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Analysis of Modeling Performance and Simulation Tools for Wireless Sensor Networks

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Abstract: Wireless sensor networks rapidly invaded several application domains. The nodes that make up these networks are electronic devices designed and sized to meet the needs of surveillance, data collection and transport, communication, etc. However, Operation and design of the wireless sensor network systems require reliable and efficient simulation tools before actual implementation of the application. In this paper an analysis of the performance of the modeling phase of the network and simulation tools was presented as a synthesis to evaluate the performance of the systems of a wireless sensor network.

Keywords: Wireless sensor networks; modeling; simulation; routing; energy consumption; OPNNET; OMNeT $^{++}$; NS2.

1. INTRODUCTION

Wireless sensor networks have been increasingly successful in scientific and industrial research communities. Their general function is the detection of information in the most hostile environments. Wireless sensor networks provide many solutions for the detection and monitoring of our environment, this allows many possibilities for new applications. System modeling and network simulation are two important steps to reduce the cost and duration of the deployment process.

The design and realization of wireless sensor networks are influenced by several parameters, such as radio module status, limited resources, limited bandwidth, dynamic topology, scalability, etc. These factors serve as guidelines for the development of complex algorithms and protocols that are dedicated to wireless sensor networks [1]. However, modeling techniques and simulations were used to evaluate the performance of wireless sensor network systems.

This article aims to present an analysis of the performance of modeling and simulation tools that are dedicated to networks of wireless sensors. In the following sections, we will present the interest and the important requirements of modeling in the field of wireless sensor networks. Then, a typical system model of a wireless sensor network is provided. We then describe some simulation tools and their properties. At the end, we present the results of the comparative study in the form of a synthesis. We draw the conclusion and our prospects in the final section.

2. MODELING IN THE FIELD OF WIRELESS SENSOR NETWORKS

In wireless sensor networks, models are the first steps in the realization of a new idea or a new approach. The models created are often simulated in order to estimate their validity by comparing them with other similar models [2]. The modeling of the same node or of the same network may be different according to the level of abstraction considered.

For the modeling of a wireless sensor network system according to the precision of the information wishing to validate, the designer uses in principle different varieties of levels of abstraction. Subsequently, it descends from a level of abstraction to a more detailed level by making the model more subtle and more sophisticated [3]. In other words, abstraction often involves simplifying and replacing a complex and detailed architecture of the device with a comprehensible model by which we can solve a problem. Thus, the model will be general and easily manipulable.

The modeling of the same sensor node may be different depending on the objective assigned to the simulation [4]. For example, if one wishes to optimize the energy consumption in a sensor node or in a global network, there may be a sensor node model or a sensor network model. Consequently, a node can be modeled at several levels of abstraction according to the objective of the modeling but also according to the information available during the design stage for which the model will be used. In this section, the system modeling of a wireless sensor network is studied. Then, a summary of the requirements of the modeling is presented. Finally, a typical system model of a wireless sensor network is provided.

2.1 The Requirements of Wireless Sensor Networks Modeling

In order to have credible and sufficiently realistic results thanks to simulations, a correct and well detailed modeling of the real-time properties of the sensor nodes and of the environmental models is conceivable and mandatory [1].

However, there are many requirements for modeling and simulation for wireless sensor networks such as heterogeneity, scalability, power consumption, etc.

Most of the systems in deployed wireless sensor networks are heterogeneous systems. So a modeling of different nodes and the management of the interconnections between them is really necessary. So, we must take into account the support of the heterogeneity in the modelization of a network system of wireless sensors. Due to their high density in the area to be observed, the sensor nodes must be able to adapt their operation in order to maintain the desired topology. In the case of a corrupt or damaged node for an energy reason, the network must be able to take this modification into account while ensuring an equal quality of service. Therefore, modeling must take into account the entry or loss of nodes in the network in order to solve the problem of scalability [5]. In terms of energy consumption, network designers need to obtain accurate power and timing data to adjust their applications before deployment in real-world environments. Because the malfunctioning of a node implies a change in the topology and imposes a reorganization of the network.

2.2 A Typical Model of Wireless Sensor Networks System

In order to properly simulate a wireless sensor network system, it is necessary to reproduce the behavior and operation of a wireless sensor in a computer environment. A wireless sensor network consists mainly of three parts: a node system, the network and the physical environment. The figure above represents a typical model of the wireless sensor network system.

The node system in the model shown is composed of two parts: a hardware and other software part. For the hardware platform, it consists of a processing unit which collects data from the capture unit, processes it and decides when and where to send it. It must also carry out programs and different protocols communication. The platform also consists of an RF transceiver, a sensor and a battery whose energy is the most valuable resource in a sensor network, as it directly affects the lifetime of micro- Sensors and therefore of an entire network. Additional components may be added depending on the field of application, such as, for example, a location system such as a GPS, an energy generator or a mobilizer enabling it to move [6]. The software model includes operating system, protocol stack, and application software implementation etc. The nodes are connected among by the wireless network.

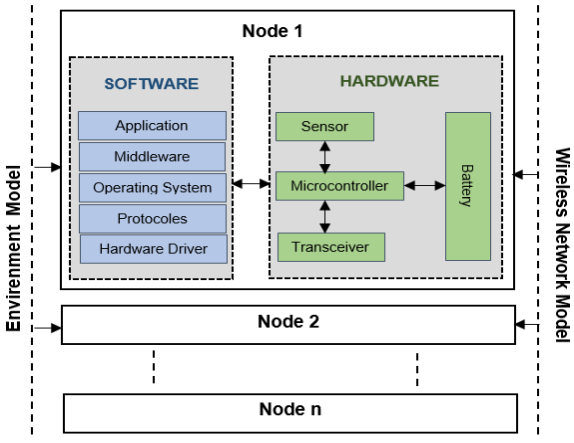

Figure. 1 A Typical Model of Wireless Sensor Networks System

This figure shows a model that contains the topology of the network and transfers the packets between the nodes. It also implements numerous radio frequency channel models. The environment model specifies how physical parameters in the environment vary both spatially and temporally.

Choices on modeling techniques, communication between sensors, had to be made. The development of a simulation environment and a simple example of a sensor network was essential [7]. We needed a modular environment to choose the type of component to be integrated into the simulation in order to make this simulation reliable. We will be able to predict the proper functioning of the network, its performance, its organization, its energy consumption, etc.

3. SIMULATION TOOLS AND ENVIRONMENTS FOR WIRELESS SENSSOR NETWORKS

Several simulators are developed for wireless sensor networks. These simulators allow to simulate models of nodes or networks in a virtual environment. The simulations provide a good approximation to verify the different diagrams and applications developed for wireless sensor networks at low cost and in less time.

The most well-known simulators are OPNET [8], OMNeT $^{++}$ [9] and NS2 [10] which are used to simulate the characteristics of networks with specific sensor nodes. In addition, they are mainly used to compare the efficiency of the algorithms used in the network (MAC, routing, etc).

In this section we describe some simulation tools and describe their characteristics based on information published for the study of wireless sensor networks. A comparative study of these simulators, as well as the emulation tools is then carried out. This analysis is also presented as a mapping of the simulators according to the level of abstraction and the design stage of the sensor node to which they are dedicated.

3.1 OPNET Modeler

OPNET Modeler is a network simulator developed with the C ++ language and based on an intuitive graphical interface. OPNET is considered the main simulation and modeling tool for commercial networks in the world [11]. It can be used as a research tool and also as a network design / analysis tool, its handling and its use is relatively easy.

The use can build a network model using predefined node models and provided by the OPNET library from equipment and commercially available fixed networking protocols. The simulation under this tool also provides as standard a list of implementations of routers, switch workstations. In wireless networks, the strong point of OPNET lies in the precise modeling of radio transmission, modeling in detail different characteristics.

The OPNET Modeler simulator has three levels of hierarchical structure to define each aspect of the system, from the highest level to the lowest level (network domain, node domain and process domain) [8]. This simulator is free only for universities, it comes with a version for academic use, but with limited capacities.

3.2 OMNeT $^{++}$

OMNeT $^{++}$ is an open source simulation environment that uses the C ++ language for simulation models. This simulator

offers a robust graphical interface for animation and debugging, and an integrated simulation kernel, so it has graphical tools for real-time simulation of construction and evaluation of results.

The main purpose of OMNeT ++ is to simulate network communications and also IT systems, it provides the basic implementation of various hardware modules (base radio, CPU) and software (routing schemes Simple) for wireless sensor networks. It adapts mainly to very large network topologies. Indeed, thanks to its flexible basic architecture, it is able to simulate hardware architectures [9]. This platform has become known not only within the scientific community but also in the industrial world. And it is thanks to this modular architecture that it is easier to implement new protocols. The OMNeT ++ simulator provides both the estimate of the energy consumed in the communication unit and in the processing unit. There may be a single module or a compound module. The first module is a .cc file and an .h file. The second module comprises simple modules or other connected modules connected among. The parameters, sub-modules and ports of each module are specified in a .ned file.

The most recent general purpose simulation environment for sensor networks is called Castalia, it is modular and extensible [11]. The problem with OMNeT ++ is the lack of a library of modules specific to wireless sensor networks, but many research groups are working on this point to add additional modules specific to wireless sensor networks.

3.3 NS2

Network Simulator NS2 is an open source simulation environment that uses the C ++ language for sensor networks. Its main axes are IP networks and its use consists of a good knowledge of Tool Command Language. It is a very popular discrete event simulator for research purposes [10]. He is often involved in the study of multipoint or unipoint routing algorithms, transport protocols, and session protocols. NS2 can be a good choice due to its large community.

The NS2 simulator is more suited to sensor networks because it includes a basic energy modeling, it also allows to model very well the physical layer of the OSI model with different transmission systems, wired or not. The simulator can organize a simple mobility simulations. Moreover, thanks to the .nam (Network Animator) extension, one can see the results of a simulation once completed [11]. The latter mainly considers the energy consumed in the communication unit. This energy is relative to the different internal states of its radio module (transceiver).

Among the problems of NS2 is that it has natively no graphical interface and its object-oriented design that introduces an unnecessary interdependence between the modules. Also it does not have the ability to model the execution time of the application code or the operating system in real time [12]. Thus, all simulations are carried out on the command line.

3.4 Emulation Tools

In addition to these three simulation tools, there are also other emulation tools for wireless sensor networks. The emulator is a sub-set of simulator that allows to analyze the codes intended to be embedded in the targeted platform. It allows to emulate realistically the behavior of the embedded software.

Emulation [13] can combine software and hardware implementation. The general principle of these emulators is to run on computer the applications intended to be implemented in the node. Thus, some emulators allow to estimate the energy consumption which corresponds to the details of the behavior of the node. But they are limited to the operating systems used.

There are several types of emulators and they are often dedicated to specific platforms or software. For example, those that simulate nodes that have their own operating system, such as TOSSIM for nodes that use TINYOS, or COOJA for nodes that use CONTIKI [13].

The following table summarizes and compares the three simulation tools studied according to their properties and characteristics. This comparison was made according to published information for the study of wireless sensor networks.

Table 1. Analysis and comparison of simulation tools for wireless sensor networks

	OPNET	**OMNeT ++**	**NS2**
License	Commercial	Commercial, academic	Open source
Language supported	C/C++/Java	C/C++	C/C++/OTCL
General / Specific	Specifically designed for WSN	General Simulator	General Simulator
Scalability n > 100	Excellent	Good	Fair
Mobile network simulation	✓	✓	✓
Communication with other modules	✓	-	-
3D Radio modelling	✓	-	-

4. DISCUSSION AND ANALYSIS

The target node model must take into account the different activities of the node in the network. It will have to be able to distinguish the impact in energy when adding, replacing or removing a function in the node and it must not depend initially on the technologies, since the results of simulation must give information to the designers from the first stages of node design. The modeling must start at first with a high level of abstraction. This makes it possible to take into account the phases of specification and functional design very early in the progress of the design process. However, low-level abstraction modeling is often designed to simulate node systems after design steps, and is not suited to describing the different activities of nodes in the network.

Several simulation tools are developed for wireless sensor networks, three of these simulators have been analyzed, compared and presented on table 1 according to their performances. The node models in NS2 and OMNeT ++ are made up of different modules, such as the PHY module, the MAC module, etc. These two simulators provide the energy consumption according to the configuration of the nodes. Moreover, the two node models that exist in NS2 and OMNeT ++ do not take into account the energy consumption in the acquisition device. Indeed, in node models, although the user can propose applications in each module of the model, the user can not implement communicating, dependent applications that must run simultaneously in different modules. No module supports data processing such as data

compression, decision making, etc. However, in order to have better and more accurate simulation for a wireless sensor network, both OMNeT $^{++}$ and NS2 software must be well extended or modified.

For better modeling, the OPNET simulation tool offers better support, better maintenance and proven simulation models. In addition, this simulator offers excellent scalability to large networks. It is capable of communicating with other modules, so it is the only one of the other two simulators that offers 3D radio modeling. It is also equipped with several MAC standard and routing support [12] (802.11, 802.16. 8, UMTS, SMART MAC, GRP, OLSR, and TORA).

Some wireless sensor network simulators do not depend on existing architectures or technologies, but offer users the ability to imagine and choose the appropriate hardware characteristics for simulation. Note that they are based on specific nodes. They often use predefined hardware / software models.

For a better simulation of a wireless sensor network model, the selected simulation tool must have a parallelism allowing the execution of several tasks simultaneously. The simulator must also have an event triggering property in order to synchronize several functions or trigger a change of state of a function. It must also have the notion of a pause which makes it possible to stop a running process and to restart it at the desired moment, as well as the time management allowing to generate a loop period duration, as an internal clock, a function. The results of the chosen simulation tool must provide the evolution over time of the variation in power consumption. These results would help the designer in choosing the hardware and software to be used in the early design stages of the node. In order to consider the energy impact of the different functions to be implemented in the node model, it is necessary to model the direct link between each of the functions and their respective consumptions.

5. CONCLUSION

Wireless sensor networks are paving the way for a variety of applications in many fields and are of considerable interest and a new stage in the evolution of information and communication technologies.

In this paper, an analysis of the performance of modeling and simulation tools for sensor networks has been done. We have seen that simulators offer an accurate approximation at low cost and often in less time to check the different applications developed for wireless sensor networks. In addition, the simulation phase also provides an easy-to-use validation environment and a better understanding of network behaviors. However, the current state of the art on node models and simulators does not meet all design methodology requirements.

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