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Indoor solar energy harvesting for sensor network router nodes

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Abstract

A unique method has been developed to scavenge energy from monocrystaline solar cells to power wireless router nodes used in indoor applications. The system's energy harvesting module consists of solar cells connected in series-parallel combination to scavenge energy from 34W fluorescent lights. A set of ultracapacitors were used as the energy storage device. Two router nodes were used as a router pair at each route point to minimize power consumption. Test results show that the harvesting circuit which acted as a plug-in to the router nodes manages energy harvesting and storage, and enables near-perpetual, harvesting aware operation of the router node.

Keywords: Wireless sensor networks; Energy harvesting; Energy scavenging; Solar energy; Router nodes

1. Introduction

The application spectrum of wireless sensor and actuator networks seems to be growing without bounds. Some of the applications include temperature and light monitoring in remote locations, sensing chemicals in traffic congested areas, and measuring tire pressure and monitoring acceleration in automobiles. Each wireless node is intended to be deployed to a remote location to sense critical data and relay its measurements to other network nodes for monitoring and control purposes. Many foresee these embedded system devices in applications ranging from industrial automation to home networking [1,2]. These smart networks represent the next evolutionary development step in building, utilities, industrial, home, shipboard, and transportation systems automation.

Wireless sensor networks (WSNs) focused towards indoor industrial and biomedical applications face serious challenges in terms of harvesting nearby natural sources of energy for power. Presently, such network nodes use alkaline batteries as sources of energy. Obviously, these batteries have a fixed energy rating and therefore, a limited life. They have to be replaced in due time and this factor plays a major role in determining the life of a wireless sensor node. For example, a Crossbow MICAz mote [3] operating at 1% duty cycle on standard 3000 milli-ampere-hour (mAhr) AA batteries would require battery replacement every 17.35 months [4]. Often, the cost of physically deploying resources to change a node's worn out battery outweighs the cost of the node itself. The issue of powering these nodes becomes critical when one considers the prohibitive cost of wiring power to them or replacing their batteries. To make matters worse, battery technology has not improved in terms of energy density and size over the last decade, especially for low power applications such as sensor networks [5]. While an effort is being made to improve the energy density of batteries, additional energy resources need to be investigated to increase the life of sensor network nodes. Exploiting renewable energy resources in the device's environment, offers a power source limited by the device's physical survival rather than an adjunct energy source.

It is therefore necessary to exploit energy sources ubiquitous to a sensor node's operating space in order to obtain the possibility of infinite lifetime. It is possible to scavenge

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energy from several sources, and there has been a concerted effort towards a detailed comparison of energy per unit area available, and cost of the corresponding scavenging schemes [6,7]. Some of the available harvesting technologies include solar cells, piezoelectric vibration generators, and energy from thermal and acoustic noise. Table 1 compares the power generation potential of some of these energy harvesting modalities. Among these sources of energy, solar energy harvesting through photovoltaic conversion and vibrational energy through piezoelectric elements provide relatively higher power densities. This makes them the modalities of choice to power a WSN that consumes power on the order of several mW. However, the design of an efficient energy harvesting module involves complex tradeoffs due to the interaction of several factors such as the characteristics of the energy sources, chemistry and capacity of the energy storage device(s) used, power supply requirements, and power management features of the embedded system, and application behavior. It is therefore essential to thoroughly understand and judiciously exploit these factors in order to maximize the energy efficiency of the harvesting modules. Moreover, the power output from these natural sources is highly nonlinear in nature and depends upon a variety of factors.

From Table 1, it is clear that solar energy is the most efficient natural energy source available for sensor networks used for outdoor applications. However, for indoor applications, it is important to note that the efficiency of photovoltaic cells is very low. Typically, the light intensity under artificial lighting conditions found in hospitals and offices is less than 10 W/m^2 as compared to 100–1000 W/m^2 under outdoor conditions. For example, monocrystaline solar cells have an efficiency of less than 1–3% under typical indoor lighting conditions [8]. In spite of such poor efficiencies, these cells still have a power density of at least 0.5–1 mW/cm^2 under indoor 1–5 W/m^2 light intensity conditions, which is much higher than their nearest energy scavenging competitor. Although amorphous solar cells have been found to have slightly higher efficiencies of 3–7% under indoor conditions [8], they are much more expensive than their monocrystaline counterparts. This paper therefore focuses on scavenging energy from monocrystaline photovoltaic cells.

Table 1
Power densities of energy harvesting technologies

Harvesting technology	Power density
Solar cells (outdoors at noon)	15 mW/cm^2
Piezoelectric (shoe inserts)	330 $\mu W/cm^3$
Vibration (small microwave oven)	116 $\mu W/cm^3$
Thermoelectric (10 °C gradient)	40 $\mu W/cm^3$
Acoustic noise (100 dB)	960 nW/cm^3

2. WSNs in indoor applications

There are several indoor applications that seem feasible for WSNs. But to eliminate their dependence on batteries and use solar cells as an exclusive energy source would require the indoor lights to be on continuously and would therefore, seem to be impractical for a variety of indoor applications. However, indoor WSNs operating on solar power appear to be feasible for industrial and hospital environments where indoor lights are operational at a duty cycle close to 100%.

Fig. 1 shows one such concept of an in-hospital WSN that can be used to monitor patient vital sign data from instruments such as electrocardiograms (ECGs) [9], pulse oximeters [10], and blood pressure (BP) monitors [11]. These units can be interfaced to WSN nodes that are programmed as sensor nodes. These sensor nodes are required to perform the function of sensing vital sign data from the patient and are typically required to be ambulatory in nature. Therefore, it is more convenient to allow them to run on stable sources of energy such as batteries. The maximum range of data transmission for such nodes is

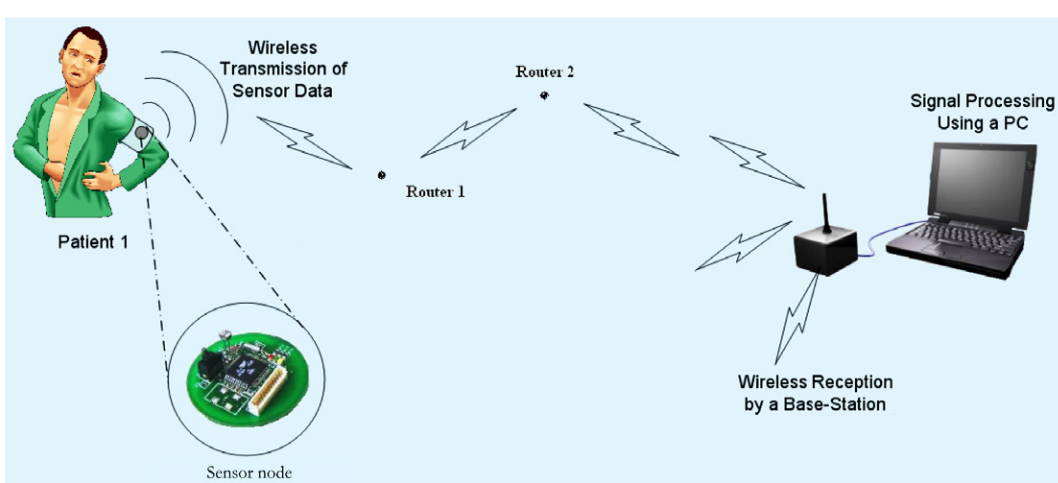

Fig. 1. Patient remote health monitoring. (Figure source: http://www.enel.ucalgary.ca/People/Haslett/WCLM/CCHE/WebPage/VijayDevabhaktuni_Wireless_Proceedings.doc).