Energy and Channel-Aware Power and Discrete Rate Adaptation and Access in Energy Harvesting Wireless Networks
Parag S. Khairnar

Synopsis

Energy harvesting (EH) nodes, which harvest energy from the environment in order to communicate over a wireless link, promise perpetual operation of wireless networks. The primary focus of the communication system design shifts from being as energy conservative as possible to judiciously handling the randomness in the energy harvesting process in order to enhance the system performance. This engenders a significant redesign of the physical and multiple access layers of communication.

In this thesis, we address the problem of maximizing the throughput of a system that consists of rate-adaptive EH nodes that transmit data to a common sink node. We consider the practical case of discrete rate adaptation in which a node selects its transmission power from a set of finitely many rates and adjusts its transmit power to meet a bit error rate (BER) constraint. When there is only one EH node in the network, the problem involves determining the rate and power at which the node should transmit as a function of its channel gain and battery state. For the system with multiple EH nodes, which node should be selected also needs to be determined.

We first prove that the energy neutrality constraint, which governs the operation of an EH node, is tighter than the average power constraint. We then propose a simple rate and power adaptation scheme for a system with a single EH node and prove that its throughput approaches the optimal throughput arbitrarily closely. We then arrive at the optimal selection and rate adaptation rules for a multi-EH node system that opportunistically selects at most one node to transmit at any time. The optimal scheme is shown to significantly outperform other ad hoc selection and transmission schemes. The effect of energy overheads, such as battery storage inefficiencies and the energy required for sensing and processing, on the transmission scheme and its overall throughput is also analytically characterized.

Further, we show how the time and energy overheads incurred by the opportunistic selection process itself affect the adaptation and selection rules and the overall system throughput.
Insights into the scaling behavior of the average system throughput in the asymptotic regime, in which the number of nodes tend to infinity, are also obtained. We also optimize the maximum time allotted for selection, so as to maximize the overall system throughput.

For systems with EH nodes or non-EH nodes, which are subject to an average power constraint, the optimal rate and power adaptation depends on a power control parameter, which hitherto has been calculated numerically. We derive novel asymptotically tight bounds and approximations for the same, when the average rate of energy harvesting is large. These new expressions are analytically insightful, computationally useful, and are also quite accurate even in the non-asymptotic regime when average rate of energy harvesting is relatively small.

In summary, this work develops several useful insights into the design of selection and transmission schemes for a wireless network with rate-adaptive EH nodes.