Abstract

An energy harvesting node (EHN) operates using the energy harvested from the environment, e.g., solar, piezoelectric and radio frequency, which presents the tantalizing possibility of perpetually operating of sensor nodes. However, the operation of an EHN is governed by the *energy neutrality constraint* (ENC), which makes it mandatory that, at any point in time, the total cumulative energy consumed by a node must not exceed the total cumulative energy harvested by it. Due to the random and sporadic nature of the harvested energy, energy management becomes the central issue in the optimization of energy harvesting (EH) communication systems. The design of energy management policies for the systems where only the transmitter is an EHN has been considered extensively in the literature. On the other hand, designing the policies for the networks where both the transmitter and receiver use harvested energy to operate is significantly more challenging, as aspects of coordination of the transmission attempts as well as nonzero decoding cost come into play. In this thesis, we present the design of energy management policies for a variety of scenarios where all nodes in a network are energy harvesting. The main contributions of this thesis are as follows:

- In the initial part of the thesis (Chapters 2-5), we present the design of packet drop probability (PDP)-optimal power control policies for retransmission-based multi-hop EH links where all the nodes are EHNs and the cost of decoding the data at the receiver is nonzero. In order to design the policies, we first derive *closed-form* PDP expressions for multi-hop EH links employing retransmission index based policies (RIPs) that are unaware of the state-of-charge (SoC) of the batteries at the nodes. Since the transmit power prescribed by an SoC-unaware RIP is independent of the current battery state, the RIPs obviate the need to measure the SoC of the battery. In practice, it is difficult to accurately measure the SoC of the battery, and therefore this is an added benefit of the proposed policy.

- Using the derived PDP expressions, we formulate and solve a PDP optimization problem to obtain near-optimal RIPs. To design the SoC-unaware RIPs we use the notion of *energy unconstrained regime* (EUR), in which, the average energy consumed is less than the average energy harvested. We show that policies designed to operate in the EUR are near-optimal, even with finite sized energy buffers. This, in turn, allows us to replace the ENC in the PDP optimization problem with a single EUR constraint. This significantly simplifies the complexity of designing the optimal policies. We show that the RIPs obtained under EUR constraints are near-optimal and achieve the lower bound on the PDP. Moreover, these policies can be implemented in a distributed fashion.

- In the later part of the thesis (Chapter 6), we investigate impact of lack of coordination between the transmitter and receiver, i.e., when the transmitter (receiver) does not have the information about the SoC of the battery at the receiver (transmitter). The lack of coordination leads to the wastage of energy when, in a slot, only the transmitter (or receiver) is on. The goal here is to maximize the throughput between a transmitter and receiver without any explicit coordination, and only using the statistical information about the energy arrivals at both the nodes. We derive a genie-aided upper bound on the throughput achievable, by analyzing a system that has non-causal knowledge of energy arrivals. Next, we present an online, distributed energy management policy which achieves the throughput within a gap of one bit from the upper bound and requires an occasional one bit feedback. The above policy is modified to obtain a time-dilated policy which achieves the upper bound asymptotically, with the battery size at both the nodes. We also propose a near-optimal, deterministic, fully uncoordinated policy which requires no feedback from the receiver. Our simulation results confirm the theoretical findings and illustrate the trade-offs between system parameters. The policies presented here not only achieve the upper bound but are also simple to implement. Our policies allow the nodes to operate in a truly uncoordinated fashion which, in turn, completely removes the overhead in the feedback.