Virtual Organizations in Information Fusion

S. Rodríguez, D. Tapia, F. De Paz, and F. De la Prieta

Abstract. 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 on context-aware scenarios. However, it is necessary to go further and propose better ways to deal with the avalanche of data that these scenarios provide. In this sense, virtual organizations of agents are an interesting alternative because they provide the necessary capacity to handle open and heterogeneous systems. This paper presents a framework that defines a method for creating virtual organization of software and hardware agents.

Keywords: Multi-agent systems, fusion information, virtual organizations, wireless sensor networks.

1 Introduction

Scientific community within the information fusion area remains heirs to the traditions and techniques of sensor fusion, which is primarily concerned with the use of sensors to provide information to decisions systems. This has led to most models of information fusion processes are directed by data fusion in which the central core are the sensors and data. An alternative way is to take a intelligent approach as MAS within the fusion process are emerging. Agents are suitable for fusion because they can represent autonomous fusion entities by modeling their capabilities, expertise and intentions [14].

Nowadays, there are small, portable and non-intrusive devices that allow agents to gather context-information in a dynamic and distributed way [2]. 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.

MAS allow the participation of agents within different architectures and even different languages. The development of open MAS is still a recent field of the MAS paradigm and its development will allow applying the 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

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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. To this end, it is used the HERA (*Hardware-Embedded Reactive Agents*) platform and OVAMAH (*Adaptive Virtual Organizations: Mechanisms, Architectures and Tools*) platform. 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 WSN connected to the former one. And thanks to OVAMAH, the framework can incorporate the self-adaptive organizational capabilities of multi-agent systems and create open and heterogeneous systems. The article is structured as follows: next section the related approaches. Section 3 shows the system proposal, including the description of the HERA platform, the heart of the system. Sections 4 present some results and conclusions obtained.

2 Related Approaches

Information fusion can be understood as the study of techniques oriented at the combination and integration of highly heterogeneous data. The heterogeneity of the data may be due to various reasons such as the representation format, conceptual structure, or the source of the data. One of the relatively recent approaches is the use of MAS for information fusion.

Recent years have given way to a number of MAS architectures that utilize data merging to improve their output and efficiency. Such is the case of Castanedo et al.[4], that 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 [9], which cover all of the phases related to information fusion by specifying how the different computational components can work together in one coherent system.

These kinds of systems, despite having all the advantages of MAS, aremonolithic. In an environment in which the data heterogeneity is a key feature, it is necessary to use systems with advances capacities for learning and adaptation. In this sense within MAS, an approach that is gaining more weight in recent times is to consider organizational aspects [3], and more concretely those based on the virtual organizations (VO).

Currently, there are not virtual organization-based applications oriented to fusion information, however we can find some approaches that try to propose advances in this way. For example, the e-Cat System [8] focuses on the distribution and the integration of information. This system is based on enhancing the skills or abilities of members of the organization, through the definition of the different types of skills and relationships between them. This organization is aimed at ensuring the maximum independence between the different partnerships created and the information privacy. Another example, perhaps more centralized in the fusion of information, is the KRAFT (*Knowledge Reuse and Fusion / Transform*) architecture[11], 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 especially oriented to construct information fusion environments.

3 Proposed Framework

This section discusses some of the most important problems of existing approaches that integrate agents into WSNs, including their suitability for constructing intelligent environments. It also presents the proposed integration of information fusion systems that use the capabilities of MAS. With HERA, agents can invoke services in WSN, even in low resource devices. And OVAMAH provides the capability of incorporate the organizational capabilities of MAS.

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 not global control system, the data is decentralized and the computing is asynchronous [14]. There are several agent frameworks and platforms [13] 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 the context [14]. All these capacities make the agents appropriated 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, like 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 OV.

Any intelligent fusion system has to take into account the information about the context (people and their environment), which can be gathered by sensor networks. Each element of sensor network is called a node. Each sensor node is habitually formed by a microcontroller, a transceiver for transmission and a sensor or actuator mechanism. There are wireless technologies such as IEEE 802.15.4/ZigBee and Bluetooth that enable easier deployments than wired sensor networks. Whilst traditional networks aim at providing high QoS transmissions, WSNs protocols concentrate their efforts on energy saving.

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 do not even exist. Therefore, there are researches [10] that develop methodologies for the systematic development of MAS for WSNs but they are too specific and usually based on Mobile Agents. Other studies [12], try to reduce the redundancy of the data gathered by sensors from different types of networks by using mobile agents that pack the data. Other research packs the data gathered by the sensor network, reduces the reception and delivery times and saves energy in devices with a low autonomy capacity [1]. Along the lines of fusing or packing there are models that try to state the quality of the fused data and the cost of communication between the transmitter and the receiver.

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. HERA is an evolution of the SYLPH platform [5]. SYLPH follows a SOA model for integrating heterogeneous WSNs in intelligent systems. HERA contemplates the possibility of connecting wireless sensor networks based on different radio and link technologies. 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 or the radio transmission amongst the nodes that form part of the network. HERA can be executed over multiple wireless devices independently of their microcontroller or programming language. HERA allows the interconnection of several networks from different wireless technologies (e.g. ZigBee/Bluetooth). This facilitates the inclusion of context-aware capabilities into intelligent fusion systems because developers can dynamically integrate and remove nodes on demand.

The HERA Agents Layer allows running HERA agents. To communicate with each other, HERA agents use a specific communication language called HERACLES. Each HERA agent is an intelligent piece of code running over a node. There must be at least one facilitator agent in every agent platform. This agent is the first created in the platform and acts as a directory for searching agents. In HERA, this agent is the HERA-SDN (HERA Spanned Directory Node).

3.1 Information Fusion Background

What is important in a system like this is decide in what manner to combine or fuse information. In general, data can be fused at different levels [7]: (i) *sensor level fusion,* where multiple sensors measuring correlated parameters can be combined; (ii) *feature level fusion*, where analysis information resulting from independent analysis methods can be combined; and (iii) *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 as shows the Figure 1.

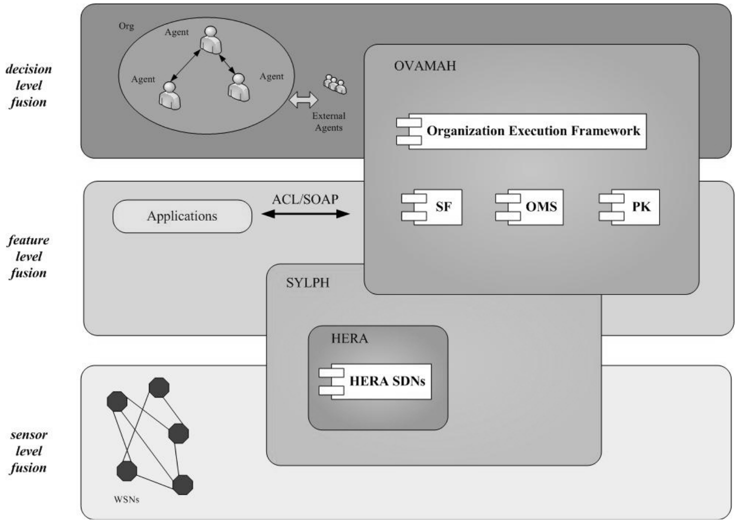

Fig. 1 Proposed framework

On the one hand, at level sensors, with HERA it is possible working with different WSN in a transparent way to the user. A node in a specific type of WSN (ZigBee) can communicate with a node in another type of WSN (Bluetooth).

On the other hand, at a higher level of features and decision, detecting changes in the environment and its consequent action in the system can be managed on the platform thanks to the services and functions that make the agents of the OV thanks to OVAMAH platform. The principal objective of the high level fusion 3 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 architecture proposes a new and easier method to develop distributed MAS, 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.

4 Results and Conclusions

The case study delineates the scope and potential VO in the design and development of information fusion processors for deployment in multi-agents environments. An organization is implemented by using the model proposed in [6]. The simulation within the virtual world represents ae-health environment, the roles that have been identified within the case study are: Communicator, SuperUser, Scheduler, Admin, Device Manager, Incident Manager.

In order to evaluate the impact of the develop of the MAS using an organizational paradigm, it is necessary to revise the behavior of the MAS in terms of performance. A prototype was constructed based on OVAMAH that could be compared to the previous existing system [6]. 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 paper provides several functional, taxonomic, normative, dynamics and adaptation properties. The organizational properties are a key factor in architecture of this kind, but the capacity for dynamic adaption in execution time can be considered as a differential characteristic of the architecture.

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 has been development. 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, they 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” every 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 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. If any HERA agent crashed it 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 (Table 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.

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 capacities of learning and adaptation 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 platform that is better capable of recovering from errors, and more flexible to adjust its behavior in execution time.

Concluding, within the proposed framework, a new infrastructure supporting seamless interactions among hardware and software agents, with capabilities able to recognize and self-adapt to a diversity of environments is being designed and developed.

Table 2. Results of the HERA performance experiments.

Total runs	55
SYLPH created correctly	53
HERA started correctly	50
All 10 HERA agents correctly instantiated	50
Total pings tried	7200
Ping-pongs not completed	15
Total restarted HERA agents in an hour	8

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