A Multi-Agent Model to simulate Intelligent Wireless Sensor Networks

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***Abstract*—The Wireless Sensor Networks(WSN) are defined as a set of nodes with limited constraints of processing, storage and transmission. Nowadays, most WSN proposals require using software agents to bring new capabilities to the network, such as autonomy, control and intelligence. However, a deployment of agents over a WSN imposes higher resources consumption and it is required to evaluate different kinds of strategies, trying that agents do not impact resources cost of a real WSN. On the other hand, current simulators for WSN try to represent behaviors of a WSN for a specific application, besides, most of these simulators try to emulate the entire hardware platform of nodes, which are going to be deployed over a real net, this involves higher processing requirements for being emulated all hardware and resources control. Hence, the goal of this paper is to propose a simulation model based on Multi-Agent paradigm, for deploying software agents over a WSN and evaluating the most suitable strategy, so agents could perform required tasks for the network without impact WSN resources. The proposed model provides required components for hardware management in a WSN, also it presents the components required to make an intelligent network.**

***Index Terms*—Intelligent Systems, Intelligent Agents, Distributed Systems, Networks, WSN, Agent Based Simulation, Multi-Agent Systems.**

I. INTRODUCTION

Wireless Sensor Networks or WSN are a distributed network nodes group, which act together in order to monitor and control diverse kind of physical environments. Each node in a WSN has limited constraints of processing, storage and transmission and a set of nodes can be programmed to interact within physical spaces. Through sensors and actuators, the nodes can perceive physical variables such as temperature, light, humidity, vibration, sound, etc. as medium to act over a specific environment according to the application domain [1].[1]

However a WSN system has limited constraints due to electronic devices whose it is composed. Nowadays, these limitations are mitigated by Artificial Intelligence (AI) [2], specifically Distributed Artificial Intelligence (DAI) techniques, such as, Multi-Agent Systems(MAS) [3], where different kind of agents interact among each other to organize their structure, assign tasks and interchange knowledge. This brings new capabilities to the network, such as autonomy, control, even intelligence, also they can control the network, optimize it, save its resources, among others.

Then, there is a issue about how to do a deployment of these agents to achieve their goals for which they were created for, how they have to be organized to really optimize limited constrains of a WSN, and how to evaluate different strategies of this deployment. It could be done a WSN real deployment but it requires high costs, another way is to do a simulation process but most simulators for WSN try to represent the behavior of a WSN for a specific application, besides most of them try to emulate hardware platform of nodes which are going to be deployed on a real net, this involves higher processing requirements being emulated all hardware and resources control.

The solution presented in this article is a Multi-Agent model for simulating WSN and providing the intelligence. Different agents are assigned to manage and control WSN resources, other agents would supply intelligence for a specific application where the net is going to perform. For this reason, in section 2 a background is presented, which is referred to principal areas took into account to do this research. Section 3 presents some related proposals, their strengths and weaknesses. Then, section 4 provides a brief description of proposed model, its features and components through a layered architectural design to put up intelligence over a WSN [4]. In section 5 it is discussed some criteria evaluation, finally some conclusions and further work are given in section 6.

II. BACKGROUND

This section is focused on the relevant related topics of this research. An overview of Wireless Sensor Networks and their application are given. Also the main characteristics of Multi-Agent Paradigm and Simulation models based on the paradigm above (MABS, Multi-Agent Based Simulation).

A. Wireless Sensor Networks(WSN)

A sensor network is a system that consists of thousands of very small stations called sensor nodes. The main function

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of sensor nodes it is to monitor, record and notify a specific condition at various locations to other stations.

In addition, a sensor network is a group of specialized transducers with a communications infrastructure intended to monitor and record conditions at diverse positions. 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. Many industrial, natural, and agricultural applications can be monitored by a WSN. Each node in a WSN has limited constrains of storage, transmission and power on its own [5], but working as a whole a group of nodes have substantial processing capabilities [6]. In addition, network nodes have input and output ports in order to interact with their close environment. Input ports are sensors to perceive or monitor changes in the environment, through physical environmental variables. On the other hand, output ports are analog-digital converters with the purpose of controlling peripherals and thus to manipulate nearby environment.

Each node takes physical measures of its environment and then these measures are transmitted through the radio. After, there are a synchronization and communication processes that are controlled by different protocols. Finally, a base station, gateway or sink node captures all network information and delivers to the end user [7].

B. Multi-Agent Systems(MAS)

An agent is a hardware or software entity able to act on behalf on its user [8]. Then, a Multi-agent system is a set of these agents that interact together to reach a global goal. Multi-agent systems are a new paradigm for understanding and building distributed systems, where it is assumed that the computational components,i.e agents, are autonomous: they are able to control their own behavior in the furtherance of their own goals [3].

There are different kinds of agents, such as, deliberative agents, which have a reasoning model to achieve their goals and communicate with other agents. Otherwise, the reactive agents do not have a reasoning model, but they act through stimulus-response process to inform the state of environment where they are deployed. Also, there are mobile agents, which can travel through the network [9], they have abilities to migrate or clone its own code and state from one machine to another. Moreover, these agents can interact with strange devices, gathering information in order to return to their home with obtained data.

In a MAS the collective behavior is more efficient than individual and intelligence is determined by cooperation, coordination, and distribution of knowledge to accomplish actions over some environment or application. MAS attends to coordinate intelligent behavior of autonomous agents. These agents can coordinate its awareness, goals and abilities to solve a global aim, they could know partially the problem and provide solutions.

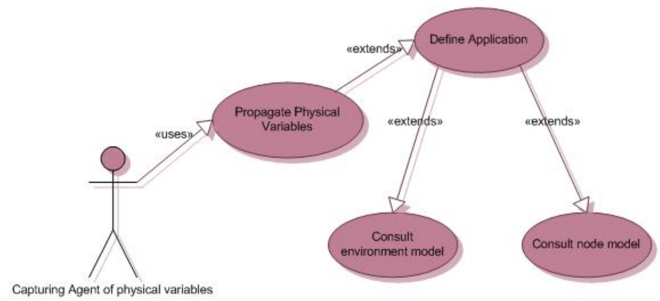

Figure 1. Propagating physical variables

C. Multi-Agent Based Simulation(MABS)

Multi-Agent Based Simulation models the behavior of agents and analyzes their interactions and consequences of their decision making process. Hence, a global result is established by agents interactions.

In practice, the MABS models are used to represent and understand social systems [10], moreover to evaluate new strategies of improvement. Formally, there is a methodology to create these models, this methodology is proposed by GIDIA research group of National University of Colombia [11]. It is a well defined methodology to represent a system following software life-cycle phases, such as, conceptualization, analysis, design and implementation and verification, finally validation and result study phase. Each phase has different artifacts for representation, such as, use case models, role models, environment model, reasoning and learning models, ontology model, coordination model, among others. The proposed model in this article is represented by this methodology,e.g Figure 1. presents a use case for propagate physical variables, it is an artifact defined already by proposed model.

III. Simulation Models for WSN

Current simulation models try to represent how a WSN works. For example, Egea-Lopez at al., in [12] 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 machine to simulate complete hardware.

Later, a new propose is presented by Cheong in [13]. Some strengths of this work are the use of different simulation tools which are already defined for WSN [14], and it permits a directed implementation from simulation. However, Cheong proposes a programming paradigm based on actors, which 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 [15], 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.

Finally, Muldoon [16] proposes a tool to develop agents on limited constrains devices. These agents have a reasoning based on BDI (Beliefs, Desires and Intentions) model [17], but there is not reference about how this tool could be implemented over WSN platforms but it is done over mobile devices like PDA, cellphones, among others. It is specified that hardware for deploying agents must have a Java Virtual Machine (JVM) to be executed. All past generation of WSN platforms are not able to run JVM, but new generations, such as SunSPOT [18], can do it.

IV. Overall model design

It is proposed a Multi-Agent hybrid model to simulate the deployment of software agents over any WSN, this is done through 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 use mobile agents to control network resources and facilitate intelligence. In order to get this, it is used the principal deterministic models specified by [12], 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, software agents are used to perform all tasks required by the application study case. Below is presented the three different layers that composed the proposed model to perform intelligence, through agents over a WSN.

A. 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 current WSN simulators. Below it is introduced some models that specify these components.

1) Node model: This model has been specified before by [12], 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 real world through a radio channel and one or more physical channels, connected to the environment component.

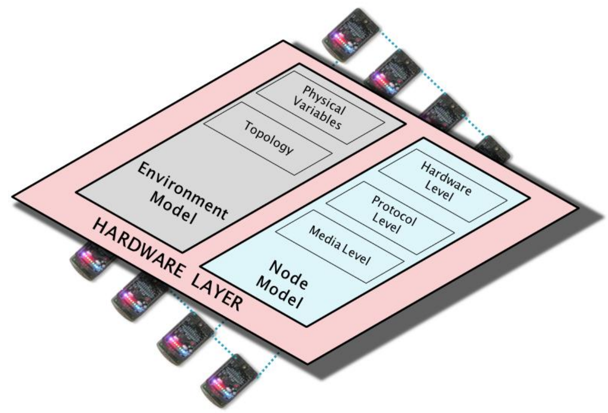

Figure 2. Hardware Layer

2) 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 [19].

B. Middle Layer

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

1) 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 to perform a task, and denies or admits to execute that agent. This is an agent that takes decisions based on a BDI model [17]. Moreover, it says if a group of tasks can be executed in keeping with the specified hardware.

2) 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 transmission of these variables.

C. 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.

1) 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.

2) Tasks Agent (TA): It is a reactive agent that performs tasks assigned by a CoA, as long as CoA said it had to be. Its life depends on CoA and its negotiation with agents in the middle layer.

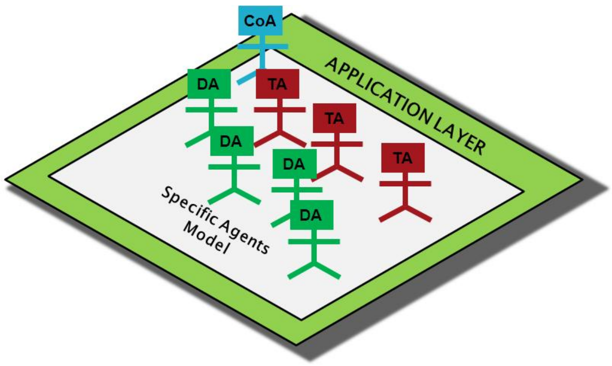

Figure 3. Application Layer

Table I
SOME TASKS AND THEIR CHARGES

Tasks	Charges
Sensors State	10
Battery State	10
Memory State	10
Light Monitoring	20
Temperature Monitoring	20
Humidity Monitoring	20
Get light data of node X	30
Get temperature data of node X	30

3) 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.

V. EVALUATION

The study case for this evaluation phase is oriented to Green Houses, which are very important for economy in our country. This is a simple greenhouse that has to be monitored, its principal tasks required to do this are showed in Table 1., also their related charges or loads, which were selected randomly in a 1 to 100 scale. Properties such as memory and battery are represented since a memory of 100 to 1 (full memory = 100 , low memory = 10 to 1). Figure 4. shows different components in the layers of proposed model.

A. Hardware Layer

Hardware layer components are determined by WSN platform, for this particular case, it is SunSPOT platform developed by Sun Microsystems [20]. This device is built upon the IEEE 802.15.4 standard. There are three physical monitoring variables which are light, temperature and humidity. Finally, there is a ad-hoc topology with 10 nodes, this is because there are simple tasks to perform and simple TA agents to deploy.

B. Middle Layer

Middle layer is the only layer that does not change for simulation process, both agents are needed to coordinate and perform tasks of synchronization between hardware and application layer.

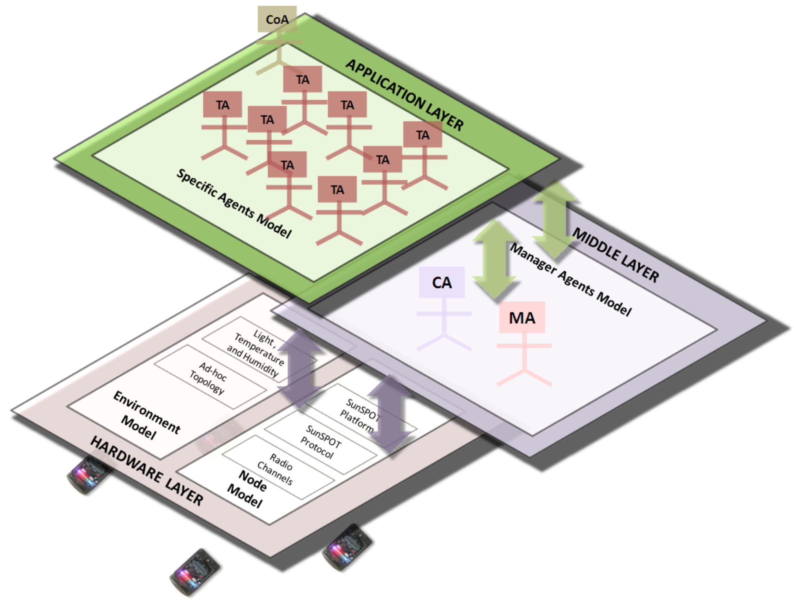

Figure 4. Study Case: Simple Green House

C. Application Layer

Application layer components are eight TA agents assigned to each task to be performed and a CoA agent that negotiates taking into account components of hardware layer for the eight required tasks. There are not required DA agents for this study case due to simple tasks to be achieved. Figure 5. shows negotiation process to assign a task to be performed by a TA agent.

First of all the CoA starts the process to assign 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 about 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.

Taking into account above process, we introduce some theoretical formula to determinate global battery unloading and memory usage, for a time in the simulation.

These data are presented graphically in Figures 6. and 7., and represent the percent for battery unloading and memory usage.

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

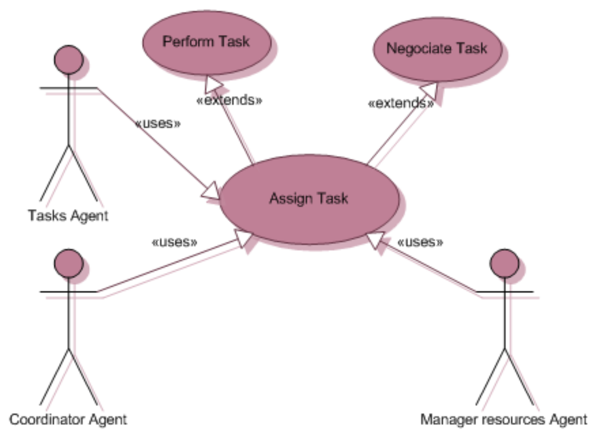

Figure 5. Use Case: Assign Tasks

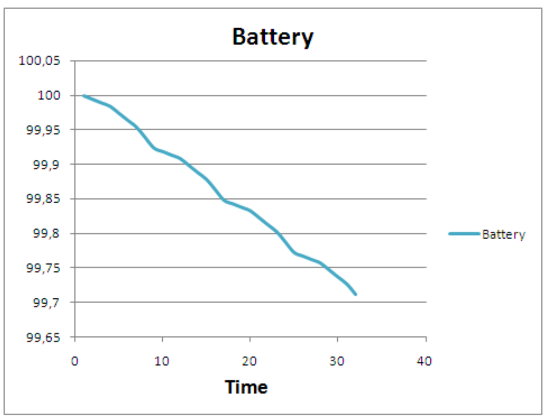

Figure 6. Battery unloading for Simple MAS model Green House

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 defined in Table 1. These tasks are negotiated in the specified order of table, from 1 to 8, and constantly repeating on tics of time.

For Memory usage, the formula required to perform or not a task,

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

In the case of battery, there is just a 0.03% lost for this simple Green House example, battery loses power in the way to process an agent or several agents. It has to be remarked that this 0.03% is over all network, that means about 0.003% per battery node and in a time of 30 tics, so this monitoring process can be done a hundred of times.

For memory usage, there is noticed intervals of every task group. Reaching a memory use about 0.02% and constant for this task group.

Battery and memory are important issues to evaluate for a WSN system, these are critical characteristics that have to be control and save, specially to deploy a MAS system.

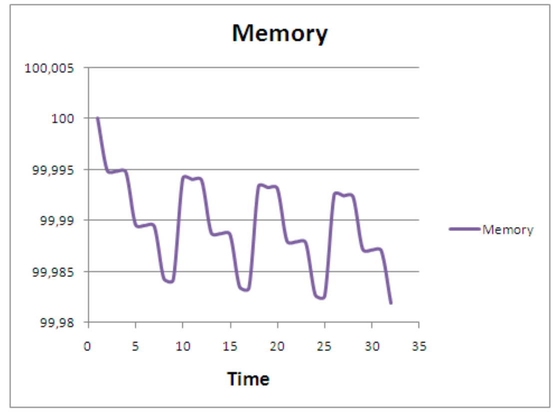

Figure 7. Memory usage for Simple MAS model Green House

Accordingly the result presented is promising to accomplish it. However the model has to be tested for complex study cases due to Deliberative Agents present more resource consuming and it could change some characteristics of the model already defined.

VI. Conclusions and Further work

The model proposed utilizes Multi-Agent Systems together with layered architecture to facilitate intelligence and simulate any WSN, the requirement is to know the application, where the WSN is going to work for. 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.

Different types of agents can be reconfigured to fit any kind of application, also to fit the most appropriate strategy to achieve requirements of practicing.

The model has still to be implemented in a real WSN, to evaluate all its components and layers due to all results presented are theoretical.

The next step to do is testing model using the Solarium SunSPOT emulator [21]. This emulator makes available a realistic testing to develop and test SunSPOT devices without requirements of hardware platform. After this testing finishes, the model is going to perform over a real WSN of SunSPOT devices.

By proposed model it is necessary to do a link between development tools (Multi-Agent programming tool and Solarium), this is going to provide direct real intelligence WSN implementation. This is a great opportunity for application and system customization using our system as a robust framework.

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