REGULAR PAPER

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Location-based services in ubiquitous computing environments

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Abstract This paper presents a framework for providing dynamically deployable services in ubiquitous computing settings. The goal of the framework is to provide people, places, and objects with computational functionalities to support and annotate them. Using RFID-based tracking systems, the framework detects the locations of physical entities, such as people or things, and deploys services bound to the entities at proper computing devices near where they are located. It enables location-based and personalized information services to be implemented as mobile agents and operated at stationary or mobile computing devices, which are at appropriate locations, even if the services do not have any location-information. This paper presents the rationale, design, implementation, and applications of our prototype infrastructure.

Keywords Ubiquitous computing · Mobile agent · Location-based services · Location-sensing system · Middleware

1 Introduction

As Mark Weiser envisioned [21], a goal of ubiquitous computing is to provide various services by making multiple computers available throughout the physical environment, but, in effect, making them invisible to the user. Another goal of ubiquitous computing is for it to integrate the physical world with cyberspace. Actually, perceptual technologies have made it possible to detect the presence or positions of people and any other object we care to think about. Context-awareness, in particular user-awareness and location-awareness, is becoming an essential feature of services that assist our everyday lives in ubiquitous and mobile computing environments.

However, ubiquitous/pervasive computing devices are not suitable for providing multiple-purpose and personalized services, because most devices tend to have limited storage and processing capacities and are thus incapable of internally maintaining a variety of software and profile databases on the users. In fact, although there have been many attempts to develop location-based or personalized information services thus far, most existing systems have inherently focused on particular services, such as user navigation for visualizing locations on maps and information providing the information relevant to the user’s current location. As a result, it has been difficult for these systems to support other services for which they were not initially designed. Furthermore, they have often been implemented in an ad-hoc manner with centralized management. Therefore, it is difficult for the systems to dynamically reconfigure themselves when new services are needed.

This paper presents a framework for deploying and operating location-based or personalized information services to solve these problems and this is based on two key ideas. The first is to introduce mobile agent technology [7] as a mechanism for the deployment of services. Since many computing devices in ubiquitous and mobile computing environments only have limited resources, they cannot provide all services required due to limited computational resources, even if they are at suitable locations. Therefore, our framework provides an infrastructure for dynamically deploying service-provider agents to support services at computers that need the services. The second idea is to separate application-specific services from the infrastructure. Since each mobile agent is a programmable entity, the framework enables application-specific services, including user interfaces and application logic, to be implemented within mobile agents. Using mobile agents makes the framework independent of applications, because application-specific services are implemented within mobile agents instead of the infrastructure. Since the framework is responsible for automatically deploying mobile agents at appropriate computers, they can provide their services without any location-information. It delegates agent migration to its underlying mobile agent platform to execute
and migrate mobile agents over a network. Nevertheless, it is available with various existing mobile agent platforms because it has been designed to be independent particular platforms.

In the remainder of this paper, we describe our basic ideas (Sect. 2) and the design of our framework (Sect. 4). We explain how information services can be bound to physical entities and places (Sect. 5) and describe the current implementation of the framework (Sect. 6). We also discuss our experience with several applications, which we developed with the infrastructure (Sect. 6.2). We briefly review related work (Sect. 7). We also provide a summary and discuss some future issues (Sect. 8). We describe programming models (Appendix).

2 Approach

The goal of the framework presented in this paper is to provide a general infrastructure for supporting multiple location-aware and personalized services in ubiquitous computing environments.

2.1 Example scenarios

To outline the goals of this framework, we present two typical scenarios for it. The first provides personalized services to users without portable computers. When a user enters an unfamiliar building, he/she may lose his/her way or may not be able to find any cafes there. The framework provides his/her personal agent that can assist him/her in his/her personal form any location. This is because these agents can migrate between computers and be executed on public terminals on streets or electric displays in front of cafes or restaurants. As the user moves, they follow the user’s movements. When the user stops in front of the electric display of a cafe, the agent migrates to a computer in front of the cafe and displays the list of his/her favorite cafes on the screen of the computer. The second assumes that the user is carrying a PDA. Suppose that a room has many electric lights. When he/she only wants to turn the electric lights near him/her on, he/she may occasionally know which switches on the wall-mounted central control panel controls the lights. This framework enables his/her PDA to be used as a universal remote controller. When a user goes near the lights, the framework displays a graphical user interface for the lights on the screen of the PDA for him/her to control them. The interface can turn the lights on or off through a stationary agent running on the control panel. When he/she leaves from the vicinity of the lights, the framework automatically closes the interface from the PDA, because of the device’s memory small.

The first scenario is where its services are contained in the environment rather than carried on the person. The second is where services are carried by users rather than contained within the environment. Existing approaches aim at supporting one of either of these scenarios, whereas our framework can support the both scenarios with a unified approach.

2.2 Location sensing systems

The framework offers a location-aware system where spatial regions can be determined within a few square feet, which distinguishes between one or more portions of a room or building. Existing location-based services are typically tailored to a particular type of tracking or positioning technology, such as GPS. The current implementation of the framework uses RFID (radio frequency identification) technology as an alternate approach to locate objects. An RFID system consists of RFID readers (so-called sensors or receivers), which detect the presence of small RF transmitters, often called tags. Advances in wireless technology enable passive RFID tags to be scanned over a few meters. For example, the Auto-ID center (currently called EPCGlobal) [1] and its sponsors are working to develop flexible tags and readers operating at ultra-high frequency (915 MHz in the US, 868 MHz in the EU, and 950 MHz in Japan). It expects that RFID tags will cost around 5 cents when produced in bulk and RFID readers will cost around a 100 dollars in volume. The framework assumes that physical entities, including people, computing devices, and places will be equipped with RFID tags so that they will be automatically locatable.

The framework reads to provide a unified model for spatial information to hide the differences between the underlying location-sensing systems from applications as much as possible. Spatial information should also be bound within the requirements of an application that uses it to avoid unnecessary exposure of details on underlying tracking and positioning systems. Therefore, the model is based on symbolic location. This is because the framework aims at building location-aware applications for annotating and supporting people, objects, and places and such applications are often associated with semantic and structural spaces, such as buildings, rooms, and portions of a room or building, rather than geometric locations.

2.3 Dynamically deployable services

Suitable services should be operated on suitable computing devices in the sense that the services are both required according to the location of users and their associated contexts and the locations and capabilities of the devices can satisfy the requirements of the services. However, most ubiquitous and mobile computing devices often have only limited resources, such as restricted levels of CPU power and amounts of memory. As a result, even if a device is at a suitable location for the required service to be provided, the device may not be available because of a lack of software or capabilities, such as input or output facilities, to execute the software. Various kinds of infrastructure have been used