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Artificial Intelligence for Wireless Sensor Networks Enhancement

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1. Introduction

Whereas the main objective of Artificial Intelligence is to develop systems that emulate the intellectual and interaction abilities of a human being the Distributed Artificial Intelligence pursues the same objective but focusing on human being societies (O'Hare et al., 2006). A paradigm in current use for the development of Distributed Artificial Intelligence is based on the notion of multi-agent systems. A multi-agent system is formed by a number of interacting intelligent systems called agents, and can be implemented as a software program, as a dedicated computer, or as a robot (Russell & Norving, 2003). Intelligent agents in a multi-agent system interact among each other to organize their structure, assign tasks, and interchange knowledge.

Concepts related to multi-agent systems, artificial societies, and simulated organizations, create a new and rising paradigm in computing which involves issues as cooperation and competition, coordination, collaboration, communication and language protocols, negotiation, consensus development, conflict detection and resolution, collective intelligence activities conducted by agents (e.g. problem resolution, planning, learning, and decision making in a distributed manner), cognitive multiple intelligence activities, social and dynamic structuring, decentralized administration and control, safety, reliability, and robustness (service quality parameters).

Distributed intelligent sensor networks can be seen from the perspective of a system composed by multiple agents (sensor nodes), with sensors working among themselves and forming a collective system which function is to collect data from physical variables of systems. Thus, sensor networks can be seen as multi-agent systems or as artificial organized societies that can perceive their environment through sensors.

But, the question is how to implement Artificial Intelligence mechanisms within Wireless Sensor Networks (WSNs)? There are two possible approaches to the problem: according to the first approach, designers have in mind the global objective to be accomplished and design both, the agents and the interaction mechanism of the multi-agent system. In the second approach, the designer conceives and constructs a set of self-interested agents whose then evolve and interact in a stable manner, in their structure, through evolutionary techniques for learning. The same difficulty applies when working with a WSN perspective seen from the perspective of DAI. Can the principles, algorithms and application of Distributed Artificial Intelligence be used to optimize a network of distributed wireless sensors? Is it possible to implement a solution that enables a sensor network to behave as an intelligent multi-agent system? From a perspective of multi-agents, artificial societies, and simulated organizations, how must a distributed sensor network be installed in an efficient manner and achieve the proposed objectives of taking measures of physical variables by itself? What are the union points between Distributed Artificial Intelligence and Wireless sensor networks? The fundamental idea is this chapter is to propose a model that enables a highly distributed sensor network to behave intelligently as a multi-agent system.

2. Wireless Sensor Networks

A Sensor Network (SN) is a system that consists of thousands of very small stations called sensor nodes. The main function of sensor nodes it is to monitor, record and notify a specific condition at various locations to other stations. Also, a SN is a group of specialized transducers with a communications infrastructure intended to monitor and record conditions at diverse locations. Commonly monitored parameters are temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels and vital body functions.

Sensor nodes can be imagined as small computers, extremely basic in terms of their interfaces and their components. Although these devices have a very little capability on their own they have substantial processing capabilities when they are working as an aggregate, (CRULLER et al., 2004). Each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust (Romer & Mattern, 2004). A sensor network normally constitutes a wireless ad-hoc network, meaning that each sensor supports a multi-hop routing algorithm (several nodes may forward data packets to the base station). It is important to underline that SNs are subject to more severe power constraints than PDAs, mobile phones, or laptops. The whole network is usually under the administration of one controller: the base station. The main functionality of the base station is to act as gateway to another network, and is a powerful data processor and storage center. Advances in microelectronics and wireless communications have made WSNs the predict panacea for attacking a host of large-scale decision and information processing tasks. The applications for WSNs are varied, typically involving some kind of monitoring, tracking, or controlling. Specific applications include habitat monitoring, object tracking, nuclear reactor control, fire detection, and traffic monitoring. In a typical application, a WSN is scattered in a region where it is meant to collect data through its sensor nodes. A number of WSNs have been deployed for environmental monitoring (Davoudani et al., 2007). Many of these have been short lived, often due to the prototype nature of the projects. Wireless sensor networks have been developed for machinery Condition-Based Maintenance (CBM) since they offer significant cost savings and enable new functionalities.

Although a number of new WSN systems and technologies have been developed, a number of new problems or challenges are yet to be solved or improved on. Examples of such problems are optimal routing strategies, lifespan of the WSN, lifetime of the nodes are often very limited, reconfigurability without redeployment, etc.

Finally, since WSNs become popular there is not a common platform. Some representative designs have broader users and developer communities, such as Berkeley Motes, which was the first commercial motes platform. However, many research labs and commercial companies prefer to develop and produce their own devices since a sensor node is a processing unit with basic components. Some platforms are: Mica Mote (http://www.xbow.com), Tmote Sky (http://www.moteiv.com), BTnode(http://www.btnode.ethz.ch/), Waspmote(http://www.libelium.com/products/waspmote), Sun Spot(http://www.sunspotworld.com/SPOTManager/), G-Node (http://sownet.nl/index.php/en/products/gnode), TIP series mote (http://www.maxfor.co.kr/), among others.

3. Artificial Intelligence and Multi-Agent Systems

Classical Artificial Intelligence aimed at emulating within computers the intellectual and interaction abilities of a human being. The modern approach to Artificial Intelligence (AI) is centered around the concept of a rational agent. An agent is anything that can perceive its environment through sensors and act upon that environment through actuators (Russell & Norving, 2003).An agent that always tries to optimize an appropriate performance measure is called a rational agent. Such a definition of a rational agent is fairly general and can include human agents (having eyes as sensors, hands as actuators), robotic agents (having cameras as sensors, wheels as actuators), or software agents (having a graphical user interface as sensor and as actuator). From this perspective, AI can be regarded as the study of the principles and design of artificial rational agents.
However, agents are seldom stand-alone systems. In many situations they coexist and interact with other agents in several different ways. Examples include intelligent Web software agents, soccer playing robots, e-commerce negotiating agents, computer vision dedicated agents, and many more. Such a system that consists of a group of agents that can potentially interact with each other is called a Multi-Agent Systems (MAS), and the corresponding subfield of AI that deals with principles and design of multi-agent systems is called Distributed AI (DAI).

4. Wireless Sensor Networks and Artificial Intelligence

An intelligent sensor is one that modifies its internal behavior to optimize its ability to collect data from the physical world and communicates it in a responsive manner, to a base station or to a host system. The functionality of intelligent sensor includes: self-calibration, self-validation, and compensation. The self-calibration means that the sensor can monitor the measuring condition to decide whether a new calibration is needed or not. Self-validation applies mathematical modeling error propagation and error isolation or knowledge-based techniques. The self-compensation makes use of compensation methods to achieve a high accuracy. The types of artificial intelligence techniques widely used in industries are: Artificial Neural Network (ANN), Fuzzy Logic and Neuro-Fuzzy. Intelligent sensor structures embedded in Wireless Sensor Networks result in wireless intelligent sensors. The use of Artificial intelligence techniques plays a key role in building intelligent sensor structures. Main research issues of the WSNs are focused on the coverage, connectivity network lifetime, and data fidelity. In the recent years, there has been an increasing interest in the area of the Artificial Intelligence and Distributed Artificial Intelligence and their methods for solving WSNs constrains, create new algorithms and new applications for WSNs. Resource management is an essential ingredient of a middleware solution for WSN. Resource management includes initial sensor-selection and task allocation as well as runtime adaptation of allocated task/resources. The parameters to be optimized include energy, bandwidth, and network lifetime. In this particular case Distributed Independent Reinforcement Learning proposed the use of collective intelligence in resource management within WSNs (Shah et al., 2008). Finally, intelligent networking and collaborative systems are also proposed as components for WSNs' enhancement.

5. Multi-Agent Based Simulation

MABS refers to the simulation aim at modeling the behavior of agents in order to analyze their interactions and consequences of their decision making process. Hence, a global result is closely determined by agents' interactions. In practice, MABS models are used to represent and understand social systems (Conte et al., 1998), moreover to evaluate new strategies of improvement and politics on different kind of systems. Due to MABS is a recently area, there are actually few techniques and tools for its development. In fact, some contributions come from system simulation, software engineering and agent-oriented software engineering (AOSE). Facing this constrain, a methodology was proposed by GIDIA research group from National University of Colombia, which defines several stages and artifacts for every phase of a software lifecycle (Moreno et al., 2009). This methodology allows the representation of main characteristics of the distributed system, including key aspects such as organization, reasoning, communication, and coordination mechanism, among others. The main function of WSN simulators is to emulate a WSN operation and simulate entire characteristics of hardware for each node in simulated WSN, instead of providing strategies to do a deployment. The fundamental idea is to propose a model that enables a highly distributed sensor network to behave intelligently as a multi-agent system. It is important to note that most simulators are used to simulate a specific system, be a MAS or a WSN, but not both of them. Besides, it is needed to identify the relationships existing between agents and sensor nodes for getting intelligence from the multi-agent system and monitoring from the WSN. From WSNs' point of view, MABS provides understanding on WSNŠs performance and network autonomous capabilities when acting as an agents society. In this case, agents collaborate together to save and improve resources within the WSN. Finally, MABS can highly contribute to define deployment strategies and operation politics related to the simulated application.

6. Multi-agent Model proposal

Model proposal is a Multi-Agent hybrid model to simulate the deployment of software agents over any WSN, this is done by a layered architecture that utilizes deterministic models of hardware with agent based intelligence, in order to evaluate different strategies, such as different agents for a specific application. It utilizes mobile agents to control network resources and facilitate intelligence. In order to get this, it is used principal deterministic models for WSN performing, such as, protocol model, which comprises all the communication protocols and their operation usually depends on the state of the physical platform of nodes, physical model, which represents the underlying hardware and measurement devices, media model, which links the node to the "real world" through a radio channel and one or more physical channels, battery model that is responsible for checking if the node has exhausted its battery through computing power consumption of the different components, among others (Egea-Lopez et al., 2006). Moreover, it is added the topology and physical variables according to the application that is going to be simulated. Then, it is used software agents to perform all tasks required by the application study case.

6.1 Simulation Models for WSN

Present simulation models try to represent how a WSN works. For example, Egea-Lopez at al., in Egea-Lopez et al. (2006) have proposed a general simulation model taking into account current components of a WSN simulator. Hence, there are several deterministic models to represent hardware, environment, power, radio channels, among others. These models are useful in the way of knowing about how a WSN performs in a real life but they do not offer the potential of evaluating different strategies of deployment, moreover, the simulation nodes number is really far of a real network, due to scalability is affected by all required processing to simulate complete hardware.
Later, a new propose is presented by Cheong in Cheong (2007). Some strengths of this work are the use of different simulation tools whose are already defined for WSN Levis et al. (2003), and it permits a directed implementation from simulation. However, Cheong proposes a programming paradigm based on actors, whose are a concept between objects and agents. Actors are objects with data flow for communication, but they are not aware of its environment neither able to take decisions for acting.
Another approach is presented by Wang and Jiang in Wang et al. (2006), where is presented a strategy to control and optimize resources in a WSN through mobile agents. Optimization of resources such as, power, processing and memory of devices is done, but it is not defined how devices and agents are related for getting this optimization.

6.2 Model Proposal

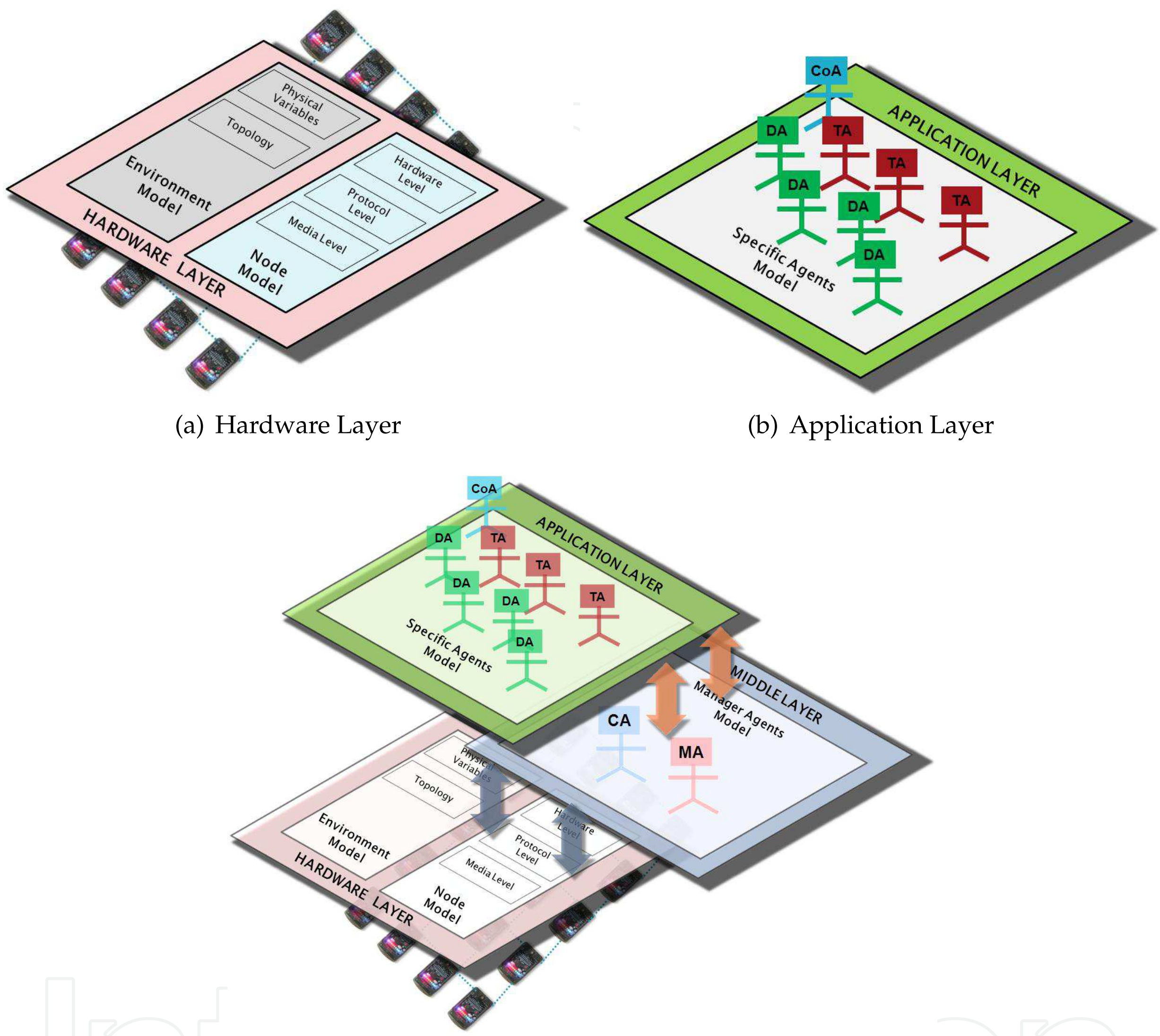
It is proposed a Multi-Agent hybrid model to simulate the deployment of software agents over any WSN, this is done by a layered architecture that uses deterministic models of hardware with agent based intelligence, in order to evaluate different strategies, such as different agents for a specific application.
We aim to utilize mobile agents to control network resources and facilitate intelligence. In order to get this, it is used the principal deterministic models specified by Egea-Lopez et al. (2006), these models set features, such as, platform of nodes, power consumption, radio channel and media. Moreover, it is added the topology and physical variables according to the application that is going to be simulated. Finally, it is used software agents to perform all tasks required by the application study case. Below is presented three different layers that let to perform intelligence through agents over a WSN.

6.2.1 Hardware Layer

The hardware layer is responsible to specify all components that are related to characteristics provided by hardware and the environment where network is going to be deployed. Most models of this layer are already defined by the present WSN simulators. Below it is introduced some models that specify these components.

- Node Model: This model has been specified before by Egea-Lopez et al. (2006), where a node is divided by protocols, hardware and media. Protocols operation depends on hardware specifications and comprises all communications protocols of a node. Hardware represents the underlying platform and measurement devices. And media, links the node to the Şreal worldŤ through a radio channel and one or more physical channels, connected to the environment component.
- Environment Model: This model includes principal variables of physical area where the network is going to be deployed. The sensors of a node have to be able to sense these variables otherwise the agents of higher layers will not be executed. Besides, this

model specifies the topology, i.e. the structure of how the nodes are organized, there are different topologies to a WSN such as square, star, ad-hoc, irregular Piedrahita et al. (2010).



(a) Hardware Layer

(b) Application Layer

(c) All Layers

Fig. 1. Hardware, Application Layers and Complete Model Proposal

6.2.2 Middle Layer

The middle layer is responsible to attach a WSN with the needed agents for a specific application. Hence this layer has two agents that perform control and resources manage.

- Manager resources Agent (MA): It is a specialized mobile agent that takes decisions about controlling resources of memory and power. It is aware of required charge for an agent performs a task, and denies or admits to execute an agent. This is an agent that takes decisions based on a BDI model Georgeff et al. (1998). Moreover, it says if a group of tasks can be executed in keeping with the specified hardware.

- Capturing Agent of physical variables (CA): It is a mobile agent that is aware of physical variables according to a specific application. It takes decisions about propagation and transmitting of these variables.

6.2.3 Application Layer

The application layer represents specific study case or application for which the WSN is going to be deployed. Therefore this layer has agents that perform application required tasks.

- Coordinator Agent (CoA): It is an agent aware of required tasks by a study case so it has a queue of application tasks. Hence, it manages, organizes and negotiates them, for being executed by a TA successfully. Also, it takes decisions based on a BDI model.
- Tasks Agent (TA): It is a reactive agent that performs tasks assigned by a CoA, as long as CoA said it had to be.
- Deliberative Agent (DA): It is a mobile agent that takes decisions based on a BDI model too. It does not need that a CoA manages, organizes and negotiates its tasks, it does by its own. Accordingly, it performs a set of tasks to achieve its own goal or a goal established by a MAS which it belongs to.

It is a specific treatment for an application multi-agent system, due to not all sensor nodes platforms can perform a rational agent i.e. for a simple application there is a group of TA with a CoA that manages and coordinates entire system, and for a complex application there is a group of DA that interact to achieve a global goal.

6.3 Interaction Process

First of all, the CoA(or a DA, depending of required type agents) starts the process for assigning a task, it has the belief that a task needs to be done, it has this belief because there is a tasks list related to the application. Its desire consist of ensure that a task is done successfully by a TA. Then, its first intention is to interact with MA and to ask task feasibility.
Now, MA beliefs about its hardware characteristics and charge task, and its desire consist to inform if there are enough resources to do the task, for this reason its intention is reasoning if charge task processing fits on available resources. It informs true or false.
If MA answer is true, CoA second intention is to create an instance of a TA, and assign this task. Finally, its last intention is to be sure that the task was done then it asks to TA, if it is done and depending on this answer it starts with another task or the same.
In the case of DA multi-agent system any DA starts the interaction process with agents in the middle layer. MA beliefs about its hardware characteristics and charge on a plan (task group). If MA confirms available resources, the DA starts its process, otherwise it waits until get an affirmation from MA.
Taking into account above process, we introduce some theoretical formula to determinate global battery discharge (see Equation 1 and 2) and memory usage (see Equation 3 and 4), for a time period in the simulation.

$$B_{(t)} = B_{(t-1)} - P(CoA)(MA) - P(TA)L_{(t-1)} \quad (1)$$

$$B_{(t)} = B_{(t-1)} - P(DA)(MA) - P(DA)L_{(t-1)} \quad (2)$$

Where $B_{(t)}$ is the battery state at time t, $P(CoA)(MA)$ and $P(TA)$ are the processing of CoA and MA agents and TA agent respectively and $L_{(t-1)}$ is the task charge. For equation 2 $P(DA)$

and $P(MA)$ are the processing of DA and MA agents and $L_{(t-1)}$ is the plan charge. These tasks and plans are negotiated in a specified order, and constantly repeating.
For Memory usage ($M_{(t)}$), the formula required to perform or not a task or a plan,

$$M_{(t)} = M_{(t-1)} - P(CoA)(MA) - P(TA)L_{(t-1)} + P(TA)L_{(t-2)} \quad (3)$$

$$M_{(t)} = M_{(t-1)} - P(DA)(MA) - P(DA)L_{(t-1)} + P(DA)L_{(t-2)} \quad (4)$$

7. Conclusions and future work

The principles, algorithms and application of Distributed Artificial Intelligence can be used to optimize a network of distributed wireless sensors. The Multi-Agent System approach permits WSN optimization using rational agents to get this achievement.
It is possible to implement a solution that enables a sensor network to behave as an intelligent multi-agent system through the proposed model due to it utilizes multi-agent systems together with layered architecture to facilitate intelligence and simulate any WSN, all needed is to know the final application, where the WSN is going to be deploy. Also, a layered architecture can provide modularity and structure for a WSN system. Moreover, proposed model emphasizes about how a WSN works and how to make it intelligent.
From a perspective of multi-agents, artificial societies and simulated organizations, a distributed sensor network can be installed in an efficient manner and achieve the proposed objectives of taking measures of physical variables by itself with different types of rational agents that can be reconfigured to fit any kind of application and measures, also to fit the most appropriate strategy to achieve requirements of physical variables monitoring.
Further work to do is testing model using a real WSN. Some study cases of multi-agent systems for specific applications are required to do a complete testing. A useful tool to use is the Solarium SunSPOT emulator. This emulator makes available a realistic testing to develop and test SunSPOT devices without requiring hardware platform. After this testing finishes, the model could be performed over a real WSN of SunSPOT devices.

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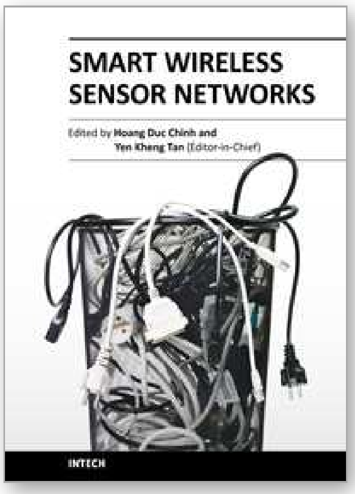

Smart Wireless Sensor Networks
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The recent development of communication and sensor technology results in the growth of a new attractive and challenging area â€“ wireless sensor networks (WSNs). A wireless sensor network which consists of a large number of sensor nodes is deployed in environmental fields to serve various applications. Facilitated with the ability of wireless communication and intelligent computation, these nodes become smart sensors which do not only perceive ambient physical parameters but also be able to process information, cooperate with each other and self-organize into the network. These new features assist the sensor nodes as well as the network to operate more efficiently in terms of both data acquisition and energy consumption. Special purposes of the applications require design and operation of WSNs different from conventional networks such as the internet. The network design must take into account of the objectives of specific applications. The nature of deployed environment must be considered. The limited of sensor nodesâ€™ resources such as memory, computational ability, communication bandwidth and energy source are the challenges in network design. A smart wireless sensor network must be able to deal with these constraints as well as to guarantee the connectivity, coverage, reliability and security of networkâ€™s operation for a maximized lifetime. This book discusses various aspects of designing such smart wireless sensor networks. Main topics includes: design methodologies, network protocols and algorithms, quality of service management, coverage optimization, time synchronization and security techniques for sensor networks.

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