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Wireless Sensor Networks: Trends, Power Consumption and Simulators

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***Abstract*—WSN technology involves a set of challenges ranging from determining resource characteristics of the wireless network, when and how to optimise energy and how much processing to do in each node, to principles for management of entire sensor networks and how the data produced by sensor networks can be managed, used and presented. A simulation environment seemed to be then essential, since the test of the hardware and software is hard and difficult. Beyond cost and time savings, the simulator offers the great opportunity to extend the potential and the features of WSN. As there are many simulators, we make an attempt in this paper to specify the important ones related to energy consumption. In fact, we discuss the performance, reliability and usefulness of each of them to better see the disadvantages of these simulators and their strong points to be able to develop a better model.**

Keywords-Wireless Sensor Networks; energy consumption; energy consumption model; Simulators; NS-2; PowerTOSSIM; MATSNEL;OMNET

I. INTRODUCTION

Recently, wireless sensor networks (WSN) are expected to carry out high functionalities in various scopes. It's more evident, now, to support heterogeneous WSN's applications with different sensors: temperature, pressure, image, sound, video instead of sampling temperature and sending a value to a base station[1]. Unfortunately, energy remains the major handicap in front of this progress due to the limit capacity of node's batteries. Therefore the energy optimization becomes more and more a necessity for sustaining a sufficiently long network lifetime [2]. In the state of art, there are many techniques to reduce power consumption of a node at different levels. In our work, we will focus on Dynamic Power Management (DPM) techniques and especially the Dynamic Voltage and Frequency Scaling (DVFS).

However, applying DPM techniques must be well studied to not to cause an overconsumption due to the transition between modes. Therefore, we need to determine the energy consumption of the node before and after applying these techniques. In this context, we present our work: a study of wireless sensor network simulators.

The paper outlines the evolution of wireless sensor networks and their need for new techniques that reduces the power consumption. In the second section, we present an overview of techniques for reducing power consumption. Next, we will state the different available simulators and then, we will discuss the performances of those simulators. Finally, we conclude.

II. EVOLUTION OF WIRELESS SENSOR NETWORK

Wireless sensor networks have become an equipment key in many industrial applications. Indeed, WSN have proved their efficiency in monitoring, tracking, or controlling phenomena. This is why they invade military, medical, agricultural, industrial, and many other different scopes. In fact, WSN set up, today, more complex applications with heterogeneous sensors: temperature, pressure, humidity, vibration, microphone, camera, etc. as shown in figure 1.

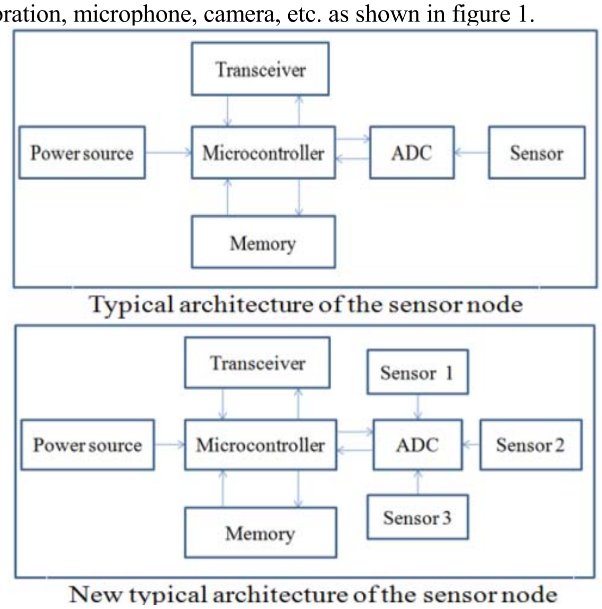

Figure 1. Evolution of the node architecture

To guarantee the new requirements of today's application, WSN's node have to involve their resources in parallel. As it shown in Table1, new platforms have 32Mbyte as RAM memory and the same capacity as flash memory and they resort sometimes to an external memory of 2Gbyte. In other cases, they use reconfigurable HW-SW for more resources [3]. In addition, they support DVFS technique thanks to the range of frequency supported by the processor.

We should note here that, these resources involve WSN's application but they limit the nodes lifetime in the other hand. In fact, when the complexity of node architecture increases, its power consumption increases too. In addition to this overconsumption, WSN nodes are powered by an

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irreplaceable source of energy. Thus, the depletion of this source of energy costs the disconnection of the node from the network which can also disconnect other node. This is why

TABLE I. HARDWARE MOTES EVOLUTION

Node name	**WeC**	**Dot**	**Mica2**	**Imote1**	**Imote2[4]**	**Shimmer [5]**	**Cookies [3]**	**Egs [6]**
Development	1999	2001	2003	2005	2007	2008	2008	2010
Processor(MHz)	4		7	12-48	13-400	8		96
Flash	8K	16K	128K	512K	32MB	48KB +external memory 2GB	4 Mbit	256 KB +external memory 2GB
RAM	0.5K	1K	4K	64K	32MB	10KB	4 Kbytes + 62 Kbytes	52KB
Transceiver	RFM		ChipCon	Bluetooth	Zigbee	Bluetooth and 802.15.4 (WML-C46A, CC2420)	ETRX2 TELEGESIS	CC2520 :802.15.4 and 2 Bluetooth modules
Microcontroller	Amtel			ARM 7TDMI	XScale PXA271	MSP430 processor	ADUC841 + Spartan 3FPGA	ARM Cortex M3

implementing dynamic power management techniques become more and more obligatory to extend the lifetime of the node and of the entire network.

III. Techniques for Reducing Power Consumption

There are many techniques to reduce power consumption for WSN. Commonly, these techniques are classified in three categories according to the level in which they act[7]. The first category contains hardware techniques: conception of low power component, selection of appropriate hardware architecture, using reconfigurable circuit, etc[1]. Among these techniques, we mention designing specific low power electronic components. The second category is software techniques consisting in optimizing the algorithm to minimize its power consumption. This is obtained in using specific instruction, specific loops, etc.We can consider MAC protocols and all optimizations in the configuration of the network as a software technique to reduce the power consumption not only of the node but also of the hole network. The last category of techniques is hybrid techniques which adapts the hardware and the software to consume the minimum of energy. In fact, this technique adapts the power consumption of the system according to its state and to the workload [1]. It's a dynamic power management technique (DPM). The first techniques that were proposed have tried to exploit the low power modes of the processor [8]. The goal was to minimize the idle time of the processor and to optimize the time spent in the low power modes. Nowadays, the use of the low power modes of the processor is often coupled with the dynamic voltage and frequency scaling (DVFS), which allows a significant reduction in the peak power consumption of the processor [9]. In fact, DVFS processors, if used properly, can dramatically reduce the energy consumption of real-time systems employing such processors [10][11]. In concrete terms, DVFS allows processors to dynamically switch to different operating voltages and frequencies. Choosing a lower voltage would reduce the power consumption. However, because the voltage cannot be changed independently of the frequency, it could also result in some degree of degradation of performance [12].Also, applying, power management techniques records transitions costs between power states which can be a source of overconsumption. Thus, the estimation of energy consumption of the node with a different configuration before to deploy it in the network becomes an essential precaution to verify. We present in the next section an overview of some simulator of WSN especially those that support the estimation of the power consumption of nodes.

IV. Simulators

Power management is not just knowledge of energy strategies but at what level is needed and when these techniques become a source of overconsumption[1]. Therefore, we need to estimate the power consumption of the node before and after applying DPM techniques to be sure of their utility mainly to apply the best configuration of the node according to the application. The operation of a WSN can be reproduced through a virtual numerical simulator. WSN simulators are many and varied, but few of them allow the estimation of power consumption of these systems. We will focus in this part on different energy model of WSN simulators to determine which one is more adequate to estimate power consumption of node running under DVFS technique.

A. Ns2 and Ns-3

Energy Model, as implemented in Ns, is a node attribute. The energy model represents the level of energy in a mobile host. The energy model in a node has an initial value which is the level of energy the node has at the beginning of the simulation. It also has a given energy usage for every packet it transmits and receives [13]. The energy available in each node is used only for sending and receiving packets until the energy level goes down to zero. The energy model implemented in Ns-2 is based on the: initial energy, transmitting power(TXpower), receiving power(RXpower), receiving threshold and the time of activation of transmission and reception module. The reception threshold is a given RX-power, whereby the signal is ignored and an error is reported and calculated by the MAC layer.In this context, Ns-2 presents three radio propagation models to predict the power of the signal received from each packet: free space model, two-ray ground reflection model and the shadowing model. The first one assumes an ideal radio propagation between the transmitter and the receiver; one clear line-of-sight path. Thus, it depends only on the distance between the node in communication. The second model is more realistic, it considers both the direct path and a ground reflection path. This is the Two-ray ground reflection model. The last model, “shadowing model” was developed to take in account the reality that the received power at certain distance is a random variable due to multipath propagation effects, which is also known as fading effects. In fact, the above two models predict the mean received power at distance d and represent the communication range as an ideal circle [13]. In brief, NS-2 presents a well established model for the power consumption of the radio communication unit of a node. Nevertheless, it doesn’t take in account the consumption of the other units of the node even with NS-3, but it evolved by supporting new models as: the “RV Battery model” and the “WIFI radio energy model”. In fact, the ns-3 Energy Framework is composed of 2 parts: Energy Source and Device Energy Model. Thus, it’s easy to involve the framework by implementing new energy models for the source or for new devices.

B. PowerTOSSIM and PowerTOSSIM-z

PowerTOSSIM is a scalable simulation environment for wireless sensor networks that provides an accurate, per-node estimate of power consumption. PowerTOSSIM is an extension to TOSSIM, an event-driven simulation environment for TinyOS applications [14]. Specifically, PowerTOSSIM determines the energy consumption of each device in all nodes in a WSN by applying the following formula of the energy:

$$E=V*I*t \qquad (1)$$

With V the fixed voltage that powers the device, I the current consumed by a peripheral in a node and t : the duration of access to that device during the simulation time. PowerTOSSIM defines experimentally an energy model for each type of node giventhat the current depends on the type of hardware. In addition, the consumption of peripherals depends on the application. So, it was necessary to establish a detailed energy model for each type of node. The first model was made for Mica2 and integrated in PowerTOSSIM table 2.

TABLE II. POWER MODEL FOR THE MICA 2

Mode	Current	Mode	current	Mode	current
		LEDs	2 ,2 mA	TX (-20 dBm)	3,7 mA
CPU	8,0 mA	**Sensor**	0,7 mA	TX (-19 dBm)	5,2 mA
Active	3,2 mA	**board**		TX (-15 dBm)	5,4 mA
Idle ADC Noise	1,0 mA	**EEPROM**	6 ,2 mA	TX (-8 dBm)	6,5 mA
Reduce	103 mA	**access**	565µs	TX (-5 dBm)	7,1 mA
Power-Down	110 mA	Read	18,4 mA	TX (0 dBm)	8,5 mA
Power-save	216 mA	Read time	12,9 ms	TX (+4 dBm)	11,6 mA
Standby	0,93 mA	Write		TX (+6 dBm)	13,8 mA
Extended Standby		Write time	7 mA	TX (+8 dBm)	17,4 mA
Internal Osciallator		**Radio**		TX(+10 dBm)	21,5 mA
		RX			

Later, another simulator was needed when the team TinyOs migrated to TinyOs 2.x. Thus, the team designed PowerTOSSIM-z [14] for the mote MicaZ, running with TinyOs-2. Once the power model established, the access time to each peripheral is determined via TOSSIM. Finally, via PowerState, the designers related the energy model to TOSSIM. Each hardware component is wired to the PowerState module as shown in the figure 2. Whenever a power state change occurs, the corresponding command in PowerState is invoked to generate a state transition message[15].

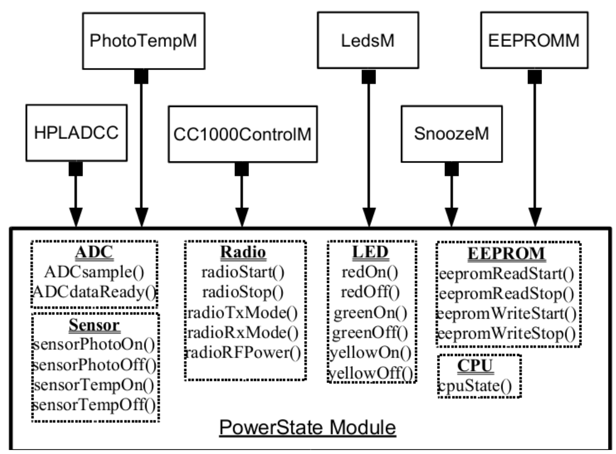

Figure 2. Wiring of PowerState module

C. OMNeT ++

OMNeT++ is a discrete-event simulation environment. It provides several services including modeling communications in a network, modeling communication protocols and validation of hardware architectures [16]. Recently, the team involved it by adding a new extensible framework: “Energy Framework” for modeling battery consumption in wireless networks, particularly sensor networks. The key abstraction in the energy framework is a Battery module that provides a well defined message interface to one or more energy consumption Device(s). Each Device models its energy consumption by sequence of messages to the Battery including the amount of continuous (current) or discrete (energy) draw [17].

D. MATSNL

MATSNL is a package of MATLAB M-files for computing wireless sensor node lifetime/power budget and solving optimal node architecture choice problems. It has been initially developed for predicting node lifetime and power of different types of wireless sensor platform so that make rough decision for architecture prior to actual implementation. Now its functionalities are expanding to more complex platform architecture [18].In addition, MATSNL compares the consumption of two platforms for the same application using the set of motes: mica2, XYZ, Telos and imote2.

MATSNL estimate the energy consumption of a node using probabilistic methods based on stochastic processes. Moreover, this tool identifies two main sensing schemes commonly employed in sensor nodes today: trigger-driven and schedule-driven [19]. The trigger driven operation sensor is coupled to a preprocessor that senses the environment and wakes up the rest of the node once an event is detected. In schedule driven operation, the node processor directly drives the sensors so that the node processor wakes up to sample the sensors according to a schedule. Thus, with MATSNL, we can determine the most appropriate operating configuration for a given platform and application.

V. Discussion

After the presentation of the most popular simulators that support an estimation of power consumption for WSN's node, we should discuss the performance, reliability and usefulness of each of them to analyze their weak point and their strengths in order to design a better model. To compare these different models, we present the decomposition of a node and discuss for each part how it was modeled in the other works. A sensor node is typically made of four basic components, which are the sensing unit, the processing unit, the communication unit and the power supply unit.

A. Power supply unit

The WSN's nodes are usually powered by batteries, a very limited energy resource. From simulators seen previously, the most common battery modeling is a linear model [15][16]. We attribute to the supply unit a nominal voltage and a capacity in Ah. Then, after each processing at the node level, we decrease the battery capacity in proportion to the pulsed current and its duration in time.

B. Sensing unit

The sensing unit is generally composed of two subunits: the sensor itself and an Analog/Digital converter(ADC). The sensor is a device that transforms the state of a physical quantity observed in a usable size. Indeed, it is responsible to provide analog signals from the observed phenomenon, to the Analog/Digital converter. Then, the ADC transforms the signals into a digital signal understandable by the processing unit. The energy consumption of this unit is small compared to the communication or processing unit. Several simulators (OMNET ++, NS-2, etc.) ignore and those which consider it, such as PowerTOSSIM, they try to determine it experimentally. The power of a sensor is often given with its datasheet.

C. Communication unit

The communication unit or radio unit or even transmitting/receiving unit is the unit which ensures all communications between the node and the outside world either to other nodes, a data collector (sink) or other. This communication is provided by a wireless support Wifi: IEEE 802.11 or Bluetooth IEEE 802.15 or Zigbee: IEEE 802.15.4. This module is the most consuming in energy compared to the other units of the node and proportionally to the emission power and the frequency of this unit in the application. For this reason, NS2 is restricted only to the consumption of this unit. Indeed, the radio signal is still weakened and undergoes noise effect due to the distance and the obstacles in the environment impact. NS2 presents three models of propagations taking into account these factors, while other simulators [11] [12] [14], consider just the power emission and reception as a factor affecting the consumption of this unit.

D. Processing unit

The processing unit of a node in a WSN consists of a processor associated with a storage unit. PowerTOSSIM considers seven modes of operation of the CPU while MATSNL considers two configurations of the node with five modes of operation for each estimating also the energy transitions cost from one mode to another. Experimentally, we measure the CPU consumption in all operation modes thanks to a high precision hardware and benchmarks. Besides, PowerTOSSIM considers the consumption of access to the memory according to the type of treatment whether is writing or reading.

E. Power Management

Managing the use of the modules that form the sensor motes is much more important than the consumption itself. These simulators support the 'Dynamic Power Management' (DPM) techniques. TinyOS proposes seven operating processes of among them six are considered low consumption. On the other hand MATSNL proposes configurations of the system as well as the consumption of the system in each one of these configurations.The imminent progress made in the WSN field require more resources and especially better management of consumption than the DPM policy. New platforms (imate2) are equipped with processors with the 'Dynamic Voltage and Frequency Scaling' (DVFS) policy. Unfortunately, currently, no WSN Simulator supports an estimate of the consumption of the nodes with this technique.

TABLE III. COMPARISON OF WSN SIMULATORS

Tools	Radio	Treatment	Sensors	Power supply	Remarks
Ns-2	3 models of signal propagation	Not considered	Not considered	Linear model	Does not take into account the consumption of the processing and capture unit
PowerTOSSIM	transmit power of 10 power reception	7 modes of CPU and 4 modes of memory access	Diodes consumption	Not considered	Specific energy model and well defined set of platforms with a material with high accuracy using microbenchmarks
OMNET++	2 modules of network device	Not yet established	Not considered	Linear model (future) chemical model	New model not yet finalized
MATSNL	Probabilistic model based on a stochastic process	Probabilistic model based on a stochastic process for 2 configurations: • Trigger driven • Schedule driven	Not considered	Not considered	It can: • determine the lifetime • compare the consumption of 2 platforms • compare 2 configurations of the same platform

VI. CONCLUSION

Simulators have contributed considerably to the evolution of WSN. Indeed, by their difference of action and their performance, they become a pillar of the emergence of WSN. In addition, the study made in this paper has delivered many benefits mostly concerning the estimation of energy consumption. As prospects we plan to develop a better model based on this comprehensive overview.

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