ABSTRACT

Future generation wireless networks are required to support high data rates and massive connectivity while ensuring an enormous reduction in energy consumption. The inclusion of the Internet of Things (IoT) and machine-to-machine (M2M) communication in 5G networks has increased the need to prolong the battery lifetimes of low-power machine-type devices (MTDs). To avoid frequent battery replacements, harvesting energy from RF signals to implement self-sustaining communication nodes is clearly well motivated. Unfortunately, the harvested energy is often quite small and random, which lowers the reliability of communication links with such energy harvesting (EH) nodes. Storing energy in batteries or super-capacitors until there is sufficient energy to transmit is a solution. However, rechargeable batteries make devices more complex and expensive besides increasing their form factor, while super-capacitors cannot store charge for a long time. Moreover, storing energy this way can increase latency in communications. Such self-sustaining nodes will be the future as low power signalling techniques are developed. Currently however, the energy requirement of nodes is too large to be met by energy harvesting with acceptable QoS. For these reasons, augmenting the harvested energy with as little battery energy as possible is a promising alternative for the immediate future, and can ensure increased battery life while simultaneously attaining the desired quality of service (QoS). The added battery energy helps in overcoming the problem of the random nature of the harvested energy. Such battery-assisted energy harvesting nodes can prolong battery lifetimes, and are immediately realizable. However, suc h battery-assisted EH nodes need careful optimization to ensure best throughput and energy efficiency. Technologies like full-duplex relays (FDRs) and non-orthogonal multiple access (NOMA) are proposed for achieving the goals of higher spectrum efficiency (SE) and massive connectivity. New standards for 5G suggest the use of IoT devices and MTDs with a large lifetime and enhanced connectivity. To realize these goals, understanding how to optimize NOMA and FDR networks with battery-assisted EH nodes is essential. However, this has never been attempted before. It is noted that in such networks, since battery energy consumption is of concern, node-level energy

efficiency is of importance in addition to system-level energy efficiency.

The main objective of this thesis is the analysis of performance and optimization of battery-assisted EH nodes in different networks so as to improve the QoS in terms of SE and energy efficiency (EE). In battery-assisted EH nodes, the precise battery energy management scheme used influences the amount of battery energy consumed. A fixed battery energy (FBE) scheme in which a fixed amount of battery energy is drawn in each symbol interval is taken up first because of its low implementation complexity. The performance of a dual-hop cooperative network with a battery-assisted EH half-duplex (HD) relay is analyzed assuming the presence of a direct channel from the source to the destination. In this context, the performance of selective decode-and-forward and incremental relaying schemes is analyzed. The importance of optimal choice of EH parameters is also brought out for throughput maximization and battery energy savings. Next, to further improve the SE, a dual-hop FD cooperative network is studied. Considering decode-and-forward (DF) and amplify-and-forward (AF) relaying at the FD relay, expressions are derived for the throughput with time-switching (TS) and power-splitting (PS) EH protocols. In the case of FD relaying, it is shown that a unique battery energy value exists that maximizes the throughput. Expressions are derived for the optimal TS/PS parameters for desired target throughput requirement so as to minimize the average battery energy consumption.

Use of EH nodes in cooperative NOMA (C-NOMA) and FD relaying based NOMA networks can enhance both EE and SE to a great extent. The performance of a C-NOMA network in which a battery-assisted EH FD near user (NU) assists in information transfer to multiple far users (FUs) is investigated. The NU is allowed to switch to a non-cooperative mode in a hybrid scheme to ensure that its own performance is not degraded due to the FU. Considering nonlinear EH at the NU, expressions are derived for the outage probability and throughput at NU and FU. Use of this hybrid scheme provides higher immunity to residual self-interference and higher EE. To further increase the range of C-NOMA, an R-NOMA framework is studied where the base station directly communicates to the NU, while a dedicated FD relay is used for forwarding information to the FU. Considering PS and TS EH protocols, performance is analyzed in terms of the outage probability and throughput. The performance of FU is maximized by optimally choosing the TS/PS parameter while ensuring the desired target QoS at NU. To further improve energy efficiency, a new dynamic battery energy (DBE) scheme is proposed in which the battery energy drawn depends on the amount of harvested energy. It is demonstrated that using the DBE scheme to manage the battery energy ensures higher energy efficiency than is possible with the FBE scheme.

In wireless sensor networks (WSN) and body area networks, it is often desired that a node assists other nodes in its vicinity. The battery lifetime and communication range of such nodes are quite limited. Using EH at the relaying node can ensure that its battery lifetime is not decreased significantly. In many practical systems, the instantaneous CSI can be estimated with reasonable accuracy. It is shown in this thesis that the availability of instantaneous CSI can help the self-sustaining EH devices in prolonging their battery life significantly. To investigate the impact of CSI knowledge in a two-hop FD relay framework, a dynamic TS protocol is proposed with intelligent battery management at the relay. Performance of the static and CSI dependent (dynamic) TS EH protocols is analyzed in terms of throughput and average battery energy consumption. Use of dynamic TS provides substantial performance gains for both FBE and DBE energy management schemes over the static TS scheme. Also, by optimally choosing the TS EH parameter, the dynamic TS with DBE achieves enormous battery energy savings at the relay.

In view of the rapid growth in low-power devices in communication networks, the insights developed in this thesis are quite valuable to system designers for optimizing the throughput performance and battery lifetime.