Energy Harvesting-Based Green Wireless Communication Systems

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The limitation on the amount of energy that can be stored in compact batteries has severely constrained the capabilities and applicability of conventional wireless sensor networks that operate using battery-powered nodes. The ability to harvest energy from a variety of renewable sources of energy such as using solar, wind, vibration, radio energy, and thermoelectric effects, to facilitate sensing, computation, and communication has the potential to solve this challenging problem. Unlike a conventional battery-powered sensor node that dies once the energy in its battery drains out, an energy harvesting node can harvest energy from the environment and become available for communication later. Thus, the energy harvesting capability promises to transform wireless sensor networks into maintenance-free, perpetual, energy-aware networks that are capable of sensing and communicating vast amounts of data. Given its promise as a sustainable and environment-friendly technology, energy harvesting is receiving increasing attention from the academia and industry. It finds applications in a variety of systems such as wireless sensor networks, body area networks for health monitoring, and cellular mobile radio communication systems.

The inclusion of the energy harvesting functionality into a wireless system is exciting from a research point of view because it forces us engineers to revisit the design of various layers of the communication protocol stack. The system has to grapple with uncertainty in the amount of energy it can harvest at any time and the times at which this energy is available. The design focus fundamentally shifts from conserving as much energy as possible – and at any cost to the overall system performance – to judiciously utilizing the harvested energy and ensuring that it is available when required. This has recently led to considerable research work by several groups globally on a broad range of topics such as theoretical modelling, performance analysis and optimization, and hardware prototyping of energy harvesting-based wireless networks.

To illustrate and understand the new design issues that arise, we shall delve deeper into two promising and rather different applications of energy harvesting, namely, opportunistic multi-hop relaying in cooperative wireless networks and hybrid wireless sensor networks. In opportunistic relaying, intermediate energy harvesting relays help a source node communicate with a destination node by forwarding the source’s packet to the destination. Energy harvesting helps the relay replenish the energy it loses in the process of forwarding the packet. Its effectiveness depends on the transmission protocol used by the relays, how many relays help forward the packet, and the transmit power settings of the relays, all of which need to be jointly optimized. Hybrid wireless sensor networks, on the other hand, are an interesting new class of wireless networks that consist of a mixture of energy harvesting nodes and conventional battery-powered sensor nodes. These are motivated by cost considerations, a gradual upgrading of legacy wireless sensor network deployments, and by scenarios in which some of the energy harvesting nodes do not harvest energy for long periods of time. Here, an altogether new set of measures need to be defined to evaluate and compare system performance. These measures should capture the irreversible decline in the battery energies of the conventional nodes and also the occasional unavailability of the energy harvesting nodes when their batteries are running low on energy and are yet to be replenished with harvested energy. We present two novel and simple performance metrics that address this issue, and develop computationally-efficient approaches to evaluate them.