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Java Thread를 이용한 무선 센서 노드 에너지 수확 시뮬레이터

Wireless Sensor Node Energy-harvesting Simulator Using Java Threads

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요　약

주변 환경으로부터 에너지를 수확하는 것은 많은 응용 분야에서 센서네트워크의 에너지를 고갈시키는 상황을 완화시키는 데 필수적이다. 주변환경으로부터 얻을 수 있는 에너지는 적절하게 관리되고 수확된다면 시스템을 더욱 오랫동안 지속할 수 있게 한다. 이제까지 많은 시뮬레이터 들은 전원을 에너지 수확에 의존하는 센서네트워크를 시뮬레이션 하였다. 노드들이 에너지를 다양한 주변 에너지원으로부터 수확한다고 가정하고 시뮬레이션을 할 수 있다는 것은 매우 중요한 일이다. 또한, 에너지의 잔량을 지속적으로 추적하고 이에 따라 노드의 활동을 조정하는 것도 필수적이다. 본 연구의 목적은 각기 다른 에너지원에 따른 에너지 수확의 효과를 보여주는 단일 노드 시뮬레이터를 제안하는 것이다. 본 연구의 결과는 향후 더욱 정교한 시뮬레이션을 위하여 확장이 가능 하다.

주제어 : 무선센서노드, 에너지수확, 시뮬레이터, Java Thread

ABSTRACT

Harvesting energy from the environment is essential for many applications to slow down the deterioration of energy in sensor networks. Energy from the environment is an inexhaustible supply which, if properly managed and harvested from the sources, can allow the system to last for a longer period. Many simulators simulate whole sensor networks where the nodes rely on energy harvesting for their source of power. It is important to be able to assume and simulate a node that can harvest energy from different sources of ambient energy. It is also essential to be able to keep track of the energy levels of the node and adjust node activities based on its energy status. This study aims to develop a prototype for a single node simulator that will show the effects of harvesting from different sources of energy. The results of this study can later be extended for more complicated simulations.

☞ keyword : WSN(Wireless Sensor Node), Energy Harvesting, Simulator, Java Thread

1. INTRODUCTION

Wireless sensor nodes are found today in many different application areas. From health and lifestyle, to automotive, smart spaces, smart buildings, machine and infrastructure maintenance, RFID tags and security infrastructures, wireless sensor networks are present everywhere [1]. Other examples include habitat monitoring [2] and structural health monitoring. Sensors are also used in pervasive health applications which include tele-assistance, tele-rehabilitation, posture and activity analysis and vital constants monitoring.

A wireless sensor network consists of a number of small, self-powering sensing devices that communicate with each other using a wireless medium [1]. A network is usually composed of hundreds or even thousands of wireless devices that are deployed in hazardous or hard to reach areas. Human intervention to replace the batteries often poses a difficult challenge and it is sometimes even impossible to do.

Instead of relying on a single source of energy, developers have resorted to harvesting energy from the environment. But often, the sources of ambient energy are not stable and cannot provide adequate amounts of voltage to power a sensor node. Thus, they are often stored in super capacitorsto be used later on. It is important to be able to able to track the status of the harvested energy and adjust microcontroller activities based on this.

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The contribution of this paper is to present a simple simulator for energy harvesting and energy consumption on a single wireless sensor node to keep track of the changes brought about by harvesting from different energy sources. In the simple program that will be developed, users can change the sources of energy as well as other parameters necessary to simulate a working wireless sensor node.

Section 2, we discuss different backgrounds for energy harvesting and energy sources, and simulators. Section 3 reviews some related projects and existing simulators for wireless sensor networks. Section 4 details the proposed structure of the node energy simulator as well as the specifications of the different modules consists it. Section 4 draws conclusions and outlines future directions of the research

2. BACKGROUND

2.1 Energy Harvesting

The greatest problem faced by wireless sensor networks is energy. Research in wireless sensor networks has predominantly assumed the use of portable and limited energy sources to power the sensors. In most cases, the devices in these sensor networks are small in size and thus, they cannot support large batteries that can store more energy. In order to last for a longer time, these devices need bigger batteries but would be very impractical. We should also consider the fact that these devices are deployed in unreachable areas (e.g. forests, buildings, bridges) wherein manually replacing the batteries can be very dangerous or almost impossible.

Batteries with much higher capacities are notexpected to be developed anytime soon and the level of battery technology today could limit the use of these wireless sensor networks. Due to the small batteries and other factors like current leakages, these devices are energy-constrained and have a limited lifetime. Usefulness of a wireless sensor expires when its battery runs out - it cannot contribute to the utility of a network as a whole -connections will be disrupted, whole sensor node groups will be isolated, increased latency, increased data loss, etc.

Protocols and high-end electronics have been developed to minimize power consumption or properly manage the resources of these devices but there is still a need for these devices to replenish the lost energy during specific states in their deployment. These devices should be able to make do with whatever energy is present in its environment.

The concept of energy harvesting generally relates to the process of using ambient energy, which is converted, primarily (but not exclusively) into electrical energy in order to power small and autonomous electronic devices. The phrases "power harvesting" or "energy scavenging" are also used to describe the same process. The concept is not new and has wider applications that are more common [3].

Energy harvesting could be a solution to making WSNs autonomous and could enable these systems to last for longer periods of time. With energy harvesting or energy scavenging, WSNs would be able to perform their sensing functions and wireless communication without any supervision, configuration and maintenance.

2.2 Simulators

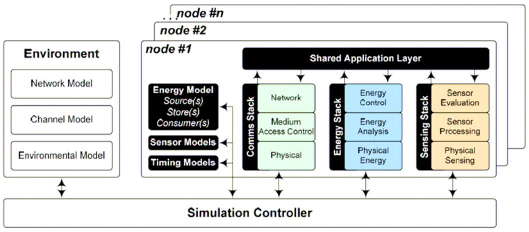
Energy-aware sensor nodes are usually tightly energy constrained, execute energy-efficient algorithms, have the ability to interrogate and control the devices used for storing and consuming energy, and often feature one or more sources of energy harvesting. [4] It is important to be able to simulate the effects of energy harvesting on a sensor node and how the energy levels of the device change over time as one or more energy sources are attached and detached from an energy multiplexer system.

Simulation is only one of 3 techniques for evaluating and analyzing networks. It is also the most widely adopted method for analyzing WSNs. [4] Simulation of WSNs requires a 'sense-able' physical environment and accurate energy models. Many researches have already published close to accurate models for simulating energy usage [4].

Knowing how different energy sources affect the energy of the node when attached and detached from the device is important. A similar study has been conducted in [3] but not having the devices to conduct such experiment. It is important also to be able to demonstrate the effects of energy sources coming and going.

3. RELATED WORK

In [4], the researchers investigate the suitability of a number of state-of-the-art simulators for evaluating energy-aware WSNs, and subsequently propose a novel structure for simulating energy-aware WSNs. The proposed structure (Figure 1) provides diverse, flexible and extensible hardware and environment models, and integrates a structured architecture for embedded software to enhance the design of energy-aware sensor nodes. To illustrate an implementation of the structure, details of - and observations obtained using - an in-house simulator (WSNsim) are presented.



(Fig. 1) The proposed structure for simulating energy-aware wireless sensor networks

In [3], they developed and demonstrated an integrated approach to energy management across a network of independent, autonomous, energy-harvesting sensor nodes. Part of the node design was an energy multiplexer subsystem which functions to permit the connection of multiple energy harvesting and storage modules to the core node system, providing a regulated supply voltage to the microprocessor and permitting interrogation and monitoring of the individual modules connected to it. The multiplexer system is designed to support up to six harvesting or storage modules in any combination.

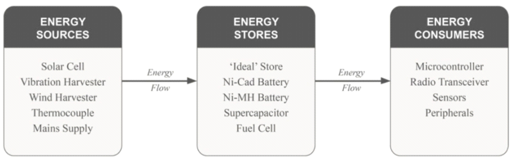
In Egea-Lopez et al. [5], the authors propose a model (shown in Fig. 3) for WSN simulation which shares many similarities with that of SensorSim. The model provides a physical parameter/sensor channel and a node-level physical sensor layer, and also introduces an 'energy producer' object (to represent sources of energy) in addition to the 'battery' and 'power'objects (representing energy stores and consumers respectively). While we believe that this is the model most suited to energy-aware WSN simulation that has been proposed to date, it is not without its limitations and shortcomings; these are discussed in the following section.

4. SYSTEM MODEL AND METHODS

4.1 Energy Components of Wireless Sensor Nodes

Nodes in a WSN are usually highly energy-constrained and expected to operate for long periods from limited on-board energy reserves. To permit this, nodes - and the embedded software that they execute - must have energy-aware operation. Energy efficiency has been of significant importance since WSNs were first conceived but, as certain applications have emerged and evolved [6], a real need for ultra-miniaturized long-life devices has re-emerged as a dominant requirement. Because of this, continued developments in energy-efficient operation are paramount, requiring major advances to be made in energy hardware, power management circuitry and energy-aware algorithms and protocols.

The energy components of a typical wireless sensor node are shown in Fig. 1. Energy is provided to the node from an *energy source,* whether this is a form of energy harvesting from sources such as solar, vibration or wind, or a resource such as the mains supply or the manual provision and replacement of primary batteries. Energy obtained from the energy source is buffered in an *energy store* this is usually a battery or supercapacitor. Finally, energy is used by the node's *energy consumers* these are hardware components such as the microcontroller, radio transceiver, sensors and peripherals. [4]



(Fig. 2) The energy components of a typical wireless sensor node

Energy Stack - Components that are used to store the energy; examples are supercapacitors, fuel cells and batteries (Ni-Cad, Ni-MH, etc.) In the proposed simulator, a supercapacitor will be assumed to store the energy for the sensor node. A capacitor's cycle life is quoted as greater than 500,000 cycles, whereas batteries are specified for only a few hundred cycles. This makes the supercapacitor an ideal "set and forget" device, requiring little or no maintenance. [17]

The energy removed from the store (E_{used}) is equal to the amount of energy consumed by the circuit ($E_{consumed}$), and the energy added to the store (E_{added}) is equal to the amount of energy provided by energy harvesting ($E_{harvested}$). These are shown in equations (1) and (2) [7]

$$E_{used} = E_{consumed} \quad (1)$$

$$E_{added} - E_{harvested} \quad (2)$$

It is also essential to simulate energy leakage from the energy storage. Initial leakage current is a critical parameter in any supercapacitor application. The manufacturers of supercapacitors rate their leakage current after 100 hours of applied voltage while the initial leakage current in those first 100 hours may be as much as 50 times the specified leakage current.

The voltage across the capacitor has a significant effect on its operating life. When used in series, the supercapacitors must have balanced cell voltages to prevent overcharging of one of the series capacitors. Passive cell balancing, where a resistor is placed across the capacitor, is a popular and simple technique. The disadvantage of this technique is that the capacitor discharges through the balancing resistor when the charging circuit is disabled. The rule of thumb for this scheme is to set the balancing resistor to 50 times the worst case leakage current, estimated at 2μA/Farad. Given these parameters, a 10F, 2.5V supercapacitor would require a 2.5k balancing resistor. This resistor would drain 1mA of current from the supercapacitor when the charging circuit is disabled. [17] It is important that this concept is also reflected on the simulator.

Energy Consumers - these are components of a sensor node that consume energy in order to operate [7]; examples are microcontrollers, RF transceivers, sensor modules and other peripherals attached to the core node.

Energy Harvesters -these are the components of the sensor node that harvest energy to be used by the device; examples are miniature wind turbines [10], photovoltaics [10], piezoelectric materials [10], etc.

Photovoltaic Cells - Solar Energy Harvesting - convert incoming photons into electricity. Outdoors there are an obvious energy sources for self-powered systems. This is a relatively mature technology, inexpensive and highly compatible with electronics, and the available power levels can be up to mW per cm^2. However, the drawback isthat the sensor must be in a well-lit location, correctly oriented and free from obstructions. Indoor use requires a fine-tuning of the cell design to the different spectral composition of the light and the lower level of illumination [3] [10]

(TABLE 1) CURRENT DRAINS USED IN THE ENERGY CONSUMER MODEL

Consumer	Current Drain
microcontroller power mode 3 [12] [full sleep]	0.3μA
microcontroller power mode 2 [12] [slow wakeup sleep]	0.7μA
microcontroller power mode 1 [12] [fast wakeup sleep]	190μA
microcontroller power mode 0 [12] [medium activity, 32MHz XOSC]	10.5mA
radio receive [12]	16.2mA
radio transmit1 [12, 13] [with a radiated power Ptx (mW)]	7.6mA+ $P_{tx}/(V_{store}*\eta)$
monitor energy store voltage [12]	1.2mA
sense temperature [14]	1.2mA
sense light [15]	1.36mA
RTC standby [16]	0.2μA
RTC signal [16]	0.4mA

Kinetic Energy Harvesting - Vibrational, kinetic and mechanical energy generated by movement of objects in our surroundings can also be harvested. [8] These vibrations are present all around us and are prominent in factories (machines), bridges, railroads, automotive, and household appliances. There were also papers published that analyzed the effects of placing an energy harvester inside the sole of a shoe [3] [18] and other indoor locations like staircases [3]. Energy is present in all of these vibrations and it can be extracted using a suitable mechanical-to-electrical energy converters. For converting these vibrations to electricity, the established transduction mechanisms are electrostatic, piezoelectric and electromagnetic.

〈TABLE 2〉 POWER DENSITIES OF DIFFERENT ENERGY

Harvesting Technology	Power Density
Solar Cells (outdoor at noon)	10-15 mW/cm^2
Solar Cells (indoor)	≈ 10μW/cm^2
Piezoelectric (shoe inserts)	≈ 300μW/cm^3
Vibration (small microwave oven)	≈ 100 μW/cm^3
Thermoelectric (10°C gradient)	≈ 40 μW/cm^3
Acoustic Noise (100dB)	≈ 1 μW/cm^3

Thermal Energy Harvesting - Thermal energy harvesters are based on the Seebeck effect. It is one of three reversible thermoelectric phenomena (often known simply as thermoelectric effects), and the first to be discovered, the others being the Peltier effect and the Thomson effect. An electrical current is present in a series circuit of two dissimilar metals, which provides the junctions of the two metals are at different temperatures [8].

Pressure Variations - can also be used to generate power for wireless sensor networks. One could imagine a closed volume of gas that undergoes pressure variation as the daily temperature changes. A survey of atmospheric conditions around the world shows that an average atmospheric pressure change over 24 hours is about 0.2 inches Hg or 677 Pa, which corresponds to an energy change of 677 μJ/cm^3. If the pressure cycles through 0.2 inches Hg once per day, for a frequency of 1.16 X 10^{-5}, the power density would then be7.8 nW/cm^3. [10] [3]

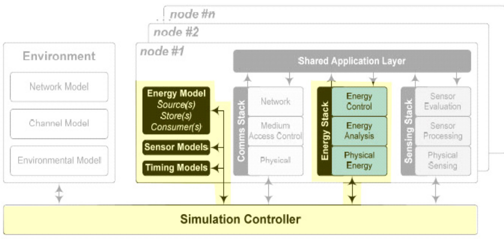
Wind / Air Flow - On a large scale, wind power has been used for centuries to aid in many human activities. Today, many large windmills are still used and are common in vast and windy countries such as South Korea, India and South Africa. Wind power is commonly tapped to help produce electrical energy to supplement the energy brought by coal, diesel and nuclear power plants. It is noteworthy to that the number of countries that use wind energy is increasing and these countries are growing their wind turbine stock on an annual basis. [9] [3]

4.2 Simulator

The energy harvesting units will be "attached"to a central controller which acts as a multiplexer [3]. These modules are separate threads in Java that can be turned on or off depending on the preference of the user.

As a result of the findings summarized in Section 3, we propose a novel structure for energy-aware WSN simulation. To overcome the identified shortcomings, such a structure should satisfy the following requirements:

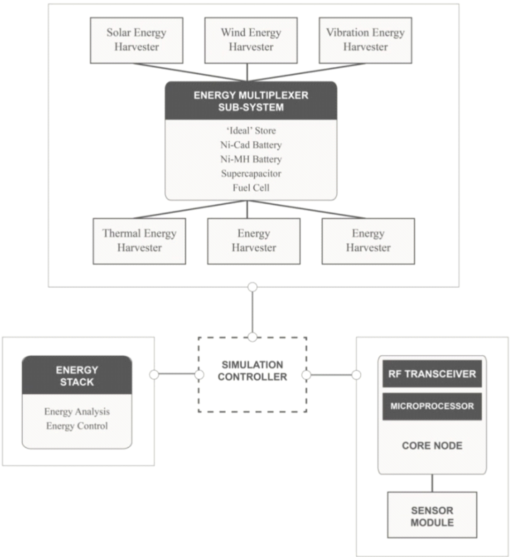
- Provision of adequate modelling for node hardware including, but not limited to, energy sources (for example energy harvesting devices), energy stores (for example batteries and supercapacitors), and energy consumers. Hardware models should be extensible to allow the future incorporation of other hardware.
- Provision of an integrated and extensible environment model to integrate with any hardware or other environmental model. The environment model should be dynamic to allow the modelling of 'real world' environments. The proposed energy-aware WSN simulation structure of [4] is shown in figure one. But in this paper we only focus on a specific part of the node



(Fig. 3) Area of focus for the WSN Simulator

Our focus is on the energy harvesting and analysis for the node. So, based on the figure above, we now come up with a modified figure (Figure 4) involving all the energy harvesting modules as well as the energy consumers and the modules for analyzing the amount of energy harvested.

The simulation will basically run different threads to execute the different energy harvesting activities. These activities can be turned on or off by the user and thus simulating the attachment or detachment of an energy source from a sensor node.



(Fig. 4) Proposed modular structure for simulator

Theoretically, the distributed simulation has more benefits than the sequential simulation; however its practical use is not obvious and depends heavily on the availability of software and hardware components which support this kind of techniques. Communicating threads in Java language provide such support and can be used to design distributed simulators. Since Java is platform independent, these simulators are very portable. Furthermore, the performance is an important issue in simulation, and a multi-threaded simulator can benefit from a powerful multiprocessor machine if available. [11]

5. CONCLUSIONS

In this paper, we proposed a simple simulator that will demonstrate the effects of multiple energy harvesting by a wireless sensor node. During the implementation of this application's prototype, the users should be able to set different parameters for the sensor node like MAC timing, total simulation time, packet size, etc. The user will also be able to simultaneously "attach" or "detach" energy sources from the core node module during runtime. This simulates energy sources appearing or disappearing in the environment of the sensor node being simulated. The objective of this prototype is quite trivial but will be a step to further developing a more complex simulator that focuses more on the energy harvesting aspect of a sensor node.

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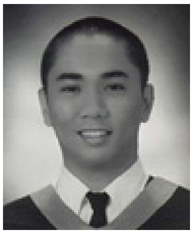

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