Chapter 6

Conclusion and Future Work

This chapter recapitulates some key research findings of our research work on two-hop green cooperative D2D wireless systems and green C-SSS. We also present the future research scope and the possible extensions for the design and development of next-generation green wireless systems and networks.

6.1 Conclusion

The work carried out in the thesis was on modeling, design, and performance analysis of novel relay selection and the relaying policies for two-hop cooperative D2D communication systems and C-SSS. Initially, we analyzed a two-hop cooperative D2D communication system model that comprises of regenerative relays. For it, we proposed a simple PRSP with conventional non-power-adaptive DAF relaying. The proposed relay selection policy is a partial relay selection policy. Hence it reduced the burden of CSI acquisition required for the relay selection.

To enhance the performance of the cooperative D2D communication system model with PRSP, we proposed a novel PA-DAF relaying policy and derived it. According to the relaying policy, the PA-DAF relay optimally sets its gain and transmit power based on the channel conditions between the relay and the destination. The novelty of the proposed policy lies in its dependence on second hop CSI for the relaying policy and first hop CSI for the relay selection policy. To analyze the performance of the proposed policy, we derived FASER, FASE, and FAEE. To gain more insights, we also analyzed the diversity order of the proposed policy. The numerical results presented serve as a useful theoretical benchmark for cooperative D2D communication systems. We validated derived analytical results via simulation and compared the proposed relaying policy with the benchmark policies. We observed that the proposed policy outperformed the benchmark policies for different PHY layer performance measures. Specifically, we show that the proposed PA-DAF policy achieves energy efficiency 2.2 times higher compared to the benchmark fixed gain DAF relaying policy at 5 dB.

Energy efficiency is a crucial parameter for next-generation wireless systems. Noting this importance, we analyzed the multi-EH time-switching based green cooperative D2D wireless system model. For this system model, we proposed an outage-constrained EH-based relay selection policy. In this policy, the relay which harvests maximum RF is selected to forward the signal. The novelty of the relaying policy lies in outage-constrained transmissions in the second hop. The selected EH relay conserves its power if the link outage occurs between the relay and the destination. For the system model, we analyzed the outage probability, FASE, and FAEE performance measures. We numerically evaluated outage probability, FASE, and FAEE and compared them with two benchmark policies. For a specific source transmit power, we observed the following: i). the benchmark partial relay selection policy has 1.25 times more outage probability, and ii). RRS policy has 2.2 times more outage probability when compared to the proposed relaying policy. Furthermore, we observed FAEE performance improvement of 9.9% compared to partial relay selection policy and 56.8% compared to RRS policy.

Lastly, we analyzed the application of cooperative communication techniques in spectrum sharing systems. We considered two different system models, that is, i.) Non-EH (N-EH) relay-assisted underlay C-SSS and ii.) EH relay-assisted underlay C-SSS. We assumed that the secondary source transmits the information signal to the secondary destination via secondary relays for both the system models considered. For such a system model, we proposed an IC-PA-DAF policy. The proposed relaying policy performs DAF operations and amplifies the information signal based on CSI of relay's local links. Furthermore, the transmit power of the relay is constrained such that it should not create interference at the primary destination. For the N-EH relay-assisted system model, we considered PRSP for relay selection, and for the EH relay-assisted system model, we considered EH based relay section policy. Furthermore, we derived the FASE and FAEE performance measures for both the system models and compared the proposed policy with the benchmark policies. It was observed that the proposed policies outperform all the considered benchmark policies. Specifically, we see that the proposed policy achieves energy efficiency 1.7 times higher compared to the fixed gain DAF policy for the non-EH system model and a performance gain of 1.2 times higher compared to the simple DAF policy for the EH system model.

6.2 Future Research Scope

Below we list the possible extensions or future scope of the research work presented in this thesis.

1. *Multi-antenna cooperative and spectrum sharing systems (SSS):* An exciting and potential future work could be to model, design multiple antenna-equipped

four-node, two-hop energy-efficient cooperative systems and power-adaptive, interference-aware regenerative relaying policies for them.

2. *Models with imperfect CSI:* In all the system models, we assumed perfect CSI. In practice, the nodes have to acquire this knowledge using estimation protocols, for example, pilots-assisted channel estimation techniques. Another exciting avenue for future work includes modeling green cooperative SSS (cognitive radio) systems with imperfect CSI and investigating their performance.

3. *Artificial intelligence (AI)-enabled cooperative SSS models:* Application of AI or machine learning (ML) or deep learning (DL) is another challenging future work for large-scale cooperative IoT systems. There are open problems in the design of autoencoders for such systems. Specific to the system model considered in this thesis, DL can be used for optimum relay selection, estimating optimum RGF, and channel estimation, to name a few. Furthermore, an optimum EH duration can also be derived for the EH system model to improve spectral and energy efficiency performance.

4. *Extensions to other radio systems:* The current research trends include mmWave communications, TeraHertz (THz) communications, and reconfigurable intelligent surfaces (RIS). Designing and developing cooperative mmWave SSS, THz cooperative cognitive radio systems, and RIS-assisted SSS are other future works in next-generation radio communication systems.

Practical applications of the proposed policies: The application of cooperative communication to spectrum sharing wireless systems and networks has gained a great interest in next-generation cellular standards. The proposed policies in the thesis are useful to enhance the performance of several advanced wireless systems and networks. The wide range of applicability is due to the performance gains achievable when compared to the benchmark policies. These applications include (but, not limited to): i). RF-EH unmanned aerial vehicle (UAV)-assisted cooperative spectrum sharing networks [147]. ii). Hybrid terrestrial and underwater cooperative communication network [150] iii). SWIPT-enabled cooperative cognitive internet of things (IoT) network [151]. iv). Cognitive inter-vehicular cooperative communication network [146].

Furthermore, the united nations proposed seventeen SDGs. One of the important SDGs is climate action. It is possible to reduce the carbon footprint caused by automotive intelligent transportation systems by employing optimal policies proposed in the thesis. However, to extend use cases that involve mobility, the proposed models should be carefully modified and generalized to high mobility scenarios.