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The Value of Information in Energy Harvesting Sensor Networks

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Abstract

We study optimal data collection in energy harvesting sensor networks. The sensed data-stream constitutes a sequence of stationary ergodic random variables and, assuming that timely data is valued more, the value of the data is discounted over time such that frequent collection is required to avoid a loss in value. However, unlimited data collection is constrained by both the cost of data collection and the availability of energy.

Keywords: energy harvesting, sensor network, performance evaluation

1 Introduction

As the key constituent of the Internet of Things (IoT), wireless sensor networks (WSNs) have attracted considerable research interest. Sensor networks collect and monitor spatially distributed data like temperature, humidity, movement and noise [1] and have a variety of applications including military, environmental, home and health applications [2, 3]. Sensor networks enable fast data-to-decision applications that act in real time on the collected data, the value the information brings to the decision not only depending on the quality but also on the timeliness of the information. Therefore, analogous to Quality of Service which measures the performance of a data communications network, the term "Quality of Information" (QoI) has been introduced to evaluate performance of sensor networks [4, 5].

In this letter, we study the optimal data collection rate for the hybrid WSN of Zhou et al. [6] which consists of static sensors responsible for sensing environmental variables, and mobile sensors called IoT mobile sinks that move to designated sink locations where they gather the data that is sensed by the static sensors. In particular, we investigate the QoI collected by the IoT mobile sink from a single static energy-harvesting sensor. Energy harvesting sensor nodes mitigate their dependence on batteries by harvesting energy (solar, wind, heat, etc) from their environment [7]. The sensor node under consideration operates energy neutral which means that all energy for sensing and transmissions is harvested, a small on-board battery providing for temporary energy storage. As the node solely depends on harvested energy, one needs to account for the possibility of temporarily running out of energy. Therefore, the sensor node at hand can only transmit when the IoT mobile sink is in range and the sensor has sufficient energy for transmitting.

2 Analytic model

We consider an energy harvesting sensor node operating in discrete time. That is, time is divided into fixed length intervals or slots and all transmissions are synchronised with respect to slot boundaries. The sensor node is equipped with on-board memory to store sensed information and a battery for storing harvested energy. For ease of analysis, we discretise the battery levels: the battery can store up to C discrete units (or chunks) of energy.

Let H_n denote the number of energy chunks that are harvested during slot n. H_n only includes the energy that is available for transmissions. That is, accounting for any conversion loss, and assuming that the node can constantly harvest sufficient energy for sensing, H_n is the excess energy that can be used for transmissions. The amount of energy provided by a single chunk corresponds to $1/N$th of the energy required to make a single transmission which is assumed to be constant and independent of the value of the information. The choice of a large N corresponds to a fine-grained battery model. However, the same battery capacity then corresponds to more energy chunks (C is larger) which implies that the performance analysis is more computationally demanding (cfr. infra). The sequence H_n

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