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Validating ambient intelligence based ubiquitous computing systems by means of artificial societies

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ABSTRACT

This paper introduces a new methodology based on the use of Multi-Agent Based Simulations (MABS) for testing and validation of Ambient Intelligence based Ubiquitous Computing (UbiCom) systems. An ambient intelligence based UbiCom is a pervasive system in which services have some intelligence in order to smoothly interact with users immersed in the environment. The motivation for this methodology is its application in UbiCom large-scale systems where large numbers of users are involved and in applications which deal with dangerous environments. In these cases, real tests are impractical and an artificial society is required. MABS allows building cheap and quick prototypes which can describe UbiCom systems. Analyzing these prototypes, if they are sufficiently descriptive, allows requisites violations in functionality of real UbiCom system designs to be discovered. MABSs and particularly the most descriptive ones can present very complex behaviors. Therefore, the MABS analysis obtained with the presented methodology is not trivial. Consequently, this paper also proposes two techniques for the analysis of general complex MABSs: forensic analysis and the use of simpler simulations. Moreover, the methodology proposes to inject elements of the actual UbiCom system in the simulated world to increase the confidence of the validation process. The proposal is illustrated with a detailed case study that considers a building on our campus and an AmI service for evacuation in case of fire.

1. Introduction

Ubiquitous Computing (UbiCom) is a vision for computer systems to merge the physical world and human and social environments [40]. And Ambient Intelligence (AmI) [46] is concerned with such kind of systems but it lays the emphasis on how they interact with people. UbiCom technology is based on the use of lots of small, cheap devices that are present in the physical environments of users, including home, office and others. The term *ubiquitous* suggests that small devices will be so pervasive in everyday objects that we will not realize them [12]. This discipline, which means the integration of computing with our environment, is also known as *Pervasive computing* and *everyware* [22].

AmI based UbiCom applications are endless: smart homes, health monitoring and assistance, hospitals, transportation, emergency services, education, workplaces, etc. [11]. This technology, with origins in science fiction,[1] has already begun to change our lives. For example, South Korea plans to spend $25 billion on New Songdo, the world's largest "*ubiquitous city*"

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[1] *Ubik* is a 1969 science fiction novel by Philip K. Dick. In 2005, Time magazine named it one of the 100 greatest English-language novels published since 1923.

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[36] (construction will be done by 2014). This city implements many UbiCom ideas on a city-wide scale [11]. One example of these ideas is the use of pressure-sensitive floors in the homes of older people that can detect the impact of a fall and immediately contact help [36]. Whatever the application domain is, the UbiCom software must be validated like any other software.

According to the IEEE Standard Glossary of Software Engineering Terminology [16]: "Validation is the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements". So, the software validation is the process of checking that its functionality is correct. Hence, a validation failure occurs when software does something different to what it should do by its design. On the other hand, verification is the process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase [16]. As the validation ensures "you built the right thing" and verification that "you built it right", validation is an activity of a higher level of abstraction than verification. Another important concept is "testing" which is "the process of executing a program with the intent of finding errors" [34]. Obviously, verification and validation cannot be performed without previous testing. Validation, verification and testing are concepts related to software quality [3].

If validating traditional software is important [3] much more important is validating AmI based UbiCom applications with critical services as, for example, emergencies management. Many UbiCom applications are tested and validated directly in real environments called *Living Labs*. A Living lab is an space for experimentation and creation of AmI based UbiCom applications with real users in imitated real environments. However, these Laboratories are only practical on small scales like a house. Besides, building a Living Lab may require considerable economic investment. Traditional usability engineering methods and tools fail in the development of UbiCom applications [13]. Established organizations such as the Usability Professional's Organization have recognized the need for new approaches to usability testing and validation [13]. This paper tries to be one such approach for the last stage before the deployment of AmI based UbiCom applications which involve testing, verification, validation and debugging. The proposal focuses on the validation process.

The contribution of this paper is a methodology for the validation of UbiCom applications focusing on the use of artificial societies. The idea is quite intuitive. Let us think about how to validate an application of the New Songdo City like traffic management. This city will accommodate 65,000 habitants and 300,000 workers [36]. One quickly realizes that all we can do is simulate an artificial society to study if the application behavior is the expected one. Real tests are not an option in these large-scale domains. So the motivation of this paper is the validation of UbiCom applications where real tests are impractical. This may occur for numerous reasons: many people are involved, too many tests are required, the cost of the real tests is too high, the application deals with dangerous environments such as emergencies, etc. Besides, a simulation-based approach has many collateral benefits. Developing simulations is quick and cheap. Simulations also allow applications to be developed before the actual hardware is available. Tests in simulations can be studied intensively to get a deeper understanding of the application (running a set of simulations with a wide range of parameters). Moreover, simulations help developers to interpret the phenomena produced in such a complex system as an ubiquitous space. In this sense, a simulation is a kind of advanced visualization technique. *Multi-agent based simulations*, MABS will be used to simulate the artificial societies in this approach. Let us explain what MABSs are.

MABSs are computational models characterized by the existence of many autonomous individuals called agents who act and interact with each other autonomously [4]. MABS allow modelers to handle different levels of representation (e.g. "individuals" and "groups", for instance) within an unified conceptual framework. Such versatileness makes MABS one of the most interesting support tools for the simulation of complex systems [14]. MABS is used in more and more scientific domains [14]: sociology, biology, physics, chemistry, ecology, economy, etc. This paper proposes the use of a MABS-based methodology for the validation of AmI based UbiCom applications.

Returning to the proposal presented in this paper. It specifically deals with complex AmI based UbiCom applications with a large number of users. The testing of the social behavior of user groups is interesting in these applications. That is, the macro-social perspective. Therefore, the overall objective of our research is to increase the usability of this type of complex UbiCom applications by testing and validating them with MABS.

Besides the use of MABS for the validation of AmI based UbiCom applications, this proposal is innovative in many ways. The problem starts with a relatively complex simulation. Because of this added complexity, the methodology proposes to isolate some conflicting elements from the main simulation. These elements can be validated in simpler simulations before using them in the main simulation. A further innovation is the use of a *forensic analysis* process (i.e. a validation process performed on previously recorded data from the MABS run). This forensic analysis is also integrated into the methodology to study the results. Finally, the methodology also proposes to inject reality (to integrate real elements with the simulation) in order to get results as reliable as possible.

The paper also provides a detailed case study to illustrate the above methodology. The particular case is a service for emergency management. This AmI service will be used in a real building. This example shows how the presented methodology allows easy development and running of simulations in order to validate the service. The quality and quantity of the tests performed would be impossible without the use of MABS.

The paper is structured as follows. The next section will discuss the related works. Section 3 explains the proposed methodology for the validation of AmI based UbiCom applications. Section 4 shows an use of the methodology for an emergency management service in an UbiCom application. Finally, the conclusions and future works are presented.