Abstract - Nowadays there is a clear trend towards using methods and tools that can develop multi-agent systems (MAS) capable of reorganization and adapting to changes within their environment. To that end, this article intends to identify and analyze the research topics that deal with the development of open MAS based on virtual organizations. Additionally, a case study will be presented in which it was possible to apply a high level abstract architecture specifically addressed for the design of open multi-agent systems and virtual organizations.

Keywords: Multi-agent systems, virtual organizations, Open multi-agent systems

1 Introduction

Autonomous, robust, flexible and adaptive are typically the preferred characteristics when it comes to designing current application software. To achieve this, it is necessary to have theories, models, mechanisms, methods and tools that can develop systems capable of reorganization and adaptable to future changes in their environment. This new type of proposal is very useful for the design of applications in complex and highly dynamic domains such as autonomic or ubiquitous computing.

One of the goals of multi-agent systems is to construct systems capable of autonomous and flexible decision-making, and of cooperating with other systems within a “society”. This “society” should take certain characteristics into account, such as distribution, constant evolution, or a flexibility that allows its members (agents) to enter and exit at will, a correct organizational structure, and the ability for the system to be executed on different types of devices. Each of these characteristics can be achieved through the open multi-agent system and virtual organization paradigm. This paradigm was conceived as a solution to the management, coordination and control of the agents’ behavior.

Organizations should not only be able to describe the structural composition (i.e. functions, agent groups, interactive and relationship patterns between roles) and the functional behavior (i.e. agent tasks, plans or services), but should also be able to describe the behavioral norms for the agents, the entry and exit of dynamic components, and the formation, which is also dynamic, for the groups of agents.

Dynamic agent organizations that automatically adjust to optimize their current surroundings are becoming more and more important. These organizations could appear in dynamic or emerging agent societies such as what is seen with Grid domains, ambient intelligence or others in which the agents are dynamically grouped in order to offer combined services and can evolve with time. The social factors that permit arriving at a solution within multi-agent system organizations are also becoming more important for structuring interactions within open and dynamic worlds. Any infrastructure that can support the execution of multi-agent applications within these environments must be robust, efficient and adaptive over time [10].

Given the characteristics of these open environments, particularly their dynamism, it is essential to find a new approach to support the evolution of these systems and to facilitate their growth and update in execution time.

In general, it is necessary to define the standards and platforms required for the interoperability of the agents that meet these requirements. This article attempts to identify and analyze the research topics that touch on the development of open MAS systems based on virtual organizations. Additionally, it will present a study in which a high level abstract architecture was applied with the specific intent of addressing the design of open multi-agent systems and virtual organizations.

The article is structured as follows: section 2 describes the panorama of open and adaptive MAS; section 3 presents the challenges for Open-MAS; sections 4 and 5 introduce an abstract architecture specifically adapted to the design of open multi-agent systems and virtual organizations, as well as an application in a case of study; finally some conclusions are given in section 6.

2 Multi-agent Systems Outline

MAS is a general technology software that is driven by fundamental research-oriented questions about autonomy,
cooperation, group formation, etc. A MAS can be classified as either open or closed, whereby the fundamental difference between the two is that the closed MAS is created with a single structure and fixed objectives, while in an open system, the agents can enter or exit dynamically and are not necessarily designed to share common objectives. This study focuses specifically on open systems.

2.1 Open Multi-agent Systems

Open systems [32] exist in dynamic operative environments in which new components are integrated, or existing components continuously leave the system, and in which the actual operating conditions can change unpredictably. Open systems are characterized by the heterogeneity of their participants, limited trust, conflicting individual objectives, and a high probability of discontent with the specifications [15].

The design and construction of agents and their subsequent behavior depend not only on the internal architecture for the agents, but also on the agent platform on which they are located. The main function of an agent platform is to establish a framework for the execution of the agents that comprise the platform. With this in mind, the last few years have seen a number of research projects that attempted to offer such a framework: Electronic Institutions [13], RICA-J [26], Magentis[15], SIMBA [18] [28], SPADE [12].

The platforms that existed up until a few years ago focused on the design of the agents participating in the system. As such, they could not be directly applied to the development of open multi-agent systems in which the participants of the system were not known a priori. The THOMAS (MeTHods, Techniques and Tools for Open Multi-Agent Systems) [1] platform, which will be discussed in section 4 of this article, focuses on the interaction between agents, regardless of their characteristics, and arose from the need for a platform that focused on organizational concepts capable of influencing and limiting the scope of action of the agents forming part of the platform.

2.2 Adaptive Multi-agent Systems

The Agentlink Technical Forum on Self-Organisation in MAS [9] established two definitions for self-adapting systems, one in the more strict sense, the other less so:

i) self-adapting systems can change their organization without a centralized, explicit, implicit, external or internal control;

ii) self-adapting systems can be reorganized as a result of planning carried out by an internal central control.

The different proposals for obtaining adaptive multi-agent systems can be divided into the following classes, according to the mechanisms used:

- Mechanisms based on direct interactions: these work by using the basic principles of location and emission of messages, together with interactions and local calculations for the agents, in order to offer an overall coherent system state [31]. These studies focus on the change in structural aspects such as the topology for agent communication.

- Mechanisms based on indirect interactions: these mechanisms obtain a complex behavior/performance for the system based on the indirect interaction between agents. These interactions are a result of changes in the environment [24].

- Reinforcement-based mechanisms: these kinds of proposals are based on the ability of the agents to dynamically modify their behavior according to some type of reinforcement. This assumes that positive reinforcement increases agent behavior while negative reinforcement, in turn, produces a decrease [30].

- Cooperation-based mechanisms: these kinds of jobs are based on the primitives for the composition and decomposition of agents. Decomposition includes the separation of an agent in two, thereby attending to an overload that can take place at any particular moment. Composition, on the other hand, is the reverse mechanism whereby two agents are fused into one when there is a low work load [6].

- Mechanisms based on generic architectures: these mechanisms are based on meta-models and architectures that reference agent organizations that are modified and adapted according to the needs for each particular application. These dynamic modifications can be carried out automatically or through user intervention [23].

3 Requirements for Open MAS

The complexity of open-systems is very high and current technology to cover all the described functionalities is lacking.

There are some new requirements that still need to be solved. These requirements are imposed mainly by:

- computation as an inherently social activity
- emergent software model as a service
- a non-monolithic application
- computational components that form coalitions, or virtual organizations, with an autonomous and coordinated behavior
- distributed execution environments with wireless connection technology
• multi-device execution platforms with limited resources
• security and privacy policies for information processing; etc.

In order to satisfy all of those requirements, current technology must provide interaction features between independent (and usually intelligent) entities, that can adapt, coordinate and organize themselves.

Agent computation is a promising paradigm since it offers a clear support for those requirements. However, satisfying these requirements calls for an agent technology capable of incorporating several methods, techniques, tools and frameworks that support these new computational needs in an efficient and robust way. The main open issues that have been identified for obtaining real open MAS are the following:

• A detailed research and analysis of existing methodologies for the analysis and design of open MAS. Recently, researchers have carried out several studies that offer new procedures and methodologies for enabling the design of open MAS. Some examples of those approaches are Tropos [14], RICA [26] and the new version of Gaia [32]. Many of the recent studies focus not only on the employment of organizational structures during the design process, but also on the regulation of open multi-agent systems (Electronic Institutions [21], Moise+ [17], OMNI [11]), which are normally classified as “virtual organizations”. Nevertheless, the abstractions and tools currently available are still not enough for many kinds of open multi-agent systems that deal with real world problems.

• Definition and development of multidevice support platforms that allow the secure and optimized management of multi-agent open systems. In the last years, many research or commercial works have appeared offering this framework. Most notable are JADE, FIPA-OS, Grasshopper, Jack, ZEUS, AgentScape, MadKit, EIDE, RICA-J [26], SIMBA [18] and SPADE [12]. These platforms cannot be directly applied to the development of open multi-agent systems where organizational structures can emerge and change dynamically at runtime. Therefore it seems necessary to create new platforms that offer a suitable execution framework for the development of virtual organizations.

• Improving the coordination methods in decentralized open systems, based on locating techniques and composition of both syntactic and semantic services. Most current studies are strongly associated with Web services, so they do not take into account regulation aspects and mainly focus on heterogeneity problems in MAS systems (“intelligent” location). It is necessary to employ expressive-marked languages such as OWL [22] for the creation of domain ontologies.

• Necessity of adaptive mechanisms for creating organizational structures that allow optimizing the coordination in open systems taking the heterogeneity of agents and services into account. It is necessary to have the possibility of employing basic mechanisms that - based on certain desirable criteria – are able to locate adequate services in open decentralized systems and, if necessary, construct new services through service composition.

• Existence of regulatory mechanisms that guarantee a globally efficient coordination in open systems taking into account the impossibility of controlling (the majority of) the agents and services directly.

• Adaptation of the most appropriate wireless technology for the implementation of this kind of systems, allowing the communication between agents on intermittent channels to be decentralized. Nowadays, there are still many problems with the wireless transmission of data and security that need to be resolved. Some of those problems are low bandwidth, security, mobile routing or heterogeneity of devices.

• Development of light reasoning mechanisms based on planning and replanning systems in execution time appropriate for agents in any device. Some current studies, such as [19], employ planning techniques that cannot tackle environmental changes nor produce real-time modifications. The research in [5] proposes an architecture that tries to be more flexible in the replanning process. However, it cannot be applied to problems in which the system dynamics forces decisions to be made in real time. In this last field, several based-case reasoning planners have been employed, providing different degrees of success, such as PARIS [4] or PRODIGY [29].

• Development of a security policy at the agent-level, which is still a problem to solve in agent based systems and is an even bigger problem in open systems. Suggested solutions include a kind of library or service that offers security mechanisms for agents based on Public Key Infrastructure (PKI), for example [20]. Others have adopted the idea of “intelligent objects” that propose employing secure agents that engage in protected communication [16].

4 Architecture Model

In order to model open and adaptive multi-agent systems, it becomes necessary to have an infrastructure that can use agent technology in the development process and apply decomposition, abstraction and organization techniques, while keeping in mind all of the previous requirements. The proposed methodology used in this study uses the
THOMAS architecture [1][7], a multi-agent system in a dynamic environment, to deal with decomposition and abstraction.

THOMAS [1][7] is the name given to an abstract architecture for large scale, open multi-agent systems. It is based on a services oriented approach and primarily focuses on the design of virtual organizations.

The architecture is essentially formed by a set of services that are modularly structured. THOMAS uses the FIPA architecture, expanding its capabilities with respect to the design of the organization, while also expanding the services capacity. THOMAS has a module with the sole objective of managing organizations that have been introduced into the architecture, and incorporates a new definition of the FIPA Directory Facilitator that is capable of handling services in a much more elaborate way, following the service-oriented architecture directives.

From a global perspective, the THOMAS architecture offers a total integration enabling agents to transparently offer and request services from other agents or entities, at the same time allowing external entities to interact with agents in the architecture by using the services provided.

5 Case of Study

The real case study proposed for the analysis is a shopping mall. Within this framework, open multi-agent system technology will make it possible to provide better services to the shopping mall clients. The main goal is to develop an open system, capable of incorporating as many agents as necessary, that can provide useful services to the clients not only in a shopping centre, but also in any other environment such as the labor market, educational system, medical care, etc.[3][8]

Over the years, shopping malls have become the most common alternative to traditional store shopping, with the added benefit of offering leisure areas, food and entertainment within the same complex. The size, store specialties, common services and additional activities are generally determined by demographic factors. Despite the differences that may exist, all shopping malls have certain common characteristics with regards to their management and image. Generally speaking, a shopping mall can be seen as a large, adaptive virtual organization whose management depends on the variability of its products, users, opinions, etc. [5].

The example of the shopping mall is an application that facilitates interaction among users (the mall clients) and the store information, sales and recreational activities (entertainment, events, attractions, etc.) that determine the services that can be requested and offered.

The system controls which services should be offered by each agent. The internal functionality of those services is the responsibility of the “Provider” agents. However, the system imposes certain restrictions with regards to profile, request orders, and service results. Below is a detailed description of the elements that comprise the organization of a shopping mall.
Firstly of all it is necessary to analyze the shopping mall dimensions, and then identify the structure that is best suited to apply to the system [2]. Our case study is modeled as a conglomerate (ShoppingUnit) made up of five units, each one dedicated to one type of a single functionality within the setting [25]. The five units are: (i) ClientUnit, which contains the roles associated with the client: Communicator, Finder, and Profile Manager; (ii) BusinessUnit, which contains the roles associated with a business: Promotions Manager, Warehouse Operator; (iii) ManagingUnit, which contains the roles assigned with global management tasks for the mall: Incident Manager, Client Manager, and Analyst; (iv) RecommendationUnit, which contains the roles dealing with recommendations or suggestions made to the client: Planner and Directory Manager; (v) DeviceUnit, which contains the roles associated with the management of devices: Device Manager.

The clients use the agents on their devices to consult the store directory for the mall, to receive notices for special offers or personalized promotions, to ask for a recommended path to follow through the mall, or to locate other clients (using RFID (Radio Frequency Identification) technology [27]). The Guiding agent, which can be considered the heart of the system, receives updated information from each of the stores and interacts with the clients by providing personalized service.

The main idea, which can be considered the base of the system, is the ability of users in a shopping mall to be able to access information related to products, offers or leisure activities (entertainment, events, attractions, etc.) by using their mobile phone or PDA. In this way, the shopping mall users can use a suggestion and guidance system that allows them to follow suggested recommendations that make the best use of the time and money available according to their personal characteristics and preferences.

This type of open system has to be modeled. Thus, an appropriate analysis and design methodology has to be chosen or has to be developed, and an organizational structure must be designed.
Considering the example and our experience in the multi-agent area, the requirements of section 3 need to be solved.

6 Conclusions

An important issue in the development of real open multi-agent systems is to provide developers with methods, tools and appropriate architectures which support all of the requirements of these kinds of systems. Traditional MAS development methodologies are not suitable for developing open MAS because they assume a fixed number of agents that are specified during the system analysis phase. It then becomes necessary to have an infrastructure that can use the concept of agent technology in the development process, and apply decomposition, abstraction and reorganization methods.

Based on this, we identified a set of requirements for the construction of complex software systems that address this kind of problems and have come up with a set of requirements for a multi-agent architecture aimed at notoriously open environments: THOMAS. In presenting this architecture, we have considered each of these points in the process of integrating our previous study [3]. As this article points out, the current focus in this type of system does not take sufficient advantage of the organizational aspects of MAS.

The hypothesis in this study involved applying autonomous capabilities to a virtual organization, thus allowing a dynamic response when facing the expected changing situations produced by the adaption and/or evolution of the actual organization. As a result, the organization would be capable of detecting potential situations of interest, such as functioning errors, and be able to manage them by maximizing its flexibility and adaptive ability. The adaption of the organization involves, among other aspects, its norms, agreements, obligations and topological structure.

For these reasons, the goal of our research was to supply the mechanisms, architectures, tools and models related to the reorganization of dynamic agent organizations. The main objective of the THOMAS architecture that we presented is to provide multi-agent based technologies that are necessary for the development of virtual organizations in open environments, but without considering aspects related to adaption or reorganization, given that the organization needs to evolve as a consequence of the changes in its surroundings. This study identified the main points that can help to improve THOMAS and other similar architectures.

The complexity of the system proposed in the case study is very high and current technology to cover all the described functionalities is lacking. OVAMAH is based on THOMAS; as such it is in THOMAS where we will make the necessary modifications so that the system can be used as a model for adaptive virtual organizations.

The next steps in our research agenda include further refinement and a more rigorous specification of our abstract architecture. At the same time, we will advance on the integration of our existing software components, and the development of new functionalities required by the THOMAS architecture. Finally, towards the end of the THOMAS project, we intend to validate our approach through additional case studies in environments similar to the one described in this paper in the Tormes shopping centre at Salamanca.

References


