Organizations of Agents in Information Fusion Environments

Dante I. Tapia[1], Fernando de la Prieta[1], Sara Rodríguez González[1], Javier Bajo[2], and Juan M. Corchado[1]

[1] University of Salamanca, Salamanca, Spain
{dantetapia,fer,srg,corchado}@usal.es
[2] Pontifical University of Salamanca, Salamanca, Spain
jbajope@upsa.es

Abstract. Information fusion in a context-aware system is understood as a process that assembles assessments of the environment based on its goals. Advantages of intelligent approaches such as Multi-Agent Systems (MAS) and the use of Wireless Sensor Networks (WSN) within the information fusion process are emerging, especially in context-aware scenarios. However, it has become critical to propose improved and efficient ways to handle the enormous quantity of data provided by these approaches. Agents are a suitable option because they can represent autonomous entities by modeling their capabilities, expertise and intentions. In this sense, virtual organizations of agents are an interesting option/possibility because they can provide the necessary capacity to handle open and heterogeneous systems such as those normally found in the information fusion process. This paper presents a new framework that defines a method for creating a virtual organization of software and hardware agents. This approach facilitates the inclusion of context-aware capabilities when developing intelligent and adaptable systems, where functionalities can communicate in a distributed and collaborative way. Several tests have been performed to evaluate this framework and preliminary results and conclusions are presented.

Keywords: Information Fusion, Wireless Sensor Networks, Multi-Agent Systems, Virtual Organizations.

1 Introduction

At present there are small, portable and non-intrusive devices that allow agents to gather context-information in a dynamic and distributed way [1]. However, the integration of such devices is not an easy task. Therefore, it is necessary to develop innovative solutions that integrate different approaches in order to create open, flexible and adaptable systems.

The scientific community within the realm of information fusion remains heir to the traditions and techniques of sensor fusion, which is primarily concerned with the use of sensors to provide information to decision systems. This has led to most models of information fusion processes being directed by data fusion in which the

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sensors and data are the central core. One way to accomplish this process is to apply an intelligent approach such as MAS within the fusion process. Agents are suitable for fusion because they can represent autonomous fusion entities by modeling their capabilities, expertise and intentions [22] [2].

MAS allow the participation of agents within different architectures and even different languages. The development of open MAS is still a recent field in the MAS paradigm, and its development will enable the application of agent technology in new and more complex application domains. However, this makes it impossible to trust agent behavior unless certain controls based on social rules are imposed. To this end, developers have focused on the organizational aspects of agent societies to guide the development process of the system.

This article describes an agent approach to fusion applied to dynamic contexts based on the HERA (*Hardware-Embedded Reactive Agents*) [1] and OVAMAH (*Adaptive Virtual Organizations: Mechanisms, Architectures and Tools*) platforms [14].

In HERA agents are directly embedded on the WSN nodes and their services can be invoked from other nodes (including embedded agents) in the same WSN, or another WSN connected to the former one. The OVAMAH platform allows the framework to incorporate the self-adaptive organizational capabilities of multi-agent systems and create open and heterogeneous systems.

This article is structured as follows: the next section presents the related approaches. Section 3 shows the framework proposal, including the description of the HERA and OVAMAH platforms, the core of the system. Sections 4 and 5 present some results and conclusions obtained.

2 Technological Approaches

Recent trends have shown a number of MAS architectures that utilize data merging to improve their output and efficiency. Such is the case of Castanedo et al. [4], who propose the CS-MAS architecture to incorporate dynamic data fusion through the use of an autonomous agent, locally fused within the architecture. Other models, such as HiLIFE [17], cover all of the phases related to information fusion by specifying how the different computational components can work together in one coherent system.

Despite having all the advantages of MAS, these kinds of systems are monolithic. In an environment in which data heterogeneity is a key feature, it is necessary to use systems with advanced capacities for learning and adaptation. In this regard, an approach within the field of MAS that is gaining more weight in recent times is the consideration of organizational aspects [3], and more concretely those based on virtual organizations (VO).

Currently, there are no virtual organization-based applications oriented to fusion information. However it is possible to find some approaches that try to propose advances in this way. For example, the e-Cat System [10] focuses on the distribution and integration of information. This system is based on enhancing the skills or abilities of members of the organization by defining the different types of skills and relationships that exist between them. This organization aims to ensure the maximum independence between the different partnerships created, and information privacy.

Another example, perhaps more centralized in the fusion of information, is the KRAFT (Knowledge Reuse and Fusion / Transform) architecture [12], which proposes an implementation of agents where organizational aspects are considered to support the processes of heterogeneous knowledge management.

The approach proposed in this article presents an innovative model where MAS and VO are combined to obtain a new architecture specifically oriented to construct information fusion environments.

The following section discusses some of the most important problems of existing approaches that integrate agents into wireless sensor networks, including their suitability for constructing intelligent environments. It also describes the proposed integration of information fusion systems that use the capabilities of multi-agent systems for a particular activity, including reading data from sensors and reacting to them.

3 Integration Framework

3.1 Motivation

An intelligent fusion system has to take contextual information into account. The information may be gathered by sensor networks. The context includes information about the people and their environment. The information may consist of many different parameters such as location, the building status (e.g. temperature), vital signs (e.g. heart rhythm), etc. Each element that forms part of a sensor network is called a node. Each sensor node is habitually formed by a microcontroller, a transceiver for radio or cable transmission, and a sensor or actuator mechanism [11]. Some nodes act as routers, so that they can forward data that must be delivered to other nodes in the network. There are wireless technologies such as Wi-Fi, IEEE 802.15.4/ZigBee and Bluetooth that enable easier deployments than wired sensor networks [16]. WSN nodes must include some type of power manager and certain smart features that increase battery lifetime by having offering? worse throughput or transmission delay through the network [16].

In a centralized architecture, most of the intelligence is located in a central node. That is, the central node is responsible for managing most of the functionalities and knowing the existence of all nodes in a specific WSN. That means that a node belonging to a certain WSN does not know about the existence of another node forming part of a different WSN, even though this WSN is also part of the system. For this reason, it is difficult for the system to dynamically adapt its behavior to changes in the infrastructure.

The combination of agents and WSNs is not easy due to the difficulty in developing, debugging and testing distributed applications for devices with limited resources. The interfaces developed for these distributed applications are either too simple or, in some case, do not even exist, which further complicates their maintenance. Therefore, there are researches [20] [23] [8] [5] [6] [13] that develop methodologies for the systematic development of MAS for WSNs.

The HERA platform tackles some of these issues by enabling an extensive integration of WSNs and optimizing the distribution, management and reutilization of the available resources and functionalities in its networks. As a result of its underlying platform, SYLPH [18], HERA contemplates the possibility of connecting wireless sensor networks based on different radio and link technologies, whereas other approaches do not.

HERA allows the agents embedded into nodes to work in a distributed way and does not depend on the lower stack layers related to the WSN formation (i.e. network layer), or the radio transmission amongst the nodes that form part of the network (i.e. data link and physical layers).

HERA can be executed over multiple wireless devices independently of their microcontroller or the programming language they use. HERA allows the interconnection of several networks from different wireless technologies, such as ZigBee or Bluetooth. Thus, a node designed over a specific technology can be connected to a node from a different technology. This facilitates the inclusion of context-aware capabilities into intelligent fusion systems because developers can dynamically integrate and remove nodes on demand.

On the other hand, if current research on agents is taken into account, it is possible to observe that one of the most prevalent alternatives in distributed architectures are MAS. An agent, in this context, is anything with the ability to perceive its environment through sensors, and to respond through actuators. A MAS is defined as any system composed of multiple autonomous agents incapable of solving a global problem, where there is no global control system, the data is decentralized and the computing is asynchronous [22]. There are several agent frameworks and platforms [20] that provide a wide range of tools for developing distributed MAS.

The development of agents is an essential component in the analysis of data from distributed sensors, and gives those sensors the ability to work together. Furthermore, agents can use reasoning mechanisms and methods in order to learn from past experiences and to adapt their behavior according to the context [22]. Given these capacities, the agents are very appropriate to be applied in information fusion.

The most well-known agent platforms (like Jade) offer basic functionalities to agents, but designers must implement nearly all organizational features, such as the communication constraints imposed by the organization topology. In order to model open and adaptive VO, it becomes necessary to have an infrastructure than can use agent technology in the development process and apply decomposition, abstraction and organization techniques. OVAMAH [3] 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 VO.

In HERA agents are directly embedded on the WSN nodes and their services can be invoked from other nodes (including embedded agents) in the same WSN or other WSNs connected to the former one. By using OVAMAH, the framework can incorporate the self-adaptive organizational capabilities of multi-agent systems and create open and heterogeneous systems.

3.2 Proposed Information Fusion Framework

The way in which information fusion is held together is the key to this type of system. In general, data can be fused at different levels [9]:

- sensor level fusion, where multiple sensors measuring correlated parameters can be combined;
- feature level fusion, where analysis information resulting from independent analysis methods can be combined;
- decision level fusion, where diagnostic actions can be combined.

These levels generally depend on many factors. In order to provide the most generic and expandable system that can be applied to a wide variety of engine applications with varied instrumentation and data sources, we have chosen to perform the information fusion at the three levels shown in Figure 1.

At the level sensors, HERA makes it possible to work with different WSNs in a way that is transparent to the user. A node in a specific type of WSN (e.g. ZigBee) can directly communicate with a node in another type of WSN (e.g. Bluetooth).

At higher levels (features and decision), it is possible to detect changes in the environment and its consequent action in the system. This consequent action can be managed on the platform as a result of the services and functions that comprise the agents of the organization. For example, if a change within a node (a change of light for instance) is detected at sensor level, the agents at a higher level can decide to send a warning message or perform an action.

This scheme provides for the potential inclusion of a variety of sensors as well as other devices of diagnostic relevant information that might be in the form of maintenance records, monitoring and observations. The framework provides for information synchronization and high-level fusion [21].

The principal objective of the high level fusion shown in Figure 1 is to transform multiple sources of several kinds of sensors and performance information into a monitoring knowledge base. Embedded in this transformation process is a fundamental understanding of node of WSN functions, as well as a systematic methodology for inserting services to support a specific action according to information received by the node.

The framework proposes a new and easier method to develop distributed multi-agent systems, where applications and services can communicate in a distributed way, independent of a specific programming language or operating system. The core of the architecture is a group of deliberative agents acting as controllers and administrators for all applications and services. The functionalities of the agents are not inside their structure, but modeled as services. This approach provides the systems with a higher ability to recover from errors, and a better flexibility to change their behavior at execution time.

The agents in the organization can carry out complex tasks as well as react to changes that occur in the environment. To do this, the agents incorporate an innovative planning model that provides the organization with advances self-adaptive capacities [15].

3.3 The HERA Platform

As indicated in the previous section, this paper aims to describe a new framework for information fusion based on the concept of virtual organizations of agents and multi-agents. This framework uses a sensor platform (HERA) in order to gather the data. Consequently, the description of HERA is general, and describes only the most relevant aspect related to the framework.

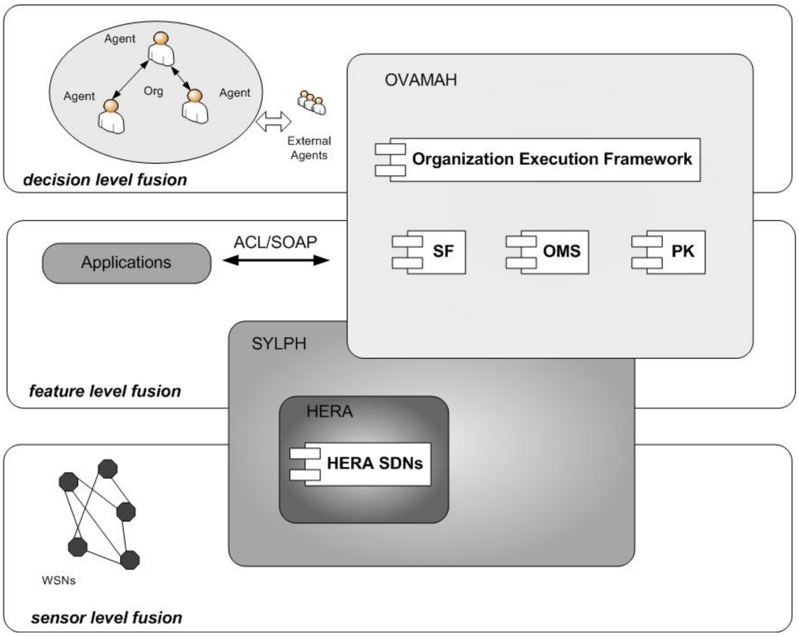

Fig. 1. Proposed framework

HERA facilitates agents, applications and services communication through of using dynamic and self-adaptable heterogeneous WSNs. In HERA, agents are directly embedded in the WSN nodes and their services can be invoked from other nodes in the same network or from other networks connected to the former one. HERA is an evolution of the SYLPH platform [18]. SYLPH follows a SOA model for integrating heterogeneous WSNs in intelligent systems. HERA goes a step beyond SYLPH by embedding agents directly into the wireless nodes and allowing them to be invoked from other nodes either in the same network or in another network connected to the original.

The HERA agent platform adds its own agent layer over SYLPH [18][19]. Thus, HERA takes advantage of one of the primary features of SYLPH: it can be run over any wireless sensor node regardless of its radio technology or the programming language used for its development.

The HERA Agents Layer (or just HERA) can run HERA agents, which are specifically intended to run on devices with reduced resources. To communicate with each other, HERA agents use HERACLES, the agent communication language designed for use with the HERA platform. Each HERA agent is an intelligent piece of code running over a node. As explained below, there must be at least one facilitator agent in every agent platform. This agent is the first one created in the platform and acts as a directory for searching agents. In HERA, this agent is referred to as the HERA-SDN (HERA Spanned Directory Node).

The HERA Communication Language Emphasized to Simplicity (HERACLES) is directly based on the SSDL language. As with SSDL, HERACLES does not use intermediate tags and the order of its elements is fixed to constrain the resource needs of the nodes. This makes its human-readable representation, used by developers for coding, very similar to SSDL. When HERACLES is translated to HERACLES frames, the actual data transmitted amongst nodes, they are encapsulated into simple SSDL frames using “HERA” as their service id field.

Every agent platform needs some kind of facilitator agent that must be created before other agents are instantiated in the platform. Facilitator agents act as agent directories. This way, every time an agent is created, it is registered to one of the existing facilitator agents. This allows other agents to request one of the facilitator agents in order to know where an agent with certain functionalities is located, and how to invoke its (desired?) functionalities. As HERA is intended to run on machines that are not more complex than the sensor nodes themselves, it was necessary to design some hardware facilitator agents that do not need more CPU complexity and memory size than what a regular sensor node has. In HERA, the hardware agents communicate with each other through the HERA Communication Language Emphasized to Simplicity (HERACLES).

Because HERA is implemented over SYLPH through the addition of new layers and protocols (HERA Agents and HERACLES), it can be used over several heterogeneous WSNs in a transparent way.

3.4 OVAMAH

OVAMAH is the chosen platform for the creation of the organization of agents in the proposed framework. The most well-known agent platforms (e.g. JADE) offer basic functionalities to agents, such as AMS (Agent Management System) and DF (Directory Facilitator) services; but designers must implement nearly all of the organizational features by themselves, such as the communication constraints imposed by the organization topology. In order to model open and adaptive virtual organizations, 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 requirements cited in the previous section. OVAMAH is the name given to an abstract architecture for large-scale, open multi-agent systems. It is based on a service 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. It uses the FIPA architecture, expanding its capabilities with respect to the design of the organization, while also expanding the services capacity. The architecture 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 service-oriented architecture directives.

OVAMAH consists of three principal components: Service Facilitator (SF), Organization Manager Service (OMS) and Platform Kernel (PK).

The SF primarily provides a place where autonomous entities can register service descriptions as directory entries. The OMS component is primarily responsible for specifying and administrating its structural components (role, units and norms) and its execution components (participating agents and the roles they play, units that are active at each moment). In order to manage these components, OMS handles the following lists: UnitList: maintains the relationship between existing units and the immediately superior units (SuperUnit), objectives and types; RoleList: maintains the relationships between existing roles in each unit, which roles the unit inherits and what their attributes are (accessibility, position); NormList: maintains the relationship between system rules; EntityPlayList: maintains the relationship between the units that register each agent as a member, as well as the role that they play in the unit. Each virtual unit in OVAMAH is defined to represent the "world" for the system in which the agents participate by default. Additionally, the roles are defined in each unit. The roles represent the functionality that is necessary for obtaining the objective of each unit. The PK component directs the basic services on a multi-agent platform and incorporates mechanisms for transporting messages that facilitate interaction among entities.

Open-systems are highly complex 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: (i) computation as an inherently social activity; (ii) emergent software models as a service; (iii) a non-monolithic application; (iv) computational components that form virtual organizations, with an autonomous and coordinated behavior; (v) distributed execution environments; (vi) multi-device execution platforms with limited resources and (vii) security and privacy policies for information processing. In order to satisfy all of those requirements, the architecture must provide interaction features between independent (and usually intelligent) entities, that can adapt, coordinate and organize themselves [14] From a global perspective, the architecture offers total integration, enabling agents to transparently offer and request services from other agents or entities and at the same time, and allowing external entities to interact with agents in the architecture by using the services provided. Reorganization and adaptation features in the agent´s behavior are necessary for this platform, for which we have proposed a social planning model [15]. This social planning model offers the possibility of deliberative and social behavior. It is worth mentioning that this is a unique model that incorporates its own reorganization and social adaptation mechanism. The architecture facilitates the development of MAS in an organizational paradigm and the social model adds reorganization and adaptation functions.

4 Results

The case study shows the potential of VO in the design and development of systems for information fusion. In order to evaluate the proposed framework, different tests were performed. In this section we present the results obtained with the aim of valuating two main features: Firstly, the advantages obtained with the integration of the HERA platform as related to the use of resource constrained devices, and secondly the impact and performance of the organizational structure.

An organization is implemented by using the model proposed in [7]. The simulation within the virtual world represents an e-health environment, and the roles that were identified within the case study are: Communicator, SuperUser, Scheduler, Admin, Device Manager, Incident Manager.

In order to evaluate the impact of the development of the MAS using an organizational paradigm, it is necessary to revise the behavior of the MAS in terms of its performance. A prototype was constructed based on OVAMAH, which could be compared to the previous existing system [7]. The MAS shown in this study is not open and the re-organizational abilities are limited, since the roles and norms cannot be dynamically adapted. As can be seen in the Table 1, the system proposed in this study provides several functional, taxonomic, normative, dynamics and adaptation properties. The organizational properties are a key factor in an architecture of this kind, but the capacity for dynamic adaptation in execution time can be considered as a differential characteristic of the architecture.

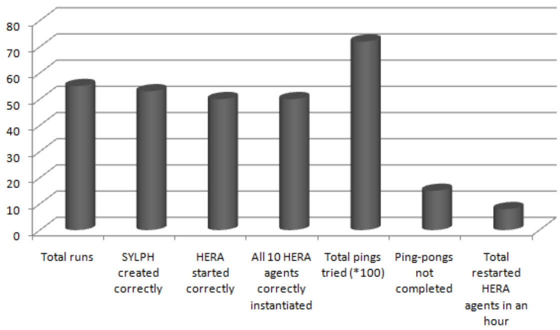

Fig. 2. Results of the HERA performance experiments

Table 1. Comparison of organizational and no organizational systems

Features		**No organization system**	**Organizational system**
Functional	BDI Model	Yes	Yes
Taxonomic	Group		Yes
	Topology		Yes
	Roles		Yes
	Interactions	Yes	Yes
Normative	Norms		Yes
Dynamics	Agent Joining	Yes	Yes
	Role Enactment		Yes
	Behaviour control	Yes	Yes
	Org. Joining		Yes
Adaptation	Taxonomic		Yes
	Normative		Yes
	Functional	Yes	Yes

In order to test the HERA platform, a distributed WSN infrastructure with HERA running over it was developed. This experiment consisted of trying to start a platform with HERA over a ZigBee SYLPH network infrastructure. The infrastructure consisted of a ZigBee network with 31 nodes (sensors of actuators).

The nodes were distributed in a short-range simple mesh, with less than 10 meters between any router and the coordinator. Each time the ZigBee network was formed, nodes were powered on different times, so that the mesh topology was different each time. However, there were some constraints: the maximum depth was 5 and the maximum number of neighbors or children for each node was 8.

After the entire network was correctly created, the coordinator and SDN tried to instance a HERA-SDN. HERA-SDN instanced itself and started the HERA platform registering a special SYLPH service called “HERA” on the SDN. Then, 10 of the 30 SYLPH nodes tried to instance one HERA agent, each of them in the HERA platform. Once the HERA-SDN and the 10 HERA agents were successfully instantiated, HERA-SDN started to “ping” each of the ten HERA Agents with a request HERACLES frame including an inform-if command and waiting for a inform frame as a “pong” response. This experiment was run 50 times to measure the success ratio of the platform start and the agent instantiation. However, if the SYLPH network could not be correctly created, or if the HERA platform could not be completely started and created, these runs were also discarded and not taken into account as forming part of the 50 runs. Any HERA agent that crashed was immediately restarted. HERACLES messages were registered to measure when a ping-pong failed and if a HERA agent had to be restarted.

The results (Figure 2) indicate that it is necessary to improve SYLPH creation and the instantiation of HERA Agents. In the first case, a better ARQ (Automatic Repeat Request) mechanism could increase SSP-over-WSN transmissions. In the second case, it is necessary to debug the implementation of the agents and fix errors. In addition, the robustness of the HERA agents should be improved by introducing a mechanism to ping and keep running.

5 Conclusions

In summary, this paper proposes a new perspective for information fusion where intelligent agents can manage the workflow. These intelligent agents collaborate inside a model based on VO. The agents take advantage of their learning and adaptation capabilities in order to provide information fusion models. Moreover, HERA facilitates and speeds up the integration between agents and sensors. A totally distributed approach and the use of heterogeneous WSNs provides a platform that is better capable of recovering from errors, and more flexible to adjust its behavior in execution time.

In conclusion, within the proposed framework, a new infrastructure supporting seamless interactions among hardware and software agents, and capable of recognizing and self-adapting to diverse environments is being designed and developed.

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