System support for integrated ubiquitous computing environments

Rui José, Helder Pinto, Filipe Meneses, Noé Vilas Boas, Helena Rodrigues and
Adriano Moreira

Information Systems Department, University of Minho
Azurém, 4800-058 Guimarães, Portugal
email {rui,helder,meneses,noe,hcr,adriano}@dsi.uminho.pt

Abstract. This paper describes an ongoing research on the issues of interoperability and seamless integration between a global user environment and the ubiquitous computing environments corresponding to the physical locations visited by that user. The novel concept of Value ADded Environment (Vade) is introduced as an administrative and physical domain, where the locally available facilities can be combined with the external home environments of users within its boundaries to enable an integrated and enhanced functionality. The main goal of our work is to allow generic applications to access and benefit from resources and context information that are normally only available to applications created specifically for a particular ubiquitous computing environment. Our preliminary results, highlight a number of key integration issues and show a possible path for the convergence between ubiquitous computing research and mobile services.

1 Introduction

The overall objective of making computation and networking ubiquitous features of our daily lives has attracted considerable research in recent years, resulting in a large number of systems that may be classified as prototype ubiquitous computing environments. While such systems may differ considerably in terms of their approach and their target scenarios, they are always characterised by a strong integration between the physical and computational infrastructures. For example, short range communication technologies, such as bluetooth or IR, may be used as a means to associate services or context information with a particular physical location. The main advantages of this strong coupling with the physical environment are essentially the possibility to support functionality that is very specific to that environment and also the possibility to produce, manage and use rich context information. The main limitation, however, is that such level of integration can only be reasonably achievable for systems aimed at small and specific physical infrastructures, meaning that, in the course of a day, a user will have to interact with a multitude of independent ubiquitous environments, one for each visited location. This limitation is even more important due to the lack

of an administrative structure that could be used across domains to support key features, such as authentication, user profiles or billing.

On the other hand, mobile network operators (MNO) are also launching services that use the position of mobile terminals to provide users with information that is associated with their particular location. These location-based services have a strong administrative framework, but have the limitation that the server is expected to provide information for any of the potential locations of the client, which implies the ability to consolidate all location content into large warehouses, posing operational and data integrity issues that are costly to overcome [1]. Without the assistance of a local infrastructure, these applications do not have the potential for reaching the same level of richness and context-awareness as the ubiquitous computing applications created for a specific physical infrastructure.

This research aims to combine the two previous approaches, and is specifically targeted at the issue of interoperability and seamless integration between a user home environment and the ubiquitous computing environments corresponding to the physical locations visited by the user. Our approach introduces the concept of Value ADded Environment (Vade) as an administrative and physical domain, e.g. a shopping centre or an airport, where the locally available ubiquitous computing facilities can be combined with the external home environment of visiting users. We assume that user home environments include some form of mobile information space where users may activate applications that match their specific needs. The overall scenario is that when entering a Vade, the mobile user is provided with functionality that corresponds to the dynamic combination of pre-defined user preferences, currently active applications, current user context and locally available services and applications. A Vade system may thus be seen as an abstraction for an ubiquitous computing environment where the local infrastructure is available for applications that have not been produced specifically for that particular environment, and where it is possible to build functionality that combines global and local elements. The global elements provide the common ground necessary for giving users a familiar application environment, whereas local elements provide the local infrastructure that is indispensable for achieving depth and versatility in mobile systems.

Our research has essentially highlighted some of the key integration issues that result from providing external access to ubiquitous computing environments and also explores a possible model for the convergence between ubiquitous computing research and mobile services. In the remainder of this paper, we describe the key functionality supported by a Vade system, and present some preliminary results of our experience of deploying a prototype Vade for our university campus.

2 The Vade System

2.1 Vade functionality

The idea behind the Vade concept is that when a user enters an ubiquitous computing environment that also happens to be a Vade system, the functionality

available to that user should be the combination of global and local functionality. In order to clarify the multiple roles that exist in the system, we have grouped its functionality into three separate domains, more specifically: the User, the Vade, and the External domains. The User domain corresponds to the physical and logical elements carried by a person that is within the physical boundaries of a Vade. The Vade domain is the local infrastructure that supports the Vade functionality, including core services, information services, and all sorts of sensors, positioning mechanisms, and interaction devices that are locally available. Finally, the external domain corresponds to all the other elements that interact with the Vade but are not part of the Vade, or user domains. Our main assumption about the external domain is the existence of a structured framework for customer relationship that is able to support some horizontal services, such as personal context management, user profiles, and a personal information space, possibly in the form of a mobile portal. We have been particularly interested in scenarios in which this domain corresponds, at least partially, to a Mobile Network Operator (MNO), as this would enable interaction between Vades and important 3GPP services such as billing, authentication, micro-payments, user profiles and terminal location.

2.2 Application models

Regarding user applications, we have considered two distinct application models that may benefit from the the Vade approach.

Vade-aware global applications - A Vade-aware global application is an external application that, when the user enters a Vade, is able to enhance its functionality by taking advantage of the locally available services. A global application is not aimed at any Vade in particular and may be used regularly outside any Vade. We assume that these applications are context-aware, and also that, as users move, they are continuously searching for additional location-based resources. Entering a Vade is thus a major opportunity for finding new, probably much more specific, resources and context information that can be used to improve the coupling with the physical environment of the user, and thus the value of the functionality provided. For example, it is simple for a global map application to present a detailed map of the area where a shopping centre is located, but for the people inside the shopping what would be real value would be have access to a detailed plan of the shopping. It is this type of enhanced functionality that a Vade-aware application should be able to provide. This application model is particularly suited for generic functionality, such as "what is near me", "find a ..", "guide me to ..". The main challenge is to be able to discover, recognise and use the potentially very vast range of services that may be found at different environments.

Vade local applications - A Vade local application provides functionality that is specifically associated with a particular Vade. When a user enters a Vade, these

applications should seamlessly integrate the user's mobile information space. i.e. the user should not need to look for them, configure them or study their functionality. The main advantage of this application model over the Vade-aware model is that, since these are local applications, they can be tailored for the particular environment for which they have been produced. The two main challenges for this type of application are how to manage the integration of their functionality into the user information space, and how to have access to user profile and context information without breaking privacy constraints.

2.3 System Architecture

Considering the specific objectives of our work, we have focused mainly on the core services related with resource and context management, but there is obviously an open-ended range of other services that may be available within the Vade domain.

   The core services supported by a Vade system are essentially aimed at enhancing the processes of context management and service discovery, and are represented in the reference architecture in Fig. 1.
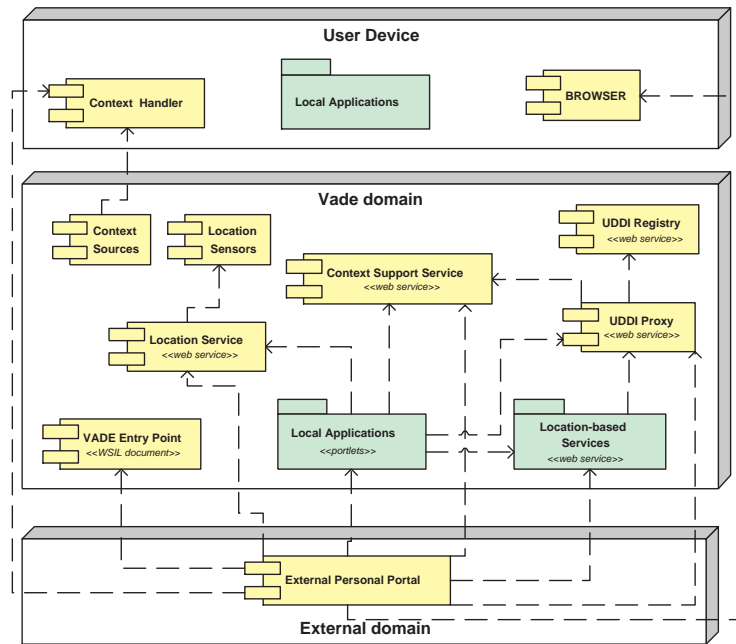
Fig. 1. Reference architecture for a Vade system

   All access to Vade services is HTTP-based, and albeit not represented in the figure, an HTTP server is the entrance gate to the system. The initial reference

to the vade core service can be obtained from the domain name through a simple bootstrap mechanism, called Vade Entry Point, that is essentially a Web Services Inspection Language (WSIL) document at a well-known location.

Our context management approach assumes the existence of an external context management service associated with each user that will try to access the local context infrastructure to enrich its information about the context of users that are currently at the Vade. Such context manager should be responsible for handling multiple types of context information from multiple sources, combine them and provide high-level context information to applications, including information about the presence in a Vade. The core services in the Vade system that contribute for this function are the context support service, the location service and possibly, depending on the locally used technologies, an infrastructure of context sources and location sensors. The Vade location service supports location management within the Vade. It aims to complement any external location or context managers with more precise and dynamic information that may be collected from local positioning systems. Context information may be obtained through several complementary mechanisms, such as local context sources or positioning mechanisms, and the Vade context infrastructure may collaborate with user devices to produce or collect that information. When context information is handled at the user devices, these may communicate that information to the user context manager. When the information is collected at the Vade location service, the context manager can request it directly from that service. The Context Support Service enhances the use of context within the Vade by supporting the transformation between different forms of context based on its local knowledge about the environment. For example, "if currently in room A then probably participating in meeting X" or "if in room B.12 then also in building B". This richer context information may be very useful to context-aware applications, allowing them to offer a more valuable functionality to mobile users based on the composition of multiple context elements.

The other core functionality of a Vade system is the ability to make its services and applications available to external domains. Local services, which may be associated with the whole Vade or with specific locations within the Vade, will be used by end-user applications, global or local, as a means to enhance their association with the current physical environment of the user. To accomplish this objective, these services should meet strong interoperability and openness requirements, and should be self-describable and discoverable in order to permit dynamic finding and invocation. Local applications are user-facing applications that are specific to the Vade. When an external system discovers their availability, there should be a mechanism that enables users to benefit from their functionality.

Given our focus on interoperability, we have decided to make all these resources available as web services and to use the UDDI standards for service discovery. In the case of local applications, the Web Services Remote Portlets (WSRP) specification is used for allowing them to be integrated into external mobile Vade-aware portals. A private UDDI Registry is used as the main repos-

itory for the information about all local services and applications. In order to support the association between services and locations, and especially to support location-based queries, we had to introduce specific location taxonomies and other enhancements into the use of this registry [2]. Instead of making queries directly to the registry, external applications place their queries to an UDDI proxy that uses its privileged knowledge about the local environment to transparently support and optimise location-based discovery. This approach has allowed the UDDI standard to be supported while enabling all applications to benefit from the specific mechanisms for location-based queries.

2.4 Campus Prototype

We have been developing a prototype of a Vade system in which one of our University Campi plays the role of a Vade. For this prototype, we have created a few global applications, such as an environment browser that describes the current location of the user, and a number of local applications that integrate into our test portals, such as a virtual juke-box and a "find a person" application. We are currently about to start the user evaluation of the system and we plan to deploy other prototypes in places for which we envision the use of the model, such as shopping centres or museums.

3 Preliminary Results

We will now analyse some of our preliminary results on the implications of our approach for making the functionality of an ubiquitous computing environment available to an external domain.

Integration of functionality Integration issues are central to our research and span several aspects of the system design. One of the most specific issues, however, is how to make users aware of the additional functionality that becomes available when they enter a vade, and particularly how to organise the users' mobile information space to reflect the changes. To address this issue, we have developed two external portals for our prototype, each with its own approach regarding the integration of functionality when the user enters a Vade. Our first approach places all local applications under a "Local Environment" option that becomes available whenever the user enters a Vade. The user can then browse through the locally available applications. This is the simplest approach and the one that most clearly separates Vade functionality from global functionality. However, users may not always be willing to adapt themselves to new application environments, and are far more likely to prefer the more comfortable experience of using only their well-known applications rather than explicitly selecting a local environment option and then going through the exploration of the applications available at the new environment each time they enter a Vade. This may be particularly true if there are many environments populated with many services and applications.

Our other approach was thus to try to maintain the high-level functionality of the portal essentially the same, while allowing local functionality to seamlessly integrate into the users well-known mobile application environment. The overall idea is that when entering a Vade, the system may behave slightly different, depending on the locally available services and applications, but the user will still be presented with a familiar structure. To accomplish this, we have aggregated all applications (global and local) into portal sections associated with high-level user tasks. Applications were classified according to a very simple model, inspired in the high-level classifications described in [3], and which includes the following categories: Rememberer, Guider, Suggester, Informer and Interactor. When a local application is found, it is integrated into the thematic section in which it best fits. This approach allows the user to maintain a stable perception of its information space, even in very dynamic environments. However, the separation between local and global applications is no longer clear, as each thematic section will now contain both global and local applications. The main challenge for this approach, however, is to create section taxonomies that can adequately support the matching between applications and portal section on a large scale system.

Determining presence in a VADE The User domain needs to continuously determine if the user is currently located in a particular VADE, and should be able to do it using information from multiple sources. However, we have found it very useful to also have an external Vade directory that is able to map a geographical position into a Vade, allowing the external domain to periodically verify if the user has entered or left a Vade. The existence of this service provide a possibly trustworthy source of information, and complements the resolution of relative context information sources, such as barcodes or RFID tags, which may be too limited to also include a reference to their vade domain.

Another related issue is location authentication, i.e. how to certify that a user is in fact within a particular vade. This may be very important for the vade system, which for example may only allow certain applications to be available to users that are physically present, but it may be equally important for an external domain, which for example may only be willing to provide user information to a vade that is able to prove that the user is currently within its boundaries. We are currently investigating mechanisms to support this location authentication, but the main challenge seems to be how to combine the multitude of possible requirements that local and global applications may have.

Anonymous access to context information Privacy issues involve many aspects of the vade system, but where they are more obvious is when the external and vade domains exchange profile and context information about the user. Ideally, a user should be able to access as much as possible of the Vade functionality without having to reveal its identity or any other personal information. The challenge is to allow the external domain to obtain the context information of a particular user without allowing the Vade system to associate the context information it manages with external users. For example, a local positioning

service could locate wireless devices and identify them by their MAC address, but the challenge would be how to only allow the owner of that device to have access to that information without the vade having to identify users. We are currently investigating a number of approaches based on pseudonyms and one-time identifiers that can be suited for the most common location mechanisms.

Interoperability versus flexibility The Vade system is an example of an approach in which the environment provides an infrastructure to coordinate the locally present resources. We are aware, however, that some of the technological options we have made to promote interoperability, e.g. the use of a private UDDI, have strong implications for the ability of the system to sustain very dynamic services and third-party service provision. We are currently investigating how the Vade infrastructure can be used to promote the grouping of local peer-to-peer communities, by for example enabling aggregations based on location.

4 Conclusions

An important part of the value of pervasive computing environments is in their ability to interact with external domains in order to provide integrated functionality to users. This paper has described an ongoing work in which the concept of a value-added environment is explored as a mechanism for enabling the combination of functionality between a local ubiquitous computing infrastructure and an external home environment associated with a user. By providing services for local context management and service discovery, and also by mediating the interaction between user devices and the surrounding environment, a Vade enables a whole range of new applications for which the close relationship with the environment and a structured user framework are both important. By including a framework for describing and integrating the functionality available at different environments, this work is also a contribution for allowing interoperability to be simplified.

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