CHAPTER 7

CONCLUSION AND SCOPE OF FUTURE WORK

This chapter presents the conclusions obtained from the results and findings discussed in previous chapters, and provides the scope for future expansion of the results.

7.1 CONCLUSION

The problems derived from spectrum trading and sharing, with multiple licensed users (primary users) selling spectrum opportunities to multiple unlicensed users (secondary users), under a non-cooperative environment, have been analyzed, and different solutions are proposed. The game theoretic approach was used to model the existence of the primary and secondary user in a market scenario. In a multi-operator radio access network, utility of each party was formulated reflecting its economic incentives and system efficiency. The adoption of machine learning techniques helped to maximize the profits, while increasing the system throughput and spectral efficiency. Further, applying strategic game theory results in higher system throughput along with spectral efficiency.

The algorithm is redefined through identification of the sources of parallelism, use of multithreading and cooperative game theory concepts to compute the convergence or equilibrium point at finite time for large number of users. The algorithms were simulated, in a cognitive radio environment,
and the performance parameters, such as spectral efficiency and throughput, were evaluated.

The spectrum trading for short duration at system level requires the formulation of resource sharing policies. Because of flexibility in implementation of resource allocation in the future LTE based cognitive radio system, the proposed policies were implemented and simulated on a LTE system level simulator. The incentive to different trading policies is directly governed by the estimation of utility for each player. But any proper cooperation among PCPs and SCPs (UFRS algorithm), results in higher throughput. The application of Nash Bargaining in the game model (RERS algorithm) was another aspect of the proposed work.

The efficiency of resource sharing and utilization can be further improved through application of a suitable reinforcement technique along with the game model representing system environment. A type of reinforcement learning called Q-learning and its new variation called conjecture based Q-learning help in achieving higher overall efficiency and throughput of the system comprising multiple spectrum users participating in competitive spectrum trading process. In conjecture based Q-learning, every user estimate the competitors’ strategy decisions in response to its own actions. This added feature enabled the user equipment to effectively identify the best available resource blocks for use in LTE network. Another reinforcement learning technique, called Actor-critic learning, was formulated and developed, and the system performance was compared with Q-learning and also with conjecture based Q-learning. Resource sharing among the various users in spectrum trading environment is achieved by the proposition of three different algorithms. The simulation results showed that conjecture based Q-learning technique provide the higher throughput than Q-learning and actor critic learning. The correlated equilibrium was achieved in the
environment where all the users are non-cooperative and it maximized the overall utility of the system.

In the last part of the thesis, three strategic game theories, namely, Stackelberg, Bertrand, and Cournot game were used to develop algorithms for spectrum sharing. The utility functions are formulated on the basis of strategies of both the PUs and the SUs and algorithms were implemented on LTE system level simulator. The average user throughput, cell throughput, and spectral efficiency were observed to evaluate the system performance. The results established that a sharing policy based on utility values of individual users, for the system resource (resource blocks), could be desirable in an advanced network such as LTE, since it does not consider individual optimization of utility.

7.2 FUTURE WORK

Spectrum trading could be implemented in completely dynamic and non-cooperative environment in two stages. In the first stage, trading could occur between primary and secondary users, and in second stage market equilibrium could be achieved among all the secondary users by considering different system parameters to maximize throughput in terms of revenue and other system resource.

A dynamic game has to be characterised in which a secondary user adopts its spectrum sharing strategy by observing only the marginal profit which is a function of spectrum price offered by the primary user. A few non cooperative games, such as, evolutionary games, matching games, congestion games, that may involve many link level constraints, such as, interference and transmission power, as their strategies can be used to design the utility function to obtain the best response of every user to achieve the equilibrium state and add further enhancements to improve economic metrics.
Further analysis and formulation is needed that will guarantee Nash equilibrium among players. Consideration of the utility maximization and throughput improvement alone and not including any fairness in resource sharing among the users may not be a good approach in practice, which needs further research. The computational complexity of the algorithm using Stackelberg, Bertrand, and Cournot game requires additional analysis.

The three proposed policies were targeted at achieving higher overall throughput and resource utilization, thereby benefiting each carrier provider. This could be highly desirable in future wireless networks as demand of radio resources by high end user equipment and its applications varies in a given time and location. Moreover, a hardware test bench representing CRN environment to implement and test the designed algorithms is desirable to evaluate system performance in real-time.