Collaborative Approaches to Overlay Spectrum Sharing in Cognitive Radio Networks

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by

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Chapter 7

Conclusion and Future Direction

This thesis makes four contributions to the body of knowledge on collaborative approaches to spectrum sharing for allocation of spectrum resources among primary users (PUs) and secondary users (SUs) in overlay cognitive radio networks (CRNs). In this chapter, we summarize the main contributions made in this thesis and provide directions for future works.

7.1 Conclusion

Following conclusions are drawn from the contributions in this thesis.

- In chapter 3, we proposed a relay-based CSS scheme for single-PU multi-SU overlay CRNs. The primary objectives of our proposal were twofold: (i) To select suitable SU as a relay node based on the PU service requirement; and (ii) To optimally allocate PU resources with the selected relay node. The formulated optimization problem aimed at maximizing the utility of the PU while adhering to the reward constraint associated with the relay. We devised a heuristic solution with near optimal allocation of resources to tackle the computationally hard nature of the optimization problem. A formal proof to establish the convergence of the proposed solution and highlighting its effectiveness is provided. Simulation-based results have shown the effectiveness of the proposed scheme.
- The presence of multiple PUs creates additional challenges in efficiently pairing maximum number of SUs with suitable PUs for cooperative spectrum sharing. In chapter 4, we proposed a CSS scheme for multi-PU, multi-SU

overlay CRNs by modeling cooperative spectrum sharing as a one-to-one matching problem, focusing on two primary objectives. Those are: (i) selection of stable (PU, SU) partnerships for CSS, and (ii) optimal distribution of PU resources among the chosen partners. Our formulation takes into account the relative impacts of utility gain for both PUs and SUs, penalty costs for SUs, and the energy overhead incurred by PUs and SUs during CSS. We devised an algorithm to select stable (PU, SU) pairs for cooperative communication using a one-to-one matching approach. The algorithm ensures (i) optimal matching for the PUs, maximizing utility from their respective SUs, and (ii) stable matching for the SUs, preventing unfavorable pairings. Simulation results demonstrate the significant utility improvement for the PU network over the SU network.

- In scenarios where PUs possess comprehensive information about SUs, one-to-one matching between PUs and SUs may not suffice to achieve optimal matching equilibrium from the SU's perspective. Chapter 5 addresses this limitation by redefining the CSS problem as a many-to-one matching scenario. Here, SUs with similar PU preferences are grouped into tuples and collectively mapped with their preferred PU for CSS. This collaborative strategy among SUs prevents PUs from receiving multiple SU requests, thereby limiting utility maximization trends for PUs. The proposed many-to-one CSS model aims to achieve three primary objectives: maximizing SU participation, optimizing the group utility of cooperative SUs, and enhancing overall secondary network utility. The scheme successfully achieves optimal matching for SUs and stable matching for PUs, with theoretical proofs provided for the optimality and stability of the proposed matching game.

- Addressing energy constraints in SUs poses a significant challenge in developing effective CSS strategies. Chapter 6 tackles this challenge by introducing an energy-harvesting technique within the many-to-one CSS model, specifically designed for energy-constrained SUs. Inspired by Simultaneous Wireless Information and Power Transfer (SWIPT) technology, we propose a joint time-switching (TS) and power-splitting (PS) technique for energy harvesting at SUs. This technique aims to achieve two primary objectives: maximizing energy harvesting at SUs by optimizing TS and PS factors, and maximizing individual SU utility through optimal allocation of harvested power. Formulating these optimization problems proves their NP-hard nature, leading us to propose two heuristic strategies for obtaining suboptimal solutions within polynomial time. These solutions demonstrate 97% to 98% accuracy compared to benchmark results. Leveraging the concept of a he-

donic game, SUs autonomously form suitable clusters to collectively seek favorable PU partnerships for cooperative communication, thereby enhancing the overall performance of the secondary network in terms of SU utility. Formal proofs supporting the effectiveness of this hedonic game-based cooperative model are provided. Simulation-based results validate the efficacy of the proposed cooperative scheme over non-cooperative approaches and existing methods from the literature, showcasing improvements in individual and overall SU utility, SU satisfaction, and SU participation during cooperation.

7.2 Future Directions

In this section, we outline some of the possible directions of future research works in this domain.

- In our research, we assume that SUs are non-malicious and do not exhibit selfish behavior. However, in real-world scenarios, some SUs may become compromised and act maliciously or selfishly. As a result, incorporating mechanisms to handle both malicious and selfish behavior in SUs during relay node selection and the development of robust CSS strategies is left for future work.

- Considering user mobility is crucial when designing robust CSS schemes. Mobility causes change in SU locations and variations in received signal strength, affecting negotiations with PUs and potentially impacting utility for both parties. Integrating mobility and positioning optimization into proposed solutions and conducting thorough performance evaluations of such models are kept under future works.

- Developing matching models for CSS in a closed-market scenario, where users' resource information is concealed, is inherently complex. Implementing many-to-many matching among PUs and SUs, enabling multiple SUs to be paired with multiple PUs for cooperative communication, poses an additional challenge. It is important to address this aspect comprehensively in our proposed CSS mechanisms to enhance both primary and secondary users benefits. This is identified as a focus for future research.