Dissertation title:

Design, Analysis and Optimization of UAV- aided Sustainable Wireless Communications

Abstract:

In recent years, the concept of the Passive Internet of Things (IoT) has emerged as a transformative paradigm in wireless communication, redefining how devices connect, sense, and operate in next-generation networks. The vision outlines a future where billions of devices function without conventional power sources, enabled by radio frequency (RF) energy harvesting and backscatter communication (BSC). However, the inherent nature of BSC and RF energy transfer (RFET) introduces several challenges. The communication range of BSC systems is restricted by multiplicative fading and the double path loss associated with the backscatter link, while the low energy-conversion efficiency of RFET demands short-range operation, limiting scalability in large networks. To alleviate these constraints, uncrewed aerial vehicles (UAVs) have gained attention as mobile platforms capable of providing flexible communication and energy support. Nevertheless, UAV deployment also introduces practical challenges, including limited onboard energy, motion-induced channel variations, and imperfect hovering stability, all of which can degrade link performance and increase power consumption.

The core objective of this work is to design, analyze, and optimize a UAV-aided sustainable communication network tailored for ultra-low-power wireless sensor deployments. The study begins by developing a framework for backscatter-communication based sensor data collection using LASER-powered UAVs. Under the assumption that the UAV-to-backscatter-node channel follows Nakagami-m fading, analytical expressions for SNR outage and energy outage are derived to evaluate sustainability and reliability of the system. Building upon this baseline model, the analysis is extended to incorporate practical UAV impairments. In real deployments, UAVs inevitably experience localization inaccuracy and orientation mismatch, which directly affect both communication and energy-transfer efficiency. Motivated by this observation, the impact of UAV positional and orientation uncertainty on BSC and RFET performance is analytically characterized. Using tools from stochastic geometry, closed-form expressions are provided for expected harvested energy, energy-outage probability, SNR-outage probability, and the ergodic capacity of the backscatter link.

Since communication performance is closely tied to the UAV's limited energy resources, the work further examines the key contributors to UAV power consumption communication, hovering, and maneuvering. After analytically evaluating communication and hovering costs, attention is directed toward optimizing energy expenditure during maneuvering. This leads to the observation that a UAV cannot feasibly serve all sensor nodes within a single flight due to its constrained energy budget. To address this limitation, a reinforcement-learning-based optimization framework is introduced to determine an energy-aware UAV visiting sequence that maximizes network longevity and minimizes flight energy wastage.

To further enhance throughput and service efficiency, the investigation then considers mmWave-enabled UAV operation. A hybrid-beamforming strategy is developed to enable simultaneous communication and energy transfer to multiple backscatter nodes, thereby improving UAV efficiency and reducing mission time. An energy-optimized UAV transceiver is designed, and thereafter, a UAV-constraint-aware clustering algorithm is developed to span the entire service region, and finally, an optimization framework for per-cluster resource allocation is formulated and solved using an alternating convex optimization approach.

Collectively, these contributions present a comprehensive pathway toward sustainable, energy-efficient, and scalable UAV-assisted backscatter communication for next generation passive IoT networks.