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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 5 (1): 64-69, 2006
ISSN 1812-5638

Empowering Ubiquitous Services in Next-generation Smart Homes

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Abstract: This study proposes an architecture which integrates ad-hoc network and OSGi framework to support the ubiquitous services in next-generation smart home. The new architecture includes three-level network entities, each of which has its own capability and infrastructure. In order to realize information communication in the new architecture, a new model of protocols stack has been designed. As a result, a solution of ubiquitous services in smart home has been described in this study.

Key words: Ubiquitous network, ad-hoc network, OSGi, smart home

INTRODUCTION

The growing of Information Technology (IT) takes the information services not only into the basic services but also into every person's life. There are more and more services, such as web services, control services, entertainment services, communication services and so on, which are gradually prevalent in the smart home[1,2]. Meanwhile, advance in microelectronics technology has made it possible to integrate sensors and network devices into a single unit called ad-hoc node. The wireless interconnection of such nodes is referred to as an ad-hoc network. In the next-generation smart home, those ad-hoc nodes will become the basic components used for building home, on the base of those components the ad-hoc network could combine with other local devices to provide all kinds of services for users. Under the forming of those services and evolution of microelectronics technology, the ubiquitous services environment is emerging[3,4].

The motive of evolution IT is to provide more services for persons and make person's life more comfortable. So in the design of all future information systems, such as the smart home, the human should be located at the kernel position and the capabilities of all devices and networks just provide services for persons. In this study we discuss the solution of the next-generation smart home, in which persons could get all kinds of services at any time and anywhere. In order to realize the above scenarios, the smart home will be deployed with many sensors which can interconnect and process some basic information. The most important thing in the smart home is that the person just enjoys services without considering any other technology problems, which means the procedure of information processing is transparent for persons, especially most sensors should be invisible for persons. This is the concept of Ubiquitous Service in next-generation smart home.

As ubiquitous services in smart home are starting to emerge commercially, there is an urgent need to develop transparent mechanism for interconnecting different devices. The devices used for ubiquitous services can be divided into broad-classes based on the application for which they will be targeted. Roughly speaking we can also distinguish between Low Traffic Device (LTD) and High Traffic Device (HTD).

- LTD has very limited transmission speed. In general, the traffic capacity of LTD is below 1-100 kb/s and LTD is highly constrained with power consumption and memory size. Considering this requirement, it is likely that some terminals belonging to this group will not be powerful enough to be full IP-capable and should communicate by means of proprietary protocols.

- HTD is characterized by capacities of up to dozens of megabits per second and in which there is no stringent power constraints and memory size. So the HTD, in general, will be IP-capable.

It is a great challenge to integrate heterogeneous devices and supply ubiquitous services in the smart home. On the other hand, because the future public backbone network systems, such as IPv6 and the 4G mobile communication systems, transfer the data in IP packets. It's clear that a state-of-the-art smart home should interconnect all heterogeneous devices and communicate the future public backbone network systems with IP packets.

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Facing with above challenges and chances, many technologies have been developed for satisfying different application requirements in the smart home. In the wireless communication domain, all kinds of sensors spreading all over the smart home means that ad-hoc network is likely to be widely employed. Quite a lot of research on improving the performance for ad-hoc network has been carried out[5,6]. The interoperability and connectivity of ad-hoc networks with other heterogeneous networks/devices has been discussed[7,8]. In our approach, the ad-hoc network will play a very important role in the next-generation smart home, which collects various data and then provides it for the high layer as the main information resource. In the home network domain, how to manage the diversity and heterogeneity inherent in home network, framework, such as OSGi (Open Services Gateway Initiative)[9], is being defined in various standard organizations. Specifically, OSGi is general-purpose, managed Java software framework that supports the deployment of extensible and updatable online applications. OSGi is independent of lower-level communication protocols and provides a middleware layer that can accommodate a variety of network technologies.

Ad-hoc network: The ad-hoc network is a (possible mobile) collection of communications devices (sensors) that wish to communicate, but have no fixed infrastructure available and have no pre-determined organization of available links, as show in Fig. 1. Individual nodes are responsible for dynamical discovering other nodes which they can directly communicate with. At the same time, nodes are required to relay packets on behalf of other nodes in order to deliver data across the network. Ad-hoc network can be built around any wireless technologies, including infrared and Radio Frequency (RF). Spurred by the growing interest in ad-hoc network, a number of standardization activities and commercial standards evolved in the mid to late 1990s. Within the IETF (Internet Engineering Task Force), the Mobile Ad-Hoc Network (MANET) working group was born and sough to standardize routing protocols for ad-hoc networks. The 802.11 subcommittee standardize a medium access protocol that was based on collision avoidance and tolerated hidden terminals, making it usable, if not optimal, for building mobile ad-hoc network prototypes out of notebooks and 802.11 PCMCIA cards. HIPERLAN and Bluetooth were some other standards that addressed and benefited from the ad-hoc network according to different application requirements[10-12].

Open Service Gateway Initiative (OSGi): The OSGi is an independent, non-profit corporation working to define

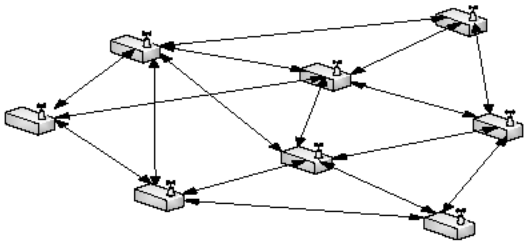

Fig. 1: Ad-hoc network architecture

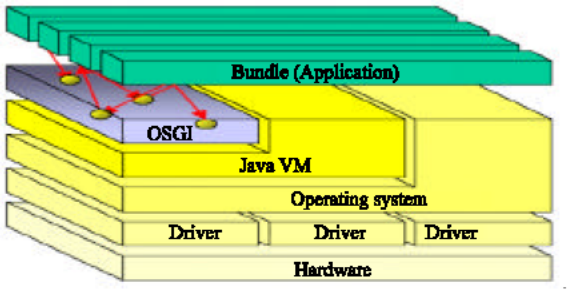

Fig. 2: The OSGi service platform

and promote open specifications for the delivery of managed services to residential users over networked environments, such as the smart home. Services can be managed remotely, thus allowing service providers to adapt their products to customer needs while keeping these products up to data without restarting system. The OSGi service platform is a flexible and open platform, which is comprised by some bundles that are specified in terms of a collection of Java APIs (Fig. 2).

OSGi service platform consists two parts: the OSGi framework and a set of definition services called bundles. An integral part of OSGi framework is the device manager, which can discovery, register, active and manage all devices. The device management mechanism of OSGi provides a very flexible environment in which devices and services can be added or removed dynamically. The object of OSGi is to open the standard of connecting the Internet and the small business devices[13].

Each system has different capabilities of speed, distance, data volume and physical media, so different protocols are suitable for different purpose. Thus a nature way of thinking is: can we find a cost effective way to combine the benefits of OSGi based on heterogeneous devices and ad-hoc network based on ubiquitous computing sensors into a smart home, which can provide ubiquitous service for users by a transparent approach?

USE SCENARIOS AND REQUIREMENTS

The following use cases and requirements are the ad-hoc network implementation in smart home using OSGi framework:

Communication between the ad-hoc nodes and local devices in smart home: The next-generation smart home enables effective communication between ad-hoc nodes and local devices connected and registered within an OSGi service platform. In order to exchange all information in a uniform format, an IP glue mechanism has been designed to enable the conversion between the IP packet and any other data format (e.g. 802.11, Bluetooth, ect.), which could be realized at some special nodes (called the master nodes). And then the master nodes could translate information between the ad-hoc nodes and the OSGi service platform. Consequently, the smart home controlled by the OSGi service platform could get enough information from the ad-hoc networks and provide the custom services for the user by enabling the local devices at any time and any where.

OSGi services realized by the ad-hoc nodes: Selected OSGi service functionality could be exported as a new driver of the ad-hoc nodes. The ad-hoc network nodes installed the new driver would be capable of the new functions supplying for the new requirements which can be based on the context awareness or user preference. Under the new architecture, the ad-hoc nodes in the smart home could dynamically realize the new function and install the new software updated online without restarting system. The new driver can be provided by the OSGi service platform which can ensure the security and compatibility of the new driver.

OSGi inter-gateway bridging heterogeneous ad-hoc networks: An ad-hoc network comprised by the same type sensors (which is called the Virtual Cluster Node) could be registered as a service in one OSGi service platform and then the information of this service could be exported by bridging bundle to another OSGi service which is an ad-hoc network comprised by another type of sensors. By the OSGi service platform the heterogeneous ad-hoc networks could realize the seamless interconnection in the smart home.

A NEW UBIQUITOUS SERVICE ARCHITECTURE FOR THE NEXT-GENERATION SMART HOME

So far we have highlighted the most important challenges for the smart home. For satisfying the ubiquitous services in the next-generation smart home, it is important that the ad-hoc network technology and OSGi technology could be integrated into a new architecture.

The entities in the new architecture: In the smart home, some ad-hoc nodes and local devices constitute the basic physical devices to carry out the ubiquitous services in terms of the context awareness and user preference. These physical devices can be classified into three-level network description.

- A small ad-hoc network, with a star topology, all nodes in this network have the same type, such as the protocol, policy and power management mechanism. The core node in the star topology is a master node, having a dual protocol stack, one is the ad-hoc network protocol (such as Bluetooth and 802.11), the other is the IP glue protocol which can translate the local data into the IP packet. The master takes charge of collecting information from ad-hoc nodes and submits those information to the OSGi service platform. The set of the ad-hoc nodes and the master is called a Virtual Cluster Node (VCN). In general, the VCN is comprised by the LTDs. The main aim of VCN is to achieve the maximum performance of all ad-hoc nodes.
- A small network comprising the VCNs and a number of local devices in a meshed topology, is known as a Virtual Person Area Network (VPAN). This VPAN can roughly be described as a network attached to a person. The mission of the VPAN is to implement the ubiquitous services for a person, which can dynamically add or remove the VCNs and local devices in terms of the application requirements.
- A larger network comprising all VPANs and HTDs in the smart home, communicates together through a star topology. One of advanced terminals will work as an OSGi gateway, which can link the smart home to the external world. This concept is called the Smart Home Network (SHN). The main function of the SHN is to connect the smart home to the public backbone network system and provide the security for the smart home.

The new architecture: In the smart home, all VCNs, VPANs and SHN have been integrated in a new architecture, as show in Fig. 3.

In the new architecture, the requirements for combining different networks dynamically and providing cross-layer optimization and configurability lead-to the need to implement a control plane. Currently no standard exists that solves this question, there is a need to provide a generic platform for enabling this information flow between different protocol layers and entities. In the Fig. 4, the new model of protocols stack has been shown. In the bottom of the new model, there is the Physical layer which includes the different nodes and devices in the smart home. The driver layer is to provide the

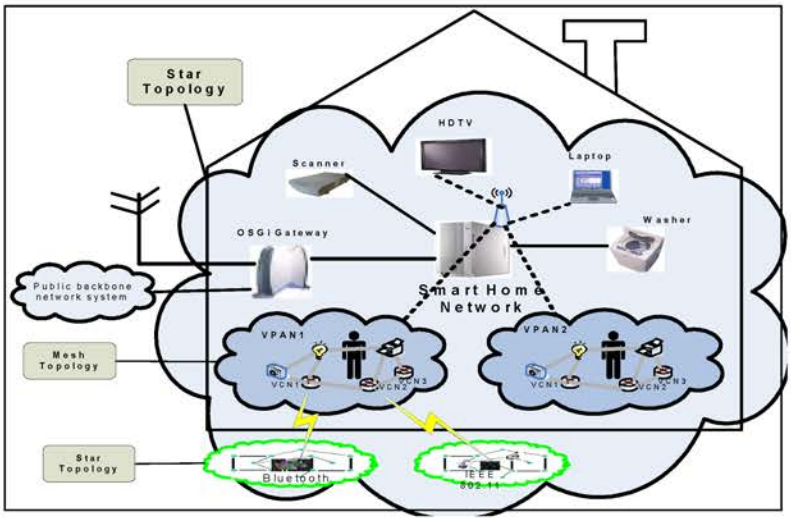

Fig. 3: The new architecture for next-generation smart home

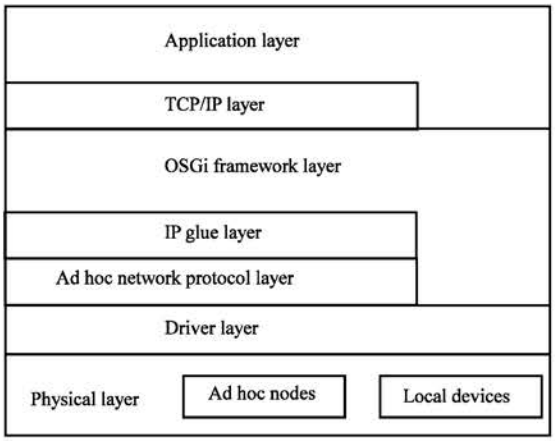

Fig. 4: A new model of protocol stack for next-generation smart home

different driver softwares for enabling different devices. The Ad-hoc network protocol layer is to implement the different protocols among the different ad-hoc networks according to the type of the ad-hoc nodes, such as the 802.11 and Bluetooth protocol. The IP Glue layer is to translate the data format of ad-hoc network protocols into the IP data format. The OSGi framework layer manages the capabilities of IP Glue layer and some local devices in the smart home. The services in the OSGi framework can be provided for the IP Glue layer to implement the corresponding data format exchange. The TCP/IP layer in this model is to carry out the communication between the smart home and the public backbone network system. The Application layer is to offer some custom services for different smart homes, which can be developed based on the OSGi APIs. Under the collaboration of the protocol layers in the new model, the information flow could be implemented between different protocol layers and entities. In the new protocols stack model, the ad-hoc network is seamlessly integrated into the smart home and the OSGi service platform can solve the heterogeneity problem and manage the total smart home.

The working flow in the new architecture: The proposed new architecture can actively provide the ubiquitous services for the user in the smart home regardless of heterogeneous ad-hoc networks and local devices. The following is one of the typical scenarios:

- In the smart home, the ad-hoc network sensors collect the information (such as brightness, temperature and user location, etc.) and send it to the OSGi service platform.
- The OSGi service platform analyzes those information and user preference and then decides to provide the custom services for the user.
- The service is carried out by some ad-hoc sensors and local devices. The softwares of the sensors and devices are supplied by the OSGi gateway. If the OSGi gateway can't match the needed softwares, it can get those softwares by downloading from the Internet.
- The OSGi service platform installs those software and drivers into the appointed ad-hoc sensors and local devices and then starts the sensors and devices to provide the custom services for the user.

The future research topics in the new architecture: Earlier, we highlighted the issues that need to be solved so that the envisaged ubiquitous services in next-generation smart home may become a reality. To some extent, all of these are being covered nowadays by different research activities, although not usually following a unified approach. The following pay attention to the most important open issues in the new architecture:

- Mobility, which is one of the most essential sources of technology problems, is a very hot issue in network communication research. For the ad-hoc network field, the MANET technology has been in-depth researched in the IETF working groups, but MANET technology is not specifically designed for the VPAN scenarios presented within this study[14]. How to solve the communication among the mobile devices with multi-hop capability in the smart home still needs more research.
- Security, is a fundamental issue in the wireless communication. It is a mandatory requirement that becomes more challenging as involving the home privacy is intrinsically more prone to suffer from various attacks. Providing good security architecture is a hard task especial in the smart home[15].
- Energy-efficient, since a limited battery source typical drives the node in ad-hoc network, designing energy-conserving mechanism in smart home becomes essential. Even when energy is not a stringent constraint, reducing energy consumption can result in less maintenance and cost[16].
- Location awareness and user preference. The ubiquitous services will need to have much knowledge of some parameters concerning both the user and his/her context and adapt their behaviors accordingly. One element that will be fundamental is user's location, allowing the creation of context-awareness service. In order to archive the ubiquitous service in the smart home, it is important that future devices will offer a set of interfaces to the application to ease the process of becoming aware of what is around me and what can it do for me[17].

THE ADVANTAGES OF THE NEW ARCHITECTURE

The new architecture is an approach for archiving the ubiquitous services in next-generation smart home, which combines the ad-hoc network and OSGi framework to overcome some limitations exist in the current smart home. The new architecture can be divided into three hierarchies and interior configuration of every part is independent with other parts, but it can realize the system optimization by improving the performance of every part in term of the devices characteristic in every part. The advantages of the new architecture as follows:

- Devices heterogeneity: Every device can be managed as a service in the OSGi service platform and the same service can be supplied by different bundles for driving different devices. As a result, the heterogeneous devices are compatible in the new architecture.
- Services transparency: In principle, the evolution of the technology is to serve the person. Consequently, the new architecture includes the VPAN which aims to provide the custom ubiquitous services for the person in the smart home. The VPAN can drive the VCNs and local devices to carry out the detailed services and get softwares and information supported from the SHN. The most important thing in this architecture is that all of those technology details are transparent for the person. He/she only enjoys the services directly provided by the VPAN.
- Ad-hoc network seamlessly integrating into the smart home: There are many different types of ad-hoc sensors in the smart home and those sensors can be used to built up different ad-hoc networks in terms of the sensor types and application motive. But all those ad-hoc networks could be seamlessly integrated into the smart home in the new architecture. Those ad-hoc networks not only communicate with local devices but also exchange information with other ad-hoc networks by bundle bridging.
- Functions dynamically installation: It is well known that the functions of devices are determined by the softwares. In the new architecture, the softwares of devices and VCNs could be dynamically updated online without restarting the system. So the functions of devices and VCNs could be dynamically installed in the new architecture.
- Open the interface of application development: OSGi framework is an open standard which can run on all kinds of hardware platforms. The APIs of OSGi framework are open for all developers, so the third party can develop all kinds of custom services without any limitations in the new architecture.

CONCLUSIONS

In this study, we propose the concept of Ubiquitous Service in next-generation smart home. Under the instruction of the new concept, a new architecture has been advanced which integrates the ad-hoc network and OSGi technology. The new architecture includes three

hierarchies (VCN, VPAN and SHN) and every part has its independent functions and structure. A new model of protocols stack has been designed for archiving the information communication and performance optimization in the new architecture. By analyzing the characteristics of the new architecture some advantages have been listed in this study. As a result, a novel solution for the next-generation smart home has been drawn. The new architecture implications along with more research issues proposed in this study are the objectives of our future research in this exciting field.

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