OSGi Based Service Infrastructure for Context Aware Connected Homes

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Abstract. This paper presents an OSGi based service infrastructure for delivering, managing and developing context aware services in connected homes. An OSGi-compliant residential gateway (RG) is deployed in connected homes to bridge the Internet and the home networks and devices. A device access system architecture has been embedded in RG and devices to facilitate device discovery, capability sharing and interoperability. Context information has been acquired, delivered, processed and derived using a novel context aware service architecture on top of the OSGi framework. A prototype has been implemented to verify the feasibility of the new service infrastructure.

Introduction

With the development of Internet broadband access, wireless communication, smart sensors/devices and home networking technologies, smart home has been a hot area for research and development in both academia and industry [1]. A smart home is a networked system of intelligent appliances fitted into the home to meet the different needs of the inhabitants. Smart homes may provide people security, energy saving, convenience and a better lifestyle, they may also provide the aged and disabled people better support for independent living, daily activities and social interaction [2]. For example, you may be notified with an MMS message when your home surveillance system detects that intruders want to enter your house or your grandfather fall down from the armchair, your favorite TV program can be recorded in your PC at the touch of a button, you may talk to your kids through a video IP phone when they are back home for your help, the forgetful grandmother can be warned by a voice message when the water runs for a long time, and the volume of TV and HiFi can be lowered automatically while the phone rings, etc.. Apparently the above mentioned scenarios can be implemented in different ways, but a flexible hardware and software infrastructure for smart home is needed to support system scalability, interoperability and context awareness.

So far, various preliminary smart home solutions have been developed, they can be roughly classified into three categories:

- Device-oriented infrastructure: focuses mainly on the device discovery and interoperability in home networks.
- Service-oriented infrastructure: focuses on service delivery, management and provisioning from Internet to home network and devices.
- Feature-oriented infrastructure: purely proprietary and exploratory, emphasizes on exploring specific features without caring about the whole smart home solution.

Of the above three categories, the device-oriented smart homes solve the device interoperability issue but cannot scale well outside one home. The feature-oriented smart homes can have many unique features such as context wareness, but there is no support for large scale home management, service providers don't have a way to remotely deliver, manage and provision devices and services. The service-oriented smart home rides on the open standards such as Open Service Gateway Initiative (OSGi) [3], Multimedia Home Platform (MHP) and Web Services, it provides a powerful and flexible system infrastructure for service delivery, management and development, but many issues like device inteoperability and context awareness were not well addressed.

The aim of this paper is to make an attempt to propose a novel system infrastructure which can combine the features of the above-mentioned three connected home solutions and offer the best of all three categories. Specifically, we propose to use OSGi based service-oriented infrastructure as the basic system framework, then we use the component-based software architecture of OSGi to incoroperate the device access functionality and context awareness functionality into the OSGi framework. In such a way, the system requirements for a smart home such as system scalability, interoperability and context awareness are all fulfilled and the system infrastructure becomes very flexible and general purpose.

1. Overall System Infrastructure for Connected Homes

In this paper, we propose an open standard-based, service-oriented system infrastructure for the context aware connected homes as illustrated in Fig. 1.

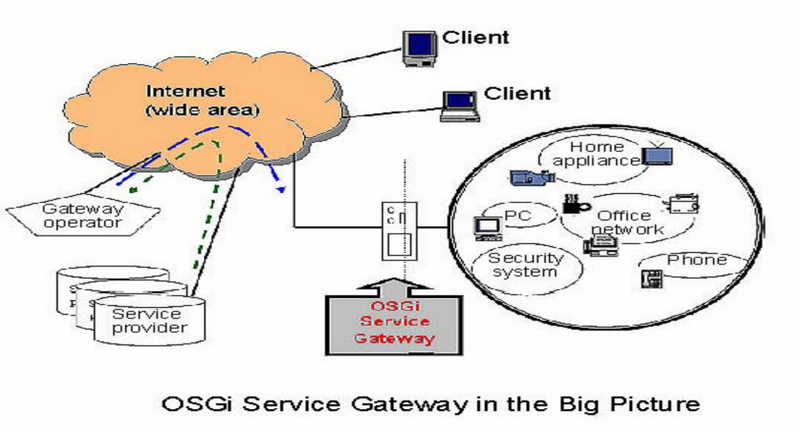


Figure 1. Overall System Architecture

The key ideas of the proposed system infrastructure are:

1. A residential gateway is deployed to interconnect all the home appliances to Internet through broadband access technologies such as xDSL, Cable etc.. The home devices are connected to the RG physically via various home networking technologies such as Ethernet, HPNA, Powerline, IEEE 1394, WLAN or bluetooth.
2. The Open Service Gateway Initiative (OSGi) specifications, which were defined for delivery and provisioning of multiple services over wide area network to home appliances, are adopted as the core service architecture. An OSGi framework is put in the RG (called a service gateway) to standardise the way for secure and reliable service delivery and provisioning, for remote life cycle mangement of services, for providing a common platform for all the services.

The gateway operator controls all the service gateways in each home through a backend system and aggregates various services provided by different service providers. Any new functionalities required in the home are implemented in the form of OSGi services running on top of OSGi framework.

3. Home devices such as PCs, appliances, smart actuators and sensors are interconnected logically using UPnP, LonWorks etc. to the service gateway. Devices work in a plug-and-play manner and can discover and deploy each other's capabilities in the individual home network domain. By putting a device access OSGi service in gateway which bridges different home network protocols, the devices in heterogeneous home networks can inter-operate with each other [4] and be accessed easily.
4. A context aware framework in the form of OSGi service is supported in the service gateway so that both implicit and explicit information can be utilized. Further more, the context acquisition and context usage are logically separated, thus adding new sensors and new context will be decoupled with context aware service development.
5. Besides the HTTP service natively provided by OSGi framework, an SIP service has been implemented in service gateway so that both HTTP and SIP terminals can be used to access the services anywhere, anytime.

In the following sections, the main components of the system infrastructure like the OSGi based service infrastructure, the device access system architecture and the context aware framwork will be described in detail.

2. OSGi Based Service Infrastructure

The OSGi service delivery and management system consists of two parts: the backend system and the service gateway platform.

2.1 The OSGi Backend System

The backend system stays with gateway operator, it enables the service/gateway operator to manage the gateways and deliver services to end users, it supports functions such as configuration, diagnostics, update/upgrade and billing. The key features of the backend system include:

- Remotely administer the connected OSGi based service gateways
- Perform service publishing and service delivery
- Start/Stop and bill delivered services
- Remotely troubleshoot and solve user problems

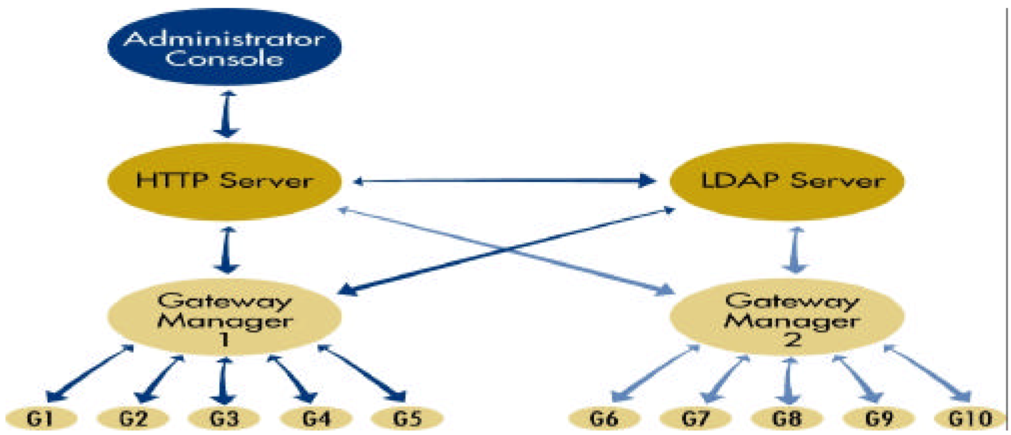


Figure 2. Basic topology of OSGi backend system

The overall structure of the OSGi backend system is shown in Fig. 2, it includes the following fundamental components:

- Service gateway (G1 – G10): the gateway where the OSGi framework is embedded.
- Gateway manager: manage a set of service gateways and interact with http server and Database.
- LDAP server: management engine for database.
- Http server: enables graphical user interface administration for the network administrator.
- Administrator console: web browser to visually manage the network.

2.2 The OSGi Service Gateway Platform

The OSGi service gateway platform refers to the software stack embedded in the residential gateway. As shown in Fig. 3, the service gateway software architecture consists of three layers: the OSGi layer, the system layer and the physical interface layer.

The OSGi layer is composed of two key components: service framework and service bundles. Service framework provides a service hosting environment as well as a set of common APIs to develop service bundles. It also includes several basic service bundles such as http service, log service, configuration management, permission administration, preferences, user manager, device manager etc.. The rest of the service bundles are provided by service developers, it is important to note that adding any new functionality in the service platform is usually translated into adding new OSGi service bundles. For instance, in order to support service access using SIP, a SIP service bundle is needed handling all the communication issues [5]. And a device access service bundle is needed to bridge the home network protocols and access the devices connected to heterogeneous home networks. Context aware service bundles are needed to support context awareness.

The system layer refers to the Java Virtual Machine and Operating System (OS) in the RG, the OS performs the functionality of IP forwarding, firewall and Network Address Translation (NAT). The physical interface layer deals with the low-level communications with various WAN and LAN connections of RG.

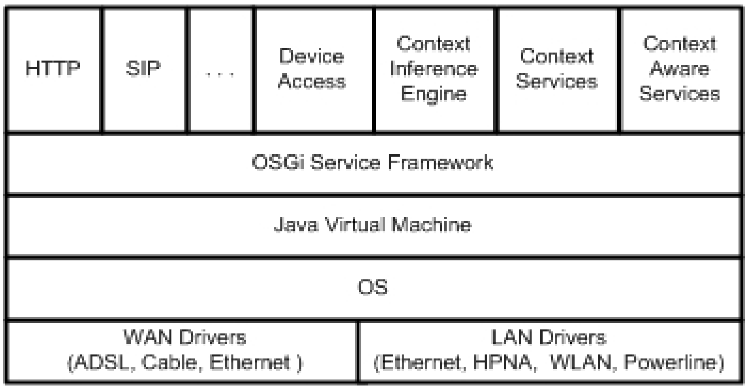


Figure 3. Software architecture of OSGi service gateway

3. Device Access System Architecture

As the home networks and devices vary and the number of devices is increasing, the device plug-and-play feature becomes very critical. In addition, automatically discovering and deploying each device's capability is highly desirable. This is enabled by the device access system architecture. The proposed device access system architecture includes the device access service bundle embedded in RG and a device access software stack embedded in each device.

As shown in Fig. 4, the software architecture of a device consists of the application layer, the device access layer and networking layer. While the application layer presents the features and capabilities of the device, the device access layer is in charge of announcing its presence to the network, discovering other devices in the network and making use of the services provided by other devices. The networking layer takes care of the data transmission in the network.

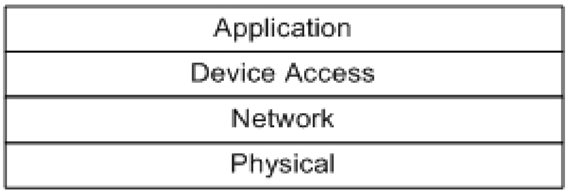


Figure 4. Software Architecture of smart devices

With the proposed mechanism, all the devices provide services which can be discovered and used by other devices in the home network, at the same time they also register the services in the service gateway, thus all the devices can interoperate with each other with the OSGi service gateway as the bridge.

4. The Context Aware Service Architecture

We have developed a context aware service architecture within our service framework, which can convert physical spaces and ubiquitous compuational entities they contain into a smart and programmable computing system. The context aware service architecture aims at enabling rapid development and practical deployment of context aware home services.

4.1 Overview of Context Aware Service Architecture

As shown in Fig. 5, there are various kinds of service components that are involved in the abstraction, inference and utilization of context information in intelligent enviroments:

1. Context Services: Context services provide abstraction to separate the details of sensing mechanisms from the high-level context manipulation. They abstract meaningful contexts from a wide variety of context sources and transform them to semantic representations so that they can be shared by distributed intelligent services.
2. Context Inference Engine: Context inference engine is a logic reasoning service that can deduce higher-level or abstract contexts from simple sensed contexts. For example, the context inference engine can deduce user's current activity based on location and environmental contexts.
3. Context Aware Services: context aware services utilize higher-level contexts to adapt themselves to rapidly changing situations.

Both context services and context inference engine act as context providers, from which context aware services as information consumers obtain contexts to assist in adapting the way they behave. All the components are packaged in form of pluggable OSGi service bundles so that they can be remotely deployed and managed.

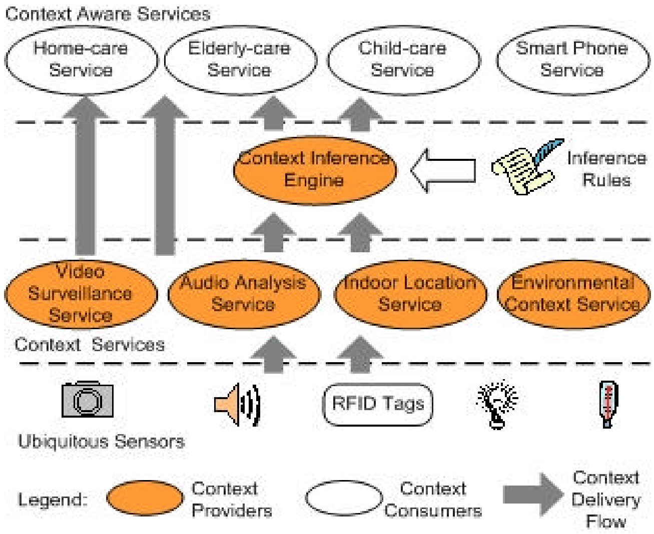


Figure 5. The Context Aware Service Architecture

4.2 Advanced Video/Audio Based Context Services

We leverage advanced video surveillance and audio analysis techonologies to provide complex contexts that can not be achieved by using traditional sensing mechanisms:

- The Video Surveillance service leverages our advanced home video surveillancesystem [6] to perform object tracking and human behavior analysis. Its core function is to transform the raw video data into high-level descriptions of scenes and events that charaterisze an specific service scenario.
- The Audio Analysis service based on auditory scene recognition [7] is integrated into the context aware service architecture to abstract abnormal audio events from raw environmental audio signals.

Table 1 shows a list of the video/audio events in human perceptuion that can be identified by the video surveillance service and the audio analysis service.

Table 1. Video/Audio Contextual Events

Video	**E1**-Stranger in house
	E2-Restricted zone violation
	E3-Child is left alone with duration exceeding threshold
	E4-The elderly is motionless with duration exceeding threshold
	E5-The elderly falls
	E6-The elderly stays in specific room (e.g.,bathroom) with duration exceeding threshhold
Audeo	**E7**-Scream
	E8-Explosion
	E9-Crying

We also have other useful context services based on traditional sensor systems. For example, indoor location is provided by the RFID(Radio Frequency Identification[]) location service, and various kinds of environmental contexts including lighting, temperature is aqcquired from ubiquitous sensors.

Developed on top of a common set of context delivery APIs, all context services enable both *query* and *subscribe* context delivery mechanisms in form of abstract service interfaces.

4.3 Rule Based Context Inference Engine

The context inference engine uses pre-defined ruls represented in first order logic predicates to infer higher-level contexts from sensed contexts. For example, we have designed a set of rules which can be used to deduce resident's current status or activities based on location and environmental contexts:

- locatedIn(User, Bedroom) ^ lightLevel(Bedroom, LOW) ⇒ status(User, Sleeping)
- locatedIn(Elderly, Bathroom) ^ status(WaterHeater, ON) ⇒ status(Elderly, Shower)
- locatedNear(Child, TV) ^ status (TV, ON) ⇒ status(Child, WatchingTV)
- ¬ (∃(Adult)X locatedIn(X, Home) ^ locatedIn(Child, Home) ⇒ status(Child, Alone)

The context inference engine allows users to freely add new inference rules to perform varous kinds of context reasoning.

4.4 Context Aware Services

One common way in which services are made context aware is to specify rules that trigger actions when a specific contextual event happens. Our context aware service architecture makes it easy to develop smart services based on event trigger mechanism. Using rich contexts provided by a context providers described above, we have designed an initial set of smart home services; Table 2 bellow shows the First Order Logic rules that describe their context aware behaviors:

Table 2. FOL Rules for Describing Context Aware Behaviors[1]

Smart Phone	*IF* status(User, Shower) ∨ status(User, Sleeping) *THEN* forward the incoming call to voice message box
	IF status(User, WatchingTV) ∨ status(User, LisentingMusic) *THEN* turn up the volume of the phone and lower the volume of TV
	IF status(User, Dinner) *THEN* set phone to vibrate mode
Security	*IF* **E1** ∨ **E2** *THEN* *IF* ∃(Adult)X locatedIn(X, Home) *THEN* alarm via loadspeaker *ELSE* alert owners via MMS
Child-care	*IF* (¬ ∃(Adult)X locatedIn(X, Home)) ^ (**E3** ∨ **E7** ∨ **E9**) *THEN* notify parents via MMS
Elderly-care	*IF* (¬ ∃(Adult)X locatedIn(X, Home)) ^ (**E4** ∨ **E5** ∨ **E6** **)** *THEN* alert the care giver via cell phone

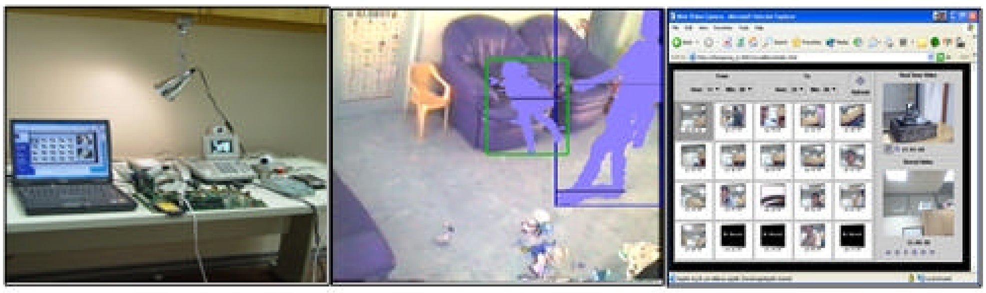
5. Experimental Set-up

[1] **E1**,**E2**,...**E9** refer to the video/audio contextual events defined in Table1

In order to verify the feasibility of the new service infrastructure, a context aware connected home prototype has been implemented as shown in Fig. 6 (a). The prototype system consists of one client PC connected to Internet, an OSGi-compliant residential gateway which connects Internet to home network, one AXIS 2100 network camera, one SIP enabled IP telephone and one media server processing audio and video context connected to RG through Ethernet.

The RG is Intel Celeron based with embedded Linux (kernel 2.4.17), developed by our team. The OSGi framework adopted is Gatespace's Distributed Service Platform. The AXIS network camera and the media server are UPnP enabled devices and their context aware related services are registered in the OSGi platform when they plug in the network. The UPnP services can then be used by other services in the OSGi framework.

Whereas the client PC has both a web browser and SIP user agent, it's used to manage and access the services. The RG hosts the OSGi framework, the HTTP services, the device control services, the UPnP bridging service, the context aware services as well as the SIP related service bundles. It provides a service repository which allows access from either HTTP or SIP terminal, it also serves as an access point which connects to all the home appliances in the local network. The network camera acquires audio and video information and the media server processes and derives the context information. The SIP enabled IP telephone set is used to show the audio/video delivery capability.



a) Prototype system set-up b) event of falling child c) Home monitering

Figure 6. Prototype system set-up and experimental results

Using the prototype, the following scenario has been implemented and tested: When your child is detected falling down and crying at home using audio and video analysis technique, a SMS message is sent to you and you can use the home monitoring service to see what is happening in your home. Fig. 6 (b) and Fig. 6 (c) show the scenes where the child is falling down and what you can see using the monitoring service, respectively.

6. Conclusions

In this paper, we have proposed and implemented an OSGi based service infrastructure for context aware connected homes. Compared with the other OSGi based smart home solutions, the proposed service infrastructure exhibites the following unique features:

- SIP is incorporated in the OSGi framework so that both SIP and HTTP can be used for service access, thus future devices like PDA, handphone, PC and notebook can all be used to deliver and access services in smart homes.

- Context is supported. Rich context information can be extracted through motion analysis and voice recognition. Context extration and usage are separated, thus the context aware service development can be independent from the context acquisition.

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