**Energy Management Policy of Wireless Energy Harvesting Sensor**

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| **Keywords:** |  | **ABSTRACT**  |
| Sensor networks, MAC protocols. |  | We study sensor networks with energy harvesting nodes. The generated energy at a node can be stored in a buffer. A sensor node periodically senses a random field and generates a packet. These packets are stored in a queue and transmitted using the energy available at that time at the node. For such networks we develop efficient energy management policies. First, for a single node, we obtain policies that are throughput optimal, i.e., the data queue stays stable for the largest possible data rate. Next we obtain energy management policies which minimize the mean delay in the queue. We also compare performance of several easily implementable suboptimal policies. A greedy policy is identified which, in low SNR regime, is throughput optimal and also minimizes mean delay. Next using the results for a single node, we develop efficient MAC policies. |
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**1. INTRODUCTION**

Sensor networks consist of a large number of small, inexpensive sensor nodes. These nodes have small batteries with limited power and also have limited computational power and storage space. When the battery of a node is exhausted, it is not replaced and the node dies. When sufficient number of nodes die, the network may not be able to perform its designated task. Thus the life time of a network is an important characteristic of a sensor network and it is tied up with the life time of a node. Various studies have been conducted to increase the life time of the battery of a node by reducing the energy intensive tasks, e.g., reducing the number of bits to transmit [3], [15] making a node to go into power saving modes: (sleep/listen) periodically [21], using energy efficient routing [18], [24] and MAC [25]. Studies that estimate the life time of a sensor network include [18]. A general survey on sensor networks is [1] which provides many more references on these issues. In this paper we focus on increasing the life time of the battery itself by energy harvesting techniques [9], [14]. Common energy harvesting devices are solar cells, wind turbines and piezo-electric cells, which extract energy from the environment. Among these, solar harvesting energy through photo-voltaic effect seems to have emerged as a technology of choice for many sensor nodes [14], [16]. Unlike for a battery operated sensor node, now there is potentially an infinite amount of energy available to the node. Hence energy This work was partially supported by a research grant from Boeing Corporation. Vinod Sharma, Utpal Mukherji, Vinay Joseph are with the Dept of Electrical Communication Engineering, Indian Institute of Science, Bangalore, India. conservation need not be the dominant theme. Rather, the issues involved in a node with an energy harvesting source can be quite different. The source of energy and the energy harvesting device may be such that the energy cannot be generated at all times (e.g., a solar cell). However one may want to use the sensor nodes at such times also. Furthermore the rate of generation of energy can be limited. Thus one may want to match the energy generation profile of the harvesting source with the energy consumption profile of the sensor node. It should be done in such a way that the node can perform satisfactorily for a long time, i.e., at least energy starvation should not be the reason for the node to die. Furthermore, in a sensor network, the MAC protocol, routing and relaying of data through the network may need to be suitably modified to match the energy generation profiles of different nodes, which may vary with the nodes.

**2. Conclusions**

We have considered sensor nodes with energy harvesting sources, deployed for random field estimation. Throughput optimal and mean delay optimal energy management policies for single nodes are identified which can make them work in energy neutral operation. Next these results are extended to fading channels and when energy at the sensor node is also consumed in sensing and data processing. Similarly we can include leakage/wastage of energy when it is stored in the energy buffer and when it is extracted. Finally these policies are used to develop efficient MAC protocols for such nodes. In particular versions of TDMA, opportunistic MACs for fading channels and CSMA are developed. Their performance is compared via simulations. It is shown that opportunistic policies can substantially improve the performance.

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