論 文 の 内 容 の 要 旨

論文題目　　A Study of Efficient Spectrum Utilization by Cooperation of Cognitive and Heterogeneous Wireless Networks

（コグニティブネットワークとヘテロジニアスネットワークの協調によるスペクトルの効率的利用に関する研究）

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The cognitive cell network and the boosting growth of 5G cell network need to explore more spectrum access opportunities to meet ever-growing traffic demand, which necessitates the use of more spectrum data to identify radio environment. This thesis highlights how to encourage Cooperation / Interaction between users in cognitive radio network (CRN) and heterogeneous cell network (HetNet) to recognize radio environment, and proposes a model to optimize the spectrum usages of the mobile network (HetNet) as well as CRN by letting HetNet act as the common control channel for cooperative spectrum sensing of CRN. The throughput of both CRN and HetNet can be improved by designing a proper incentive scheme based on coalitional game theory.

The current advancement of wireless services has resulted in higher requirements for radio frequency resources in wireless networks. The optimum spectrum usage is difficult because of two reasons. The first is that spectrum management has been a politically as well as a technically sensitive issue and it is usually difficult to access the open data of real spectrum usage. The second is that the spectrum usage optimization has been investigated within each network architecture independently from the other networks. CRN is the first architecture for the second user to share the same frequency bands as the primary user if they are not used. Although setting up stable common control channels among nodes has been recognized as difficult within the framework of CRN, no research works have been done to solve this problem using other networks. Firstly this thesis proposes a general framework to solve this problem for an environment that CRN and HetNet are cooperative with each other, where HetNet acts as the common control channel for cooperative spectrum sensing of CRN. The dynamics of CRN and HetNet

can be determined by coalitional game theory, and the throughput of these networks can be improved by giving nodes in cooperation proper incentives.

For the difficulty to access the open data of real spectrum usage, this thesis proposes grass-root based spectrum data collections, called SpectrumMap, through large-scale users' participation. Frequency awareness is shown to be important to improve the performance of dynamic spectrum access. It demonstrates the SpectrumMap database implemented in the laboratory environment and discusses in details the challenge encountered during the system development introduced by the computation complexity of the big spectrum data. Then, the spectrum measurement campaign is conducted in Tokyo area, Japan during several years to show the effectiveness of SpectrumMap. The duty cycle based spectrum utilization for typical wireless bands is shown, with the collected raw data spread from 75MHz to 3GHz. Specifically, as a study case, this part reveals spatio-temporal characteristic of Wi-Fi occupancy in the downtown Tokyo with a carefully arranged measurement schedule. It is shown that spectrum is not fully utilized; even in the crowded Wi-Fi channels observed in downtown areas.

To show how inefficient it is without any cooperation among users, this thesis analyzes multi-hop cognitive network with three restrictions. The first is no cooperation among users. The second is no common control channel between users. The third is no synchronization between users. The existing research works did not consider all these restrictions at a time. Different from the existing studies, this thesis proposes a new method to effectively reduce the decision space of users, thus can substantially reduce the complexity of decision making by the network. However, the conducted result shows that cognitive network can only obtain limited data rate when considering energy constrain.

Considering the crowdsourcing strength of public users, a theoretical model is proposed to incentivize building of the SpectrumMap database through user participation based spectrum data collections. Different from the above case, users are assumed to have a common control channel to a network center, and spectrum data collections are realized by users' cooperation. The validity of the collected data is verified by the simulation with a scenario of cognitive access to white space channels for a cell network. The dynamics of cooperation is determined by coalitional game theory, and the credits to buy white space channel resources when necessary can be improved by giving proper incentives to nodes in cooperation. The proposed data collection model is expected to work as a supplement for the conventional commercial spectrum database to improve the awareness of radio environment.

The above framework is extended to the framework for the collaboration between HetNet and CRN. CRN and HetNet are assumed to have incentive to cooperate with each other, i.e., cognitive users can use small cells in HetNet acting as relay and report the sensed data to SpectrumMap database, while small cells can find good channels by utilizing the sensing capability of cognitive radio users. This thesis formulates the cooperative behavior by utilizing coalitional game theory. Results show that, to achieve the same throughput performance for small cell, the proposed approach can reduce channel resources from 160 to 30 channels to achieve success channel access probability of 0.8, and cognitive users can

improve throughput about 10%.

Finally this thesis tries to improve the downlink transmission of HetNet since it is degraded when HetNet acts as a common control channel for CRN. This part investigates spectrum efficiency for multiple-input multiple-output (MIMO) wireless network, and proposes precoding strategy to improve spectrum efficiency of MIMO. The proposed precoding design strategy for MIMO Relaying Broadcast Channel with coordinated users can overcome the relay's half-duplex constraint and achieve the full degree of freedom (DoF) to improve the frequency efficiency. Furthermore, it evaluates a weighted minimum mean square error (WMMSE) precoding design method to jointly design the precoder of base station and beamforming matrix of relay station according to throughput and fairness criterions. Given base station equipped with Nb antennas, it has been shown that the existing scheme without considering the direct users suffers from the degrees of freedom loss, and the maximum degrees of freedom is Nb, while maximum degrees of freedom of the proposed scheme with the designed precoding strategy is 2 Nb. The conducted simulation has confirmed the effectiveness of the proposed scheme.