ABSTRACT

Next generation wireless communication networks need to meet the high data-rate demands of internet access, online games, and multimedia applications such as voice over internet protocol (VoIP), and video streaming. Machine type devices (MTDs) are already playing an important role in our lives. Battery lifetime issues and difficulty in battery replacement have received a large amount of research focus for this reason. Energy harvesting (EH) is often suggested as a solution. Energy can be harvested from several different freely available environmental sources such as wind, vibration, thermal, solar and ambient radio frequency (RF) signals. However, it is the use of RF sources that is considered to be most promising. The harvested energy can be stored in energy storage devices like supercapacitors or batteries. Due to rapidly increasing number of MTDs, promise of low cost, small form factor and theoretically infinite lifetime, such self-sustaining nodes are expected to play a very important role in next generation communications. Understanding performance of networks with such nodes is therefore of fundamental importance.

The main objective of this thesis is the accurate analysis of performance of wireless communication networks with energy buffer equipped self-sustaining EH nodes. All currently existing literature on cooperative communication with such EH nodes uses the discrete state space Markov chain (DSMC) to model the energy buffer although energy is continuous. This is an inaccurate representation, and requires high computational complexity to analyze performance. For this reason, in this thesis, the energy buffer states are modelled using a discrete-time continuous state space Markov chain (CSMC). The limiting or steady state distribution of the stored energy is used for analysis of the system performance, and makes it possible to obtain important insights. Use of the CSMC dramatically reduces the computational complexity required for analysis of performance, and ensures accuracy. Utilization of the harvest-store-use (HSU) architecture with energy buffers means that excess energy can be made available in future signalling intervals, ensuring better performance than with the harvest-use (HU) archi-

tecture and direct (relay-less) transmission. The best-effort policy (BEP) and the on-off policy (OOP) are considered for energy management in the energy buffers.

Cooperative relaying increases the system capacity and coverage range. Generally, the nodes which act as relays deplete their battery energy quickly, and use of harvested energy at the relays is well motivated. Intuitively, it can be seen that use of the HSU architecture at the relays with energy buffers can considerably enhance performance as compared to the case when the HU architecture is used. For this reason, the performance of incremental relaying cooperative network with an energy buffer at the EH relay is studied in this thesis. In this context, use of incremental relaying is doubly advantageous. Firstly, throughput is enhanced when the direct link is itself successful. Secondly, when the direct link is successful, the relay is not utilized, and energy accumulates in the energy buffer (thereby ensuring better performance in future signalling intervals). Performance of such networks is analyzed with two different energy management policies - incremental best-effort policy (IBEP) and incremental on-off policy (IOOP). To study the system performance, the limiting distributions of energy in the energy buffer are derived with both these policies. An interesting property established in this thesis is that the diversity order attained with the IBEP is two, but that attained by the IOOP is only one. In other networks too that rely on cooperation, use of energy harvesting nodes is well motivated. For example, in cooperative non-orthogonal multiple access (NOMA) networks, expecting the near-user close the source to relay information to the distant far-user is unreasonable in some scenarios since such relaying involves use of battery energy to relay some other user's symbols. When EH is used, and the harvested energy is used for relaying by the near-user, it does not have to expend its own battery energy. Performance of cooperative NOMA networks with self-sustaining EH near-users is analyzed in this thesis. It is shown that switching between NOMA, cooperative NOMA and OMA modes in a hybrid NOMA (HN) scheme can considerably enhance throughput due to accumulation of energy in the energy buffer when relaying is not required. Limiting distributions are derived for the hybrid NOMA with BEP (HN-BEP) and OOP (HN-OOP), and used to analyze throughput performance.

The communication range of self-sustaining nodes is quite limited, and use of other self-sustaining nodes in the vicinity to relay information is of practical interest. In this thesis, the performance of a two-hop cooperative network is analyzed with green self-sustaining nodes equipped with energy buffers. Insights are derived on the choice of

energy management policies at the source and relay, the choice of target rate, and the transmit powers to be used by them. Performance with adaptive rate transmission is also analyzed.

In several sensor networks and IoT applications, a wireless node in the vicinity acts as a data collector and relays information to an access point. In this thesis, we consider such links with a self-sustaining source. Due to the large asymmetry in the links, use of intelligent link selection with data buffer at the relay is well motivated. We also analyze the performance of such networks, and demonstrate how the CSMC modelled energy buffer and the DSMC modelled data buffer can both be balanced by intelligent choice of target rates and transmit powers at the source and the relay so as to maximize the throughput of the network. In typical applications, feedback of channel state information and buffer state information is not feasible, so simple link selection schemes are evolved. In the first only-buffer-status (OBS) scheme, link selection is based on energy-buffer status alone. A modified only-buffer-status (MOBS) scheme is then suggested, and its performance is analyzed. The third scheme uses both energy-buffer status and first-hop channel knowledge for link selection. Expressions are derived for throughput and limiting distributions of stored energy with all the three schemes.

In order to understand the influence of interference on performance of links with self-sustaining nodes, the performance of full-duplex communication link between two energy-buffer equipped nodes is analyzed. It is demonstrated how the choice of transmit powers and target rates of each node are influenced by the self-interference. Interestingly, it is demonstrated that due to the presence of self-interference, sum throughput of the nodes is maximized when the energy buffers are starved. The energy management policy that should be chosen at each node to maximize the sum throughput depends on the self-interference levels, as well as on the mean harvested energy levels.

The thesis makes important contributions to analysis of performance of communication links with self-sustaining nodes. Due to rapid increase in number of MTDs, the insights obtained will be useful in design of next generation communication systems.