Abstract

The widespread adoption of wireless devices, alongside the traditional fixed spectrum allocation methods, has led to a shortage of available radio spectrum. On the other hand, users holding exclusive spectrum access licenses often fail to fully utilize their allocated frequency bands, resulting in significant portions of the spectrum being underutilized. To tackle both spectrum scarcity and underutilization issues, a new communication paradigm known as dynamic spectrum access (DSA) has emerged. DSA offers opportunistic access to idle frequency bands and has shown promising results. Cognitive radio (CR) technology plays a key role in enabling DSA. CR allows unlicensed users (or secondary users) equipped with CR technology to dynamically access licensed bands from legacy spectrum holders. This access is facilitated on a negotiated or opportunistic basis, without causing harmful interference to licensed users (or primary users). Recently, cooperative dynamic spectrum access, also known as cooperative spectrum sharing (CSS), has garnered considerable research attention. In CSS, primary users (PUs) and secondary users (SUs) collaborate to share scarce spectrum resources for cooperative communication, aiming for mutual benefits. In cognitive radio networks (CRNs), direct transmission between primary transceiver pairs faces challenges due to fading and shadowing phenomena, resulting in degraded primary link performance. Relay-based CSS, where both PUs and SUs collaborate to provide assistance through cooperative services, offers potential solutions. It can alleviate interference, enhance signal quality through amplification, extend coverage significantly, and improve communication capacity. However, fostering collaboration between PUs and SUs in scenarios involving multiple PUs and SUs presents significant challenges. One major challenge is implementing perfect mapping among multiple PUs and SUs to enable CSS. This involves selecting cooperative PU-SU partners to ensure mutual preferences and optimally distributing spectrum resources among these partners to enhance individual utility. Identifying suitable partner combinations and allocating resources for CSS becomes complex due to the diverse characteristics and conflicting interests inherent in PUs and SUs. Furthermore, there is a growing demand for energy-efficient communication in

relay-based CSS, particularly due to energy limitations faced by small wireless devices acting as SUs. Recent advancements in wireless technology have introduced simultaneous wireless information and power transfer (SWIPT) technology, enabling the extraction of energy and processing of information from ambient radio frequency (RF) signals. By employing SWIPT receivers with suitable circuitry, it becomes possible to efficiently decode information and harvest energy from RF signals, thus extending the network's operational lifespan. Given the cognitive capabilities of SUs, integrating SWIPT into cognitive radio provides a promising solution to enhance energy efficiency for SUs.

This thesis takes a comprehensive approach to tackle the challenges associated with partner selection and resource allocation in cooperative spectrum sharing (CSS). It accounts for the diverse characteristics and conflicting interests of PUs and SUs, with a particular emphasis on enhancing energy efficiency for SUs.

We begin by devising relay-based CSS strategies tailored for scenarios featuring a single PU but multiple SUs within CRNs. These strategies consider how selecting the most advantageous SU as a relay node impacts the gains in utility for the primary network, while also ensuring that the chosen SU adheres to transmission constraints. Depending on the quality of service requirements of primary traffic, the proposed CSS scheme either assigns optimal bandwidth segments or allocates optimal time fractions among the selected PU-SU pairs. To address the computational complexity inherent in the formulated CSS problem, we introduce a heuristic approach that delivers a sub-optimal solution within polynomial time.

In our second scheme, we address relay-based CSS within multi-PUs and multi-SUs CRN scenarios. Our objective is to optimize the distribution of PU access time among selected PU-SU pairs. Initially, we frame the resource allocation among these pairs as a multi-objective optimization problem, considering the trade-offs between SU utility gains and penalty costs. Given the computational complexity of this optimization problem, we propose a heuristic method that provides near-optimal solutions for resource allocation within polynomial time. Subsequently, we tackle the user pairing problem among multiple PUs and SUs using matching theory. We demonstrate that the resulting one-to-one matching converges to a stable matching for SUs and an optimal matching for PUs.

In our next research, we introduce a cooperative strategy among the SUs aimed at enhancing both individual and overall performance of the secondary network. We leverage the concept of many-to-one matching theory, grouping the most suitable SUs together and collectively pairing them with the most preferred PU for relay-based CSS on a rotational basis. The resulting many-to-one matching converges to a stable match for the set of PUs, an optimal match for the set of SUs, and maximizes the overall utility of the secondary network.

Finally, we develop an energy harvesting scheme for energy-constrained SUs to enable energy-efficient CSS in a multi-PUs, multi-SUs CRN environment. Initially, we formulate a joint optimization problem to optimize power and time allocation, striking a balance between energy harvesting and information decoding rates. Subsequently, we devise another optimization problem to determine the optimal distribution of harvested power, considering the trade-off between SUs' utility gains and PUs' achievable rates. We illustrate that both optimization problems are NP-hard and thus propose heuristic solutions that provide near-optimal outcomes within polynomial time. To implement relay-based CSS among multiple PUs and SUs, we employ a hedonic cluster formation game, dividing the set of SUs into suitable clusters and assigning each cluster to an appropriate PU. This CSS scheme enhances the utility of each SU within its cluster, thereby improving the overall utility of the secondary network.
Keywords: Cognitive Radio Network, Dynamic Spectrum Access, Primary User, Secondary User, Spectrum Sharing, Cooperative Spectrum Sharing, Optimization, Resource allocation, Matching theory, Energy harvesting, and Utility.