 (2010)

