Locating Users to Develop Location-Based Services in Wireless Local Area Networks*

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Abstract

Nowadays the proliferation of mobile computing devices and local-area wireless networks has fostered a growing interest in location aware systems and services. The challenges of these services are: 1) to discover the location of the user (or his device), 2) to minimize the network connections, due to the high communication cost, 3) to deal with continuous change of location, 4) to consider network disconnections, and 5) to adjust its behavior to low bandwidth networks.

In this paper we describe an infrastructure that allows the development of location-dependent data services in wireless local area networks. To show its feasibility, a user locator service and a mobile music application have been implemented as sample location-based services.

Keywords: Wireless networks, context-awareness, mobile computing, mobile and multiagent systems

1 Introduction

The proliferation of mobile computing devices and wireless local-area networks [1] are fostering a growing interest in location-aware systems and services. Global location systems, as GPS (Global Positioning System [8]), are rapidly becaming a popular technology amongs drivers and PDA users. The explanation for this interest in positioning systems is that there exist *many* applications in different areas as transportation, agriculture, civil engineering, education, health, etc. Therefore, new techniques are being developed to obtain the location of users in global area networks, as the European Satellite Navigation System (GALILEO) [7], as well as in local area networks, with the purpose of supporting indoor and outdoor location-based applications.

The location of a user/device could be not very useful by itself, but we can use this information as input parameter of data services. Thus we can develop, for example, data services to locate the position of a moving car on a road map, show the location of a concrete person in a building, to look for the nearest police station, etc, the list is endless. Thus we are currently witnessing the development of new location-based services (LBS's), i.e., new applications that, based on the location of the user device (obtained automatically by the underlying infrastructure), provide the wireless user with services that customize their behavior to his location.

In this paper we describe an architecture based on mobile agents [10, 13] that obtains the geographic location of wireless devices, like, for example, PDAs (Personal Digital Assistants), in wireless local area networks, like

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Wi-Fi[1] [5] or Bluetooth [11] networks. In order to show the advantages of our architecture two different location-based services have been developed.

The prototype implemented is based on the Wi-Fi (802.11b) technology so the system is able to locate mobile devices in indoor areas. GPS does not work indoors: as soon as the mobile device enters a building, GPS looses its location (at least four GPS satellites must be seen directly). Wide-area networks like GSM or GPRS also provide some users with location information but this data has a resolution of a cell: they obtain under which celll the user (device) is located, and cells can range from a hundred meters to several kilometers. Thus, our system offers functionalities that current global systems cannot achieve[2].

The rest of the paper is as follows. In Section 2 we present the underlying technological aspects of our proposal. In Section 3 the system architecture and its main agents are detailed. The method used to create power maps and how they are used to locate users can be found in Sections 4 and 5, respectively. Two sample LBS's based on the proposed infrastructure are shown in Section 6. Related work is commented in Section 7 and, finally, conclusions and future work are described in Section 8.

2 Information Used to Estimate the Location of a Mobile Device

In this section we detail the kind of information used to estimate the position of a mobile device. It is necessary to identify some information that depends on the geographical position of the mobile device. Different parameters of the wireless communication protocol could be considered:

- *Power of the received signal*: it is the power whereupon a base station detects a device; it decreases with distance.
- *Noise of the received signal*: it is a measure of the interferences detected in the reception of the signal.
- *Time of data transport*: it is the time since a package is sent until it is received and it can be also a measure of the location of the device: the more distance between a device and a base station, the more time those packages transmitted by the device take to reach the base station.

The time of data transport not only varies with the distance, it also depends on other factors, like the overload of the network. That is why signal power is preferred to time of transport by many researchers that work on the positioning of mobile devices [4, 9, 17]. Therefore, we use the signal power and the noise detected to estimate the location of mobile devices.

2.1 WiFi vs. Bluetooth

Once we know the kind of information we need for the localization of devices we must find out how we can access it. To obtain the signal power of messages coming from a mobile device we access the information available on the communication protocol stack and a network sniffer that captures and analyzes the data packages transmitted. These tasks depend completely on the wireless technology used, so we summarize in the following the conclusions extracted from the tests performed on Bluetooth and Wi-Fi networks:

- *Bluetooth:* Although the Bluetooth stack provides us with data about signal power, unfortunately it is not possible to use this information to locate devices because in Bluetooth communications the signal power does not vary with distance. The explanation is that when two Bluetooth devices detect each other they avoid spending more energy than what they need, i.e, the signal power is automatically readjusted by the Bluetooth protocol to maintain the quality of service [15]

[1] Although there exist different substandards under the name Wi-Fi (IEEE 802.11b, 802.11g, etc), in this paper there is no need to distinguish between them.

[2] The satellites of the GALILEO project will be able to detect devices indoors, but it will not work until 2008.

while optimizing the use of energy. Thus, when two Bluetooth devices get closer the signal power (i.e. the quality of service) is kept constant by the communication protocol. In addition, different Bluetooth devices at the same location could need different signal power to connect to the same base station, it depends on the kind of Bluetooth chip that they have.

- *Wi-Fi:* We found out that we can locate wireless devices with Wi-Fi technology, using the power received by base stations, because the signal power does change when the distance between the user device and the base station also changes, this fact is shown in Figure 1.

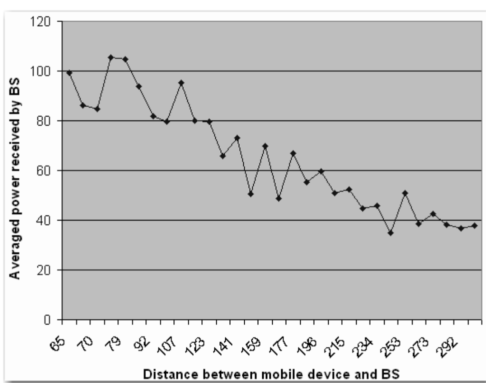

Figure 1: Signal power received by a base station when a wireless device moves away

2.2 Power Maps

Initially one could think about estimating the distance from a base station to a user (device) by transforming the signal power value into a distance magnitude, considering how the signal power decreases with distance. However, in indoor environments, the number of (static and moving) physical obstacles (walking people, doors opened/closed, walls, etc) is so high that the definition of such a transformation function is not possible.

An alternative is defining *power maps* that relate a geographical area with the signal power received by a known (static) base station from a mobile device located in that area. These geographic areas can be of different size and topology, depending on the kind of precision needed. This technique to gather the values of the parameters in concrete places and their later analysis is known as *fingerprint* [4, 12]. In this way we can built different power maps for areas under the coverage of different static base stations; thus, the estimation of the mobile device will be more precise by using triangularization techniques [3].

3 Architecture of the System

In this section we present the basic elements of the localization system (see Figure 2) and their main goals: 1) *User device*: it is a mobile device that is wirelessly connected, 2) *Base stations*: they are computers in the fixed network that provide mobile devices within a certain geographical area with coverage/connectivity, and 3) *Location Server*, a computer in the fixed network that computes the location of mobile devices.

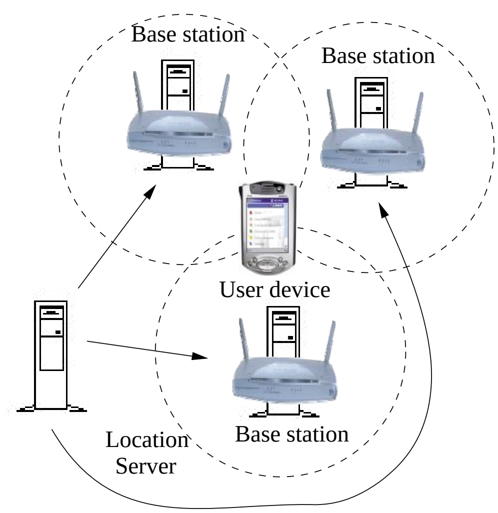

Figure 2: Components of the localization system

The main goal of base stations is to provide users with coverage, to capture the data packages transmitted by mobile devices and, for positioning purposes, to extract from those packages the signal power and the received noise. These data are sent to the location server by all the base stations that detect the user device. Then the location server consults the power map of each base station to estimate the location of the user device.

The main agents[3] of the proposed architecture and their goals are the following:

- *The Sniffer agent*: located at each base station, it analyzes the data packages sent by mobile devices and extracts the parameters needed to estimate their locations.

- *The Beacon agent*: this mobile agent can move (under request) to user devices to send messages/packages, also called *beacons*, which will be detected by base stations in range.

- *The Location Database Manager*: located at the Location Server, it automates the generation of the power map of each base station in the infrastructure, it stores them in a database, and it estimates in run-time the location of mobile devices when requested.

Localization services need to execute a *Localization client* which is an agent that provides them with an API that can be used to retrieve the current location of a given mobile device, it is the interface to our proposed localization architecture (it interacts with the Location database Manager). This client is a mobile agent, so it can travel to the user device when a location-based data service requests its functionality.

The Sniffer Agent

The Sniffer is a specialized agent that analyzes the information of each data package received by a base station. It is the only agent in the localization architecture that should be changed if the communication technology changes. Each transmitted data package includes the headings of each TCP-IP level [6]. For example, the Wi-Fi standard [5] defines that the MAC address, which identifies different mobile devices, must be stored in each packet. However, it is also necessary to analyze the physical level headings to extract the power and the noise of the signal[4].

There must exist a Sniffer agent at each base station to allow the development of location dependent services. Each Sniffer agent is in charge of obtaining the signal power and the noise of the beacons transmitted by a mobile device and detected by its base station. The Sniffer sends those parameters to the Localization Database Manager agent, which generates the power map corresponding to each base station. Therefore, the localization of the mobile device will be made by means of the combination of those different power maps associated to each base station.

4 Creating Power Maps

In this section we present how power maps are created and how this task can be performed semiautomatically.

A power map corresponding to a concrete base station contains information about the power and noise of signals detected by that base station and transmitted by mobile devices within certain geographical area. Thus the whole coverage area of a base station is divided into small areas where the signals detected from mobile devices have similar features (power and noise). Therefore, given a concrete power and noise of a signal detected by that base station, the power map will tell us which known geographic area(s) that signal comes from. If the same device is detected by different base stations the location information provided by their power maps can be combined to estimate the location of that device. The location database also stores the geographic location of base stations because the location of devices is calculated taking as basis the position of the base stations that detect them.

[3] We use Grasshopper [14] as mobile agent platform.

[4] The format of these headings depends on the kind of device [2].

To create the power maps of base stations, a Sniffer agent is executed on each base station to capture the power and noise of signals received from a mobile device within their coverage area. Then we use a mobile device to execute a Beacon agent and a tool that shows us a map of the area. This tool allows us to manually select the real location where we are at that moment (see Figure 3). Those real location coordinates are sent to the Location Database Manager by the Beacon agent; the Sniffer agent at each base station can detect the signal corresponding to that transmition: each base station detects it with different power and noise due to their different distance to the mobile device. These signal power and noise data are transmitted by Sniffers to the Location Database Manager which stores them in a database. Thus we can continue sending new signals with new real locations. In this semiautomatic way, we can cover all the geographic area of interest for our location-based services. Notice that using this method we create the power maps for all the base stations with just one "walk" by the area of interest.

5 Localization of the User Device

The localization of user devices is carried out by the Location Database Manager using the previously calculated information in power maps. The localization task starts with a request of some Localization client concerning a given user device and ends with the answer to that request by returning the current location of the specified user device. This task is divided into the following substeps:

1. *Request of localization*: it can be carried out from a mobile or fixed device that is looking for the position of a concrete user device. This request is received by the Location Database Manager (see Figure 4, step 1).

2. *Request of monitoring communications with the user device*: The Location Database Manager sends a message to

Figure 3: Creating power maps: specifying the user location

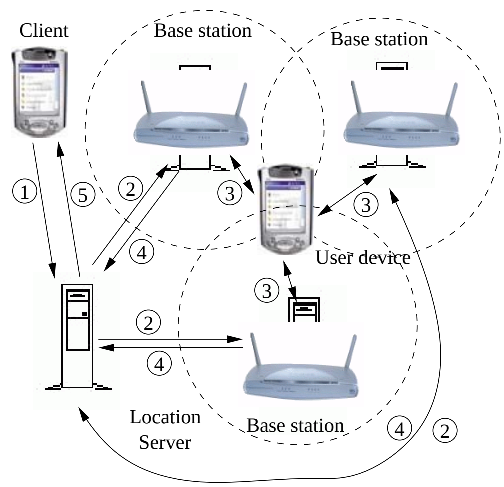

Figure 4: Locating a mobile device

each base station[5] (Figure 4, step 2) and

[5]When the specified mobile device is out of the coverage of a base station, the request is simply ig-

their Sniffer agents send a Beacon agent to the user device which will send messages at a certain frequency.

3. *Monitoring wireless communications*: Each Sniffer agent monitors the beacons received by its base station and coming from the user device (Figure 4, step 3). Then Sniffers extract the signal power and noise from data messages and send them to the Location Database Manager (Figure 4, step 4).

4. *Estimating the location of the user device*: The Location Database Manager consults the power map of each base station communicating signal power and noise detected from the user device, correlates data and obtains the location of the user device. This data is returned to the Localization client as requested (Figure 4, step 5).

If at least three base stations detect the user device, the Location Database Manager can estimate the location of the user device with a good precision using triangularization techniques [3]; in other case, there will exist more than one possible location of the user device.

6 Sample Location Dependent Data Services

In this section we describe two services developed to use the localization mechanism defined in this paper. The first service can be used to locate users by detecting the location of their mobile devices. The second service is closely related to ambient intelligence issues where a song selected by the user "follows" him wherever he goes.

6.1 Locating People on a Map

This service shows on a map the location of a list of selected persons. We can relate mobile devices ids (MAC addresses) to real people (their owners) and then the task is just to locate those mobile devices and show the associated person's name on a map. The location of people can be presented under request or in a continuous way. The results of the developed application can be shown in Figure 5.

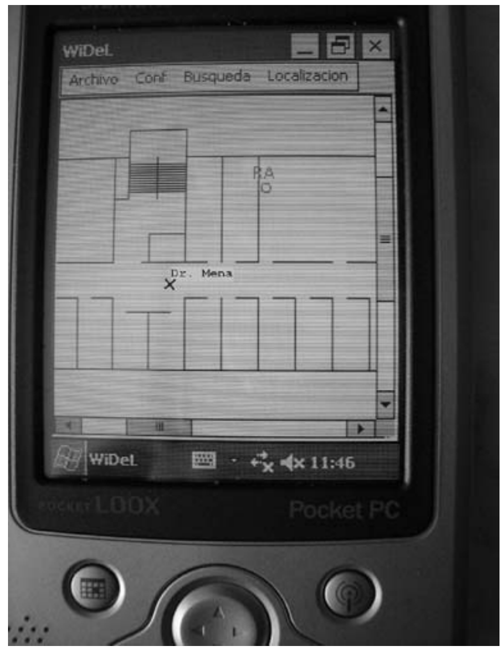

Figure 5: Service that locates people

To deal with moving users, the system uses a predictor agent that is in charge of filtering locations that imply an abrupt change in the movement pattern. Also, to soften the movement of icons/users shown on the screen (data packages can take more time to arrive, or get lost), the predictor agent estimates the location of the mobile device even when it is not receiving new data continually. The movement of the user in this situation is based on the trajectory that he has been following before.

This service have many applications. For example, in an university department different questions can be posed like "where is Dr. Mena?" or "list people inside classroom A3". In domotics, it can be used to locate people living in the same house/building.

nored.

6.2 Service for Mobile Music

After reading about the Andante project [16], we decided to create a mobile application that plays the song selected by the user, automatically changing to a new computer with audio capabilities as the user moves. Therefore, this application 1) monitors the user device location, 2) plays an audio file on a computer as close to the user as possible[6], traveling from computer to computer as the user moves, 3) plays the music without unwanted interruptions while it travels, and 4) allows the user to change the audio file to play.

To fulfil the above requirements, this service is based on the mobile agent technology. In the following we describe the main modules of the system:

- *Mobile Music client*: this application is located at the user device and allows the user to select a song from a predefined list.
- *Player agent*: This mobile agent is created on the closest computer by the Mobile Music client. It has two main goals; the first goal is to keep as close as possible to the user device, traveling from computer to computer whenever necessary. To achieve this goal, the Player agent requests a continuous update of the user device location using the Localization client proposed in this paper. The second goal is to play the selected song on the speakers of the computer closest to the user.

Notice that the Player agent is not able to play music while it travels to a new computer because the user moves. Then, in order to achieve a continuous play, the Mobile Music client creates *two Player agents*: while the first clone plays the music, the second one monitors the user's location, travels to the most appropriate computer when needed, then it synchronizes with the first clone, and continues the song reproduction[7] right before the first clone stops playing and begins monitoring the user. Thus both mobile agents swap their roles (playing music and monitoring user's location) synchronously to avoid music interruptions due to mobility. In Figure 6 we show a tool that monitors the mobile music service for a given user (shown as a cross); the computer that plays the music is shown as a small circle in light grey.

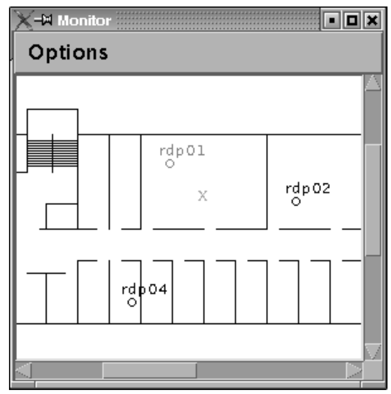

Figure 6: Service for Mobile Music

More complex synchronization models could have been implemented, for example, to create a surround musical environment around the user (playing several computers at the same time). However, the purpose of this service was just to show one of the many applications of the mobile device localization mechanism described in this paper.

7 Related Work

The RADAR system [4, 3] is a radio-frequency based system for locating and tracking users inside buildings. Both approaches are based on the strength of the signal and generate power maps. However our architecture is based on mobile agents which allow sending applications (as the Beacon agent) wherever necessary without keeping a static infrastructure on mobile devices.

In [12] they explain several methods to calculate the location of a mobile device indoors, they also estimates the localization of the user

[6]We assume that the user device does not have audio capabilities to play a song with the required quality.

[7]In our prototype, MIDI audio files are used due to their small size.

device using the signal power. However, they correlate the power maps using a neuronal network while we use triangularization techniques to locate the user device.

In [9] they automatically create power maps using bayesian networks. However, we have found that works that create power maps semi-automatically (taking real readings as basis) obtain more accurate results.

8 Conclusions and Future Work

We have presented in this paper an architecture based on mobile agents to estimate the location of mobile devices in wireless local-area networks. The proposed architecture has the following advantages:

1. It achieves a precision accurate enough to allow the development of indoor location-based services, so it can be applied to domotics, ambient intelligence, etc.

2. It minimizes the use of the resources of mobile devices due to the mobile agent technology.

We have also implemented two location-based services to show the applicability of our proposal, one to locate people and the other to play mobile music.

As future work we consider to ease the creation of power maps, as well as to abstract the extraction of signal power and noise from the specific wireless communication protocol and kind of devices used.

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