Multiagent Systems and Wireless Sensor Networks convergence for an intelligent waterway ambient

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Abstract: - Lately Maritime research areas have moved their interests to cover new areas conferring a more general character to them. BOYAS project is proposed including these new perspectives as well as the classical ones. Trying to get this integral character for the waterway ambient and its activities management, the convergence between Multiagent Systems and Wireless Sensor Networks is studied.

Key-Words: - Wireless Sensor Networks, Multiagent Systems, Buoys, Inland waterway

1 Introduction

In recent years, maritime research has broadened its views to themes like environmental protection, use of information technologies, traffic management, safety and security.

In this evolution intelligent techniques play a fundamental role. The application of Neural Networks, Expert Systems or Automatic Learning is quite common in transport systems but most of these applications are focused on road traffic management while maritime environments receive less attention [1]. Designing maritime systems that meet the objectives posed by previous mentioned new perspectives is a difficult task. But these difficulties can be alleviated by introducing appropriate technologies. BOYAS project focuses on all such aspects. Knowing the characteristics of the environment and the goals that the system has to reach, two research areas converge on the solution: Multiagent Systems and Wireless Sensor Networks.

There are some studies about the application and deployment of sensor networks for maritime environment monitoring [6]. But Wireless Sensor Networks have introduced a novel paradigm for reliable monitoring activities. They can be deployed in almost any environment and ease the transmission and information collection activities.

On the other hand, Multiagent Systems capabilities help with the information management and the system organization, being the perfect complement to the Wireless Sensor Network. At this confluence is found the BOYAS project.

The remainder of the paper is organized as follows. In Section 2, Multiagent System research area is revised. Section 3 presents the numerous Multiagent Systems application areas and so motivates its use in the BOYAS project. In Section 4 basic characteristics of Wireless Sensor Networks are revised. Section 5 presents the core of BOYAS project, focusing on its structure, main characteristics and challenging issues. Finally, in Section 6 some conclusions about the presented work are drawn.

2 Distributed Artificial Intelligence and Multiagent Systems

Distributed Artificial Intelligence (DAI) appeared around the eighties as a consequence of the evolution from centralized architectures to distributed systems. It arose from multiple disciplines so different as Sociology, Operational Research, Artificial Intelligence or Philosophy, fact that confers to DAI a very general character.

DAI can be defined as the study, construction and application of so called Multiagent Systems (MAS). A Multiagent System is a system in which several interacting intelligent agents pursue some set of goals or perform some set of tasks [3].

This research area appeared to help in the resolution of big problems whose data could be distributed, heterogeneous or even incomplete. This kind of situations requires too distributed activities and intelligence. Other appropriate areas for MAS application are those situations that just need a distributed point of view for being studied.

Solving complex problems using MAS consists basically of dividing these problems into smaller ones. The integration in the resolution process of different perspectives of analysis together with fault-tolerance mechanisms reduces the uncertainty of the final solutions. Global efficiency of the process improves considerably due to the concurrence and cooperation of intelligent agents taking part in the resolution.

MAS are specially suited to representing problems that have multiple problem solving methods, multiple perspectives and/or multiple problem solving entities. Such systems have the traditional advantages of distributed and concurrent problem solving, but have the additional advantage of sophisticated interaction patterns (coordination, cooperation, negotiation, etc.)

3 Areas of application

MAS are widely used in different areas of research and industry. Its flexibility and versatility make them appropriate for many types of problems. So, there exist applications on robotics, social systems simulation, management systems, e-commerce, medicine, etc.

There are numerous possibilities for classifying these different MAS applications. The different criterions depend on the authors' point of view. So, Ferber [2] divides the applications attending to the research area to which these applications belong, Jennings et al. [3] base their classification on the industrial or professional area of the application and finally, Oliveira et al. [4] uses as a criterion for his classification the SW/HW nature of the agent.

Anyway, MAS application domains are all characterized by some typical features, such as being distributed, complex, capable of flexible interaction, dynamic and ill-structure [5].

In a general sense, MAS can be considered as a solving problem tool. As it has already been said, a MAS is made up of autonomous, cooperative solving problem entities able to interact to solve a problem or to reach some objectives. This is why and how they have been introduced in so different areas of research and industry. In the last decade, this research area has grown spectacularly and it attracts more and more the interest of researchers, all due to its important application possibilities.

One of the fields of intense MAS application since its origins is Decision Support Systems (DSS). DSS increase performance and efficiency of the activities or environments to which they are applied. Adding intelligence to this kind of systems causes the proliferation of MAS application in areas such as transport logistics, industrial and productive systems as well as traffic management and control [10].

4 Wireless Sensor Networks

So called Wireless Sensor Networks (WSN) are used to improve the performance of systems in the same before mentioned areas too. Among its most typical application areas environmental, security monitoring tasks or traffic control tasks can be mentioned.

As its own name says WSN are composed of a generally large set of sensors able to communicate using wireless technology in order to monitor and extract information from the environment in which they are deployed.

WSN appeared recently thanks to the advance in electronics and wireless communication basically. These advances allowed the development of small low-cost and low-energy consuming sensors able to communicate via wireless technology. These and other characteristics make possible to use them to monitor different kinds of environments in which they get immersed.

So, WSN applications ranges from productive process monitoring or traffic activities to environmental applications (earthquake monitoring, flooding detection, etc.), military applications and applications in dangerous or non-accessible environments as well as in vast extensions where classic techniques may be useless.

4.1 Characteristic of a WSN

Generic and defining characteristics of a WSN are their strong limitations of communication bandwidth, process capacity and nodes available energy. These restrictions demand the use of a high number of nodes in order to be able to cover the vast regions of applications, as well as to alleviate the effect of those restrictions. This is achieved thanks to the conjunction of individual characteristics of the nodes in the network [8].

A dense network can provide a higher level of accuracy of the collected data adding properties to the system such as redundancy, reliability or fault-tolerance. It also allows increasing the available energy for the system as a whole.

This high number of components also increases the complexity of the system making the probability of collisions in the network higher. As a consequence of these collisions, communication latency increases at the same time that the energy consumption efficiency decreases. This is basically due to two main reasons: transmission collisions and energy wasting in redundant measurements that contributes with no information to the system.

To save energy as well as communication and processing resources, WSN typically use data aggregation and common processing techniques for the information collected by the nodes. Once again, resource constraints determine which routing protocols can be used and which communication techniques (usually multihop communication).

WSN application environments are usually dynamic, and even they are sometimes hostile environments. These characteristics and the specific WSN aspects, produces frequent changes on the network topology. These changes entail re-structuring and reorganizing every node tasks, as well as solving connectivity, recognition and communication problems that may arise among them.

So, creating a WSN demands conscientious studies to design its HW components, communication and routing protocols, as well as data treatment strategies. All these aspects area carried out to construct robust scalable systems capable of responding adequately to changes in the environment and, of course capable of providing efficient and reliable information about the events happening in its surrounding.

So deploying a WSN is a challenging work for which the use of MAS seems to suite in a quite natural way, just by identifying nodes of the network and agents in the MAS. This makes possible the use of techniques and tools developed for MAS in the creation of a WSN. This fact also facilitates getting desired characteristics for the network such as adaptability or resource management efficiency.

5 BOYAS project

The overlapping among different research areas is a more and more common phenomenon these days. As it has been said, the concurrence between the two previously presented areas and their application fields is happening currently. The integration between WSN and DAI takes place by AI techniques adoption to process and manage the information collected by the different elements in the network. This is the frame in which BOYAS project is developing.

Most research projects developed within this merging framework have considered networks with a small number of elements and centralized data structures. Individual sensors in this kind of networks have low autonomy and are only able to develop perception and transmission tasks. These transmission tasks just send the collected data to a central node where it is fused and processed. BOYAS project, following the most recent trends, goes one step ahead and by the identification of nodes and agents endow the first ones with autonomy and intelligence.

The aim of this project is to create an embedded intelligent infrastructure in the buoys of the river Guadalquivir covering the area shown in Figure 1.

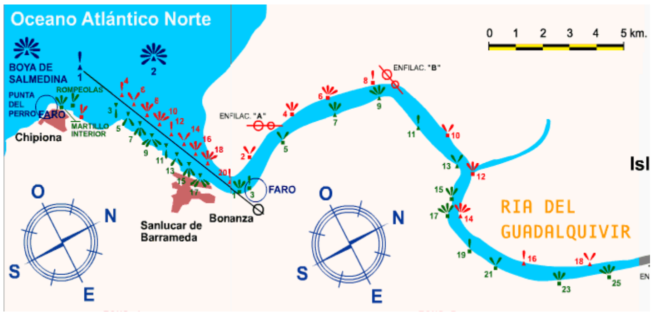

Fig. 1: Mouth and course of the Guadalquivir River.

Elements in the infrastructure are the buoys, the lock, the Head Platform of the Seville Port Authority and even the vessels navigating along the river.

Creating this infrastructure entails the enrichment of the whole system and the improvement of its functionalities as far as capacity, security and quality of service are concerned. The new infrastructure favors the integration of signaling, monitor and traffic control systems under efficiency and security conditions. The new infrastructure also provides additional improvements related to waterway ambient, such as agriculture in surrounding areas and the sustainable transport development taking place at the Seville Port installations.

BOYAS project goes beyond the simple addition of DSS, MAS and WSN concepts. Its objective exceeds the prospects of each of these individual approaches. As we are not trying to solve a concrete signaling or traffic control problem nor monitoring the environment but improving a currently working system to provide it with the most modern advances and techniques.

A general view of the characteristics of the WSN being developed is shown in the Table 1. These characteristics are presented following the taxonomy proposed in [9]. This classification allows distinguishing different kinds of WSN depending on the characteristics of its elements. According to the chosen taxonomy, WSN are classified depending on the properties of the sensing nodes, the network, the environment and the designer's goals.

Most of the sensing nodes in the network are battery-powered and only some of them, when possible and depending on the situation of the nodes, are electric-powered. Nodes can be configured by the network as this can act over them setting their properties. Nodes are also active and able to cause changes in the environment. At the same time, they are dynamic (being affected by external processes or events in the environment in which they are situated). Last, they are fully self-aware as the network can know their state and circumstances at every moment.

As far as the network is concerned, it has a heterogeneous nature as not all the nodes have the same sensors and capacities. Communication among nodes is constrained by energy limitations of the own nodes and the available communication bandwidth. The network is deployed in a deterministic way as the node positions are given by the buoys and other elements' situation along the river. The number of nodes in the network is small and limited to the number of these elements in the area to monitor. As a consequence of the dynamic nature of the sensor and the environment, the network itself is dynamic too. Finally, the network belongs to a single owner, Seville Port Authority.

The network environment is dynamic, non-deterministic and partially observable. These last two characteristics imply some kind of uncertainty on the results of the actions taking place in the environment and the own environment state.

Last, network goals determined by the designer are given by the nature of nodes' actions (individual or collective), the effects of these actions in the environment and the relation established with the environment. Sensors' actions are both directed towards group and individual targets. And in general, nodes' actions have long and short term effects.

Sensors	Power supply	Electric-powered	✓
		Battery-powered	✓
	Self-awareness	Full	✓
		Partial	
	Dynamics	Dynamic	✓
		Static	
	Configurability	Non-configurable	
		Configurable	✓
	Activity	Passive	
		Active	✓
Network	Composition	Homogeneous	
		Heterogeneous	✓
	Deployment	Deterministic	✓
		Ad-hoc	
	Communication	Restricted	✓
		Non-restricted	
	Dynamics	Dynamic	✓
		Static	
	Ownership	Single-owner	✓
		Multiple-owner	
	Number of nodes	Large	
		Small	✓
Environment	Dynamics	High	✓
		Low	
	Nature	Deterministic	
		Non-deterministic	✓
	Observability	Full	
		Partial	✓
Goals	Actions	Individual	✓
		Collective	✓
	Environment dependency	None	
		Local	
		Non local	✓
	Actions effects	Short-term	✓
		Long-term	✓

Table 1: BOYAS project WSN characteristics

So, this brief presentation shows the hard and clear influence that the environment has on the network definition.

The system structure is divided into three levels corresponding to the hardware (HW), middleware (MW) and software (SW) layers. For each of these layers different strategies are defined taking care of the most difficult aspects for the development of the network.

5.1 Hardware layer

Nature conditions of the environment are specially taken into account in the HW platform design. First, nodes have small consumption as most of them are battery-powered. They have to be very strong to stand the circumstances of a very aggressive and corrosive environment with strong swell, humidity, etc.

The information to be collected is vast and heterogeneous. So, different kinds of sensors are needed too to get these data in an efficient way. Among these sensors are visibility, pressure, magnetic sensors, anemometers, etc.

The data generated by the sensors have to be processed by embedded software that transmits the information to the Head Platform. To make this possible a wireless communication network among all nodes in the system is needed.

Each node in the network has different sensors and capacities. These differences are due to the physic nature of the system and its structure. So the characteristics of a node depend basically on its geographical position. Besides, the Head Platform of the Port Authority represents the higher level element in the system. It is the one who is able to store the historic information of the set of nodes and that also has a global perspective and power over the actions taken by the system.

Once again, the special character of the environment determines the design of the communication network too. Geographic characteristics of the environment are different along the river course and at its mouth and so demand a mixed communication network that allows local and global communication for every node in the net.

Communication security is a very important aspect in a system like the one being developed. To guarantee the security of the project, two communication channels coexist to transmit information: one based on GPRS technology and a second one using ZigBee. The use of one or the other depends on the data criticism.

GPRS is a digital technology that provides high data transfer rates. It is specially suited for Internet connections. In BOYAS project, GPRS is used as a back network and to support the ZigBee net.

GPRS is used to send critic data that may affect decisions related to node, system or environment security (data related to illegal traffic or environmental disasters).

Regular data transmission uses 802.15.4 technology (ZigBee). This communication channel is appropriate for transmitting normal data generated by the sensing nodes like environmental measurements or node state measurements, for example.

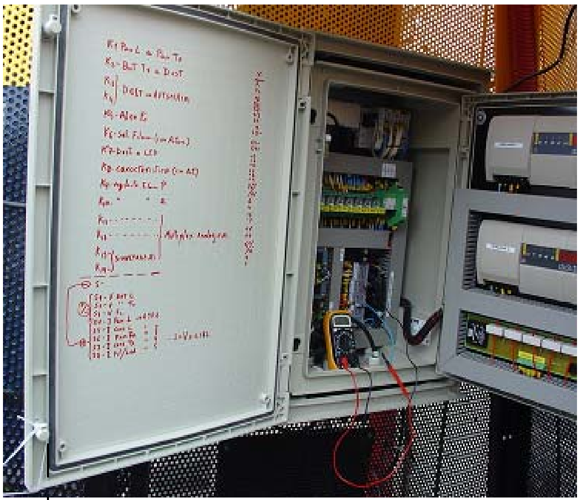

Figure 2: Devices inside a buoy.

As we said at the beginning of the section, extreme environmental conditions require good isolation for all the devices used in the system. To get this, Fig. 2 shows how cabinets should be used.

5.2 Middleware layer

The main aim of the middleware layer is to hide the complexity and distribution of the underlying HW layer. So that it is possible to develop intelligent applications over it.

MW layer makes use of DAI and MAS techniques. When a node is identified as an agent, it is considered as an intelligent, autonomous, proactive entity able to interact with other agents and its surrounding environment. So, these entities can show now behavior patterns and adaptable strategies to every condition. This is the most complicated point in the system design as defining data aggregation techniques, transmission and routing strategies determine the efficiency level of resource management.

Trying to make an efficient use of the available resources and to save energy, information collected from the environment is preprocessed by the nodes in a local and group manner. The individual preprocessing is based on an algorithm that adapts nodes sample rate to the frequency of changes in the environment (subject to logical and feasible values).

On the other side, group processing relies on dynamic group formation. According to the distance among nodes and the similarity of their measurements, different groups appear in the network at each moment. Neighbor nodes fulfilling previous requirements sense the environment and preprocess the information in a common way. Stability and group life-length depends on the coherency of the data collected by its members.

To verify data consistency, nodes check their measurements along two dimensions: internally (temporal consistency) and at the group level (spatial consistency).

One of the most challenging aspects of the WSN design refers to the routing strategies. Typical algorithms for information dissemination over the network are gossiping or flooding techniques. Point to point routing techniques distinguishes between strategies using routing tables and the ones that calculate the route depending on the demand of the source node [7]. Anyway, these classic techniques cannot be directly applied to the WSN being developed due to its special characteristics. So, new routing algorithms that take into account node limitations are being studied.

5.3 Software and application layer

The design of the system is based on open source software, which favors system extensibility and adaptation as it evolves. Besides, not requiring licenses implies lower development costs.

Over the software layer, and interacting with the two last ones, appears the application level. There are numerous applications for the system. These applications can be divided into three main groups: maritime traffic management applications, security applications and added-value applications.

In the first group are included activities like seaway light signaling, vessel data detection or river draught monitoring.

Light signaling activity is basic and of capital importance as this is the aim for which buoys were created. Besides, and thanks to the new infrastructure being developed, activities to get information from the environment and from the vessels and their move are possible too.

Agents and DAI techniques, and tools come to a first level of importance as relying on them and the cooperation among agents, the system reaches decisions about how to manage the traffic.

The aim of security applications is to protect the ships navigating through the waterway as well as the own system infrastructure. Activities in this group are: soon wave detection, acoustic signaling in difficult navigation conditions, luminous intensity regulation depending on the area and the navigation conditions, etc.

Agents manage and benefit from the collected information being able to prevent or predict dangerous situations. Learning capacity of the agents allows them to identify these potential dangerous situations.

Last, added-value applications give an additional character to the system. The huge amount of information collected by the sensing nodes can be used too to monitor the environment state. So, for example, non-authorized dumping into the water can be detected. The monitor of water quality allows determining the possibility and adequateness of its use for irrigating nearby plantations. System capacity to take meteorological measurements allows the use of it as a network of weather report stations.

Besides more natural activities, the new infrastructure can be used for tourist issues too favoring the sustainable integrated development of tourist activities within the environment.

So, the global and integrating nature of the system for this particular maritime-river environment in which artificial and natural activities coexist (freight transport and agriculture, for example) can be appreciated and motivates the work and effort to develop the project.

6 Conclusion

BOYAS project appears from new trends in maritime research areas, trying to cover classic research aspects like security and traffic management as well as more global and integrative activities like environmental protection.

This project represents a real good frame for the study and comprehension of two growing and important research areas: MAS and WSN. It presents too the multiple aspects to be taken into account when developing or implementing a MAS, a WSN or a combination of both, noting most challenging issues.

Besides this work presents the theoretic aspects that have led to the confluence between both previously mentioned research areas. So it could be used as a starting point for proposing or developing new solutions to future problems.

It is worth noting once more the special character of the BOYAS project, as its generality represents the most notorious feature of the work being developed and its main contribution to the new trends in maritime research areas.

References:

[1] P. Davidsson, L. Henesey, J. Törnquist, F. Wernstedt. An analysis of agent-based approaches to transport logistics. Transportation Research: Part C. Emerging Technologies, Vol.13, No.4, 2005, pp. 255-271

[2] J. Ferber. Multi-Agent Systems, An Introduction to Distributed Artificial Intelligence. Addison-Wesley, 1999.

[3] N. Jennings, K. Sycara, M. Wooldridge. A Roadmap of Agent Research and Development. Autonomous Agents and Multi-Agent Systems, Vol.1, 1998, pp. 7-38

[4] E. Oliveira, K. Fischer, O. Stepankova. Multiagent Systems: Which Research for which Applications. Robotics and Autonomous Systems, Vol.27, No 1, 1999, pp. 91-106

[5] H.V.D. Parunak. Industrial and Practical Applications of DAI. In G. Weiss (ed) Multiagent Systems, A Modern Approach to Distributed Artificial Intelligence. The MIT Press, 1999, pp. 377-421

[6] D. Pompili, T. Melodia, I. Akyildiz. Deployment Analysis in Underwater Acoustic Wireless Sensor Networks. Proceedings of the 1st ACM international workshop on Underwater networks. 2006

[7] E. Roger, C. Toh. A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks. IEEE Personal Communications, Vol.6, No.2, 1999, pp. 46-55

[8] M. Tubaishat, S. Madria. Sensor Networks: An overview. IEEE Potentials, Vol.22, No.2, 2003, pp. 20-23

[9] M. Vinyals, J.A. Rodriguez-Aguilar, J. Cerquides. A Survey on Sensor Networks from a Multi-Agent perspective. Proceedings of the 2nd International Workshop on Agent Technology for Sensor Networks, 2008

[10] G. Weiss. Multiagent Systems, A Modern Approach to Distributed Artificial Intelligence. The MIT Press, 1999