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A Context-Aware Multi-Agent System for AmI Environments

PhD Thesis proposal

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1 Introduction

Ambient Intelligence, or AmI, is one of the priorities of current development in the ICT domain [DBS+01]. Ambient Intelligence deals with assisting people in their day to day activities, by means of an integrated, ubiquitous electronic environment that is interconnected by a heavy-duty network infrastructure and providing intelligent user interfaces. AmI will use a very large number of electronic devices that have different capabilities, different sizes and different performance, all of them interconnected by wireless or wired networks, working together and cooperating towards the resolution of tasks. By means of these devices, AmI will be sensitive to the environment and to the presence and state of people, and will be able to react to their needs and actions [RAS08, AM07, Sat01]. The final goal is to assist the user and take away the burden of repetitive, annoying activities, as well as helping people with disabilities to integrate better into the society and the urban environment. There are great challenges in the development of AmI, like advanced human-machine interfaces, knowledge representation, context-awareness, information management, security and privacy, device heterogeneity and many hardware-related requirements [Sat01, BCL+05].

Many times AmI is explained by means of scenarios revealing the features, but also the challenges, of AmI systems. I will give here a short summary of a scenario developed by Canut, Dubois and Glize [CDG+09]: a new student arrives on the campus of his university. His smartphone obtains from the campus's information system a map of the campus. As the screen is quite small, it contacts a nearby advertisement screen to display the map in a more appropriate size. The student can manipulate the map and obtain more relevant information by using the large public screen. On the next day, the smartphone, noticed by the information system, guides the student towards the venue of a course that had been relocated just a few minutes before beginning. During the course, the student is examined and the professor obtains from the information system data on the student's progress in previous years, which serves for more appropriate evaluation of his situation. As a fire alarm goes off, the students receive on their devices exact evacuation plans with pre-calculated routes, in function of their individual location. Later, the AmI system helps students that need to study on the same subject meet each other and collaborate, also suggesting adequate books and references. At lunch, the system helps students find appropriate restaurants, find other students that have common interests, and manages their electronic wallets.

Among other common subjects of AmI scenarios [DBS+01, Sat01, JFW02, KBM+02, BCL+05, VMC+08] there are the smart conference room, the intelligent home, the urban transport system and the airport. There are several points that are common to most AmI scenarios. They include awareness of the user's state and preferences and advanced human-machine interfaces (HMIs) that allow the system to interpret image (from video cameras), voice, vital signs, and user input like gestures and speech, but also to deliver information in a flexible and intuitive way, by using displays or other media. Also, the possibility to control different parameters of closed environments (lighting, temperature, etc). AmI systems should make heterogeneous devices interoperable and support seamless – but also secure and privacy-aware – transfer of files and other content between devices (belonging to the same or to different users). Above all, AmI systems must be ubiquitous, secure, transparent and non-intrusive [DBS+01, Sat01, BCL+05]. These features also create the challenges in the design and implementation of the AmI vision.

When it comes to the implementation of AmI, there are several directions of development. Some directions target the development of specific applications such as smart conference rooms [JFW02], assistance of people with disabilities [SM06] and smart campuses [SBS+08, SGK05]. Other research directions focus context-awareness and knowledge representation [FAJ04, VMC+08], interoperability of devices [Hel05], intelligent user interfaces [RVD05] and middleware platforms for ambient intelligence [CFLZ05, Hel05, LW05, SBS+08]. In the latter, intelligent software agents have already been used, due to their features favourable to the implementation of AmI: autonomy, proactivity, adaptability and mobility. However, few attempts have been directed towards the use of multi-agent systems (MAS) composed of a large number of generic, coordinating agents, as required the realistic scale of AmI: a huge number of people and devices, producing extremely large quantities of information that must be processed, aggregated and exchanged in order to assist the users in their activities.

The **goal of my research** is to develop a multi-agent system based model for the context-aware exchange and processing of information in an AmI system. The model will be conceived considering the requirements and restrictions that come from other layers of an AmI architecture, taking into account, for instance, user mobility, device heterogeneity, network instability and security concerns. The model will comprise the formal specification of the agent types and behaviour, the representation of the agents' beliefs, goals, plans and context information, the communication and coordination mechanisms, as well as the overall system architecture. The model will be implemented, leading to experiments within a simulated environment, but also in more realistic scenarios including the deployment on several computing devices.

2 State of the Art

My research is situated in the domain of Ambient Intelligence, but also draws inspiration from other fields. Self-organisation and emergence are concepts that have many things in common with Ambient Intelligence: a large number of individuals, requirements of robustness and flexibility, the need for the individual behaviour to be simple enough, but to result in complex properties of the system as a whole. Also, there cannot be proper AmI without context-awareness and a flexible representation for knowledge and context data, so these are fields that connect with this research as well.

2.1 Ambient Intelligence

Ambient Intelligence is a domain who's name was coined at the end of the 20th century, making it one of the technologies to be developed in the 21st. The ideas of Ambient Intelligence have been, however, developed about 10 years earlier. Among others, in the seminal work of Mark Weiser from Xerox PARC [Wei93, Wei95], who introduced the concept of Ubiquitous Computing, talking about the "Computer of the 21st Century". The domain of Ambient Intelligence – or AmI – has gained additional momentum when it was made a main priority in the domain of ICT by the European Commission, following advice from the Information Society Technologies Advisory Group [DBS+01].

Basically, AmI refers to a ubiquitous electronic environment that supports people in their daily tasks, in a proactive, but "invisible" and non-intrusive manner [RAS08, Wei93].

The existence of AmI relies on three essential elements: Ubiquitous Computing, Ubiquitous Communication and Intelligent User Interfaces [DBS+01]. That means that computing technology will exist in everything that surrounds us – devices, appliances, objects, clothes, materials – and that everything will be interconnected by an ubiquitous network. The system formed by all these intelligent things – also called the Internet of Things – will interface with humans by means of more advanced interfaces, that are natural and flexible and that adapt to the needs and preferences of each user [DBS+01]. The final goal is to have an adaptive and "intelligent" system that assists humans in their day to day activities. The computing power will become invisible and the computer will not be the focus of one's attention, like it is now, but a mere tool that will help the human in his activity that concerns things from the real world [Wei93]. Such a computing system will become natural, without distracting the humans, and intervening only when it can improve the result of one's activity, providing assistance without being intrusive or annoying [RVD05]. Also, AmI should bridge the gap that has formed between the real world and the virtual space (the Web), and reassociate real objects with their virtual presence, in terms of real-time information and control [KBM+02].

As a result, the main features of Ambient Intelligence are ubiquity, transparence and invisibility, support of user and device mobility, scalability, resiliency and robustness, non-intrusiveness, proactivity and anticipation, adaptivity, security and privacy.

As technologies, AmI comprises features that have been previously developed by the fields of distributed systems – remote communication, fault tolerance, availability and security – and mobile computing – mobile networking, mobile information access, energy saving, location sensitivity. It also adds smart interfaces and particular challenges related to localization and heterogeneity (see Figure 1 in [Sat01]).

As with any new, pervasive, technology that is supposed to influence the life of so many people, the domain of Ambient Intelligence implies many concerns related to security, privacy and ethics [BCL+05]. In an environment where so much information will be exchanged between devices there is little knowledge on how to counter malicious action. The very features that make AmI useful also make it usable as a surveillance tool. Moreover, its power, combined with its infiltration in everyday life, require it to be extremely reliable, as failures may render many people unable to lead their (now AmI-integrated) normal lives. Advanced adaptation to the user means that the information that the user receives is selected by the system, and if it is mistaken the user may be deprived of valuable information that might have otherwise been useful. Therefore, it is very important for Ambient Intelligence to consider its impact on its users, and it is very important that it is predictable, dependable and manageable [BCL+05].

As Ambient Intelligence presents the researchers with many challenges, the search for the implementation of AmI has yielded several main directions of development: usage of tags and sensor networks for sensing objects / people; assistance services based on localization and other indications of context; personalisation of user's experience and anticipation of intentions; advanced, "intelligent" user interfaces that allow multimodal input and output as well as interaction management; knowledge representation, context modeling and awareness; interconnection of heterogeneous devices and coordination towards the resolution of complex tasks; support infrastructures (middleware) for the exchange and management of information. These domains are not necessarily disjunct.

At the core of the AmI architecture there is the software infrastructure that is responsible for most of its features. In a layered vision of AmI [Seg08], the software infrastructure exists on top of the layers of hardware – comprised of sensors, actuators, mobile devices, computers, etc. – and network, and below the layer of intelligent interfaces. This infrastructure will be itself composed of two layers: one that will allow uniform communication among heterogeneous devices – using different hardware and different types of connections to the network – and will enable easy information transfer and code migration between devices; and one that will be more oriented towards knowledge and semantic information and will offer context-aware services to the layer above – the interface.

This upper layer that resides below the interface is vital for the "intelligent" features of AmI. It is this layer that must work with knowledge and semantic information and that must assure that users get the information that they need, where and when they need it. It is here where AmI must use the achievements of Artificial Intelligence, trying to model, understand, anticipate and, finally, assist the people in the real world. For these tasks, AmI must feature sensing capabilities, autonomy, reasoning, proactivity, social abilities and learning [RAS08]. Considering these features, one especially appropriate paradigm for the implementation of this layer in an AmI system is Multi-Agent Systems, or MAS. MAS employ software agents, that have the exact same characteristics that are required by AmI, and that were mentioned above.

In the field of agent-based Ambient Intelligence platforms there are two main directions of development: one concerning agents oriented towards assisting the user, based on centralised repositories of knowledge (ontologies), and one concerning the coordination of agents associated to devices, and potentially their mobility, in order to resolve complex tasks that no agent can do by itself, also considering distributed control and fault tolerance.

The first approach is closer to Intelligent User Interfaces and local anticipation of user intentions, coming from the field of intelligent personal assistants. For instance, embedded agents form an AmI environment in the iDorm implementation [HCC+04]. Agents are used here to manage the diverse equipment in a dormitory, resulting in the control of light, temperature, etc. They learn the habits of the user and rules by which to manage those parameters. The system does not require the attention of the user, except for those moments where the user is unhappy with the system's decision and overrides the controls. This way the system learns and, in time, becomes invisible to the user. The organisation of the system is fairly simple, and its main component is a central agent associated with the building. MyCampus [SGK05] is a much more complex system, in which agents retain bases of various knowledge about their users, in what the authors call an e-Wallet. There are also agents associated to public or semi-public services (e.g. printers). The e-Wallet manages issues related to security and privacy. It represents knowledge using OWL and accesses resources as Web Services. The e-Wallet provides context-aware services to the user and learns the user's preferences. Other components of the system are the Platform Manager and the User Interaction Manager, that offer directory and authentication services in a semi-centralised way. The ASK-IT project [SM06] uses agents for the assistance of elderly and impaired persons. It uses the FIPA PTA (Personal Travel Assistance) architecture. There are several types of agents that have different specialization: information retrieval, environment configuration, user monitoring, service provision, etc. The structure and functions are however quite rigid, and there is little adaptation or flexibility of the system's features.

The second approach to agent-based AmI platforms concerns solving different issues like user mobility, distributed control, self-organisation and fault tolerance, having a more global perspective on how an AmI platform should function. The SpacialAgents platform [Sat04] is a very interesting architecture that employs mobile agents to offer functionality on the user's devices. Basically, whenever a device (supposedly held and used by a user), which is also an agent host, enters a place that offers certain capabilities, a Location Information Server (LIS) sends a mobile agent to execute on the device and offer the respective services. When the agent host moves away, the agent returns to the server. Sensing the movement of agent hosts in relation with LISs is done by use of RFID tags. The architecture is scalable, but there is no orientation towards more advanced knowledge representation or context-awareness, however it remains very interesting from the point of view of mobile agents that offer new capabilities.

The LAICA project [CFLZ05] brings good arguments for relying on agents in the implementation of AmI. It considers various types of agents, some that may be very simple, but still act in an agent-like fashion. The authors, also having experience in the field of self-organisation, state a very important idea: there is no need for the individual components to be "intelligent", but it is the whole environment that, by means of coordination, collaboration and organisation, must be perceived by the user as intelligent. The work is very interesting as it brings into discussion important issues like scalability, throughput, delegation of tasks and a middleware that only facilitates interaction, in order to enable subsequent peer-to-peer contact. The application is directed towards generic processing of data, which is done many times in a fairly centralised manner. The structure and behaviour of agents is not well explained, as their role in the system is quite reduced – the middleware itself is not an agent. However, the architecture of the system remains very interesting.

The AmbieAgents infrastructure [LW05] is proposed as a scalable solution for mobile, context-ware information services. There are three types of agents: Context Agents manages context information, considering privacy issues; Content Agents receive anonymised context information and execute queries in order to receive information that is relevant in the given context; Recommender Agents use more advanced reasoning and ontologies in order to perform more specific queries. The structure of the agents is fixed and their roles are set. Although it may be proven effective in pre-programmed scenarios, the system is not very flexible.

The CAMPUS framework [SBS+08] considers issues like different types of contexts [CK00] and decentralised control. It uses separate layers for different parts of an AmI system: *context provisioning* is close to the hardware, providing information on device resources and location, as well as handling service discovery for services available at the current location; *communication and coordination* manages loading and unloading agents, directory services, ACL messaging and semantic mediation, by using the Campus ontology; *ambient services* form the upper layer, that agents can use in order to offer other services in turn. The architecture is distributed, having only few centralised components, like the directory service and the ontology.

There are other resembling proposals for AmI middleware that do not explicitly employ agents. Hellenschmidt et al [HK04, Hel05] propose a generic topology and a self-organising middleware for ambient intelligence (called SodaPop), aimed at coordinating appliances. The devices are not controlled by agents, but by *SodaPop Daemons* that share many features with agents, like reactivity, negotiation capabilities, and a certain degree of autonomy. Each appliance is modelled as having a user interface, an interpreter, a control application and several actuators. Between these units there are three channels, respectively: the events channel, the goals channel and the action channel. The middleware puts these channels in common and introduces negotiation and conflict resolution, so that, for instance, as a result of user input on a device, the controller on another device can action the first device together with a third device. The architecture is very interesting, however scalability is not brought into discussion.

In conclusion of this subsection, there are many approaches to the different issues in Ambient Intelligence. However, there appears to be few or almost no reference on the fact that, in a real-life implementation, AmI is supposed to work at an incomparably larger scale than the type of local scenarios that are usually presented. Also, there is little talk of a generic representation of knowledge or of a scalable manner of managing information in a large AmI system. Many times essential components of the system are centralised. And, although very interesting for different, individual issues of this domain, many times the works do not to take a holistic approach on AmI, as it has been suggested [RVD05].

2.2 Self-Organising Systems

Considering the amount of communicating devices in a real-scale AmI scenario, one may be tempted to look in the domain of self-organisation for solutions on how such a system may achieve a certain goal. Emergence and self-organization [Hey89, Hey02] provide the means to obtain complex properties out of a large number of interacting simple individuals. The possibility to obtain novel, non-additive effects of causal interactions made flourish research in both natural and artificial systems with emergent behavior. In order to model and design artificial systems, inspiration was taken either from self-organising inanimate complex systems, or from complex systems of simple living beings (like ants, wasps, spiders, etc). This is because these types of individuals are easier to understand and model.

A self-organising system is a system that, as a form of adaptation to external conditions, achieves a state of dynamical equilibrium that is characterized by a certain level of organization; organization is achieved without any external or centralised control. The advantages offered by self-organising systems are many, relating to adaptability and flexibility on the one hand, and to robustness, fault tolerance and self-healing on the other. These properties result from the fact that organization is not imposed to the individuals from above, but it is the behaviour of the individuals that contains a natural tendency towards the organised state – the organisation *emerges* from the level below [Sha01].

In the field of Multi-Agent Systems [SGK06], self-organisation has been so far researched mostly by using reactive agents, as they are simpler to implement and the system is easier to predict. Moreover, their properties and behavior are inspired from natural systems. Reactive agents are simple entities, therefore are adequate for deployment on simple devices, sensor networks and for particle computing [MVZ04].

Self-organization in reactive agent systems provides an emergent organization that is of physical (in the sense of spatial or space-related) nature. This is not very unexpected, as the language of the individuals composing the system is also space-related: it describes movement, position, and direction. The emergent property or behavior, although novel and possibly unexpected, is not of a different nature than the properties and behavior of the individual entities, it is just of a higher level.

Some studies are representative for this area of research. Randles [RZTB07] presents a simple example of resource gathering. Mamei and Zambonelli [MZ05] present a system in which, based on states and propagation rules, smart particles organize in circularly symmetric spatial shapes. Beurier [BSF02] also obtains emergent circular shapes, however multi-level self-organization is obtained. Area coverage by using "web weaving" is exemplified by Bourjot [BCT03]. A dynamical self-organization that results in establishing traffic directions spontaneously is presented by Picard and Toulouse [Pic05].

The advantage of obtaining an emergent pattern by means of self-organization is that the agents do not need to be aware of the structure in order to form it. This also applies to emergent behaviour. Moreover, self-organising structures have the properties of flexibility, redundancy and robustness – no individual agent is absolutely necessary to the structure and, to some point, damage to the structure has no permanent effect on it, as the agents reorganize and form the same pattern again. It is important to observe, however, that the resulting structure is always implicitly described in the behavior of the individual agents that form it [MZ05]. Still, explicit structure and organization awareness at the level of individual agents would indeed need agents with better capabilities of representation and reasoning.

There are examples of self-organization in agent systems based on agents having a more elaborate model than the reactive ones, but they are much less frequent [SGK06]. Hoile et al [HWBM02] present an approach in which patterns arise in the genetic codes of agents, depending on the environment they are most fit to. Hales and Edmonds [HE03] discuss emergence of policies in the Prisoner's Dilemma game, considering notions like social actions and showing that cooperative policies lead to a more stable system.

Social actions are also discussed in the context of adaptive systems formed of cooperative agents [GCG99]. This is especially relevant to our work, as it provides a methodology of building a system with emergent properties, starting from the specification of individual agents. That is, agents are designed with specific properties (recognition of cooperation patterns, choice of cooperation) and the obtained, emergent, result, at the level of the system, is a global function for which the agents have been designed, but which is not explicitly present in their specification.

2.3 Context-Awareness

Ambient Intelligence must assist the user throughout many types of daily tasks, like shopping, personal communication, research activities or business meetings. These tasks and contexts are not completely disjunct, and in order for the AmI system to be invisible to the user, there must be the same equipment, the same system software and the agents that manage all these multiple contexts.

Context-awareness is the ability of a system to autonomously adapt to the current context, in order to provide a better response and experience for the user [VMC+08]. Context information may be categorised in several groups. In function of the nature of context information, there are four types of context [CK00]: computational context – available resources, network quality and related information; user context – profile of the user, people nearby, social situation; physical context – lighting, temperature, traffic conditions; time context – time of day, date of the year. By how context information is obtained [DA00], it may be primary – information that is obtained directly, like localization, identity, activity and time – or secondary – information that is inferred or abstracted from the primary information. Context information can also be categorised [FAJ04] as user-centric – user background, dynamic behaviour (intentions, activities), physiological and emotional state – and environmental – physical, social and computational.

Dealing with context and designing context-aware applications is difficult for several reasons. First, there are many types of contextual information. Primary context may be relatively easy to handle, but it is association between different context information that a real context aware application must tackle. Henricksen et al [HIR02] model context with a great focus on the associations that exist between objects. Objects may be entities – people, devices and channels – and attributes – identifiers, location, names, types, activities. Associations may be static or dynamic (temporary); dynamic associations may be sensed, derived, or profiled (entered by the user); associations may be simple or composite – collections (simultaneous conditions), alternative or temporal sequences; finally, associations may have structural constraints, as they may be dependent one on another: for example, having a certain activity depends on being at a certain location. The quality of context information is also a great concern, and the authors propose measures for quality dependent on the type of association. For example, the information that the user has a certain location is associated with an accuracy as well as with a certainty (both of which are represented as probabilities).

As with infrastructures for AmI, and having many common features with them, several solutions have been proposed for context-aware computing. An infrastructure that supports contex-awareness must offer sharing of sensor data, context processing power and context data storage; it must define standard context data formats and communication protocols; access to context data must be controlled and sensitive data must be protected, anonymised or abstracted; finally, a good infrastructure must scale up easily [HL01].

Harter et al [HHS+02] present in great detail a system for sensing the location of users and objects, based on ultrasounds. The system is simple, scalable and offers accurate location and orientation information. The data about the involved entities exists as a distributed CORBA-based object system. The system monitors all entities and enables location-event-based applications. The results are promising, however the system only handles location information.

The Campus infrastructure for AmI uses ontologies to represent context, also discussing problems like choice of ontologies and ontology alignment [VMC+08]. However, ontologies are hard to work with on small devices, so they must reside in a more centralised system. There are other works that propose the use of centralised repositories of data that respond to queries for contex-aware information [FAJ04, LW05, CK00].

There has been little work so far in the distributed management of context information, and in the use of local information that is useful only in a certain context. Also, apart from the alignment of ontologies [VMC+08], information may be aggregated and abstracted locally, even without the use of complete ontologies, but only of concepts that are necessary in the current context.

3 PhD Thesis

3.1 Research Approach and Contribution

In a layered vision of AmI [Seg08], five separate levels may be considered: *the hardware*, composed of various sensors, actuators, devices and other things and materials that contain microprocessors and that have the capacity to interface with the environment, the users and the network; *the network*, that offers the capability of ubiquitous communication, connecting hardware by wire or wirelessly and, many times, by ad-hoc networking; *the software infrastructure*, that offers software support for communication, interoperability, mobile code and remote code invocation; *the ambient services and applications* that offer context-aware, personalised services, by considering the semantic aspect of information, knowledge aggregation and abstraction; and *the user interface* that allows the users to interact with the system in a natural and personalised fashion, by multiple modalities – voice, gestures, etc.

In the framework of this layered perspective, as the state of the art presented before suggests, many challenges in AmI lie at the level of the fourth layer – ambient applications and services. These challenges relate to the fact that, in a real-scale AmI environment, huge quantities of information will be generated throughout the system. Part of this information is private or meant only for certain users; part of it is relevant and / or interesting only in certain context, or to certain people. Moreover, AmI is mainly formed of devices that are not reliable from the point of view of the system: they may go in and out of the network coverage, they may shutdown or wake up without notice, and they may use heterogeneous hardware and different (in type, quality and cost) ways to connect to the network. Considering these conditions, the way that information should move through the system and how it should used and modified by the individual devices is particularly challenging, and it is a central concern of any AmI environment that aspires to be reliable and trustworthy.

This research tries to answer some of these challenges, by providing a model for an AmI system's application layer. The proposed solution relies on several key features that are described below.

The very nature of AmI calls for *system distribution*. The vast majority of AmI hardware is comprised of devices with small or medium computing power and storage resources, like mobile phones, smartphones, PDAs, netbooks and laptops. Not to mention the huge number of very small sensors and actuators. Even if there are more powerful nodes in the system, a reliable AmI environment must feature completely distributed control, so that its functioning will not be vitally affected by the disappearance or temporary unavailability of any device in the environment [DBS+01, Sat01].

The required characteristics of most devices in an AmI environment – especially the ones that provide a user interface – are responsiveness, an important level of autonomy, considerable proactivity and a certain level of anticipation. Semantic awareness and reasoning are also required. These features are exactly the ones that are offered by *software agents*. Therefore the use of the multi-agent system paradigm is probably the most appropriate for an implementation of AmI [RAS08].

Reliability, flexibility and fault tolerance – important requirements for AmI's property of being invisible [Wei93] – as well as the large number of locally interacting, individual, fairly limited entities imply the use of advancements from another field, related to multi-agent systems: self-organising systems. *Self-organisation* offers the means to coordinate a large number of agents and obtain, by means of local interaction and without the need for centralised control, global properties that are not even perceived by the individuals [SGK06].

Another component of the proposed solution for AmI is *context-awareness*, which is vital to any AmI implementation. All typical services offered by AmI environments take into account some type of context [VMC+08]. Most times it is location, but context-awareness also means considering the moment of time, the surrounding people, the available computing and network resources and the state of the user, its intentions and plans. Anticipating the user's actions is adding both to the invisibility (because the system will not show lack of foresight) and to the helpfulness of AmI.

3.2 Thesis Title and Goals

The title of my PhD thesis is:

"A Context-Aware Multi-Agent System for AmI Environments"

The goals of my thesis research are the following:

- to develop a multi-agent system model for Ambient Intelligence that features self-organisation, context-awareness and anticipation;
- to develop several scenarios that emphasize the requirements of real-scale Ambient Intelligence environments;
- to develop a simulation testbed that implements the elements of the said scenarios, to serve for experiments with AmI platforms;
- to implement and experiment with the developed model, using the simulation testbed, in order to prove the model's validity as a component of an Ambient Intelligence environment.

3.3 Intermediary Results

The intermediary results of my research will be presented in two research reports, that will present the progress in the development of the PhD thesis. The title and short descriptions of the reports are as following:

- *Towards a MAS-based model for Ambient Intelligence.* The report will present an in-depth state of the art on AmI research and challenges and the basic elements of the multi-agent model for Ambient Intelligence. The model will specify the types, structure and behaviour of individual agents – the representation of the agents' beliefs, goals and plans, as well as the way in which the agents interact. The agents will feature context-awareness and mechanisms related to the management, aggregation and abstraction of information.
- *Experiments with a MAS for Ambient Intelligence.* The report will present an overview of the current research efforts of using intelligent agents in AmI and details on the implementation of the model developed priorly. Several relevant scenarios will be conceived towards testing the viability of the model in conditions that are closer to real life.

3.4 Acknowledgements

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