Department of Electrical and Computer Engineering
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Modeling, Analysis, and Design of Energy Harvesting Communications Systems

Shenqiu Zhang

Supervised by
Professor Alireza Seyedi

Wireless sensor networks (WSNs) are envisioned to have a significant impact for many applications such as health monitoring and area surveillance. Despite many advances in energy aware communication techniques for WSNs, the limitation of energy supply is still a critical issue. One of the most attractive approaches to extend the lifetime of WSNs is harvesting energy from the ambient sources, such as solar, wind and vibration. However, the inherent dynamic and randomness of these sources give rise to many new challenges to modeling and management of harvested energy as well as the analysis of energy harvesting systems.

This dissertation involves modeling and analysis of energy harvesting sensors and networks: (i) A Markovian model is developed for energy harvesting sensors, which unifies the processes of energy harvesting, event arrivals, energy storages, and queueing unprocessed events. The probability of event loss and the average queueing delay are analyzed, which further guides a near-optimal design of sensor nodes, in terms of sizing the capacity of energy storage, harvesting device and event queue capacity; (ii) A mathematical model is developed for energy harvesting sensor networks with a multi-source and single-sink topology. The probability of event loss in the network is analyzed due to channel errors and lack of energy in sensors, which is utilized for the system design of sizing the storage and harvesting components of sensor nodes; (iii) Empirical human-motion based harvesting power is measured for 20 subjects. The statistical properties of harvesting power are analyzed for probability density function, auto-correlation coefficient and cross-correlation coefficient among four locations. A Markovian model of the human-motion harvestable power is developed.

This dissertation makes unique contributions in the following aspects. The proposed models derive close-form expressions for the probability of event loss and average queueing delay, which provide an insight into the performance and the system design of energy harvesting sensor nodes and networks. Statistical and Markovian models are developed for the harvestable energy measured from human motion when subjects perform normal daily activities. These are the first of such models available and will provide the research community with a proper basis for analysis and design.