Location-aware Services and Interfaces in Smart Homes using Multiagent Systems

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***Abstract*— Computer systems are fully capable of providing customized interfaces for users. Every time we log on to an e-commerce website we have used before, the interface changes in order to fit our most probable interests. Some sophisticated vehicles adjust the seat position, rearview mirror orientation and other parameters to match the preferences of the drivers when they enter the car -provided that they belong to the set of known drivers-. However, this kind of service customization has not yet reached the home environment. In the same way as computer systems with productivity, the smart home must prevent the user from performing routine and tedious tasks to achieve comfort, security, and effective energy management. In this paper we propose an architecture for building a smart home environment using multiagent systems, and we demonstrate its effectivenes with an application example where multimedia contents follow the user movements throughout the house.**

I. Introduction

Environments we interact with on a day-by-day basis, our home, our car, our office, tend to offer us a continuously increasing comfort level. New technologies allow us to communicate in ways we could not have foreseen ten years ago. The world is going digital, even in fields that were analog by nature, such as music, films, television or photography.

At the same time, we have populated our homes with an increasing number of electronic devices: several tv receivers, several music players, one or more computers, video players and recorders, security systems, etc. Devices which provide services such as centralised management of media contents are beginning to appear [1]. The number of electronic devices per square mile is growing endlessly. But this does not necessarily mean our lives are better and simpler. We can access more services, but we trade availability for ease of use. For example, the number of remote controls at home grows according to the number of electronic devices, so users need to learn to use new interfaces whenever they add a service to their home.

In this context, systems which strive for environment personalisation appear. This kind of personalisation may be seen, for example, in location-aware handheld devices, which are able to adapt to the place the user is moving into, or in any system able to adjust its behaviour depending on the preferences of the different users nearby. One of the main lines of research of our group is personalisation of both handheld mobile devices and traditional electrical appliances, providing intelligence to the digital home[2]. To achive this goal, we propose to use multi-agent systems, as they have been revealed as a very suitable technology for developing distributed, autonomous, and intelligent systems. The work we propose here outlines the architecture of our smart home, and demonstrates the effectiveness of such an approach by implementing some sample domotic services. In particular, we have turned our handheld device into a universal remote control, capable of adapting itself to the location where the user is, providing the corresponding interfaces for the services available at that location. We have implemented one of these available services: a multimedia service which allows contents requested by users to follow their movements throughout the house in real time, so that there is no loss of information for them. Software agents provide the necessary technology to achieve the required degree of distribution, autonomy and intelligence.

The rest of this paper is organized as follows. Section 2 recalls the most relevant concepts our research is based on. Section 3 present the architecture of our smart home. Section 4 describe the functionality of the different agents in the system. Section 5 describes the application scenario and a typical use case. The last section summarizes our main contributions and sheds light on some future research. The appendixes add information about some implementation details, directly related to our future lines of research. Appendix A outlines the problem of user location awarenes and describes the approach used in this first work, and Appendix B describes the different and locutions that support communication among agents in the system.

II. Smart homes

We can define a smart environment as one *one that is able to acquire and apply knowledge about its inhabitants and their surroundings in order to adapt to the inhabitants and meet the goals of comfort and efficiency* [3]. These goals are normally directed to adapt the environment to the user preferences, to increase the performance of the user in his day-to-day tasks, and to optimize the energy consumption of the systems involved.

A. Service personalisation in smart homes

System and service personalisation is not a novel issue. In fact, most research lines involving user software agents focus on the ability to configure a software system according to the user preferences. There may be an agent associated to each user, as described in [4], or a single agent to serve every user who access to the system, as in [5]. Though service personalisation is feasible for any user environment, there is no doubt that smart homes are specially suitable for service personalisation, as the home is the place where users are more prone to enjoy systems designed to provide comfort and ease of use.

The Digital Home White Book, edited by Telefonica [6], provides a taxonomy for services available at the smart home, dividing them in four categories: home management, communication infrastructure, professional activity and entertainment services.. Though this taxonomy is focused on communication technology, we can use it as a starting point.

1) Home management: This category includes all traditional domotic systems: teleassistance, appliance automatization and diagnostics, comfort services such as light and temperature control at each location, home security... An example of using multiagent systems for home management is [7].

2) Communication infrastructure: These services focus on data network management to allow communication within the smart home and with the outside. Communication networking needs for smart homes are discussed in [8].

3) Professional activities and services: Services such as tele-work, tele-education or e-business fall into this category. These are probably the most extended services, and they already provide a certain degree of personalisation.

4) Entertainment: This category includes services such as video on demand, interactive TV or multiplayer network games.

The services on the four categories can be highly personalised to better fit user preferences. For example, we can easily think about a home environment where lights turn on and off as the user moves throughout the house, where a phone call is automatically turned into a videoconference if the user has a TV or computer screen nearby, where a grocery order can be automatically placed when the refrigerator gets low on milk, or where some TV shows are restricted based on the age of the user who requests them.

B. Smart homes and Multiagent Systems

To meet these goals, a domotic system is based on a set of devices which gather information about the environment -sensors- and a set of devices able to actuate over the environment to change its conditions -effectors-. The system will process the data collected by the sensors and, according to the predefined set of goals-, will use the effectors to alter the user environment. How the system decides the necessary actions depending on the information provided by the sensors is the key problem in domotics, as it requires analyzing data from several different sources distributed throughout the entire house, and coordinating equally heterogeneous effectors. These considerations lead to requirements of distributed data mining, autonomy and intelligence that suggest the use of software agents to develop this kind of system.

There are different definitions for software agents. From the viewpoint of design and technology, we can define a software agent as a self-contained program capable of controlling its own decision making and acting, based on its perception of its environment, in pursuit of one or more objectives [9]. From a functional, user's perspective, a software agent can be seen as a software entity to which tasks can be delegated [10]. This last definition, though simpler, suggests more clearly how this technology can serve the problem of intelligent automation of the environment. A multiagent system provides a distributed and flexible framework and communication and negotiation mechanisms among its components that allows them to make complex decisions in an effective and efficient way.

III. An Intelligent Home Agent Platform

The first contribution of this work is an architecture for building an agent-based smart home, which we call iHAP - Intelligent Home Agent Platform-. The architecture relies on a set of devices distributed throughout the environment. According to the degree of autonomy and intelligence provided by the devices, mainly determined by its computational capacity to include agents, we can divide them in four groups[11]:

iHAP Central System (iHAP or CS), which may be linked to the residential gateway [12]. It contains the agent platform which supports the existence of all other agents in the house. It specifically hosts the general purpose and system agents, that is, all those agents that actuate at a global level in the house, without being associated to a specific sensor or effector or to a certain location or room in the house. Generally, the iHAP Central System contains the higher level agents of the system. It also contains those agents used to control non-intelligent devices, that is, domotic devices without enough processing capacity to host their own agents.

Though iHAP Central System reliability is essential for the system to work properly, agents distributed throughout the house can enter in *safe-mode* operation, allowing them to provide some basic functionality in case of a failure in the CS.

Personal Devices. Each user has a handheld, mobile device -cell phone, PDA- hosting the necessary agents to identify the user to the system, determine user location in the home and display the adequate interfaces to the available services when needed. Each personal device also stores the most updated copy of the user preferences.

Devices with Agents. Sensors and effectors with a certain degree of autonomy, usually provided by agents running over an embedded Java virtual machine.

Devices without agents. Sensors and effectors without autonomy or intelligence, controlled by agents hosted by the CS.

Devices without Agents depend directly on the iHAP Central System, and they are linked to it by means of standard

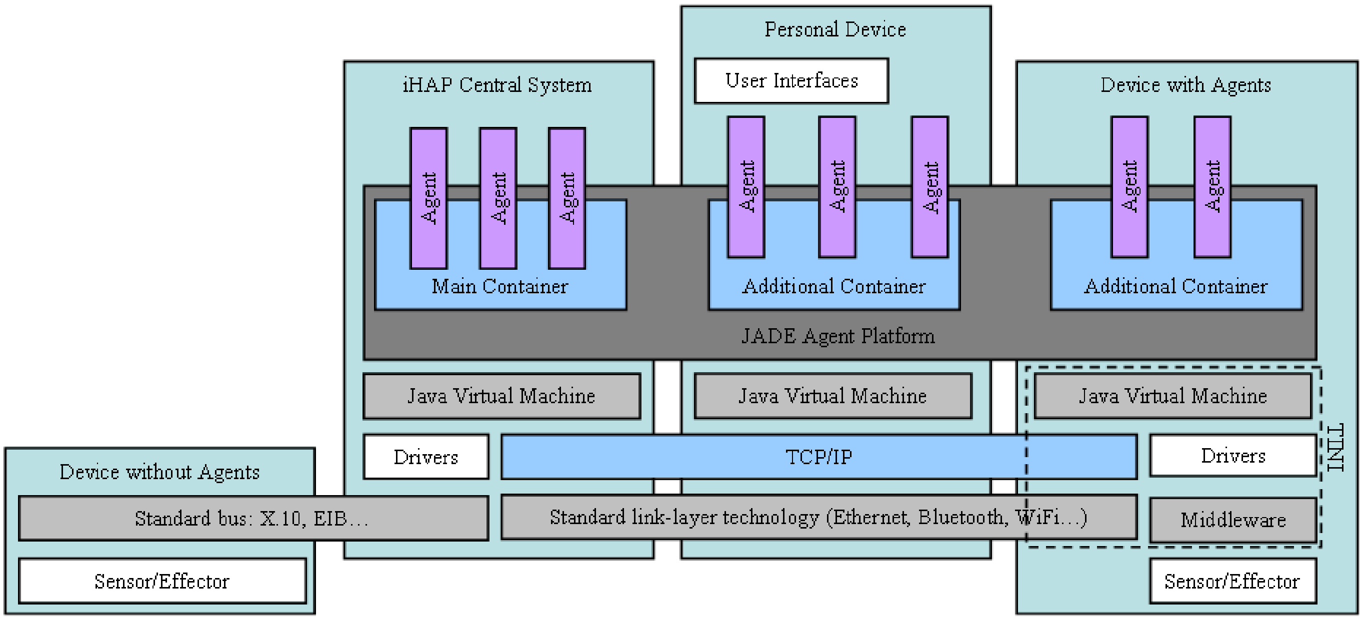

Fig. 1. The iHAP architecture

bus technologies -X.10, EIB...-. Devices with Agents, Personal Devices and the iHAP CS can communicate using TCP/IP. Though any link-level technologies can be used, we have a preference for wireless communication protocols -Bluetooth, WLAN...-. Fig. 1 shows the system architecture, where the different communication levels can be seen.

The system has been developed over the open-source agent platform JADE (*Java Agent DEvelopment framework*) [13]. Using an already established agent platform releases us from the low-level tasks about agent life-cycle and message interchange. Using Java language ensures code portability to different machines. Furthermore, JADE complies to the specifications of FIPA -Foundation for Intelligent Physical Agents- [14], which guarantees a certain degree of interoperability with other agent-based systems. Note that the JADE platform extends to all system elements containing agents, and those agents exist inside a container associated to each element. The iHAP Central System hosts the main container of the platform.

As we can see in Fig. 1, the interface between a Device with Agents and its associated sensor or effector and the interface between the device and the other elements of the system is provided by an embedded system via a Java virtual machine. At the moment we are working with different cards trying to find the more approppriate option for each device. One of the possibilities is using TINI -Tiny InterNet Interface- cards [15].

IV. Location-aware services and interfaces

For the first implementation of the iHAP system, we have considered two smart home services: multiroom audio/video distribution and location-aware user interfaces. With multiroom audio/video systems, users can retrieve media from any location in the smart home, by accessing a centralised content repository, usually placed at the residential gateway. These systems increase access to entertainment contents, but not necessarily its ease of use for the end users of the system. As we stated before, increasing the number of devices in a home environment usually implies an equal increase in the number of interfaces the user must learn to use. The service we have implemented over the iHAP makes this task easier for the users in two senses. On one hand, providing generic interface devices which adapt to the services available in a particular location. On the other hand, allowing multimedia content to follow the user if he decides to go to another room.

Fig. 2 shows the iHAP architecture, particularised to the services discussed, where we can see the different elements of the system and the software agents residing in each element to provide the required functionality, as follows:

- iHAP Central System (Intelligent Home Agent Platform): For this implementation it hosts two agents:
  - iHSA (Intelligent Home Services Agent), which coordinates service provision for the diferent users of the smart home. It is aware of the services available at each location of the home, and the state of those services. It also stores information about user location and preferences, and about the services requested by each users.
  - iHLA (Intelligent Home Location Agent), allows the system to determine the location of any user in real time.
- Mobile interface device (a PDA with an 802.11 card in our implementation): To make easier to understand Fig. 2, we have split the functionality of the personal device in two separate blocks. The first one is the mobile interface device, a PDA which can be used as a remote control to interact with the system. The interface shown adapts to

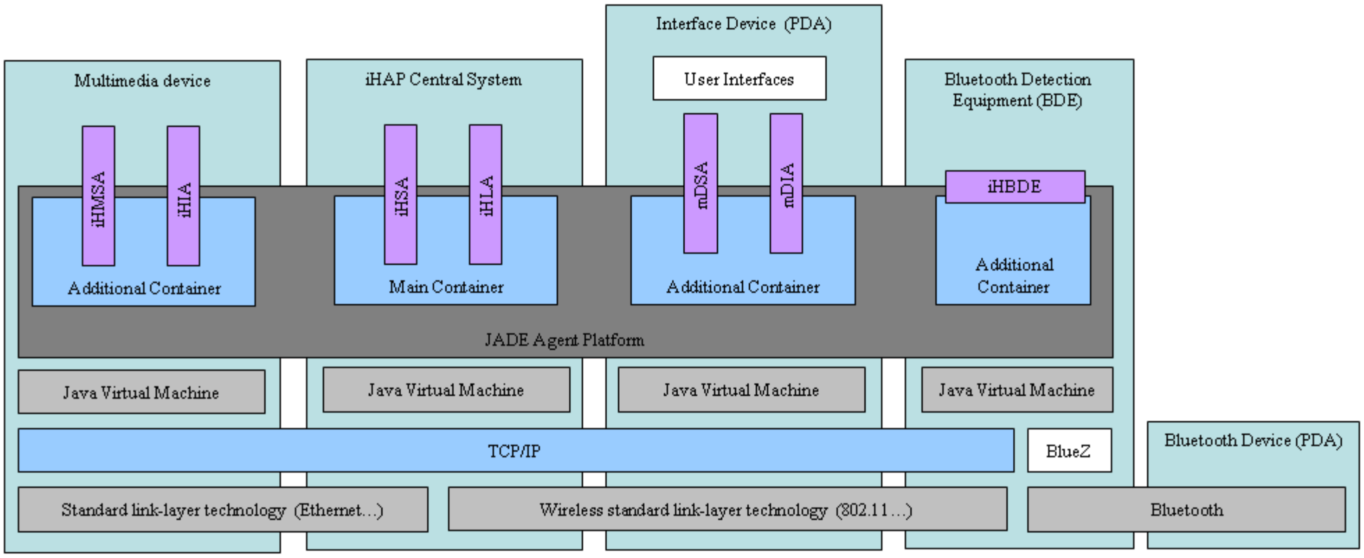

Fig. 2. Architecture of the system for the services discussed

the services available depending on the location of the user. This functionality is provided by two agents:

  - mDSA (Mobile Device Services Agent), provides any services available at the interface device.
  - mDIA (Mobile Device Interface Agent), provides to the user the adeqate interface depending on the services available at each location.

- Mobile personal device (a PDA with a Bluetooth interface): the rest of the functionality of the personal device is provided the Bluetooth interface of the PDA. This device allows the system to identify the user and to determine his location in the smart home. Though we have used the same physical device -our PDA- to act as interface device and personal device, functionality separation allow us to use, for example, a unique 802.11 remote control for the home while identifying the different users via their Bluetooth mobile phones.
- Bluetooth Detection Equipment (BDE), an embedded device with a Bluetooth interface, capable of estimating the distance to the user's personal device. This functionality is provided by the agent iHBDE. More information about how BDEs are used to determine user location is given in Appendix I.
- Multimedia device, an standard audio/video player with certain degree of autonomy provided by the following agents:
  - iHMSA (Intelligent Home Multimedia Services Agent), provides local multimedia services to the user.
  - iHMSA (Intelligent Home Multimedia Interfaces Agent), provides a local interface for the multimedia device, so that it can also be used without the mobile interface device.

For interoperability purposes, communication among agents is performed using ACL (Agent Communication Language) messages as defined by FIPA ACL Specification [16], and using FIPA-compliant communicative acts, defined in [17].

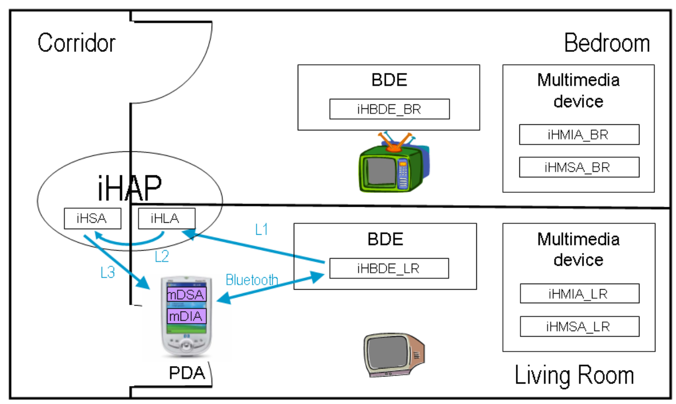

Fig. 3. User enters the living room

V. Application Escenario

Here we provide an example of the iHAP system behaviour regarding the services provided in this first implementation. We consider a simple smart home with a living room and a bedroom, each one with its Bluetooth Detection Equipment and its Multimedia Device. Both rooms are connected by a small corridor. The iHAP Central System may be located anywhere inside the home.

We will see what happens when a user enters one room, turn on the TV, and then goes to the other room. For the dialog among agents in the example we have used a notation based on *utterances* -communicative acts- and *locutions* -messages-. A brief description of the semantics of each locution is provided in Appendix II.

1) User enters the living room (Fig. 3). The Bluetooth

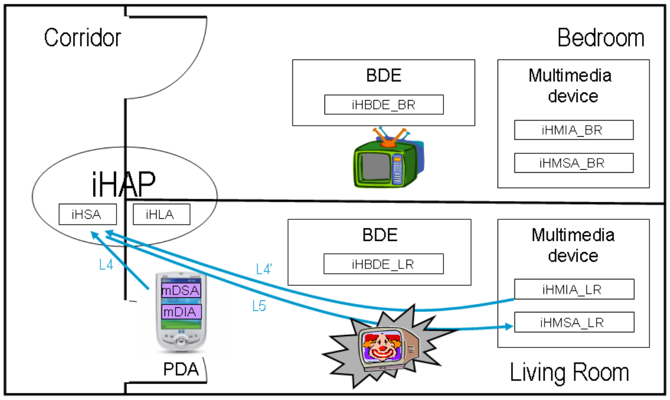

Fig. 4. User turns on the multimedia device

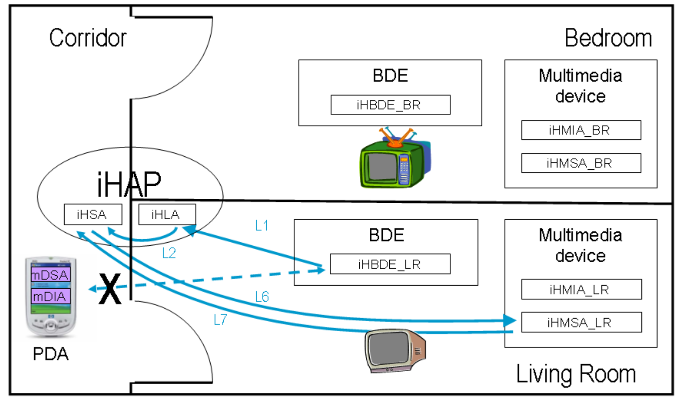

Fig. 5. User leaves the living room

Detection Equipment placed there detects the presence of the mobile personal device and evaluates the transmitted power and the quality of the connection. Based on this information, iHBDE-LR agent issues an information message to the location agent (iHLA).
U1: $iHBDE_{LR} \xrightarrow{\textbf{L1}} iHLA$
The iHLA determines the location of the user in the home using any information messages availables from the BDEs, and issues an information message to the services agent (iHSA).
U2: $iHLA \xrightarrow{\textbf{L2}} iHSA$
Finally, this agent communicates with the mobile device interface agent (mDIA) to send it the personalised interface to be displayed to the user.
U3: $iHSA \xrightarrow{\textbf{L3}} mDIA$

2) Now the user can request the playing of multimedia content using the interface offered by the PDA or using the standard interface of the multimedia device itself (Fig. 4). Requests are processed by agents mDIA or iHMIA_LR, respectively, and transmitted to the iHSA.
U1: $mDIA \xrightarrow{\textbf{L4}} iHSA$
After checking that the user request is legitimate, the iHSA forwards it to the multimedia services agent (iHMSA_LR), and the playback begins.
U2: $iHSA \xrightarrow{\textbf{L5}} iHMSA_{LR}$

3) When the user leaves the living room (Fig. 5), the agent inside the detection equipment (iHBDE_LR) notices the absence of the PDA and informs the location agent about it.
U1: $iHBDE_{LR} \xrightarrow{\textbf{L1}} iHLA$
iHLA determines the that the user has left the living room and informs the service agent about it.
U2: $iHLA \xrightarrow{\textbf{L2}} iHSA$
The iHSA then asks the service agent of the multimedia device to pause the reproduction. After executing the request, the iHMSA_LR replies with the service status -for example, the playing time-.
U3: $iHSA \xrightarrow{\textbf{L6}} iHMSA_{LR}$

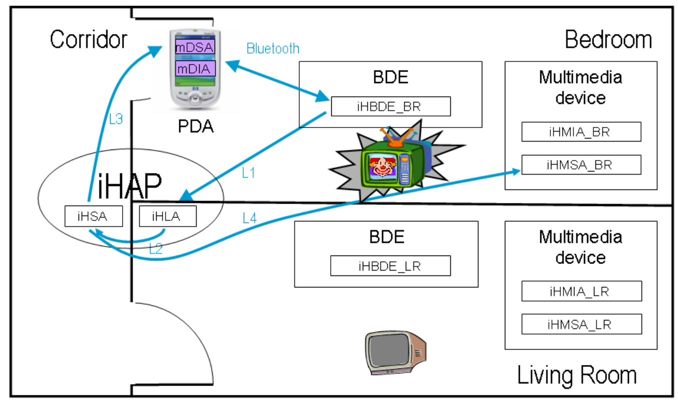

Fig. 6. User enters the bedroom and the selected service resumes execution automatically

U3: $iHMSA_{LR} \xrightarrow{\textbf{L7}} iHSA$

4) Now user enters the bedroom (Fig. 6), and an analogous detection and location process begins.
U1: $iHBDE_{BR} \xrightarrow{\textbf{L1}} iHLA$
U2: $iHLA \xrightarrow{\textbf{L2}} iHSA$
U3: $iHSA \xrightarrow{\textbf{L3}} mDIA$
In this case there is already an active service for the user: the reproduction of media content that was started at the living room. According to this, without any user intervention, the iHSA asks the multimedia device services agent (iHMSA_BR) to continue the reproduction from the point where it had been paused.
U4: $iHSA \xrightarrow{\textbf{L6}} iHMSA_{BR}$

VI. Conclusions and Future Work

This paper provides an architecture for developing smart environments using software agents. The main advantage of using agents is the autonomy that they can provide. An intelligent agent bases its behaviour on a set of high-level goals, and determines autonomously the necessary actions to meet those goals. These actions may include interaction and cooperation with other agents. In fact, multiagent systems are distributed systems, which made them very suitable for their application to domotic and inmotic environments, where coordination of distributed sensors and effectors is needed. The two services we have implemented over our proposed architecture show how software agents can help to adapt the enviroment to the preferences or desires of the user.

We are currently working on improving the Bluetooth Detection Equipments, to make the location process faster, more reliable and more efficient in terms of energy consumption. Interaction between users and the system may be made easier by integrating the personal device and the interface device in a single cell phone. New services are being developed and implemented, and interfaces for remote management of the smart home are being designed.

APPENDIX I
BLUETOOTH DETECTION EQUIPMENTS AND LOCATION AWARENESS.

Here we describe briefly how user detection is performed in our system and how user location within the smart home is determined.

Our user detection and location system is based on Bluetooth technology [18]. We have chosen Bluetooth due to its ubiquity: we can find a great variety of Bluetooth-capable mobile devices, such as mobile phones and PDAs. We use these mobile devices to identify and locate users in the system. That is, we track the Bluetooth-capable personal devices carried by users. In our first implementation, we use the unique MAC address of the mobile devices to identify each user.

The iHBDE agent periodically initiates Bluetooth scan processes to find new devices within its radio beacon range. Once a device is detected, the iHBDE performs a HCI-level connection with it. Then it evaluates the transmitted power level (TPL HCI command) and the strength of the received signal (RSSI HCI command) and it normalizes both values. This is because both values are vendor dependant. We use a hysteresis cycle and a filter function against measured power to determine when the user is inside the room and when he is outside. The filter function allows us to smooth power fluctuations. The hysteresis cycle prevents false alarms in the detections of users caused by oscillations in the measured power level.

As many mobile devices -specially cell phones- allow only one single Bluetooth connection at a time, we have implemented a token-passing based search algorithm. When a user leaves the proximity range of certain BDE, this BDE passes its token to one of the adjacent BDEs, which connects to the user's Bluetooth device and repeats the measurement process. The next BDE that determines the user is inside its proximity range keeps the token until the user leaves the range again.

APPENDIX II
LOCUTIONS USED FOR COMMUNICATIVE ACTS.

Here we describe the locutions used for agent interaction in our application scenario. Locutions are implemented using FIPA-ACL messages. For the sake of brevity, their detailed sintax is ommited here.

- **L1:** The **detectionReport()** locution:

  $$detectionReport\left(iHBDE_X, iHLA, user, measure\right)$$

  Meaning: The iHBDE at location X informs the iHLA that it has detected the presence of *user* with a metric value of *measure*. The metric is calculated using Bluetooth connection parameters such as RSSI and TPL as described in Appendix I.
- **L2:** The **userLocation()** locution:

  $$userLocation\left(iHLA, iHSA, user, location, degree\right)$$

  Meaning: The iHLA informs the iHSA that *user* is in *location*. The parameter *degree* allows us to give higher granularity to the system by specifying the degree of presence of a user to different locations.
- **L3:** The **showInterface()** locution:
  Locution:

  $$showInterface\left(iHSA, mdIA, interface\right)$$

  Meaning: The iHSA requests the mDIA at the personal device to show *interface* to the user. For this first implementation we use URLs as interfaces.
- **L4:** The **requestService()** locution:

  $$requestService\left(xXXIA, iHSA, user, service, param\right)$$

  Meaning: An interface agent -either at the personal device or the multimedia device- requests a certain *service* to the iHSA for the user. Parameters may be specified for the service in *param*.
- **L5:** The **startService()** locution:

  $$startService\left(iHSA, iHMSA_X, service, parameters\right)$$

  Meaning: The iHSA requests the iHMSA at location X to start executing a *service* -in our scenario, to play a movie-. We can specify *parameters* for service execution -for example, the starting point of the played media-. Note that the locution is general enough to be used with heterogeneous devices and services.
- **L6:** The **serviceAction()** locution:

  $$serviceAction\left(iHSA, iHMSA_X, service, action, param\right)$$

  Meaning: The iHSA requests the iHMSA at location X to take some *action* on an active *service* -in our scenario, to pause or resume the reproduction-. We can specify parameters for the action performed in *param*.

- **L6:** The **serviceStatus()** locution:

$$serviceAction\left(iHMSA_X, iHSA, service, status\right)$$

Meaning: The iHMSA at location X informs the iHSA about the *status* of a given *service* -in our scenario, that it has been paused at a certain instant-.

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