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Design and Implementation SIP & Agent-based Home Networked Appliances System

By

Zhijun Li

A thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements of the degree of

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Supervisor: Prof. Ahmed Karmouch

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ABSTRACT

Networked Appliances (NAs) is a new research field and it comes under the concept of home networking. The SIP (Session Initiation Protocol) and Agent-based NA system proposed in the thesis aims to build a smart system that provides the capability of autonomous and asynchronous control and management of NAs from both inside and outside of a home network. The SIP technology makes the NAs system well adapted for communications over the Internet; and the leading-edge agent technology presents a new approach to empower users with advanced information processing methods and reduce the workload of users. In the proposed system, various agents cooperate with each other to fulfill different tasks on behalf of homeowners. The system architecture and features are presented and a prototype model is implemented. The performance of the system is discussed to verify and validate the system design.

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Contents

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List of Abbreviations

AA	Appliance Agent
ACL	Agent Communication Language
FIPA-OS	Foundation of Intelligent Physical Agents – Open Source
HA	Home Agent
HAVi	Home Audio/Video Interoperability
HTTP	Hyper Text Transport Protocol
IETF	Internet Engineering Task Force
Jini	Java based device connectivity and discovery framework (Jini is not initials)
NA	Networked Appliance
PA	Presence Agent
PUA	Presence User Agent
RTP	Real-time Transport Protocol
SA	Service Agent
SDP	Session Description Protocol
SIP	Session Initiation Protocol
TCP	Transmission Control Protocol
UA	User Agent
UDP	User Datagram Protocol
UPnP	Universal Plug and Play
VESA	Video Electronics Standards Association
X.10	Early power line based home networking technology

Chapter 1 Introduction

1.1 Introduction

Networked Appliances (NAs) are attracting an increased amount of interest from researchers and are widely predicted to be the latest trend in Internet development. NAs are commonly defined as dedicated function devices containing at least one embedded processor and one network connection [1]. They are also known as Internet Appliances, IP Appliances, or Intelligent Appliances. A home appliances networking system can smartly fulfill tasks on behalf of humans and provide enormous convenience to people

Imagine the following scenario. Peter is taking a vacation with his family and realizes that he forgets to record his favorite TV show. Peter then uses his handheld computer or cell phone to communicate with the VCR at home to record the program during his absence. In another scenario, Susan is at her office, and at the same time remotely monitoring her home. If her home doorbell rings, she could receive a live picture of scene. NAs can provide such services, which a normal stand-alone appliance can't.

There are numerous technologies used to connect appliances into a home network such as X.10 [2], HAVi (Home Audio/Video Interoperability) [3], UPnP (Universal Plug and Play) [4], and VESA (Video Electronics Standards Association) Home Networking [5]. X.10 is an early power line-based home networking technology; HAVi is an open standard for networking digital audio/video devices which uses the IEEE 1394 bus (FireWire) as the networking medium; UPnP is an open architecture for easy and robust connection of intelligent appliances, wireless devices, and PCs from different manufactures; VHN (VESA Home Networking) provides networking and control for video appliances and is developed by the VESA consortium.

The above protocols are designed for connecting different types of appliances within a home network. But, the protocol interoperability across different networks is a concern, i.e., between home networks with different appliance-connecting protocols or between wide area networks and home networks. The Session Initiation Protocol (SIP) [6] is believed to be the best answer. SIP is an IETF (Internet Engineering Task Force) standardized signaling protocol that can establish, modify, and terminate multimedia sessions or calls over the Internet. Incorporated with other protocols like Real-time Transport Protocol (RTP) [7] and Session Description Protocol (SDP) [8], SIP can provide a wide range of Internet applications and services to the users. In a SIP-based networked appliances system, SIP could be used to set up communication sessions among different NAs, and NAs can communicate with each other without concerning about the type of protocol and networking medium [9].

Agent technology presents a new approach to empower users with more information processing that relieves them from performing complex operations. An agent can act on behalf of users to perform a job autonomously and intelligently.

By combining SIP and agent technologies, we have designed a SIP and Agent-based home appliances networking system. It aims to provide an easy-to-use, smart, autonomous, and asynchronous networked appliances controlling system that allows users to communicate with, utilize, and manipulate NAs from both inside and outside of a home network.

1.2 Motivation

The home networking is another trend following the office networking. There are rising needs towards accessing household appliances using the Internet and controlling home appliances more efficiently. Home appliances need be connected to the home network and turned to the networked appliances (NAs). NAs should be controllable and should be capable handling requests from the network. The control and operation of a NA should be simple and easy to use for home users, especially for novice computer users. The use of SIP technology could make home networks and home appliances easily accessible from a wide area network; and the use of agent technology could help transfer network appliances into autonomous, asynchronous, and smart entities. By combining these two technologies, the resulting networked appliances model can reduce the user's workload, save user's time, and most importantly can be easily accessed.

1.3 Objective

The thesis proposes an Agent-based Networked Appliances System that uses SIP for wide area access management. The objective of the thesis is to design a NA system using SIP and agent technology, which can provide fully control, autonomous operation, and asynchronous actions to NAs, and allows user to access the service from both within and outside the home network. The system should work on behalf of home users in order to reduce users' workload and provide users convenience while it performs services. The thesis also presents a prototype and implements it to realize the design idea. Additionally, test scenarios are used to verify the model and validate the performance.

1.4 Contribution

The main contributions of the thesis are as follows:

(i) *Design and implement a networked appliances system model combining SIP and agent technologies.*

The thesis provides a framework of a SIP & Agent-based NA system that presents the essential architecture and main functional elements to manage the NA controlling and network accessing. In the design, the home agent is responsible for the communication security of the home network, and the service agent supports the service management.

(ii) *Design and realization of different appliance agents in the networked appliances system*

In the system, an appliance agent (AA) is designed to fully control a corresponding NA on behalf of users. AA is not only able to perform service independent, but also able to complete functions cooperating with other AAs.

(iii) *Design and realization of a personal agent which provides a framework to assist home users to perform various tasks in the Internet environment*

A personal agent represents a specific home user. The PA is able to make decision according to the environment parameter and its user's personal database such as preference lists, contact addresses and schedule etc. The PA also provides a GUI to interact with its user. The PA is proposed to have learning capabilities and makes decision smart.

1.5 Related Terminology

This section lists and defines selected important terms used in the thesis for reader's convenience.

- **Agent:** A software program that makes decisions and performs services on behalf of users and applications in an autonomous, asynchronous, and intelligent manner.
- **Appliance Agent:** An agent that works on behalf of users to fully operate a home appliance.
- **Personal Agent:** An agent that works on behalf of a particular user to act and perform autonomous actions.
- **Agent communication language (ACL):** A communication language that is used by agents to communicate, negotiate, and share information with each other [10].
- **Networked appliance:** A home appliance with dedicated function devices containing at least one embedded processor and one network connection [1]. Also known as Internet Appliances, IP Appliances or Intelligent Appliances.
- **Session:** A period of time during which two or more computers/entities/agents maintain a connection, and transfer information between each other.

- **Service:** Any functional application provided by NAs or agents. A NA may provide more than one service. And some service may involve more than one NA.
- **Wrapper agent:** An agent that connects to a software system/application. A wrapper agent allows client agent to invoke commands and control the operations on the underlying software system via ACL messages [34].
- **SIP UA:** SIP user agent that consists of user agent client (UAC) and user agent server (UAS). UAC is used to originate calls; UAS is used to listen incoming calls.

1.6 Thesis Organization

The remainder of this thesis is organized as follows. Chapter 2 presents an overview of background knowledge and related literatures. First, it describes the SIP architecture, components, addresses, and messages. The major operations of SIP are also stated. Then, the knowledge of agent technology is presented. Finally, it provides a brief summary of current networked appliances projects and other related works in order to give the current status of the NAs research.

In chapter 3, the design of SIP & Agent-based home appliances networking system is discussed in detail. First, the home network requirement is discussed. Then, the reasons to choose SIP and agent technology using in the proposed design is presented. Finally, the design architecture and operating mechanism are described in details.

Chapter 4 describes the prototype implementations of the NAs model. The implementation details and some execution screenshots are followed by introduction of the adopted technologies and tools.

The concluding Chapter outlines the conclusion of this thesis and proposes possible future improvements and research directions in the field of Network Appliances.

Chapter 2 Background

This chapter is intended to explain techniques that are related to the contribution of this proposal. The Session Initiation Protocol (SIP) [6] and agent technology are extensively involved in the design of SIP & Agent-based home appliances networking system. They are elaborately discussed in this chapter.

First an overview of SIP is presented. The architecture, major components, operation mode and extension of SIP are then introduced. Following that, a brief introduction to software agent is presented including common definitions, classifications and characteristics of agents.

2.1 Overview of SIP

The Session Initiation Protocol (SIP) is an IETF (Internet Engineering Task Force) standardized signaling protocol that can establish, modify, and terminate multimedia sessions or calls over the Internet. These multimedia sessions can be Internet telephony calls, multimedia videoconferences, distance-learning sessions, or other multimedia applications [6]

SIP is believed to be a good option for accessing the NAs over the Internet because of the following reasons. First, as an application layer protocol, SIP is independent of transport protocols such as UDP and TCP. Second, SIP is a text-based client/server protocol, having similar syntax and semantics with Hypertext Transport Protocol (HTTP) [7]. This makes communication among appliances simple. Third, SIP supports mobility. SIP users can frequently register their current addresses with SIP registrar server and their current address will be bound to their former addresses. Thus, SIP users are reachable even when their locations change. In addition, SIP is extensible which makes the system open to new functions and features.

Following this section, the basic structure and operations of SIP are described. SIP entities, namely SIP servers and User Agents (UA) will be described in section 2.1.1. SIP addresses are identified in section 2.1.2. SIP messages are illustrated in section 2.1.3, which convey the communication information between SIP entities. Also SIP requests are described in section 2.1.4. Finally, an important SIP extension (Event Notification and Subscription [12] [13]) is briefly introduced.

2.1.1 Entities

In SIP, the main entities are the User Agent, SIP Proxy Server, SIP Redirect Server and Registrar.

- **User Agent (UA)**
    - UAC, i.e. user agent client used to originate calls
    - UAS, i.e. user agent server used to listen incoming calls

- **SIP Proxy server**
    - Forwards requests from a UA to the next SIP server or UA within the network
    - If necessary, rewrites a new request message before forwarding it
- **SIP Redirect server**
    - Accepts client requests and returns the requested server's address to clients
- **Registrar**
    - Accepts register requests and stores the registration information
    - Typically co-located with a proxy or redirect server
    - Offers location lookup services

UAs can register their latest locations to SIP Registrars. The SIP server helps to establish sessions between UAs by working in either the proxy mode or the redirect mode.

2.1.2 Address

Each SIP entity has one SIP address to be identified and this SIP address is globally unique. SIP users are bound to this address by frequently registering their latest location or address to the SIP Registrar server. Callers use SIP addresses to establish real-time communication with callees.

A SIP address is case-insensitive, must have a host part, and may include the user name, port number, parameter, etc. The email address or telephone number can also be used as additional alias. The SIP URL (Universal Resource Locator) is defined as follows:

sip: user@host

A user at his/her office may register himself/herself as:

zli@uottawa.ca

1-613-562-5800:1234@uottawa.ca

In the home domain, a NA may be given a SIP address such as:

[d=lamp, r=bedroom]@home.net

The address space is unlimited. Therefore, this generic and flexible addressing mechanism can fulfill a wide range of addressing requirements for SIP UAs.

2.1.3 Methods

SIP has six request methods: INVITE, BYE, OPTIONS, ACK, CANCEL, and REGISTER. Their functions are shown as follows:

- **INVITE:** The most important operation used to initiate a session by inviting a user/service.
  - Its message body contains the session description to indicate who is invited and which type media is used
  - Re-INVITE is used to create a new session
  - Supported by SIP proxy, redirect and user agent servers/ clients

- **REGISTER:** To register the SIP address listed in the "To" header field with a SIP Register server
- **ACK:** To confirm session establishment
  - Can be used only with INVITE requests
  - Supported by SIP proxy, redirect and user agent servers/ clients
- **BYE:** For clients to terminate sessions
  - Must be supported by proxy server; should be supported by redirect and UAS
- **OPTIONS:** To query server's capabilities
  - Supported by SIP proxy, redirect, registrar and UAS/UAC
- **CANCEL:** To cancel a pending request without affecting a completed request.

2.1.4 Message

SIP message can be either a request that a client sends to a server or a response that a server sends to a client. The syntax of a SIP message is shown as follows:

generic message = start-line
message header
CRLF
[message-body] (optional)

The start-line is either a Request-Line in a request message or a Status-Line in a response message. The message header provides information such as the media type, participant addresses, path taken by the request so far, etc. For example, in the two important message headers TO and FROM, the caller's and the callee's addresses are indicated respectively.

Message body is optional. For example, the BYE request must not have a message body. For requests such as the ACK, INVITE and OPTIONS, the message body is always a session description.

2.1.5 Operation

The basic architecture of SIP is client/server in nature. Generally speaking, SIP Registrar server is responsible for storing and maintaining users' contact information. The SIP proxy and redirector servers help to establish sessions between SIP UAs. A SIP server may operate in two modes, namely the proxy mode and the redirect mode. A SIP UA works at the client end to help the user to establish communication sessions. It also updates the user's latest location information by frequently sending a REGISTER request to the SIP Registrar server.

2.1.5.1 Registration

When an UA changes its location, it will send a REGISTER request to the local SIP Registrar to update its contact address in the location service. Later, when other users want to establish sessions with this User Agent, the latest address is retrieved.

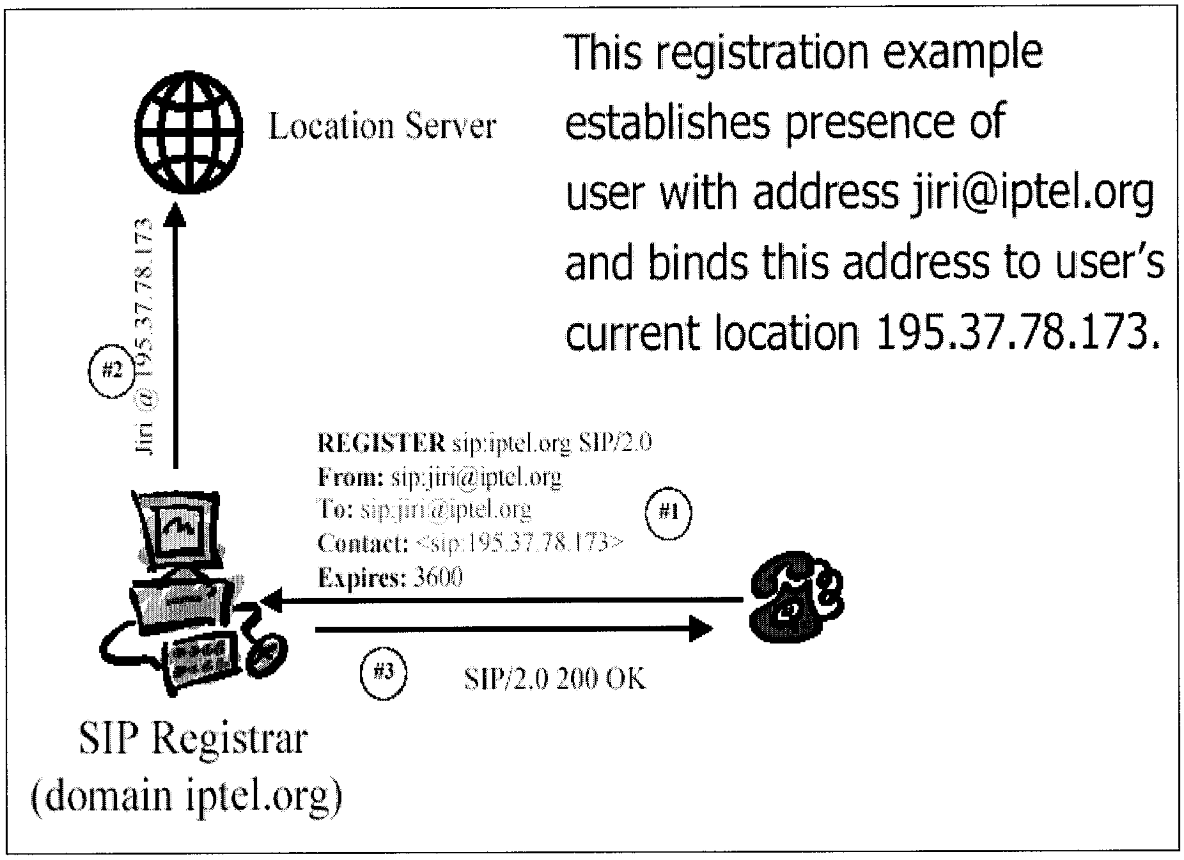

Figure 2.1 SIP Registration [11]

An example of SIP Registration is shown in Figure 2.1. The user with address jiri@iptel.org sends a new REGISTER request to the Registrar specifying that he/she is currently available at 195.37.78.173. Thus, when certain UAs desire to contact jiri@iptel.org, the SIP Registrar will direct them to contact the address 195.37.78.173 instead.

2.1.5.2 SIP operation in the redirect mode

How the SIP system works in the redirect mode is shown in Figure 2.2. The user at Caller@sip.com wants to invite the user at Callee@example.com to establish a session. This request is received by the Redirector server. The redirector then retrieves the callee's contact address from the Location Service and returns this information to the caller. After receiving the callee's contact information from the Redirector, the user at Caller@sip.com sends an INVITE request directly to the callee's contact address, i.e., Callee@home.com. After the callee accepts the invitation, a new session is established between these two users.

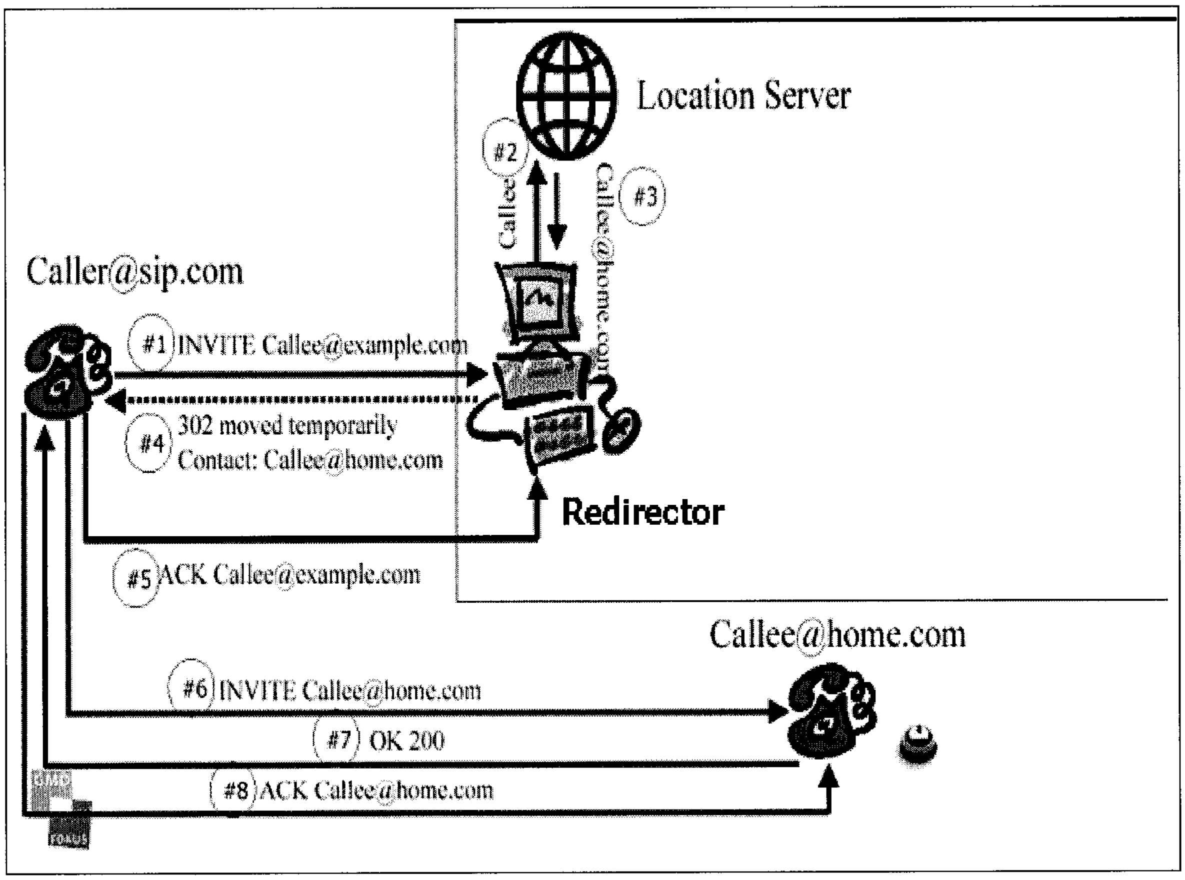

Figure 2.2SIP operation in the redirect mode [11]

2.1.5.3 SIP operation in proxy mode

The SIP operation in the proxy mode is different from the operation in the redirect mode. As shown in Figure 2.3, the user at caller@sip.com wants to establish a session with the user at jiri@iptel.org. The caller's request first goes to the Proxy. Then, the Proxy server retrieves the callee's current address by looking up the location server. Instead of returning the contact address to the caller, the Proxy forwards caller's request to directly the callee. If the callee accepts the INVITE, a session is established between these two users.

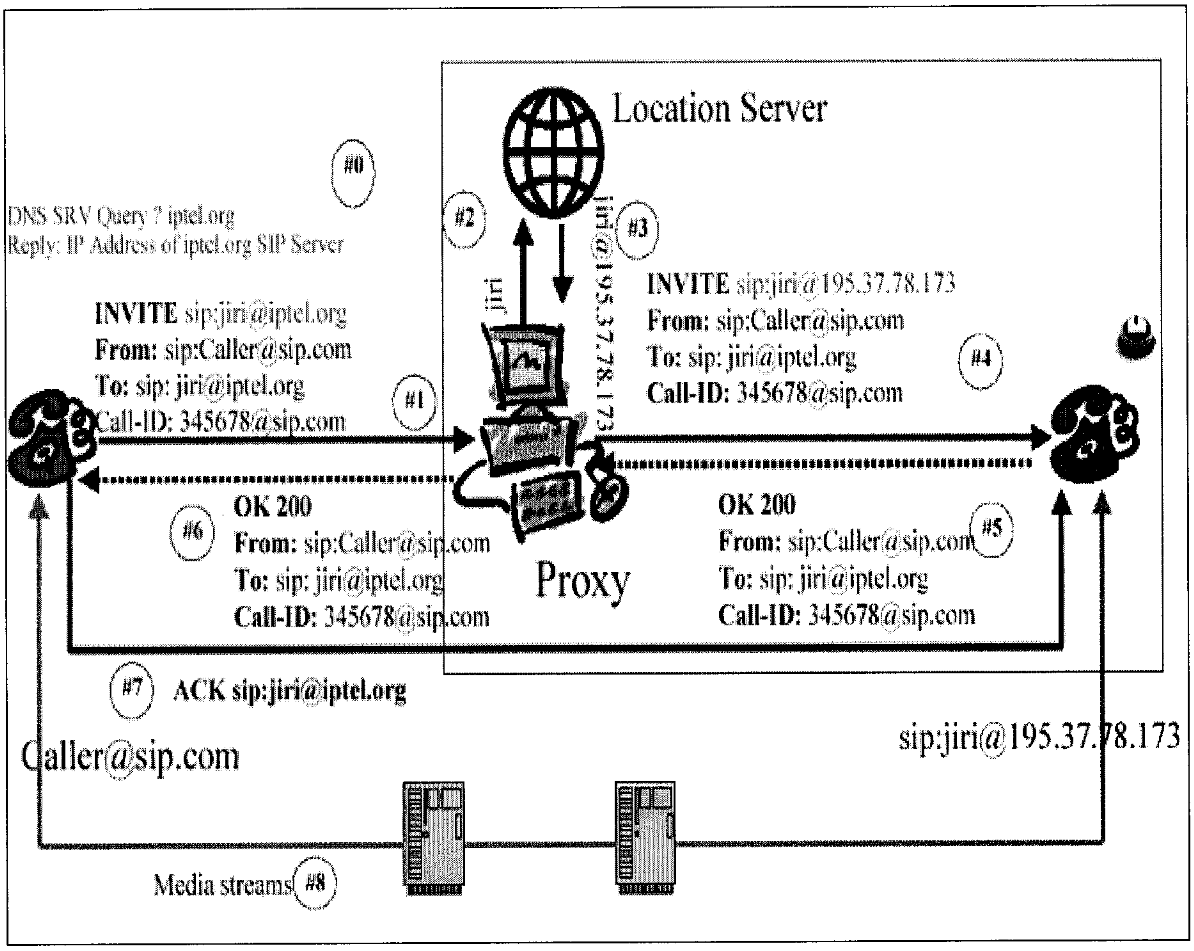

Figure 2.3 SIP operation in the proxy mode [11]

2.1.6 SIP extension – Event Notification

Event Notification is one of the important SIP extensions. Event Notification and Subscription [12] [13] can be used to realize asynchronous communication in the home appliances networking system. The mechanism of Event Notification is shown in Figure 2.4. Two more entities namely PUA (Presence User Agent) and PA (Presence Agent) are introduced to handle the event notification. Users send their SUBSCRIBE requests to the PA to indicate that they want to be notified of a certain event. The PUA then starts to monitor the present status of the event. Later, if the event occurs, the PUA will make the PA aware of this. As a result, the PA will generate corresponding NOTIFY commands and send them to the subscribers. This event notification procedure is completely asynchronous.

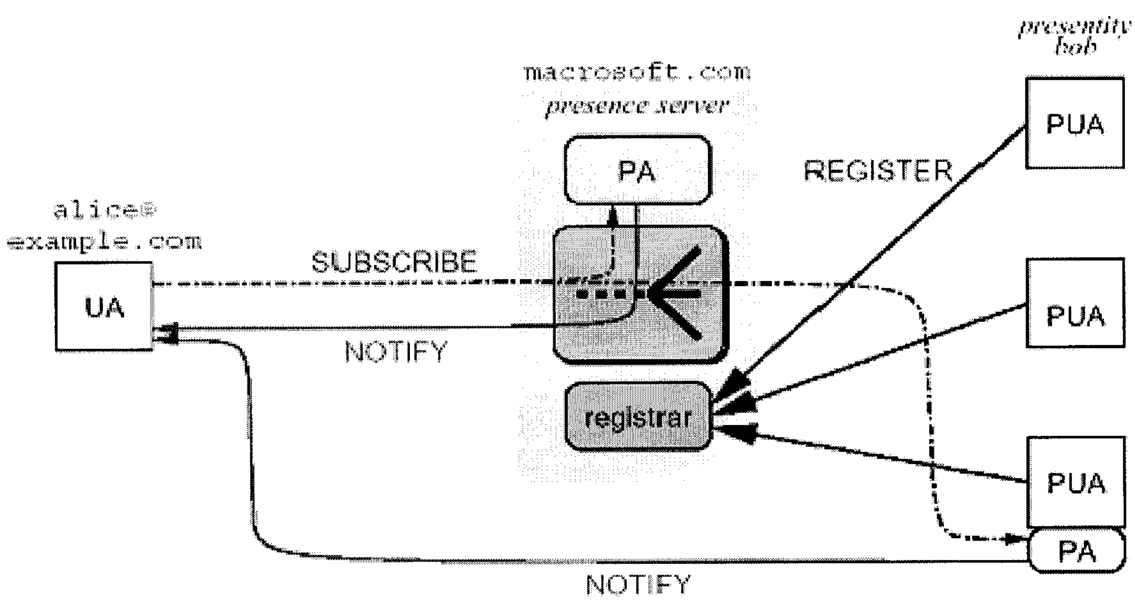

Figure 2.4 SIP presence service [14]

2.2 Agent technology

Recently, agent technology is being actively researched in the field of networked appliances. NAs could become more efficient and intelligent by employing agent technology. Agents can perform complex operations on household appliances by working on behalf of users and thereby provides user enjoyable services. In the following sections, agents and their related concepts are briefly introduced including their characteristics and classification.

2.2.1 Definition

Numerous agent definitions are given by different researchers. Among them, there are mainly two views from two different "cultures": the artificial intelligence view and the software engineering view.

The artificial intelligence view emphasizes the intelligence property of agents. A well-known definition is given by Patti Maes, who defines a software agent as "a computational system which is long-lived, has goals, sensors, and effectors, and decides autonomously which actions to take in the current situation to maximize progress toward its (time-varying) goals"[15].

From a software engineering point of view, an agent is a software component that performs tasks on behalf of a user or another program with some degree of independence and autonomy as described by Krupansky [16]. This is a more general definition of an agent, and this view is followed to design our Agent & SIP-based home networked appliances system.

2.2.2 Characteristics

Despite the differences between the above two agent definition views, there are some common characteristics that most software agents possess: [16, 17, 18,19, 40]

- **Autonomous:**

  An agent may accomplish a task or a set of tasks on behalf of a user or another entity without any direct external control or supervision.

- **Interactive:**

  An agent may interact with other agents or users to perform a process providing the agent environment permits.

- **Proactive or intelligent:**

  An agent may act by anticipating future problems, needs, or changes by learning from the reactions of the users or by interacting with the users, or by adapting to their environment.

- **Delegation:**

  An agent may represent a user to execute tasks that the user allows it to do.

2.2.3 Classification

From different dimensions, there are many different ways to classify agents [16, 17]. Agents can be mobile or static according to their movement capability. Agents can be grouped into user agents and service agents according to the tasks they fulfill. Also, agents can be dumb agents or intelligent agents according to their level of intelligence.

2.3 Literature Review

Many applications using home-networked appliances are developed. This chapter summarizes several important related research projects and these projects inspired to design our SIP & agent–based home appliance networking system.

Mr. S. Moyer presented an approach that proposed the use of basic SIP architecture and a new method extension "DO" to control and operate NAs from the Internet [1, 36]. The method "DO" conveys commands to trigger the required action(s) of target appliances. This system requires all the SIP UAs and servers to support the new "DO" method to fulfill a request.

In Soko Koki's SONA system [20], mobile agents are used to achieve an autonomous and asynchronous home NA control system. Users input their demands to a system manager and the manager makes operation plans for mobile agents according to the user's request and information acquired from the system. Mobile agents operate NAs autonomously and asynchronously according to plans.

In Anand's Smart home [21], Jini technology [22] is used to build several smart consumer devices and connect them via a network. This approach has the dynamic computing functionality. The devices can be dynamically hooked to the existing system and new features can be updated to existing devices dynamically. Also, by using the Jini's discovery process, the system can update the list of available devices and inform users of the presence of a new device or the exit of an existing device. More intelligence can be added to services during system implementation so that devices can be operated autonomously and asynchronously.

Coen's Intelligent Room [23] presented a Human Computer Interface platform with computer vision, gesture, and speech recognition systems. The user-interface is friendly and invisible since the system uses cameras, microphones, and other sensing technologies to communicate with the real world, instead of menus, mice, and windows. This distributed system has more than twenty individual software agents working together and sharing information to perform tasks [24]. The system is a non-ubiquitous computing system since some objects do not need additional computing devices to detect their status [23]. For example, a chair with a pressure sensor would "know" if someone is sitting on it without complex computation. The system requires a highly embedded computational infrastructure as there are more than twenty agents running on ten different workstations.

Werner Dilger's Intelligent Security System focused on protecting the whole intelligent home from unauthorized access [25]. In the system, a group of decentralized agents are designed to automate tasks on behalf of human users. The agents cooperate with each other. They may group with other agents to form new agents by following the principle of self-organization. Future development of this project will focus on identification of unauthorized individuals.

2.4 Summary

In this chapter, we introduced the background knowledge related to this thesis. The SIP structure and operation mechanism were presented in detail. Then, the concept of agent technology was discussed. Also, we reviewed some related work to provide a basic idea of a NA system.

The next chapter expounds the system design in detail. First, it addresses the main concernment of the home network and the requirement of the NA system. Further, the chapter proposes the architecture design and the operation mechanism.

Chapter 3 System Design and Features

Firstly, this chapter introduces the proposed architecture of the Agent & SIP-based home appliance networking system and then elaborates the system design.

Our SIP & Agent-Based Home Appliance Networking System is described in this chapter. The system architecture is stated and the operation mechanism is explained in detail.

3.1 Home Network and Networked Appliances

The world of researchers gives more attention on the development of a branch of the intranet, home networking. The workplace computing standards are now being followed in home computing too and thus, our future home will be enriched with features of new and upcoming technologies. Connecting all the home appliances into a home network and deploying the home network into the Internet would bring us another significant improvement in our lives.

Networked Appliances (NAs) are the primary elements of the new home network. A home appliances networking system can smartly fulfill tasks and provide enormous convenience to people. A home network would provide Internet accessible, convenient, fast, value-added, smart, and autonomous service to home users.

NAs are the home appliances with network connection and computing capabilities. They can perform their normal functions without any limitations, for example, a coffee maker can make coffee, a refrigerator can store and maintain good freshness etc. The primary change is that a NA is more than an appliance, but is a network device and a computing device. A fridge can report and order groceries depending on the current storage inside it; an alarm clock can decide the wake-up time for a user according to weather and road condition [26]; a coffee maker can make different flavors for different drinker [27]. All the services provided by these "smart" appliances are more beyond the capabilities of traditional home appliances. NAs can make decisions, operate themselves automatically, and include many other features. So, the NAs can provide more functions and conveniences to households.

3.2 Requirements for NAs and Home Network [28]

I. The basic requirements of a home network and NAs are listed as follows [28].

1. *Wide-area accessibility of Networked Appliances.*

   Users always demand to reach their NAs from outside of their home. All the NAs must be connected to the network by its own interworking interface or via a separate interworking device.

2. *Protocol transparency and independence*

   There is no a standard technology or protocol for internetworking or managing all the home appliances together. Right now, so many different technologies exists for different appliances. The technologies used in a NA system should be protocol transparent and independent. They must allow integration among different networking protocols such as X.10, Bluetooth, HAVi, UpnP, Jini, Salutation etc.

3. *Mobility support*

   In a home, NAs may be moved from one room to another room, from one floor to another or even across different homes. Also homeowners and users are always free to go anywhere they want. Therefore, mobility support is a requirement to locate mobile NAs and users.

4. *NA Configuration*

   A NA could be configured manually by users as usual. Further, NAs should also support auto-configuring, auto-registration, and auto-updating in order to reduce the need of manual configuring by users.

5. *Status Monitoring*

   The status of the NA systems will be monitored during the entire process. For instance, a monitoring record may be based on session or message.

II. Naming and Addressing Requirements:

1. NAs need a generic addressing format

   Each NA may have a globe or local IP address; a non-IP-capable appliance must have a generic address.

2. Classification and grouping of names must be supported.

   In a home, some NAs need to be grouped by their type, such as lights and air conditions; others need to be classified by their function, such as video recording.

3. A mechanism to search NAs' names should exist.

Using a well-known language/naming method that checks the specific name of NA that is unknown.

4. The addressing format must follow the UTF-8 transformation standard.

III. Communication Mode Requirements

1. Control:

   NAs must be controllable form both the Internet and the local network. For example, "cool down the temperature of the bedroom"

2. Queries:

   A user can check NAs' status and capabilities, such as, "how many channels does the TV have?"

3. Asynchronous events:

   Users should need not to operate the appliances on real time and within the occurring sit of the event. Event subscription and notification should be used to realize the asynchronous communication. One user subscribes to certain events and gets a notification after the events happen. Thereafter, necessary actions may be taken by the user.

4. Discovery:

   When necessary, system can check the suitable service or device. For example, what device can record the TV show today?

5. Supporting media streaming:

NA system must support audio, video or data sessions, as there could be plenty of media transmission requests. For example, TV signals should be transferred to a PC or other display device; a telephone call can be forwarded to a PDA.

IV. Security Requirements:

1. All types of communication within a home network need authentication, authorization, and privacy protection.
2. System can keep the snooper from knowing the contents and device names in the home.
3. System must authenticate and authorize the entry and accessibility of external appliances and users.
4. System can resile to good conditions from security attacks.
5. System may support error trace-back and fault control.

3.2.1 External-Home Communication- Why SIP

For any user, accessing home appliances from anywhere in the world over the Internet will provide extreme convenience and save a lot of time. For example, he/she may check the temperature of the water in the aquarium tank from his/her office; he/she may set his/her home VCR to record a TV show from his/her hotel. It's considered that the location of the user is always changing. How does the PA contact a home appliance, or how does a home appliance inform the PA when something happens? The answer is the use SIP.

SIP can totally fulfill the basic requirement of NAs.

1. A SIP UA can be reachable from the Internet. SIP is an application layer signaling protocol over IP.
2. SIP has protocol transparency and independence i.e., it can work on both TCP and UDP.
3. SIP supports personal mobility: a SIP UA always re-registers its new location and bonds this address to its former address. This mechanism would ensure that the SIP UA is reachable even after it has moved from its original location.
4. SIP has unlimited name space and provides globe unique addresses for SIP UAs.
5. The SIP extension method- Subscribe/ Notify supports asynchronous applications.
6. SIP supports media streaming. It is used to establish, modify, and terminate media sessions. Multimedia streaming such as video, audio and data can be exchanged within a session.

3.2.2 Internal-Home Communication – Why Agents

In a home, all home appliances are connected in a home network. This is done to pursue more features and to conveniently complete services. A user could simply inform an appliance about what is required to be done, and then the appliance will perform the work autonomously. Even the appliance doesn't need to be told every time, it will complete the service automatically when necessary. To achieve this goal, all the appliances should be smart; they should be capable of retrieving information from other appliances or people; they should operate autonomously, etc. All these requirements can be fulfilled by the use of software agent technology. Software agents, discussed in chapter2, would act as appliance agents and would control and operate appliances on behalf of users.

3.3 Network Architecture

In a home area network, communications are made up of Internal-Home communication and External-Home communication as shown in Figure 3.1 [1]. There is a Regional Gateway (RGW) between the home and outside world. The RGW that may co-exist with the firewall and NAT (Network Address Translation) provides a protection for the home network from being attacked.

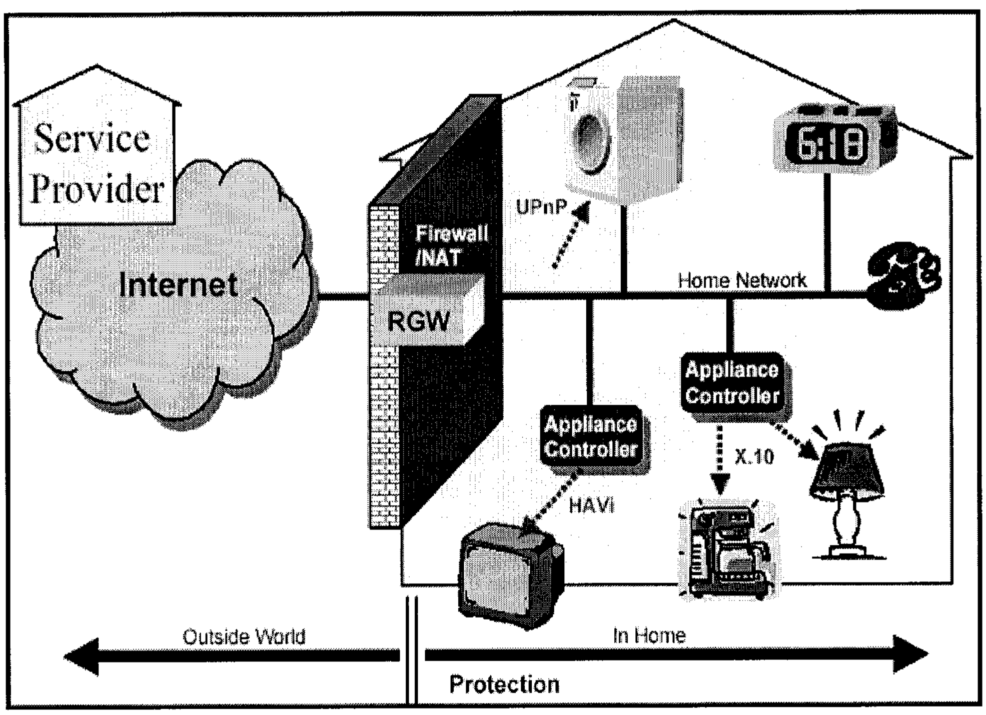

Figure 3.1 Example Home Domain Containing Networked Appliances [1]

The Internal-Home communication occurs between all kinds of home appliances and home users. These appliances can communicate with each other and cooperate to provide several different services to users. To realize full control and access to home appliances, different technologies/protocols are used to connect tradition appliances into one single domain as shown in Figure 3.1. HAVi can be used for TV and other video and audio devices; X.10 can be used for the coffee maker and lamps; UPnP can connect a wash machine into the network. Some IP-capable device such as Internet alarm clock and IP telephone can be connected into the network directly.

The External-Home communication is realized over the Internet. Outside the home, service providers locate on a wide area network. Through the Internet connection, appliances could accept services from service provides; homeowners or users could also access NAs from the outside of the home area.

We will combine SIP, agent, and other technologies to achieve a fully controlled, autonomous, and asynchronous home network.

3.3.1 Functional Architecture

The functional architecture of the Agent & SIP-based network appliance system is shown in Figure 3.2. The physical context of the SIP-based networked appliances system is the home environment. That all home appliances are converted to be the networked appliances means the following: (1) each home appliance has a computing resource and a network interface; (2) each home appliance is a SIP UA with SIP capabilities. The appliances can be classified into two groups: IP capable and non-IP capable appliances. IP capable appliances can process the incoming request themselves; examples include PCs, and Web TVs. Non-IP-capable appliances need an appliance controller to translate the IP message into the format that appliance-specific protocol understands [6] as shown in Figure 3.1.

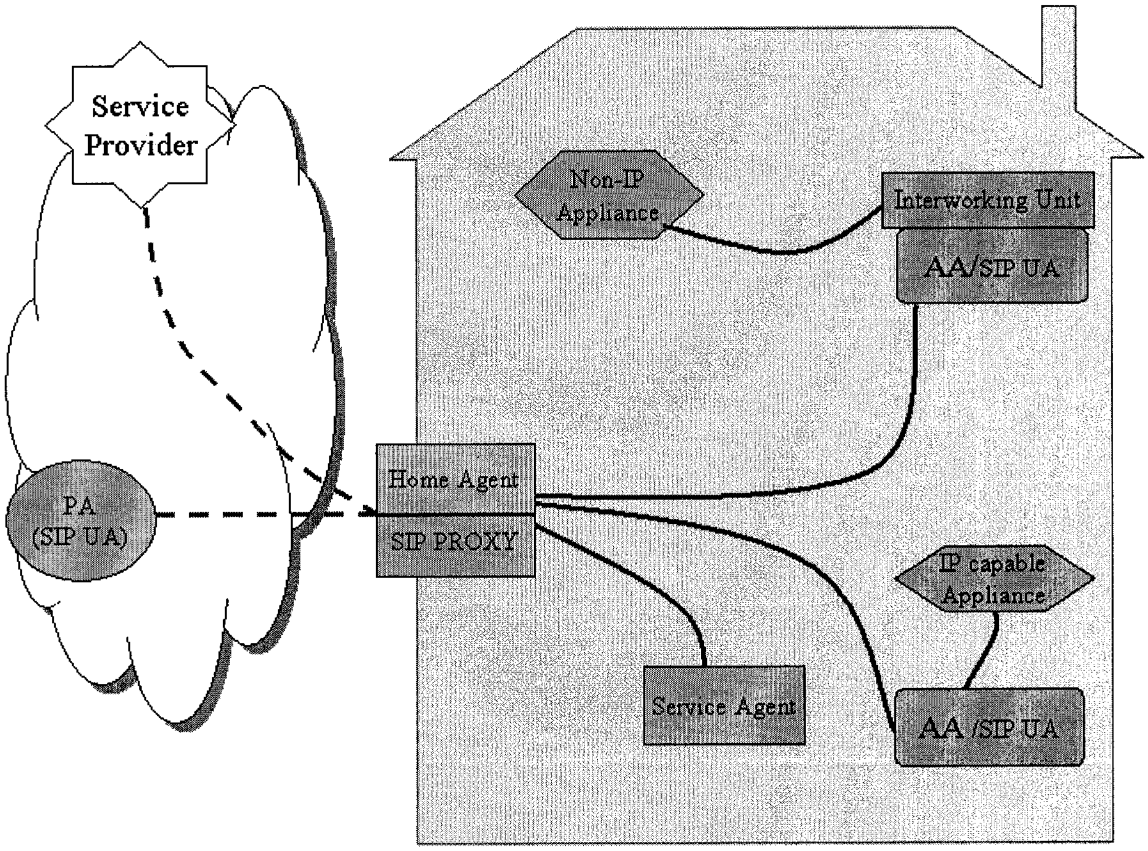

Figure 3.2 Functional Architecture

All the NAs and some functional agents such as service agent and home agent are connected to the home domain. They work together to make the home NAs system smart, autonomous, and asynchronous.

For privacy and security reasons, the NAs system is behind the RGW, i.e., protected by RGW. All the NAs are invisible from outside. All the information between the home domain and a wide-area network are exchanged through the RGW. The

Personal Agent (PA), which works on behalf of the homeowner, may run both inside and outside the home domain. Third party agents, such as service provider may also communicate with the entities within the home domain.

3.3.2 Main Entities in the NAs System

This section describes the main entities in the NAs system. Different agents cooperate with each other in this NAs system and work on behalf of home users. Collaboration among agents is essential to ensure that the whole system runs properly. A brief overview of all agents involved in the entire system is given below.

The main entities include:

Personal Agent (PA): The PA is an extremely important element in the NA system. The users access almost all the services via the PA. The PA works on behalf of homeowners to generate and send requests to specific NAs, and also receives and handles results from other agents. The PA interacts with its owner using a user GUI. The PA can directly receive the user's instruction, or alternately can collect the necessary information using some interface with the user's schedule books and contact lists etc. The PA learns and saves owner's preferences, hobbies, policies, schedules and friends' contact information with different priorities, etc, and sends service request and makes some decisions accordingly. PA may filter the result and only report the ones that user wants and needs to know.

On the other hand, the PA is also a SIP wrapper agent. It has all the capabilities of a SIP UA that provides a personal mobility support, allows PA automatically registers its location, sends and receives a SIP request. Its SIP UA is in charge of establishing, modifying and terminating sessions with the NAs.

SIP Proxy: A SIP Proxy that co-exists with the HA in the RGW (Regional Gateway) acts as a gateway between the home domain and a wide area network. It forwards incoming requests of the PA and other user agents to the appropriate SIP UA working on behalf of specific NAs. The Proxy server protects the valuable information on the home network and filters the incoming and outgoing messages.

Home Agent (HA): The Home Agent is an agent working on top of SIP Proxy. It performs security check prior to permitting message exchange from a user to the home or from the home to a user. The security check includes authentication, authorization, and encryption. After identifying the access, the HA looks up the service list on the SA. If the service is available, HA forwards the request to the matching appliance. Otherwise, the HA may refuse the request. If the operation is accomplished, or the request is rejected, it will send the result to the user.

Service Agent (SA): A SA is a service locator and manager. It has the DF (Directory Facilitator) functions, i.e., provides yellow pages service. In our design, the SA is an extension of the DF. It accepts new NAs' registration, monitors NAs' status, maintains and updates service lists that include NAs' attributes, functions and locations etc. The SA also classifies services, and puts any similar service as alternative service. When the HA sends a lookup request, SA returns the lookup result after checking its lists. If the required service fails or is unavailable, then the SA will suggest an alternative service to HA. The SA may select and combine several services to perform multiple NA operations, or compose formula services. For example, a leaving home service will turn on the alarm, lock the windows and doors, and set the electronic appliances in a power-save mode.

The SA creates and maintains the user's ID & password list. It will verify the user when there is a requirement for users authentication. This is a necessary step for security check.

The SA may also collect and update the environment data from different environment sensors, such as temperature, motion, infrared, pressure, etc. In certain scenarios, the SA may make decisions depending on these parameters.

Appliance Agent (AA): Each Appliance Agent is a specific software agent responsible for one appliance or one type of appliance. Each AA is a wrapper agent having the capabilities of a SIP UA that sends the request to callee (SIP UA) and handles the incoming request from caller. An AA manipulates an appliance (IP capable) directly or through Appliance Controller (Non-IP Appliance) according to the control message. If AAs need to communicate with each other, they contact the SA to get the destination AA's address.

In our design, there are different agents for different NAs, for example, DoorBell Agent for DoorBell, vcrA for VCR, and cameraAgent for security camera, etc. The details of each AA are described given in chapter 4.

Appliance Controller: The Appliance Controller operates the Non-IP Appliances directly according to the control message. It's an electronic device, which has computable resources and a connection interface. For example, X.10 controllers can be used for lamps, fans, and camera etc.

3.4 Operating Mechanism

This section describes how the Agent & SIP – based Home Appliance Networking System operates. We briefly explain processes such as new appliance registration, service status monitoring, access authentication, multiple NA operation, and NA sequential operation.

3.4.1 Pre-conditions

When the home network is active, some entities must be running all the time. The agent platform is ready to accept new agents. SIP server is enable and waiting for new SIP UAs. The two primary elements of the system i.e., HA and SA, are waiting for NAs.

3.4.2 New appliance Registration

When a new appliance is connected to a home network, its AA will auto-register itself. The registration consists of two parts: Firstly, the SIP UA registers on a SIP Registrar through a SIP PROXY and gets a SIP address. Then, the AA registers itself on the SA, which keeps AA's information in the service lists. When the PA sends a SIP request to the AA, the SIP Address can easily be transferred to an agent address, and vice versa.

When an AA registers itself on the SA, it sends its parameters to the latter. The SA considers these factors to realize its "yellow pages" service. The parameters may include name, catalogue, functions, operations, position, status, etc.

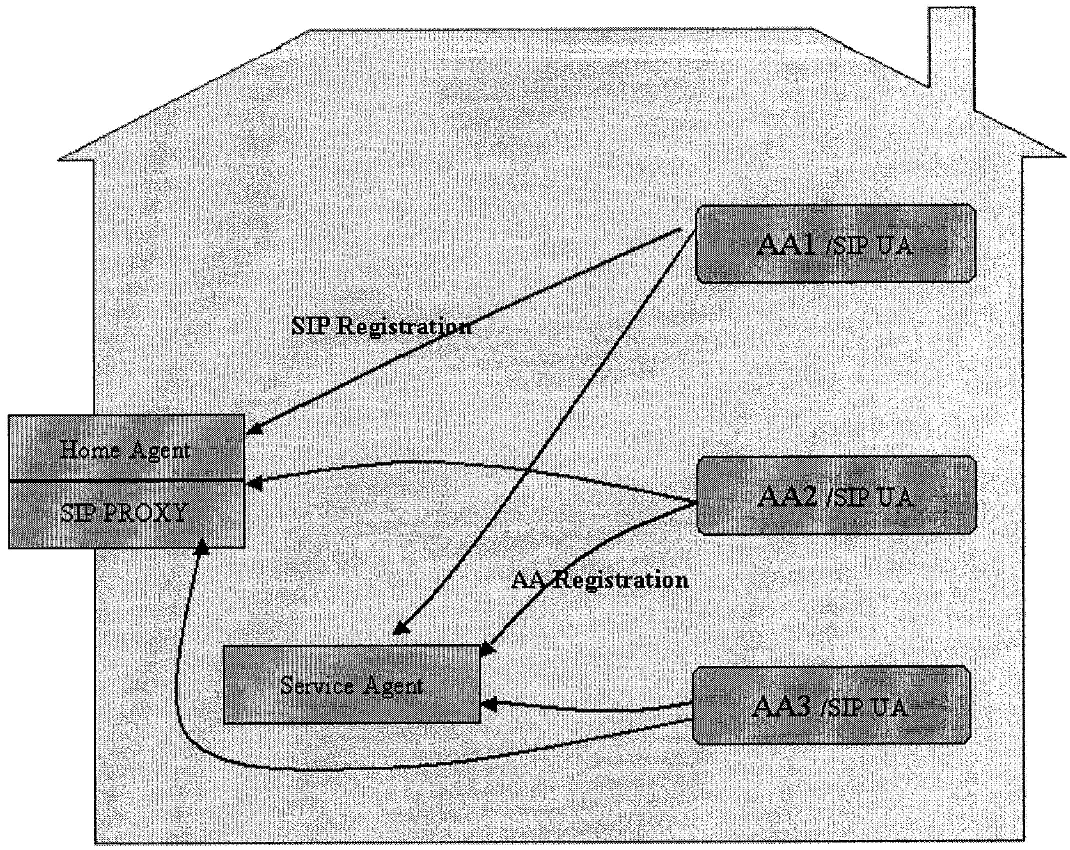

Figure 3.3 New Appliance Registration

As discussed in chapter 2, when the NA moves, its SIP UA may register itself from the new location. The SIP server then binds the AA's new SIP Address with its former address. Therefore, any incoming call to this AA will not be missed due to the change in location.

3.4.3 Monitoring and Updating Service Status

In a home network, the SA monitors and updates the service status of AAs. To do this, the SA subscribes to AAs. Thus, whenever there is any change in the appliances' status such as turning on, turning off, in operation, broken, busy, etc, the corresponding AA will notify the SA and the latter will update the service lists. If any problem occurs with AAs, the SA will request service providers (such as service companies or manufactures) for maintenance or repair.

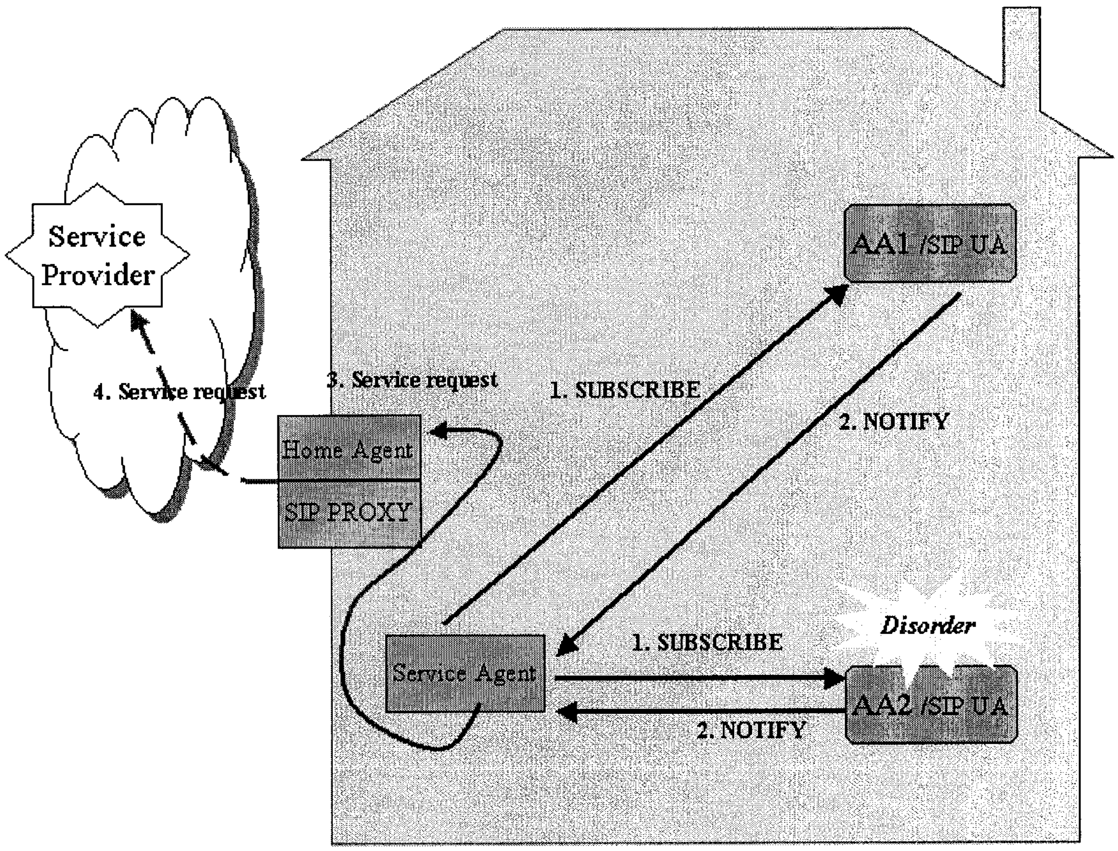

Figure 3.4 Monitoring Service Status

AAs of NAs are supposed to be always working. In case some AAs are not working (for example the host computer is down) and cannot send the notification, the SA will send periodic request to AAs, say every 30 minutes. If an AA sends back an acknowledge response, it means that the AA works properly; otherwise it is non-functional and needs repairing.

3.4.4 Security Check

Security is extremely important for a home domain. The privacy, wealth protection and security are a primary concern. One fake message from an unauthorized resource can cause a severe security issue. When receiving an incoming request, the HA should perform a security check as shown in Figure 3.5.

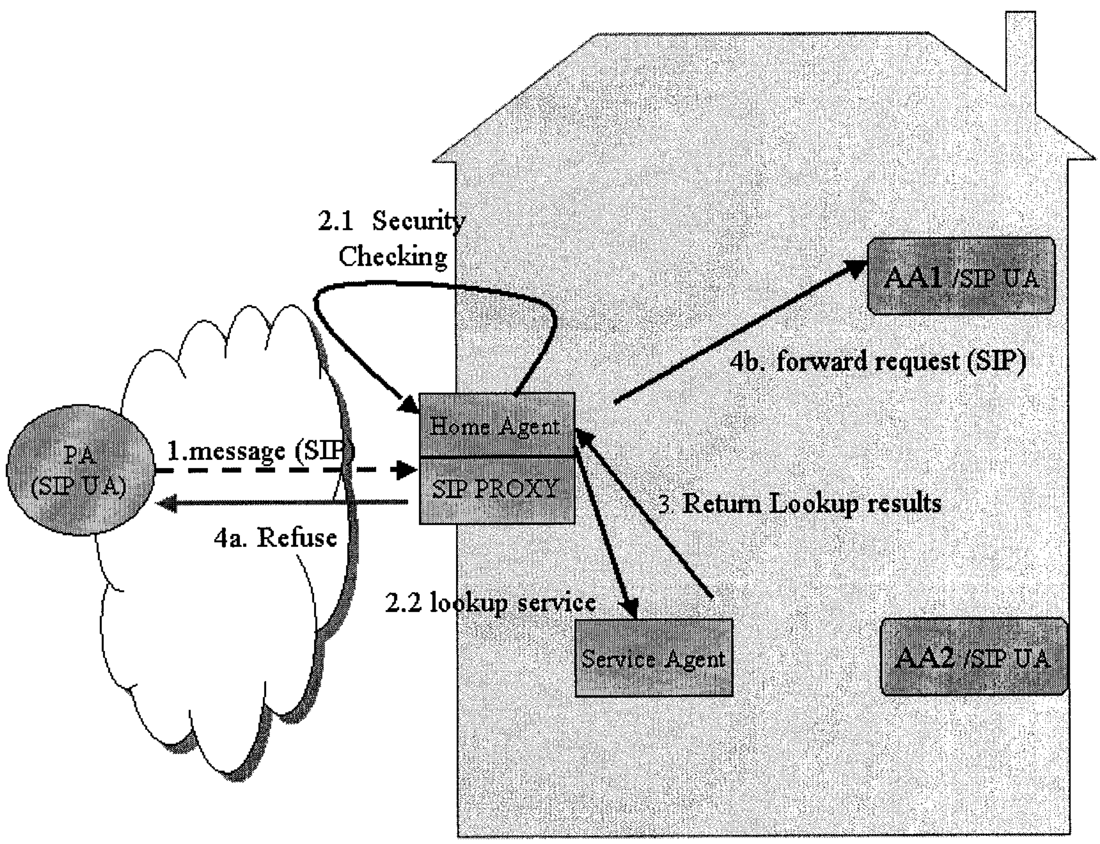

Figure 3.5 Security Checking

The security check includes:

- Authentication

  The HA verifies the integrity of transmitted messages in either direction prohibiting to be fabricated, modified and masqueraded [1]. The message from outside needs to be authenticated because it will directly generate certain results inside the home. A response from the home to the PA also needs to be authenticated because a fake message could lead the latter to make a wrong decision.

- Authorization

  The HA checks the user's identity and status, and also decides the different kinds of service that can be used. Different users may have different right and priorities for certain services. For example, parents could have a higher priority to use some appliances than their young children.

- Encryption

  The destination address in the message sent to the home network needs to be encrypted because it may contain private and sensitive information such as appliance names and location [1].

- Service availability

  The HA checks for service and appliance availabilities with the SA. If the answer is positive or if the SA recommends an alternative service, the HA grants the access; if the service is unavailable and no substitutive service could be provides, the access would be denied.

- Access rejection

  If any one of the above conditions fails, the access will be denied.

3.4.5 Service Request

There are two cases wherein a home user could request appliance services. It depends on the location of the home user (personal agent) and the location wherein request originates. If it is an external request, then the authentication process takes place. If not, the service request need not be authenticated by the HA. The PA can directly communicate with the SA or AAs using the Agent Communication Language (ACL). These two cases are discussed in the following sections.

3.4.5.1 Internal Request

If the PA is located inside the home domain when the request is being sent, the SIP characteristics will not be used. The PA will send an ACL message to the appropriate AA or SA. No SIP message is sent among the PA, SA, and AAs. All agent communications takes place using the ACL. In the home network, all agents run on the same agent platform. Therefore, the communication is fast and safe.

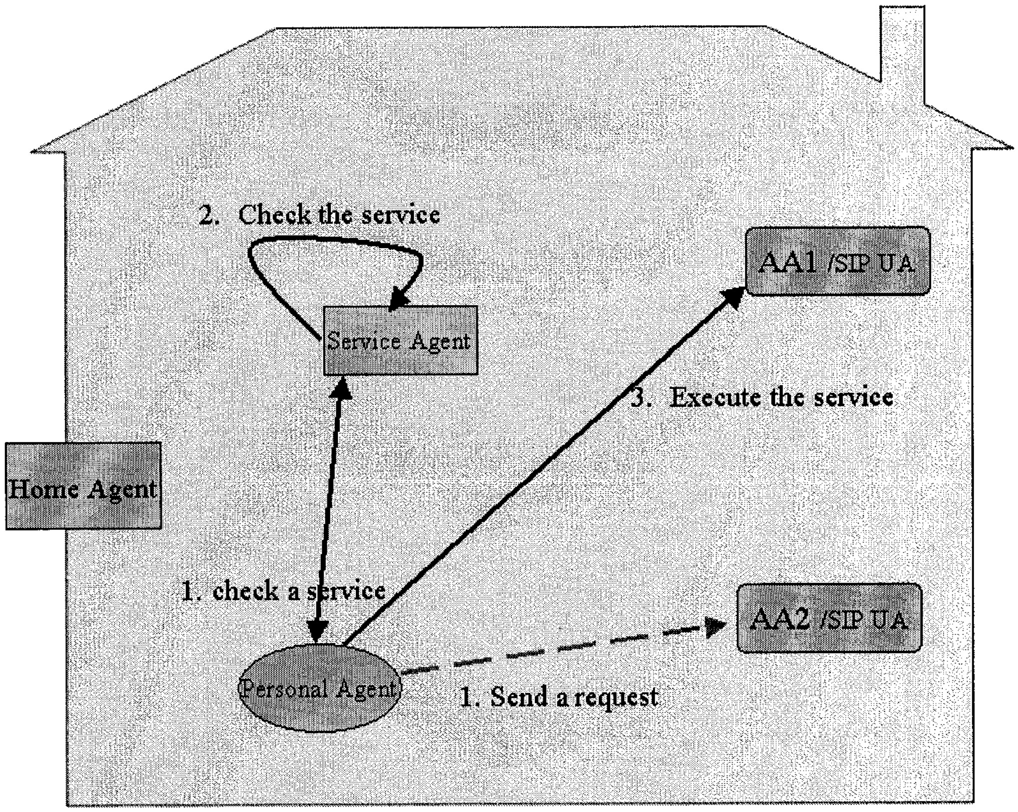

Figure 3.6 Request within the Home Domain

The communication procedure is shown in Figure 3.6:

Case a: The PA knows the address of the AA

The PA will send a service request directly.

Case b: The PA doesn't know the address of the AA

1.) The PA sends a request to the SA for checking the service.

2.) The SA returns the wanted AA's address.

3.) The PA then sends the service request to the AA.

3.4.5.2 External Request

The case in which the request is from outside of the home network, is given more focus as it involves both SIP and agent communication. As shown in Figure 3.5, the PA sends a SIP request to AA. When the SIP message is received by the SIP Proxy, it intercepts the message and forwards to the HA which works on top of this SIP Proxy. The HA then performs the security checks. If there is no security threat, the HA continuously checks the service status with the SA. If the result is negative, the HA will refuse the service request. If not, the HA permits the SIP Proxy to forward the service request to the matching AA. The AA retrieves the operating instruction from the SIP message received by the AA. The AA finally makes the service operation procedure and manipulates the NA to complete the service.

3.4.5.3 Handling the Request

After the security check, the HA would forward the request to the appropriate AAs. One request may involve more than one NA. To fulfill the requirement of the request, several appliances may need to operate simultaneously as shown in Figure 3.7.

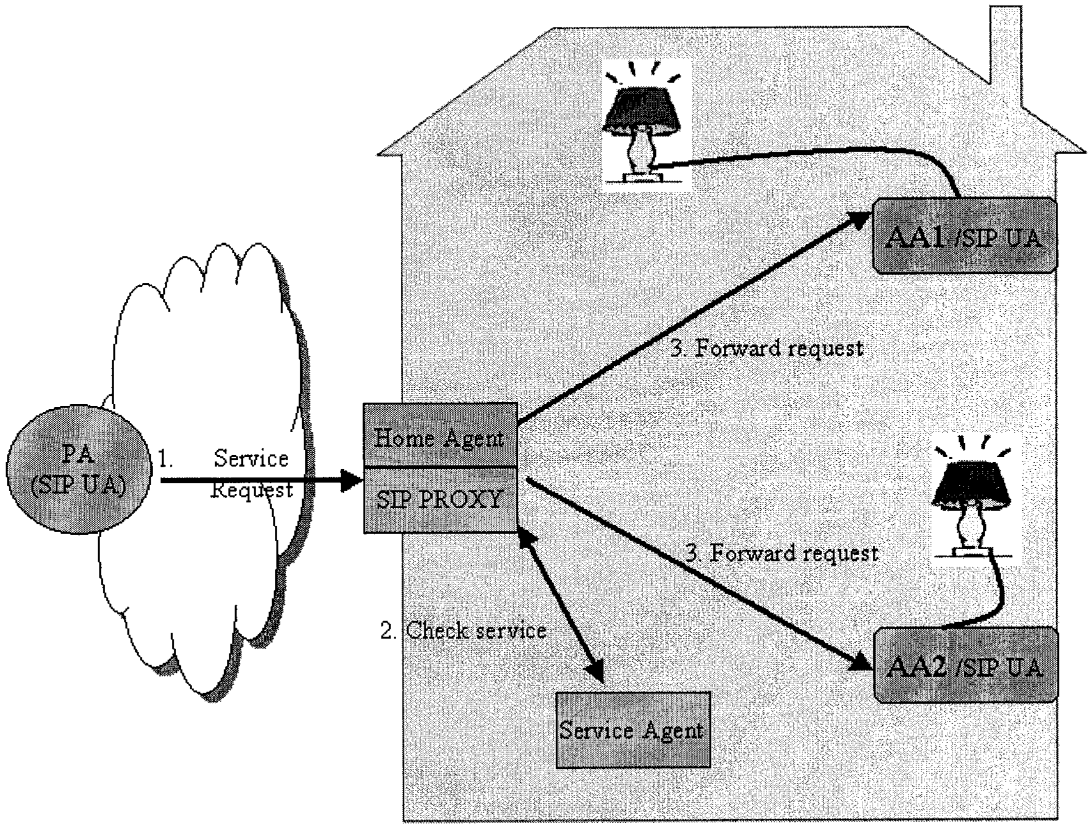

Figure 3.7 Controlling several appliances at the same time

Such a case could include more than one NA and operates them at the same time, such as turning "ON" all the light, or all air conditioners. There are no particular relations among these different services; only the actions just happen at the same time. This sort of operation may be used when a group of actions are needed.

In another case shown in Figure 3.8, the user's service request will involve several NAs but they are operated in sequence instead of simultaneous action. After the security check, the HA checks the service's status, and forwards the result to the first appliance AA1, which is required to perform the service. If the sequential service is required, after the AA1's operation, the AA1 sends the necessary command to the next appliance AA3.

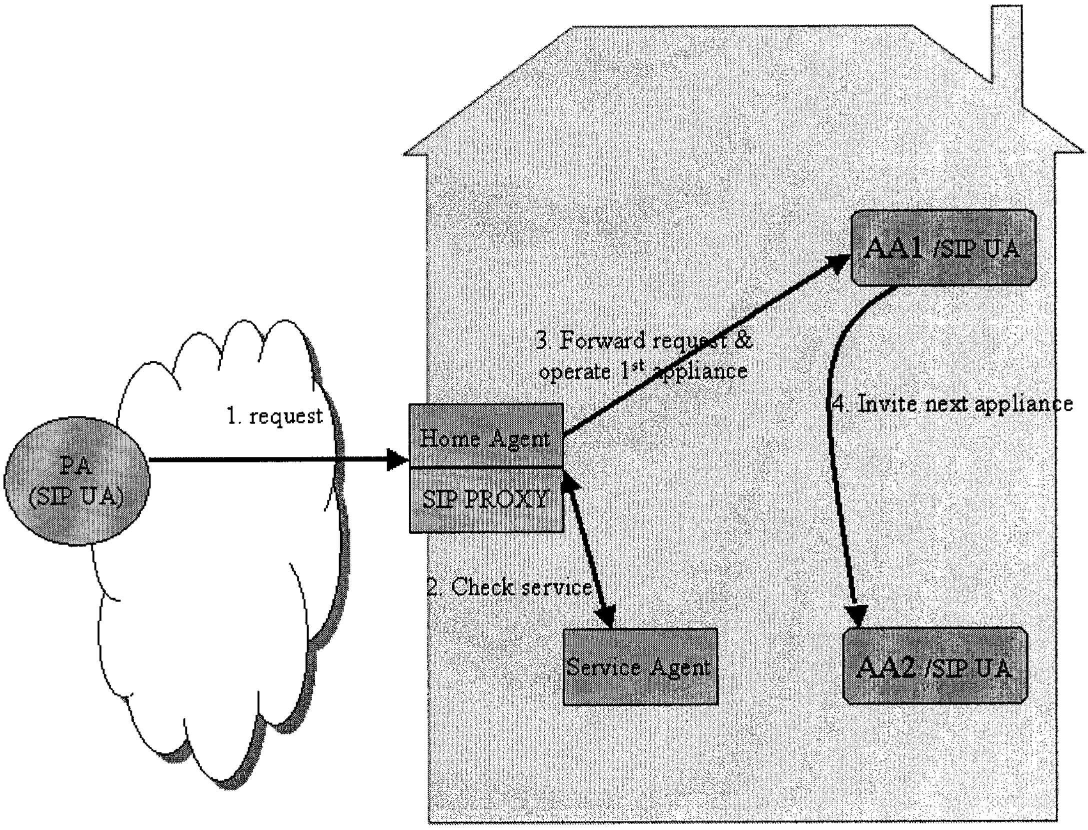

Figure 3.8 Sequential Services

These two modes can be mixed together. Each AA may have a conversation with only one other AA or several AAs at the same time. Between AAs, such as AA1 and AA3, the communication takes place in ACL format.

3.4.6 Providing Alternate Service

After the security check, the HA will check the service's status from the SA. If the service in AA1 is not available or busy when it's required, the SA will recommend an alternative service.

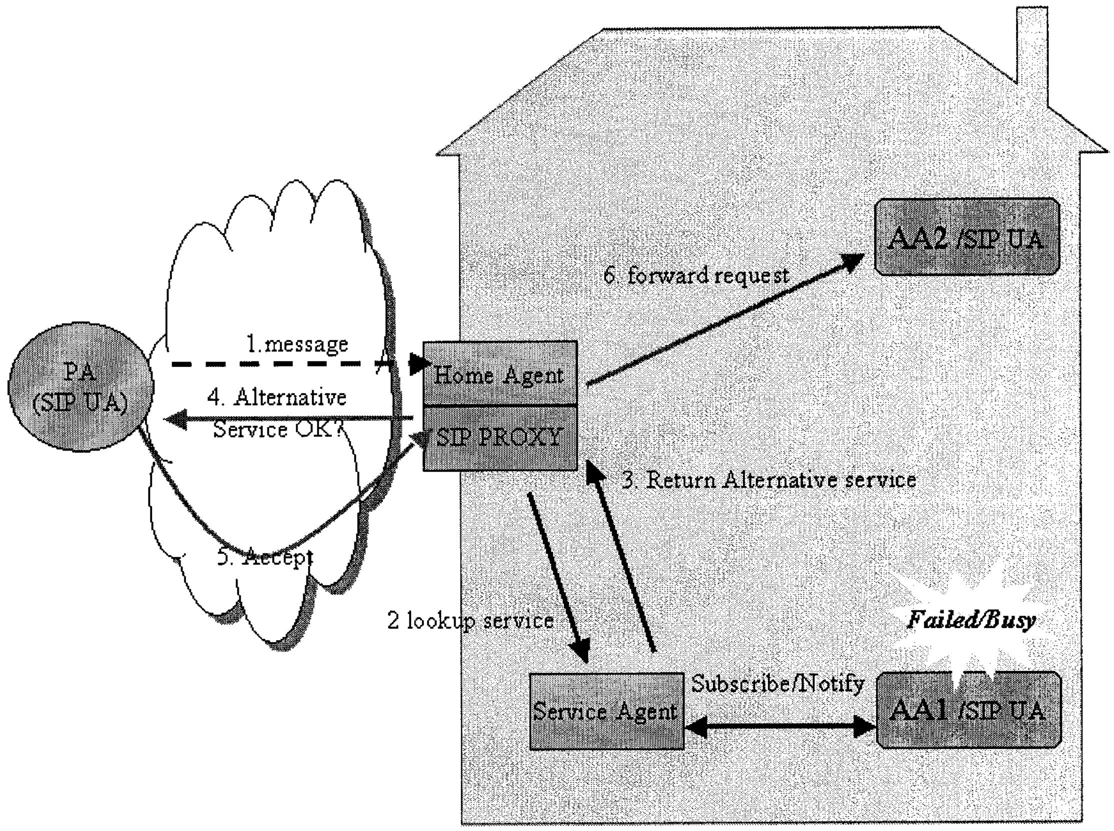

Figure 3.9 Providing Alternative Service

As shown in Figure 3.9, HA sends PA a new SIP request via SIP Proxy to confirm the latter's acceptance. If PA accepts the request, HA will forward the service request to the alternate NA--AA2. AA2 then retrieves the service request from the SIP message and operates the NA to perform the service.

3.4.7 Acquiring the Environment Data

In the proposed system, there are many factors that affect the operation of NAs. The system acquires the environment data via sensors. The environment sensors include motion detectors, door sensors, window sensors, fire & smoke sensors and temperature sensors, etc.

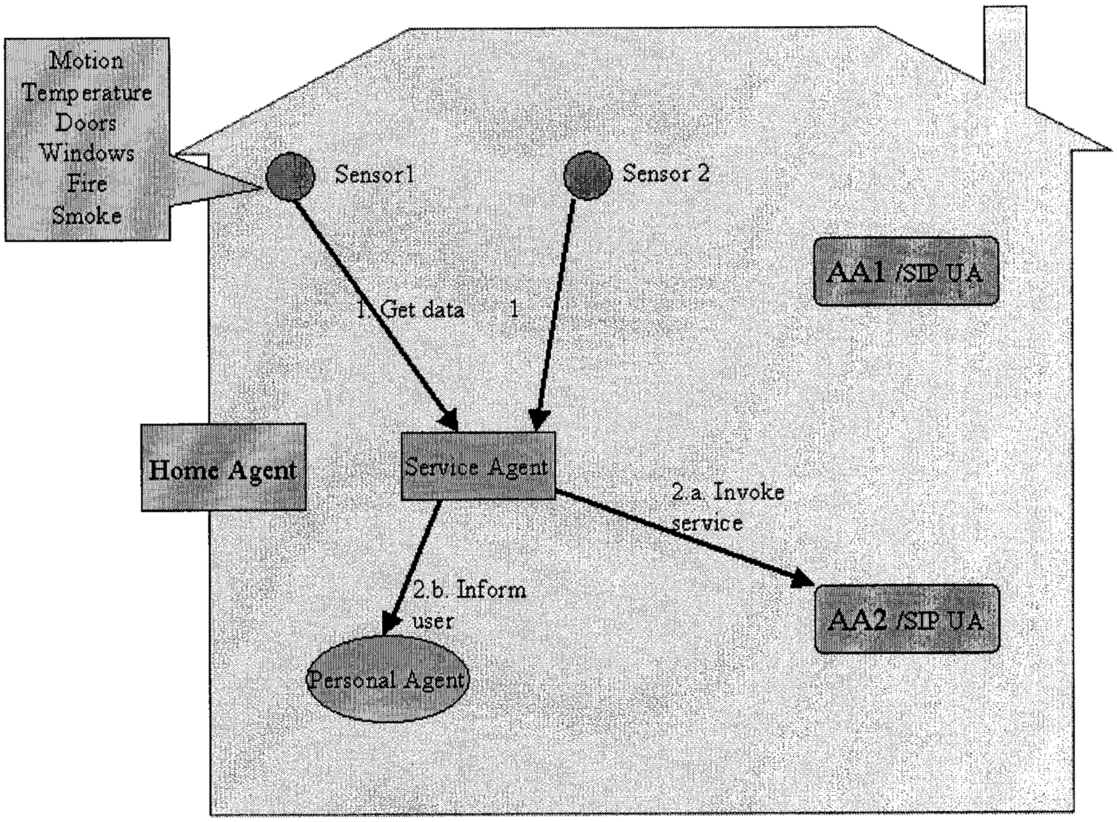

Figure 3.10 Acquiring the environment data

The parameters are sent to SA, and SA would further decide what kind of actions need to be executed. SA may invoke a service or inform the homeowner about the event.

3.5 Summary

This chapter presented the designing details of the SIP & Agent-based Networked Appliances system. Firstly, the requirements of the NA system and the reasons for choosing SIP and agent technology were discussed. Then, the system architecture was elaborated. In the last part of the chapter, the operating mechanism of the NA system was explained.

The next chapter describes the implementation details and execution results. A brief evaluation showing the flexibility and performance levels of the NA system are presented.

Chapter 4 System Implementation

The implementation details of the SIP & agent based NA system is presented in this chapter. Firstly, the implementation environments and development tools are introduced. The main aspects of the FIPA-OS (Foundation for Intelligent Physical Agent –open source) Platform and the ACL are explained next. We then look at how the SIP server and the SIP client build a session and how the tools work. Then, in the prototype description, we look at the main entities of the system and clarify how they cooperate as a system. This is followed by scenario that is used to test the implementation models. Finally, the system flexibility and performance evaluation are discussed.

4.1 Implementation Environment and Tools

The overall implementation of the SIP & agent–based home appliance networking system is done using the Java programming language. FIPA-OS v2.1.0 [29,32,37,38] is chosen as the agent platform and it supports multiple agent communications. The agents, such as the Home Agent, Service Agent, and Appliance Agents would run on the FIPA-OS platform. The ACL [30] is used by FIPA-OS as the communication medium for agents.

We used the SIP server (sipd1.0) and SIP UA from Columbia University (sipc1.1) [31]. Tools such as the VCR simulator and VIC are also used in the implementation. A brief introduction is given for each of these tools in the following sections.

4.1.1 FIPA-OS Agent Platform

The FIPA-OS agent platform (AP), which follows the FIPA agent standards, is an open-source agent platform developed by Nortel Networks. It supports multi-agent communication using the ACL. With its openness, the FIPA-OS AP is extensible. Also, the platform is good at interoperating with other agent platforms that are FIPA specific.

The FIPA-OS AP is a component-based agent platform, wherein each component is an agent. As shown in figure 4.1, every agent platform has the following entities as its mandatory and platform-specific agents: the Agent Management System (AMS), the Directory Facilitator (DF), and the Message Transport Service/System (MTS) [33].

The AMS, as its name indicates, is the agent that manages the access to and use of the agent platform. There will be only one AMS for one AP even the AP is distributed. The AMS provides "white pages" service to other agents, and all other agents in the platform must register with the AMS to get a valid Agent Identifier (AID) [33], which is used to locate and identify the agents.

The main function of the DF is providing "yellow pages" service for other agents. If any agent wants to advertise its service, it may register with the DF. On the other hand, if an agent wishes to find out about the service offered by other agents, it may query the DF as well. Unlike the AMS, there could be more than one DF within an AP [33].

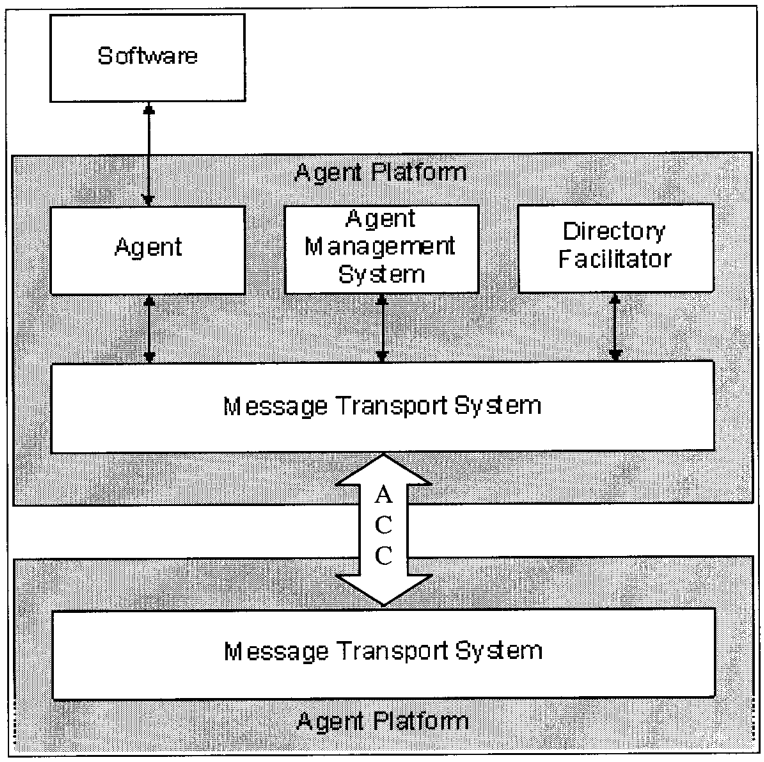

Figure 4.1 Agent Management Reference Model [33]

The MTS provides a message routing service for agents both within the AP and across APs. If an agent intends to communicate with another agent, it must send an ACL message via the MTS on its own platform. The Agent Communication Channel (ACC), as a part of the MTS, provides communication channel support for agents performing inter-platform communication [33, 39, 41].

Except for the mandatory components, agents are the essential entities on the agent platform. An agent is a software component with its own state, behavior, thread of control, and access to external legacy software, people and communication appliances. Each agent must belong to at least one owner and must have an AID to identify itself [33, 39]. A Wrapper agent normally represents a software system/application and interacts with other agents [34]. The wrapper agent allows client agents to invoke commands and control operations on the underlying software system using ACL messages. In our design and implementation, the Appliance Agents are in fact wrapper agents working on top of the SIP UA.

Agents use the ACL to communicate, negotiate, and share information with other agents within a platform or across platforms. An ACL message consists of a set of parameters that express the aspiration and purpose of the agent.

Element	**Category of Elements**
`performative`	Type of communicative acts
`sender`	Participant in communication
`receiver`	Participant in communication
`reply-to`	Participant in communication
`content`	Content of message
`language`	Description of Content
`encoding`	Description of Content
`ontology`	Description of Content
`protocol`	Control of conversation
`conversation-id`	Control of conversation
`reply-with`	Control of conversation
`in-reply-to`	Control of conversation
`reply-by`	Control of conversation

Figure 4.2 FIPA ACL Message Elements [10]

From all the FIPA ACL message elements shown in Table 4.1, there is only one mandatory element, i.e. *performative*, which indicates the type of communication acts. There are also three commonly used elements, i.e. *sender, receiver* and *content.* The se*nder* and *receiver* individually declare the two parties of the conversation, and the *content* shows the actual content of the transmission. The FIPA users are allowed to implement some specific message elements themselves. Agents will reply a *not-understood* message to those it cannot recognize or process.

4.1.2 SIP Server and SIP UA

SIP is used to build a session when the home user, i.e. the personal agent, tries to access the home appliance using the Internet. The SIP server and SIP UA tools are using sipd1.0 [31] and sipc1.1 respectively from the Columbia University. Sipc1.1 is installed in each host computer of the individual agent. Sipd1.0 is installed in the lab's server.

A typical SIP UA interface is shown in figure 4.3. The title shows the name of the host computer, for example, the one is "mmarl05". There are three buttons for making a call, canceling a call, and registering a SIP UA.

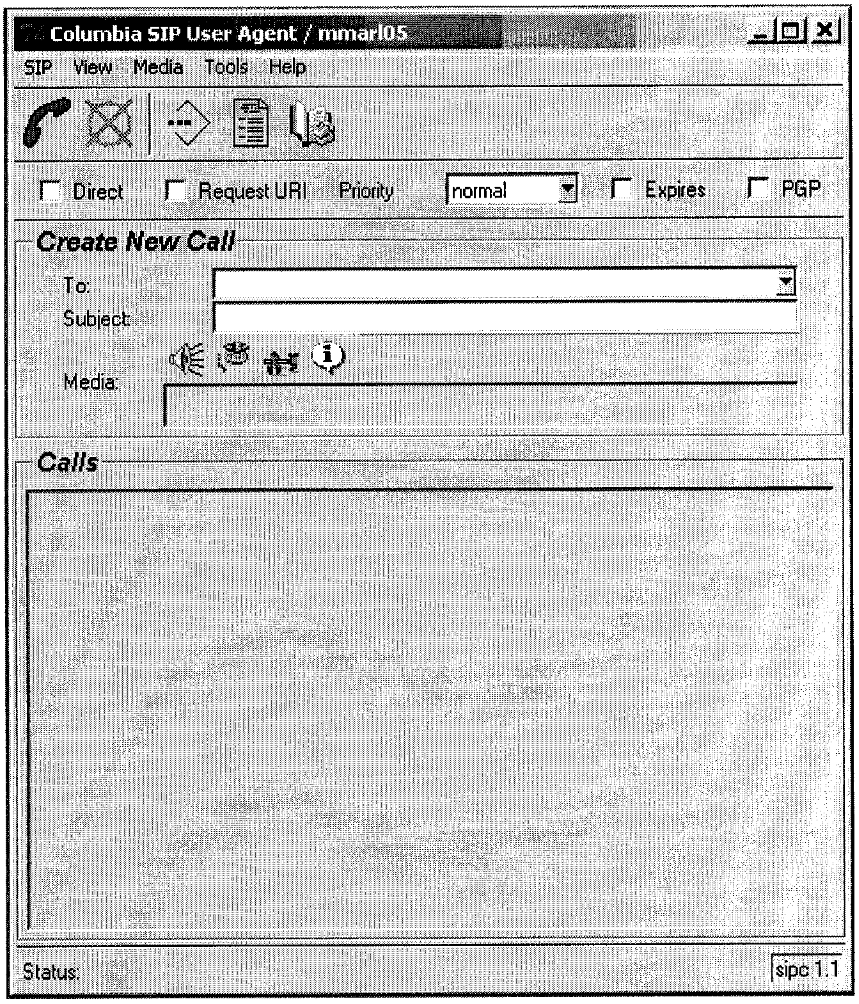

Figure 4.3 A SIP UA Interface

While the user makes a sip call, all the fields in the SIP window are filled with necessary information. A snapshot of SIP INVITE initiation is shown in figure 4.4. For each SIP call, the callee's SIP address, session topic, and media type are inputted in the "To" field, "Subject" field, and "Media" field respectively.

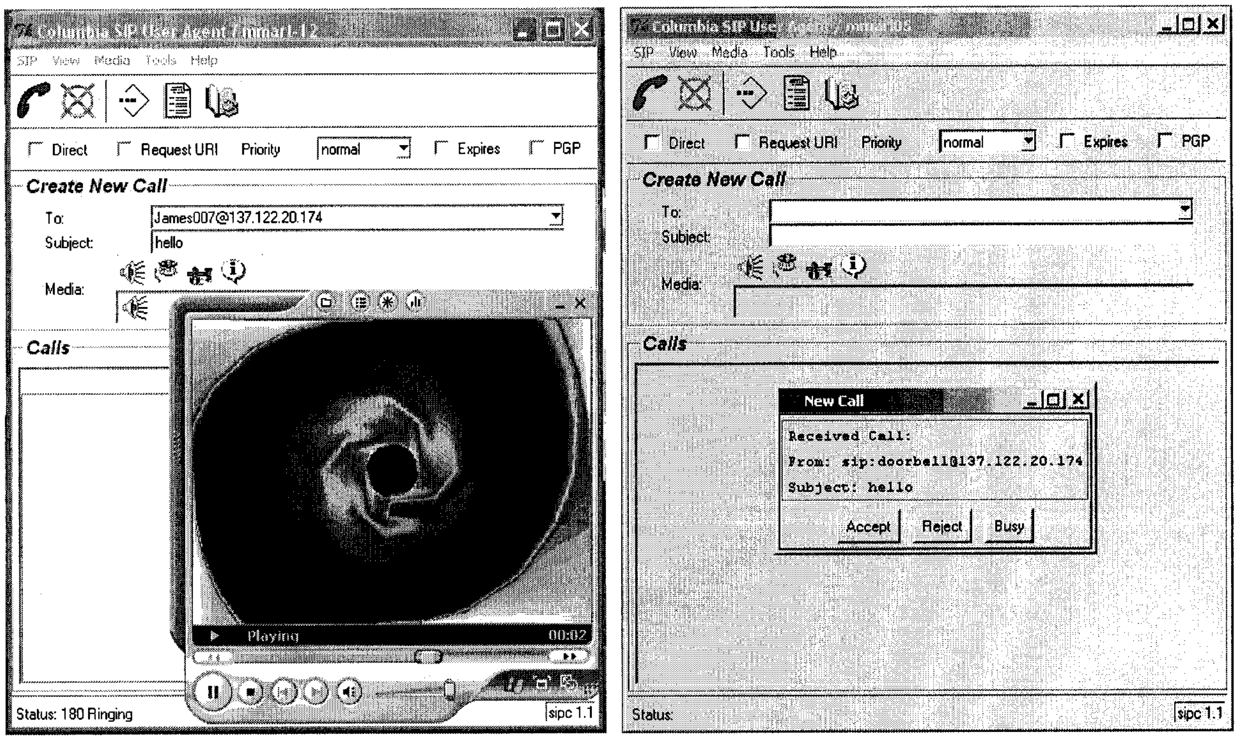

Figure 4.4 Sending a SIP INVITE snapshots

In figure 4.4, the caller at mmarl-12 sends an INVITE “hello” to the callee “James007” who registered at the SIP server “137.122.20.174”and suggests audio as the communication media. A status bar exists on the bottom of the SIP Interface window. The response from the callee James007@137.122.20.174 is shown in the snapshot. “180 Ringing” in the caller’s status bar means that the SIP UA of this callee received the INVITE call and is trying to alert its user now. In the meantime, a pop-up window at the callee’s end prompts the user about the incoming call. The caller ID and topic are displayed at “From” and “Subject” field separately. A user has three options from the incoming call: “Accept”, “Reject”, or “Busy”.

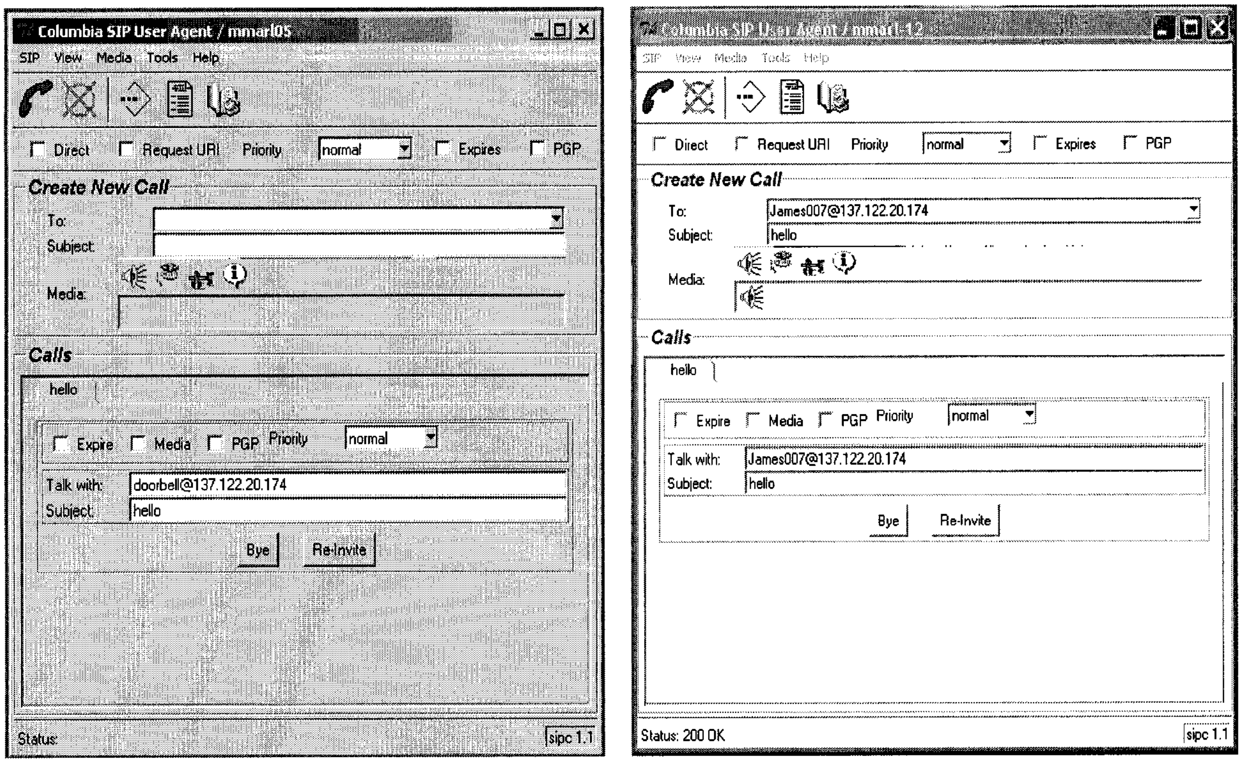

Figure 4.5 Accepting the call snapshots

After the INVITE is accepted, the caller's SIP UA receives a "200 OK" message sent by the callee's SIP UA, and a SIP session establishes between the caller and the callee. As shown in figure 4.5, each user may terminate the on-going session by clicking the "Bye" button at any time.

In our design and implementation, the actions of SIP UAs are mostly executed automatically by their corresponding agents. Agents will decide to either "Accept" or "Reject" the in-coming call, or to send an "INVITE". Thus, the involvement of human beings is reduced to a minimum.

4.1.3 Video conference Tool –VIC

VIC [42] is a video conferencing tool developed by the Network Research Group at the Lawrence Berkeley National Lab in collaboration with the University of California. This conference tool is a real-time multimedia application over the Internet.

VIC can work either on unicast connection mode or on multicast connection mode. When VIC works on multicast mode, it allows an unlimited number of participants theoretically. As shown in figure 4.6, each participant can see another's live image via the Internet Mbone (Multicast Backbone). Also, VIC can start up automatically using SDR (Multicast Session Directory) and can be set up using a command line as follows:

Vic [options] <IP address/port>

The address range used for multicast is from 224.2.0.0 to 224.1.225.255 and the port number should no smaller than 5002.

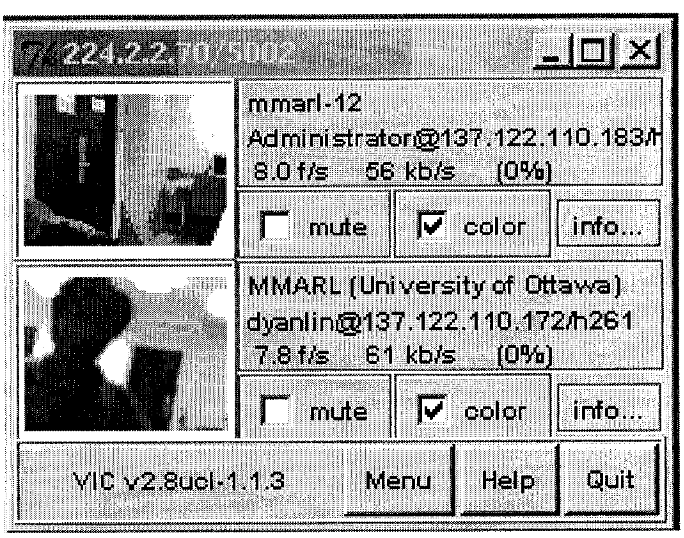

Figure 4.6 VIC on Multicast mode

When point-to-point conferencing is preferred, VIC should be used in unicast mode. The command line is as follows:

Vic [options] <remote_hostname/port>

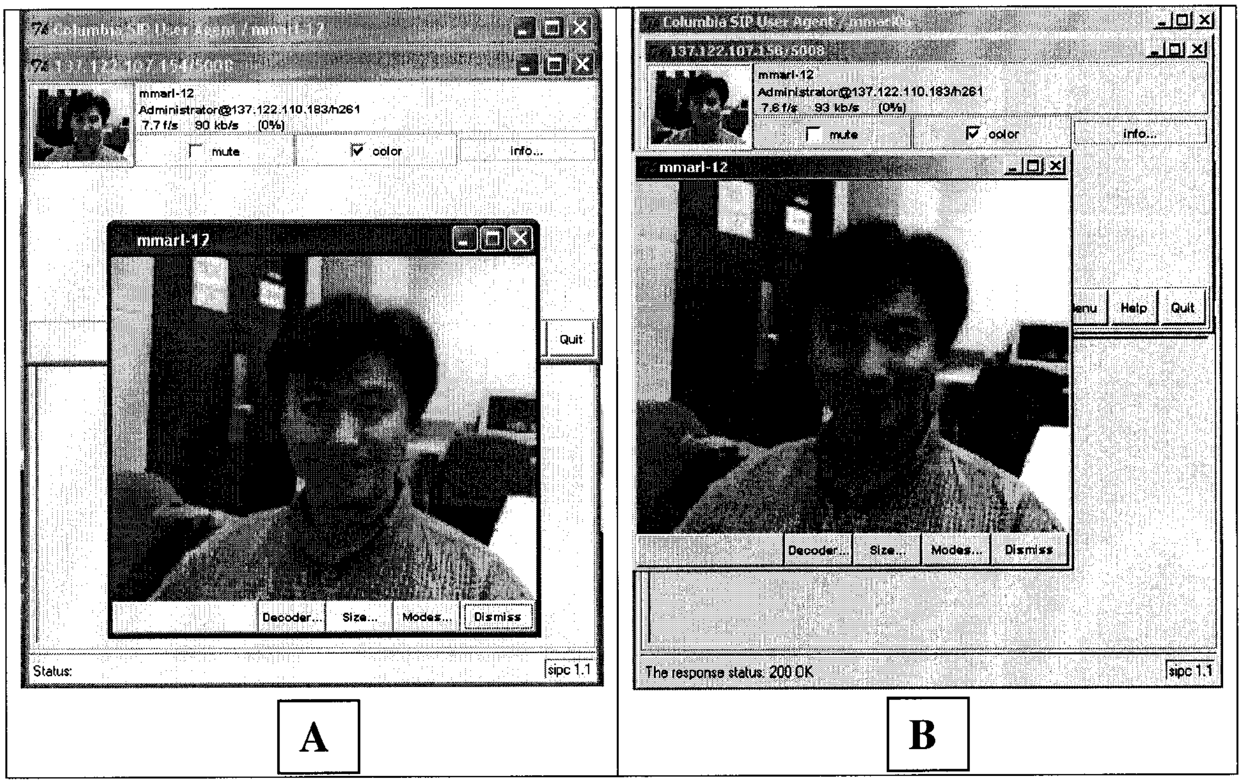

Figure 4.7 VIC on Unicast mode

The video taken in a local machine is sent to a remote computer. For example, in Figure 4.7 A, the computer mmarl-12 is the local-host with the camera. Mmarl-12 is sending the live video picture to port 5008 of the remote host computer mmarl06 that uses the IP address 137.122.107.154. The same video image is simultaneously shown in the VIC window of mmarl06. The machine need not own a camera.

In the proposed design, the homeowner uses this application to monitor the events of his/her home. When someone comes to the front door of the user's home, the camera is invoked by the DoorBell buzzing or motion detector and the live video is sent to the homeowner's personal device (PC or palm) using VIC in unicast mode.

4.1.4 VCR Simulation

In this implementation, a VCR is used as a part of a scenario. A VCR simulation program [43] is used instead of a real VCR player and the program has most of the main functions of a VCR: play, record, rewind, fast-forward, stop, setting programs, setting time, and setting channels etc.

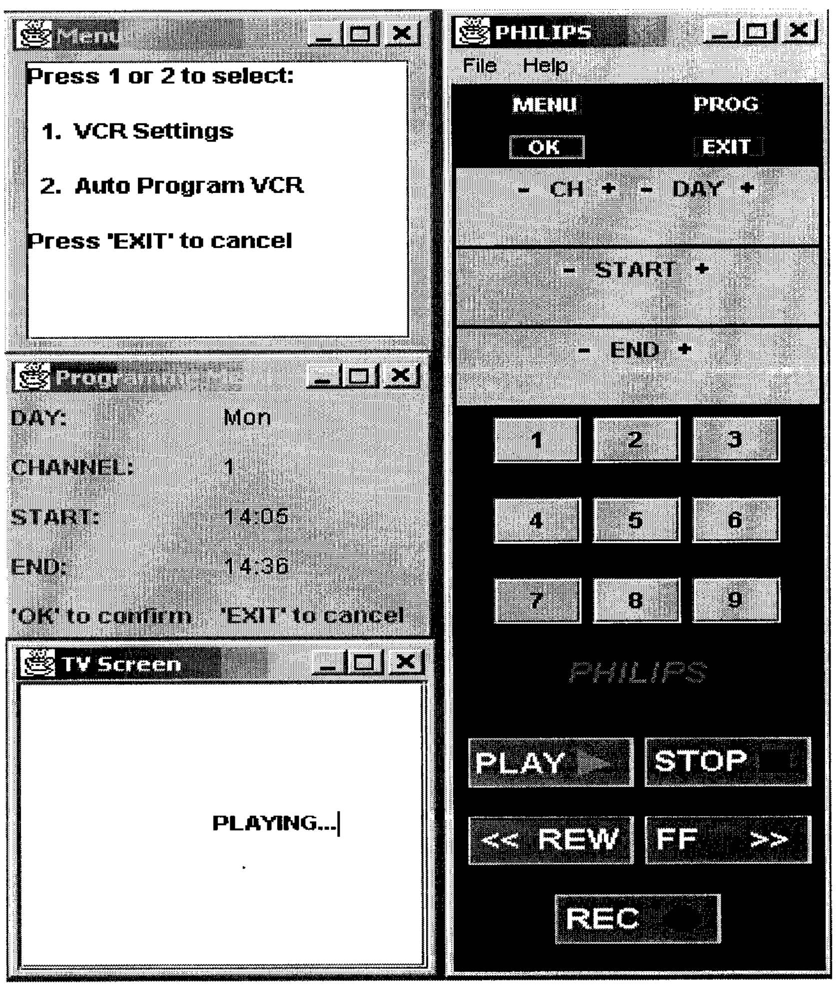

Figure 4.8 VCR Simulation Interface

The VCR program is operated manually just like a real VCR player. The program list will be displayed on the Program Menu window by pressing the "PROG" button; the menu menu list will be displayed on the "MENU" window by pressing the "MENU" button; the VCR operating status will be displayed on the "TV Screen" window when an operation is performed.

In our implementation, the vcrA agent will work on behalf of user to operate the VCR at any time. The vcrA agent cooperates with other agents to fulfill the service requirement.

4.2 Implementation Prototype Description

The implemented prototype follows the system design. However, due to the difficulty in modifying the SIP proxy server, we made a slight change from the original design. Rather than modifying the SIP Proxy, we places a SIP UA in the HA part as shown in figure 4.9. The HA re-registers the AA's SIP address and put its own SIP address as the contact address. Whenever a SIP INVITE is sent to an AA, the HA will first intercept the SIP call, then retrieve the service request, and finally sends an ACL message to the AA. This change is still according to the SIP communication rules.

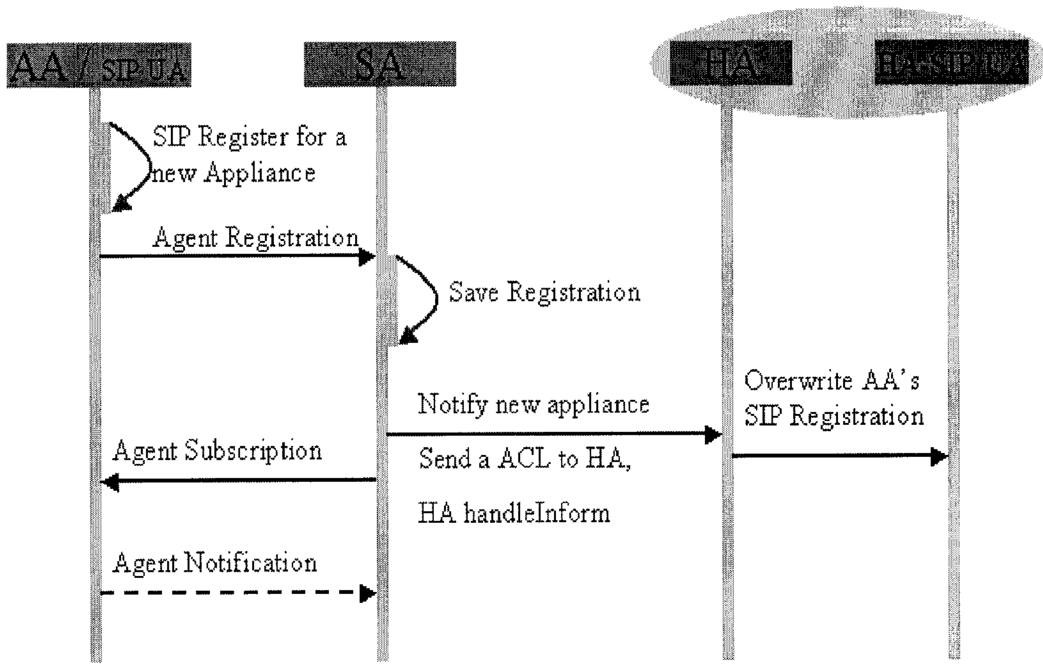

Figure 4.9 HA Re-registering a SIP address for an AA

The agents are implemented on the FIPA-OS agent platform. As shown in figure 4.9, the agents such as the HA, SA, AAs and PA within a home domain are located in a same distributed agent platform. When the user moves out of the home domain, his/her PA runs on a different agent platform. The detailed introduction of each component is presented in the rest of the section.

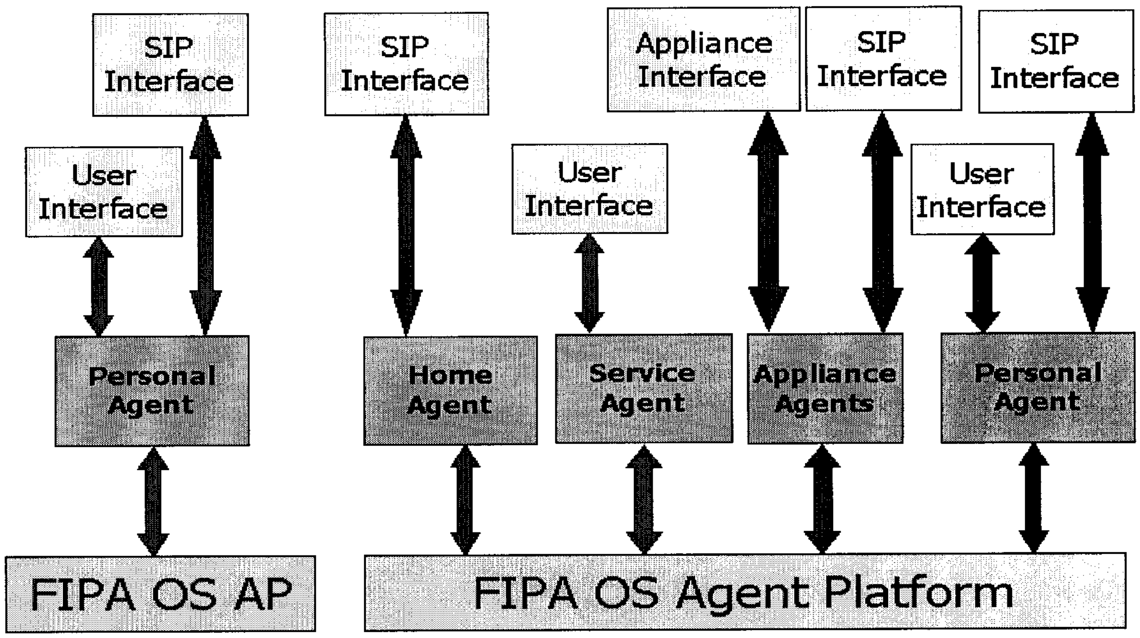

Figure 4.10 Prototype model of the system

Service Agent - SA

The Service Agent is a key agent within the home appliance network. As discussed in section 3.3, SA maintains the service list, monitors the NAs' status, classifies services and provides alternate services. In the system, SA will be the first agent turning on and remain on all the time.

When a new NA joins the network, it will register its name, address, function, and category with SA. Then SA sends a notice to the Home Agent (HA) to re-register a SIP address for this NA. Therefore, all the incoming requests can be terminated by HA for security check and service availability checks.

When a NA needs to verify a user and password, the request will be sent to SA. SA will verify the user and give the result back to the NA who original the request.

When a required service is not available, SA will check its service list and category, and will recommend an alternate service or device.

Home Agent-HA

The HA is a SIP-wrapper agent, which works on top of the RGW. It can handle requests in both SIP and ACL formats. When a PA sends a SIP request to some NA, HA always intercepts the SIP request first. It then executes the security process, checks the availability of the services or NAs, and verifies the visitor's access right. It then creates a message in the ACL format and sends the message to the corresponding NA.

After a new NA joins the network, the SA first registers the NA's information, and then sends an ACL 'Inform' to HA. HA re-registers a SIP address for this NA by sending out a new SIP REGISTER request with a higher priority to overwrite the original SIP registration of the NA. In the future, HA would intercept all the SIP calls to this NA. Further, HA repeats the same procedure to all NAs in the home network. By this way, the HA takes overall control over any established session involving NAs.

After the authentication and verification process, HA communicates with the required NA using ACL. Also, NA uses ACL to talk with HA, then the HA transfers the message as SIP call to the PA if required.

Personal Agent-PA

The Personal Agent is also a SIP wrapper agent that runs on the homeowner's personal digital device and works on behalf of a certain user. PA may run on the same FIPA-OS AP as with the home network, or could run on a different platform when it resides outside the home domain.

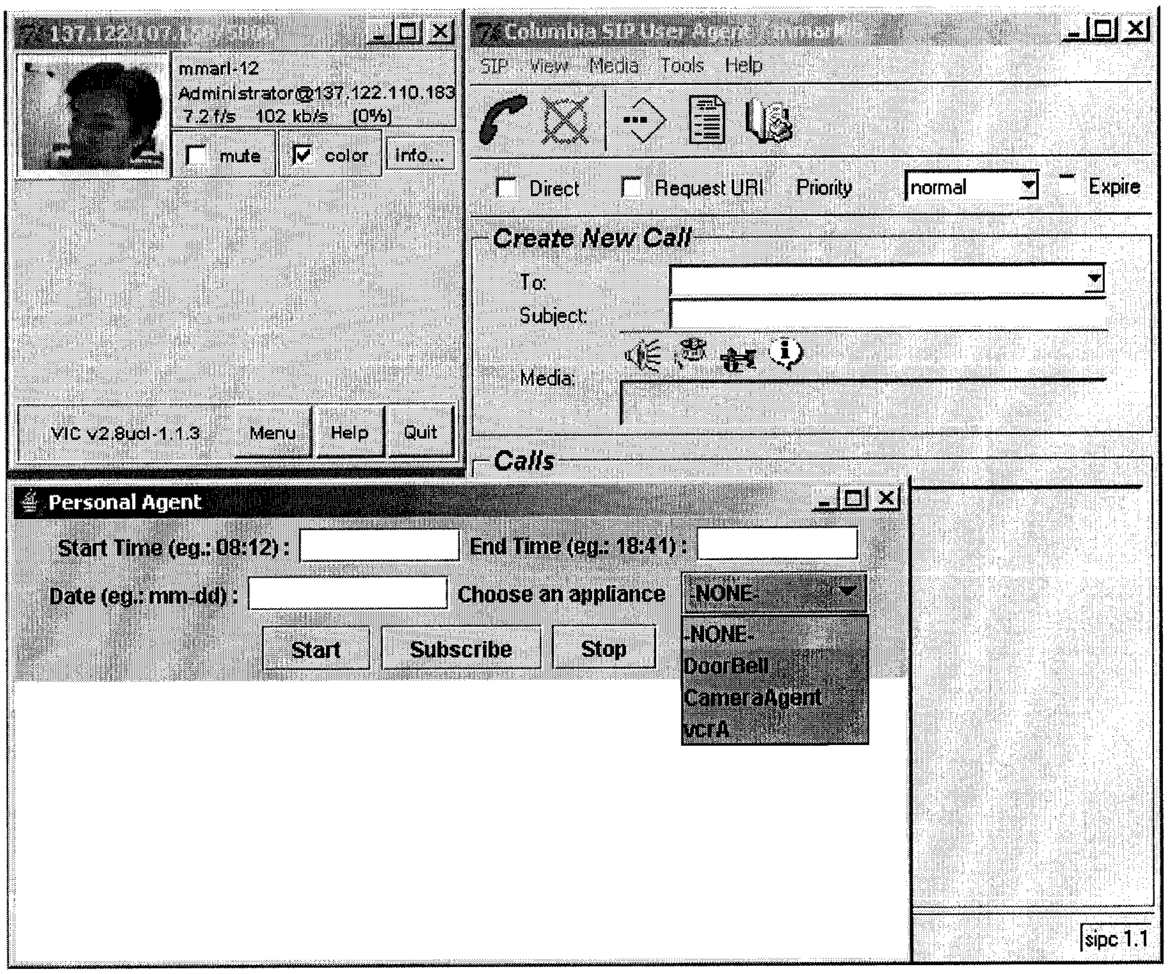

Figure 4.11 The PA interface

The PA provides a GUI to the user to display the available NAs and services in the home network. The figure 4.11 shows the interface of the PA. A user can choose an appliance from the drop-down list and can set the start time, end time, and date. If the user does not key the optional fields in, the corresponding default values will be considered. For example, the Start Time and Date will be by default the current time value. The End Time will be infinite for "Start" and "subscribe" and use the current time value for the operation "Stop".

When the PA is "ON", a VIC window is started and is ready to receive video conferencing images. Normally, there is no image shown in the VIC window by default. When the camera in the home is invoked by any reason or when the PA sends a service request to the CameraAgent, the live video will be automatically transferred to this VIC window on the user's terminal.

The SIP UA also turns "ON" when the PA is set up. When the PA runs on outside of the home domain, any operation by the PA will be sent out in a SIP message format. All the sequence procedures take place automatically and the user is not involved. The agent part of the PA and HA will make decisions on behalf of the user according to policies and gathered knowledge. On the other hand, when the PA runs within the home domain, the SIP UA is not in charge of sending messages. All the operations by the HA will switch to agent mode using ACL format messages.

Appliance Agent - AA

Each AA is a SIP wrapper agent. As a software agent, it handles incoming service requests and creates instructions to manipulate a home appliance directly or through an appliance controller.

Each AA is also a SIP UA, which can send and receive SIP messages. In the proposed implementation, the HA intercepts the incoming SIP calls to AAs for security reasons. All the communications among AAs and other agents within the home domain take place in ACL format.

1.Doorbell Agent - DBA

The DoorBell Agent is an AA for the main door. The appliance Doorbell itself is a software simulation program. The agent handles all the events happened on the door and creates the corresponding activities to other agents or homeowners, such as invoking the Door Camera and sending notices to the PA.

The DBA also provides a user interface for the visitors and asks their user ID and password. The DBA sends the inputted data to SA, and the latter verifies the visitor with its database. Finally, the DBA operates the door according to the returned result.

2.CameraAgent-CRA

The CameraAgent is an AA for the front door security camera and it fully control the activities of the camera. When the CRA receives a notice from another agent (e.g. DBA), it turns on the camera and transfers the live video image to the PA or a video recording device. The video transmission tool is using the VIC conference tools and the transmission mode could be unicast or multicast. The CRA would decide to transfer the image to which device according to the purpose.

3. VCR Agent - vcrA

The vcrA is an AA for the VCR. It collaborates with other agent to control the VCR (simulation program). When the vcrA receives the request from PA or other agents, the vcrA sets the VCR automatically. The vcrA may need to send a request another agent (program searching Agent) to get the necessary information, such as the TV program schedule, channel number and date etc. Here again, all these communications are in ACL format.

4.3 Scenario Description

The scenario of opening the door for a repairman (figure 4.12) is an integrative scene that involves multiple AAs and both External-Home and Internal-Home communication. Through this scenario, we show how the system works and how agents collaborate with each other to fulfill the service.

The pre-condition of the scenario is, for example, one day, a home appliance reports disorder. The SA gets a notification from the AA about this appliance and sends a service request to the service provider via the Internet. Then the SA sets a user name and password for the service man from the service company and informs the event to the PA.

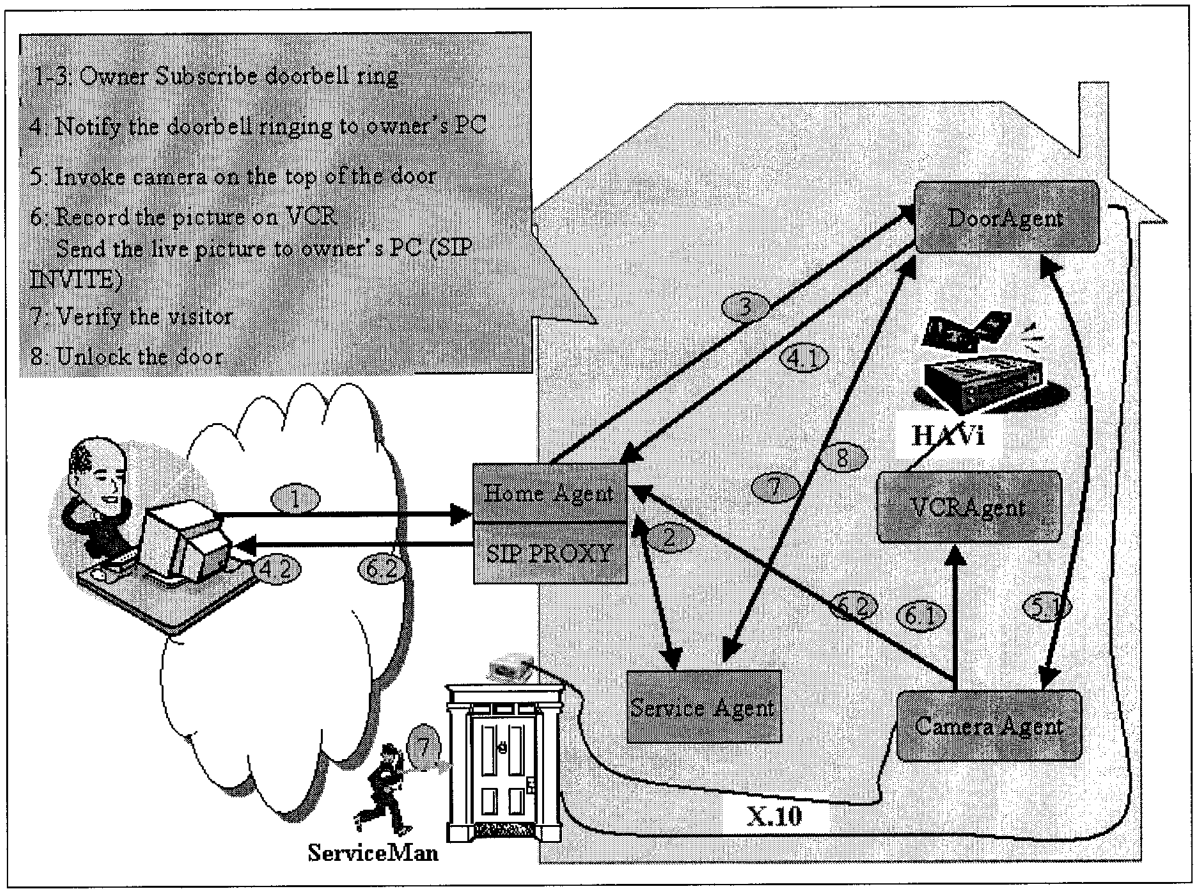

Figure 4.12 Scenario: "Open Door" Service

In consequence, the PA subscribes the Doorbell events. When the service man comes to the front door, he would buzz the doorbell. The DoorBell Agent notifies the PA about this event and invokes the camera at the same time by sending a message to the CameraAgent. The CameraAgent sends a live video stream to PA, and the vcrA also gets the notice and starts to record the video. In the meantime, a GUI pops up in the Door Interface and asks for the visitor's user ID and password. After the visitor inputs the information, the data is sent to SA for verification. If a match occurs, the SA sends an open door request to the Door Agent. The Door Agent will then open the door for the service man. During this scenario, the PA monitors the whole process. Also, the owner can cease the open door service at any time, if necessary.

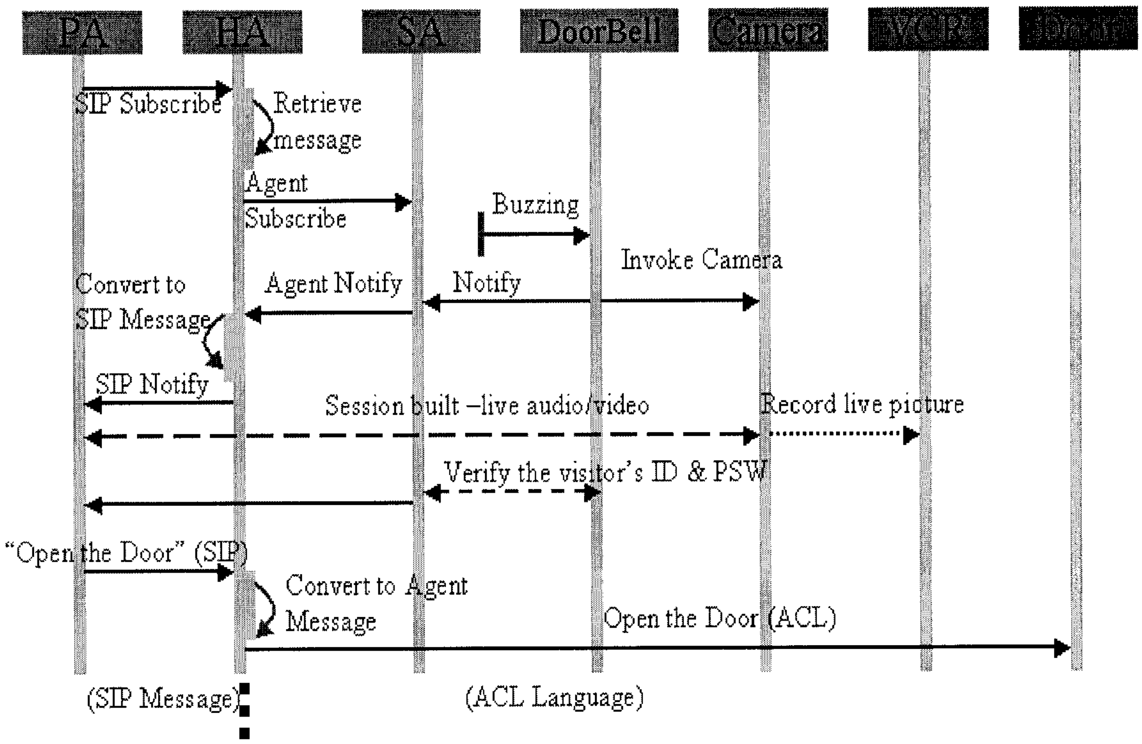

Figure 4.13 Communication between agents during the Open Door Service scenario

From the sequential diagram shown in figure 4.13, we can clearly see the step-by-step communication process among agents. From the PA to the HA, also known as the External-Home communication, the messages are in SIP format. In contrast, the Internal-Home communications takes place using the ACL. These two communication modes are effectively combined together in order to provide a fast and safe service.

4.4 Implementation Snapshots

4.4.1 The SA setup

The Service Agent is always the first agent to be setup within the system. Like all other agents in the FIPA-OS platform, the SA first gets an AID to identify itself as shown in figure 4.14:

< agent-identifier :name SA@homenetwork :addresses <sequence fipaos-rmi://137.11.107.158:3000/SA > >.

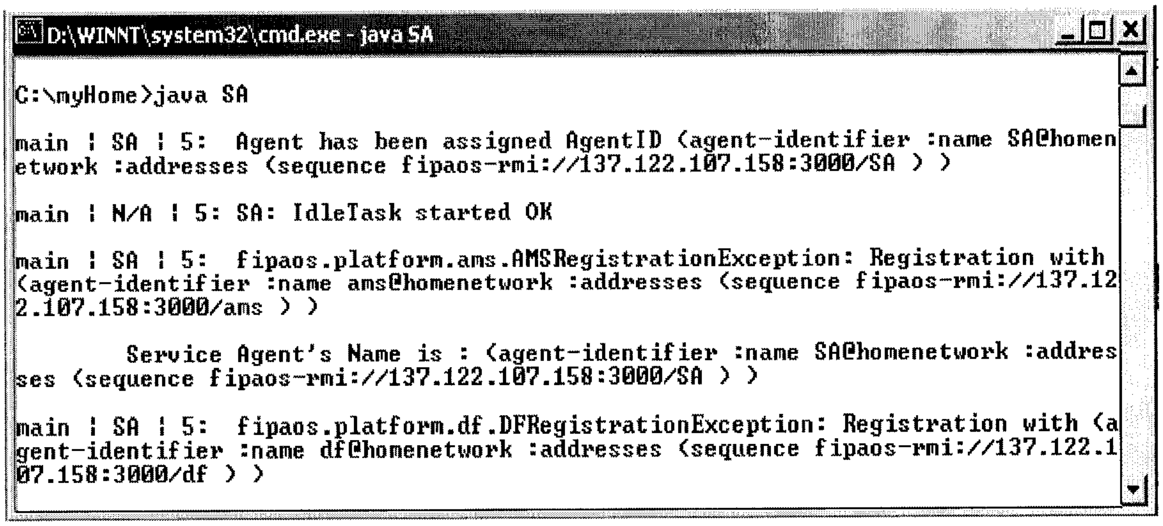

Figure 4.14 The SA setup

Then, the SA registers itself with both the AMS and DF respectively. After this step, the SA is ready to receive AAs' registration.

4.4.2 The HA setup

When the HA starts, it first registers itself with the AMS and DF on agent platform. It gets its AID as shown in figure 4.15:

< agent-identifier :name hma@homenetwork :addresses <sequence fipaos-rmi://137.122.107.158:3000/hma>>

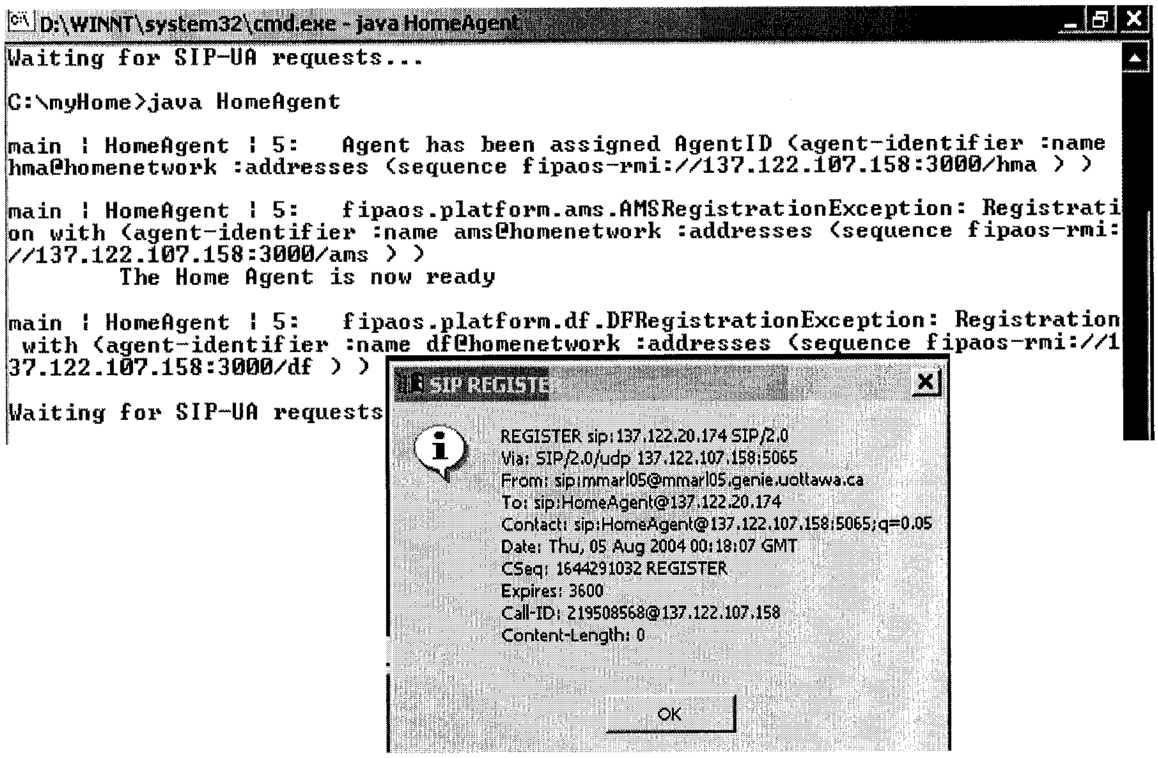

Figure 4.15 The HA Setup

As a SIP Wrapper agent HA also registers itself at the SIP server, which is located at IP address 137.122.20.174.The registration information is shown in the pop-up window "SIP REGISTER" in figure 4.15: HA gets a SIP address: HomeAgent@137.122.20.174 indicated in the "TO" field, and a contact address: HomeAgent@137.122.107.158 which is the address it can be reached. HA is now ready to function.

4.4.3 AAs setup

When an AA joins the home network, it registers itself both as an agent and as a SIP UA. As a result, it has an AID and a SIP address. Here, we use the DoorBell as an example. DoorBell's AID is

< agent-identifier :name DoorBell@homenetwork :addresses <sequence fipaos-rmi://137.122.107.158:3000/DoorBell>>

And its SIP address is DoorBell@137.122.20.174 as shown in the "TO" field of the pop-up window "SIP REGISTER". Then, the AA registers its information with the SA. The SA catches the AA's name, location, category, and functions into a hashtable as shown in the "Java SA" window of the figure 4.16.

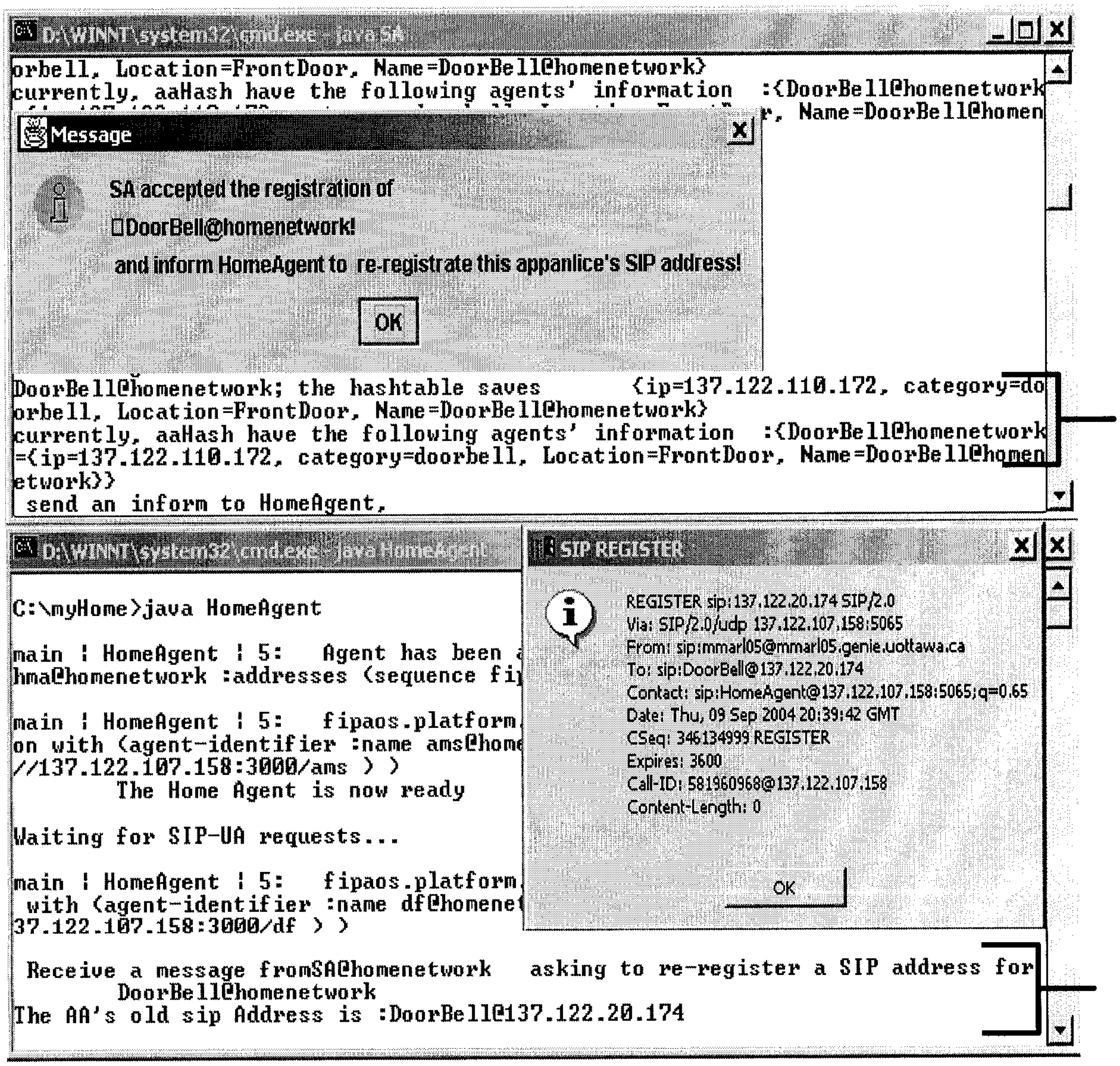

Figure 4.16 An AA setup & the HA re-registering a SIP address for the AA

After accepting the registration of the AA, SA sends a notice to the HA. The latter then re-registers for the AA using a SIP contact address with high priority to overwrite AA's original SIP address. For example, as shown in popup window "SIP REGISTER" of figure 4.16, the SIP UA DoorBell@137.122.20.174 gets a new contact address HomeAgent@137.122.107.158 with priority "0.65". Therefore, any SIP call from outside the home domain is intercepted by HA. By now, the agents are ready to handle incoming requests.

4.4.4 Door Opening Service

When a repairman comes to the front door, he/she buzzes the doorbell. The camera is invoked by the notification sent by the DoorBell agent. The CameraAgent in address 137.122.107.158 then sends the live video to the host device of the PA which is in machine 137.122.107.154 (See figure 4.17) using the unicast mode of the VIC. The VIC in the PA end is immediately invoked and starts displaying the live video as shown in figure 4.18. The pictures on both ends are exactly same and synchronous.

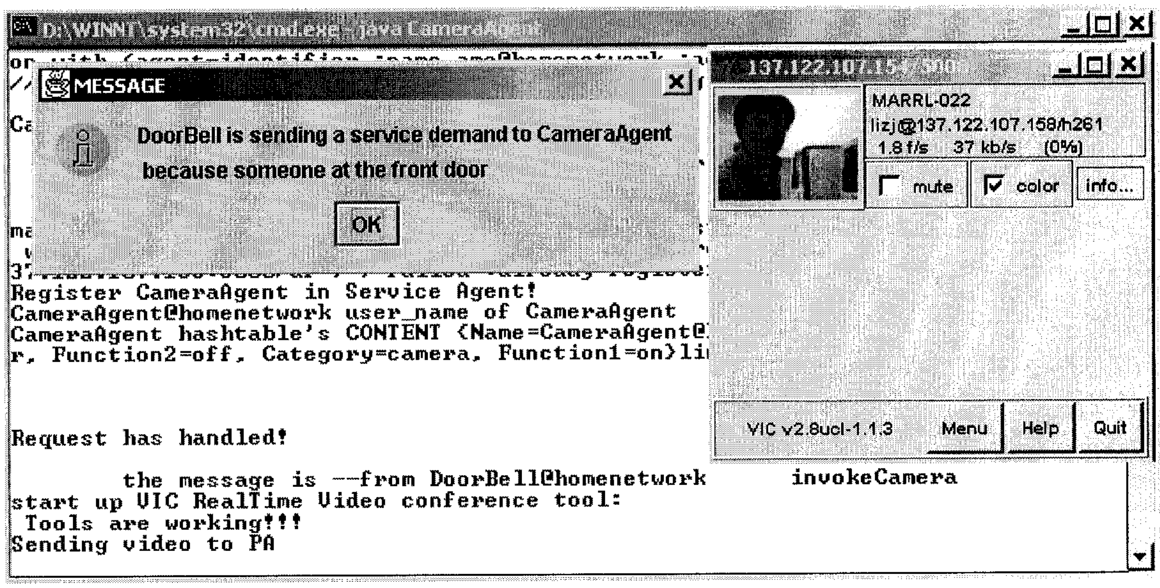

Figure 4.17 DoorBell invoking a Camera

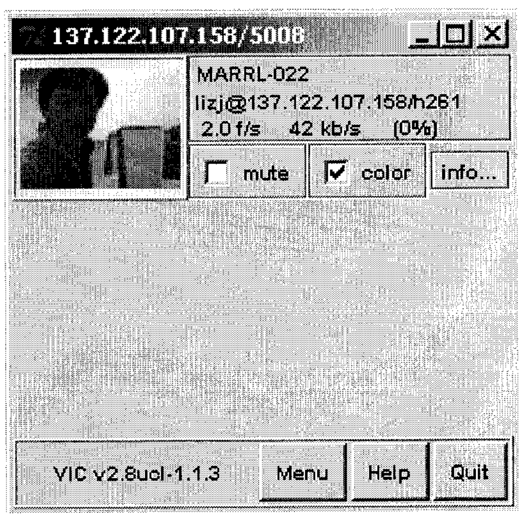

Figure 4.18 The live video in the PA interface

In the DoorBell end, a GUI pops up and requires the visitor to input his/her user name and password as shown in figure 4.19. The inputted information is sent to the SA as an ACL message and waits for verification.

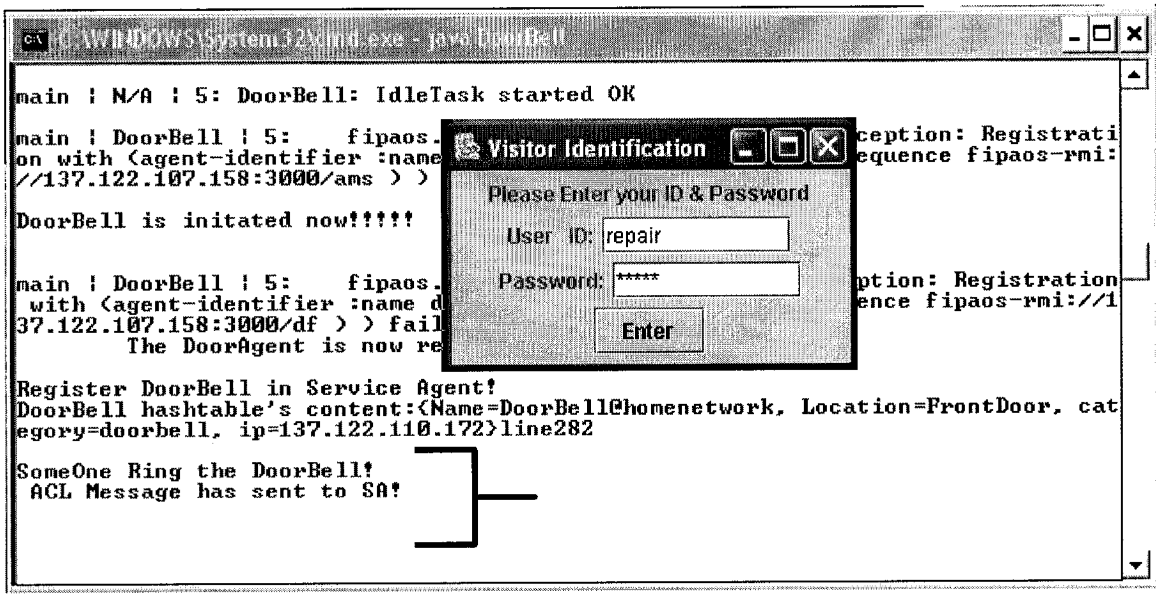

Figure 4.19 Verifying the User

When the SA receives the ACL message, it verifies the data with its database and makes its decision.

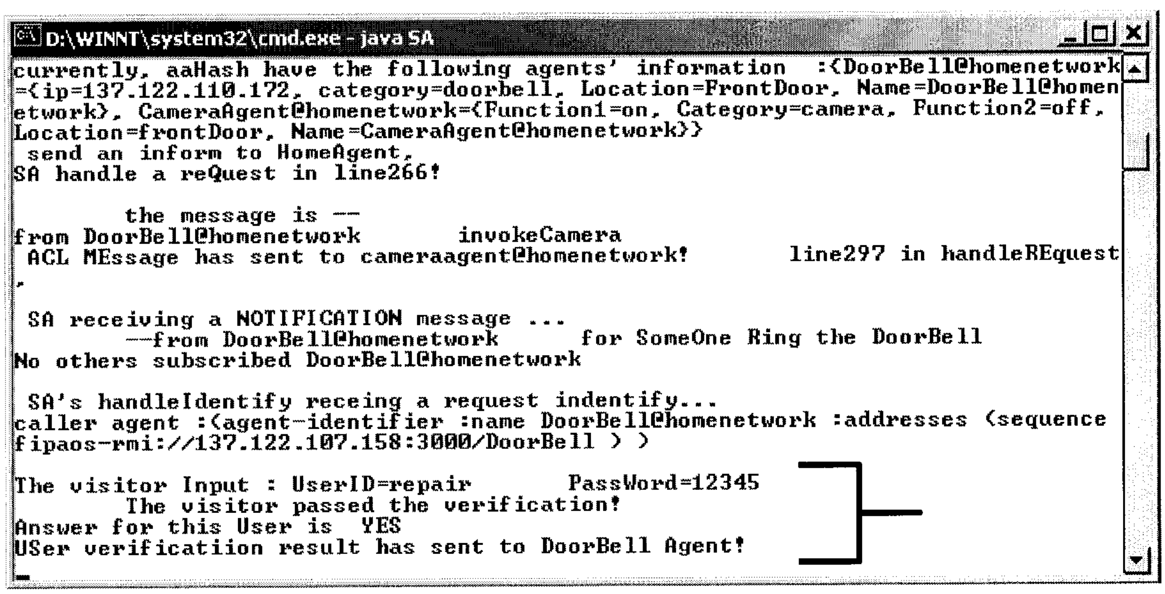

Figure 4.20 The SA verifies the visitor's authenticity

In the case of a positive match, the SA sends an 'Inform' to the DoorBell agent to unlock the door for the repairman. The greeting message shown on the door interface is shown in figure 4.22.

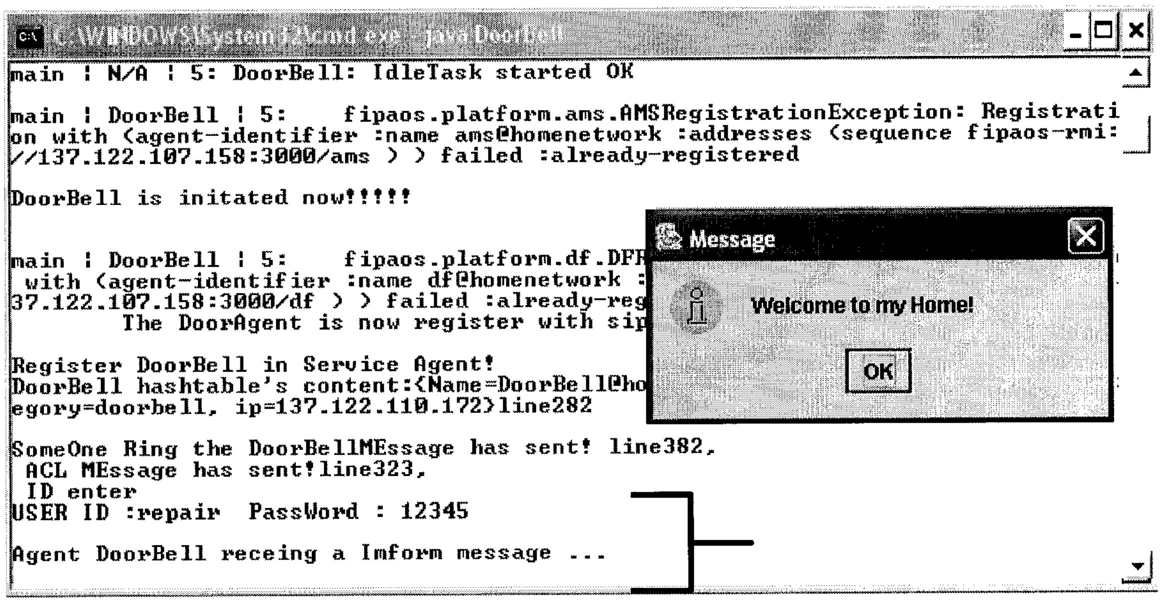

Figure 4.21Welcome message snapshot

4.5 Performance Evaluation

We performed system evaluations using scenarios similar to those described in the previous section 4.3. The agents are hosted in three desktop PCs within a domain, and the FIPA-OS AP is distributed in the three PCs as well. The SA, HA, CameraAgent, and vcrA execute on the PC1, which runs on the Windows 2000 operating system. This PC's main configuration includes two 1.67Ghz Athlon (xp) 2000+ CPU, 526MB RAM, and 10/100 Ethernet LAN adapter. The PA runs on the PC2 with the same configuration as the former one. The desktop PC3 which hosts the DoorBell agent operates on the *Microsoft Windows XP OS* and features a 2.4 GHz Pentium4 processor, 256 MB RAM, and 10/100 Ethernet LAN adapter.

It takes 12 seconds to start up the FIPA-OS AP in each PC. The SA requires 3 seconds to setup itself and the HA uses the same amount of time to setup and registers its SIP address in an instance. This means that the time required to perform the SIP registration is limited and can be ignored.

The CameraAgent takes approximately 7.5 seconds to load and register the SIP address. The vcrA takes 10 seconds to do the same job. The difference is caused due to different device simulation programs. The PersonalAgent requires 4 seconds to setup.

After the visitor activates the BoorBell button in the PC3, it takes DBA less than 1 second to transmit the ACL message. The VIC tool starts instantly and sends the live video image to the PC2 at the same time. The time consumed for this process is in milliseconds and the user verification process also consumed less than a second.
Most of the time is consumption during the system setup, while the time consumed for communications is negligible. Therefore, the performance of the system is acceptable.

4.6 Summary

This chapter first introduced the implementation environment and tools for the SIP and Agent-based Networked Appliances system. Next, the system prototype was described including each element's feature detail and operating mechanism. Then, a test scenario and the implementation snapshots were illustrated. The performance evaluation was presented in the end of the chapter. The next chapter concludes the thesis work and gives suggestions for future research directions.

Chapter 5 Conclusion

5.1 Summary

A technology based on Networked Appliances would provide great convenience to the routine life of human beings by reducing the user's involvement in manipulating home devices. Though inventions enable some new functions, they also increase the complexity and time to operate new & existing devices. The SIP & Agent solution for NA system proposed in the thesis provides a new approach for simplifying the user's operations, enriching the NAs' functionality, and enhancing the accessibility to the home network.

Agent technology is the key concept in realizing the proposed home appliance management and control system. By introducing agent technology, appliance agents work on behalf of different networked appliances to execute the homeowner's commands. For instance, the AA handles the incoming and outgoing requests and manipulates a NA automatically without any outside intervention. The Personal Agent runs on a homeowner's PC and allows the user to access NAs and services with least effort. A home user can interact with his/her PA through a GUI. The Service Agent acts as a service manager and provides "yellow pages" service. It is responsible for maintaining and updating the service lists of the home network. The Home Agent is in charge of the network security and therefore it authenticates incoming and outgoing messages, encrypts and decrypts the messages, and authorizes users. Agents in the SIP and Agent-based NAs system communicate with each other using the ACL and cooperate with each other to provide autonomous, asynchronous, and intelligent services to users.

SIP has a great advantage over other protocols on wide-area access support. Due to its mobility supportability, SIP is widely used to provide services and applications for multimedia communication over the Internet. In the proposed system, SIP helps to establish sessions between a PA and NAs, so that the PA may execute the users' manipulate-device commands. Both the PA and NAs are SIP wrapper agents, which may work as SIP UAs to process incoming and outgoing SIP messages.

By combining SIP and the powerful agent technology, the proposed SIP & agent–based home appliance management system would be an easy-to-use, smart, autonomous and asynchronous home network management system.

The entire implementation is done using leading-edge technologies, such as the JAVA environment, the FIPA-OS agent platform, SIP, and conferencing tools (VIC). The agents in the system are created using the Java programming language and execute on the FIPA-OS agent platform. The video conferencing tools, i.e., VIC and VCR simulation program have been utilized to fulfill the implementation goals.

To conclude, the SIP and Agent-based NAs management system has been designed and a prototype has been implemented. The system is open for extensions in order to encompass new features. New NAs and services could be added to enrich the capabilities and functionalities of the system.

5.2 Future Work and suggestions

This thesis presents a new approach to manage Networked Appliances. The main advantage of the approach is that it enables the wide area access and automatic control of appliances. However, further work need to be done in order to refine the system.

The functions performed by the agents could further be enriched in the future. More work could be done to strengthen agents' intelligence, thus reducing the burden of human beings. Self-learning is a valuable function that is worthy considering. Agents have the self-learning capability and therefore can learn themselves from their past experience. This feature could be implemented, so that, for example, a TV agent could remember the favorite TV shows of a particular user and thereafter it could switch channels whenever it is appropriate to do so. The system could also feature automatic creation and dispatching of a new appliance agent for every new appliance in the home network.

The Personal Agent is a key entity in the proposed system. It works on behalf of the home user and is, therefore, a full representative of the user. This leads to another question, i.e., how to make the PA be more powerful and intelligent. The PA should know everything about a user, such as the user's preferences, schedule, friends, etc. Thus, the PA could make more reasonable decisions on behalf of a home user.

Security is another important issue that is under consideration. As discussed in chapter 4, a home network is a private and security place. Therefore, further work is to be done to strengthen authorizations to perform communications between a home domain and a wide area network.

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