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Ph.D. Public Defense

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Energy Balancing in Wireless Networks with MIMO Communications

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Wireless networks are vital for supporting a range of applications. With the continuous development of wireless networks, energy conservation and energy efficiency are becoming key factors in improving the network lifetime. In conventional wireless networks, the nodes are equipped with a single antenna, and the energy conservation methods are needed since the nodes have limited capacity and may run out of energy. Although energy harvesting, which provides unlimited amount of energy to the nodes when ambient energy is available, can be helpful in solving this problem, there are times when the energy source is not available. Therefore, implementing energy efficient techniques is essential in wireless networks in order to have energy consumption balance among the wireless nodes. In multi-antenna wireless networks, however, the energy conservation problem can be addressed using the trade-off between the transmit power and the circuit energy consumption. Multiple-Input Multiple-Output (MIMO) communication is a promising approach that can be efficiently used in reducing the energy consumption for communication. In MIMO systems, the transmit power is spread among more than one antenna, which results in having a high power gain and better spectral efficiency.

To this end, I propose a system for MIMO wireless networks that optimizes the energy efficiency and provides energy balance by dynamically adjusting the number of antennas based on the nodes' energy levels. Based on the nodes' distance, remaining energy, and the target Bit-Error-Rate (BER), a multi-antenna scheme is chosen for communication on a per-packet basis. The system is modeled using a Markov Decision Process (MDP) and optimized using reinforcement learning. I define the reward function based on the remaining energy, energy consumption, and the distance between the nodes and use Q-learning to find the optimal multi-antenna scheme.

In order to extend the idea into a network with more than two nodes, I propose MAC-LEAP: Multi-Antenna, Cross Layer, Energy Adaptive Protocol for single-hop and multi-hop MIMO wireless networks. The protocol selects the most energy efficient MIMO scheme for both the transmitter and the receiver and uses the RTS/CTS hand-shake to transfer some information required by the dynamic antenna selection policy prior to the data transmission. Based on simulation results using the ns-3 network simulator, MAC-LEAP outperforms traditional protocols both in terms of network lifetime and the number of received packets in single hop and multi-hop networks. Moreover, MAC-LEAP is also implemented in a real life animal tracking application called JumboNet. I tested the protocol in three different scenarios; when the nodes have limited energy, when the nodes have unlimited energy, and when the nodes employ energy harvesting. According to the simulation results, MAC-LEAP outperforms the traditional JumboNet network in terms of energy consumption, packet delay, and packet delivery ratio.

Moreover, in order to enable network scalability, I propose Cluster-based MIMO (CMIMO), a cluster-based protocol for wireless networks in which the nodes have multiple antennas and are powered either by a non-rechargeable battery or by energy harvesting. In a cluster-based network using MIMO, the nodes are equipped with more than one antenna. CMIMO adjusts the number of antennas for communication between a normal node and a cluster-head in order to improve the energy efficiency of the network. We evaluate CMIMO in two scenarios, a network with wireless nodes with non-rechargeable batteries, and a network with mobile wireless nodes powered with energy harvesting. In both scenarios, the simulation results show that CMIMO outperforms the traditional approach in terms of number of received packets, network lifetime, percentage of dead nodes, and energy consumption.