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Cooperative and Non-Cooperative Games for Spectrum Sharing in Cognitive Radio Networks: A Comparative Study

Shelly Salim, Cheolheon Baek, Sangman Moh and Ilyong Chung

Dept. of Computer Engineering, Chosun University
Gwangju, Republic of Korea

Abstract

Spectrum sharing in cognitive radio networks is essential to ensure effective communication between secondary users. Game theory is suitable to be applied to the spectrum sharing strategies since it considers strategic interactions between users. There are two types of games based on the ability to communicate between users: cooperative game and non-cooperative game. In this paper, the two spectrum sharing methods using cooperative and non-cooperative games are analyzed and compared. The numerical analysis shows that both the cooperative game and the non-cooperative game have their own best operation environment, in terms of the secondary user population.

Keywords: Cognitive radio network, spectrum sharing, game theory, cooperative game, non-cooperative game

1 Introduction

In cognitive radio networks (CRNs), all or some of wireless devices are equipped with cognitive radios. Cognitive radios are aware of their surroundings and able to respond accordingly to the variations of the environment in a real-time manner [1]. Cognitive radio devices could utilize licensed channels that are vacant from the licensed users or primary users (PUs); provided that they do not disturb others active primary users and that they would immediately give up the channels once the primary users use those channels. In other words, the activities of cognitive radio devices have to be 'invisible' from the PUs. The cognitive radio devices are also called secondary users (SUs). However, a more practical approach is to form a spectrum market between the PUs and the SUs [2], where the PUs lease their licensed spectrum bands to the SUs in return of a payment [3]. The SUs might have to pay some fee to the PUs or they might oblige to help the PUs transmission, as in cooperative communication schemes [4].

The vacant spectrum bands, both licensed and unlicensed, that might be used by the SUs are herein called available spectrum bands. The SUs obtain the knowledge of the available spectrum bands by means of performing spectrum sensing or accessing spectrum database/spectrum broker or both. The available spectrum bands must be shared by the SUs efficiently by avoiding mutual interference between them. To do so, game theory-based spectrum sharing methods are suitable and widely applied [5]. The players of the game could be SUs only, PUs only, or SUs and PUs together. In general, there are two types of games: cooperative game and non-cooperative game. In cooperative games, the players are able to communicate between them to arrange their strategies for achieving a social goal. In non-cooperative game, however, there is no communication between players and each player aims to maximize its own profit.

Cooperative games and non-cooperative games have been applied in spectrum sharing for cognitive radio networks. Most of the existing spectrum sharing methods are based on non-cooperative games because communications between the players would add the complexity and non-cooperative environment is considered more practical. However, both cooperative and non-cooperative spectrum sharing games have their own advantages. In this paper, we analyze and compare two spectrum sharing games: one based on cooperative game and the other based on non-cooperative game.

The rest of this paper is organized as follows: Section 2 analytically discusses the two types of spectrum sharing games and compares them with respect to the utility function for the different number of SUs. Section 3 concludes this paper.

2 Analysis and Comparison

In this paper, we analyze and compare the two works of spectrum sharing games: cooperative game algorithm (CGA) [6] based on cooperative game and demand-matching spectrum sharing (DMSS) [7] based on non-cooperative game. We discuss the CGA and DMSS procedures analytically. Then, the numerical performance of CGA and DSMM is compared. CGA and DMSS are chosen to be compared because they share some properties. The players in both CGA and DMSS are SUs. They consider the application demand of SUs. They have pricing function. Lastly, they are relatively recent works.

Figure 1 shows the common network access scheme for spectrum sharing using cooperative and non-cooperative games. In the cooperative game, a central entity has the knowledge of the whole spectrum condition and manages the usage of the idle spectrum between its SUs whereas, in non-cooperative game, each SU has to obtain its own spectrum.

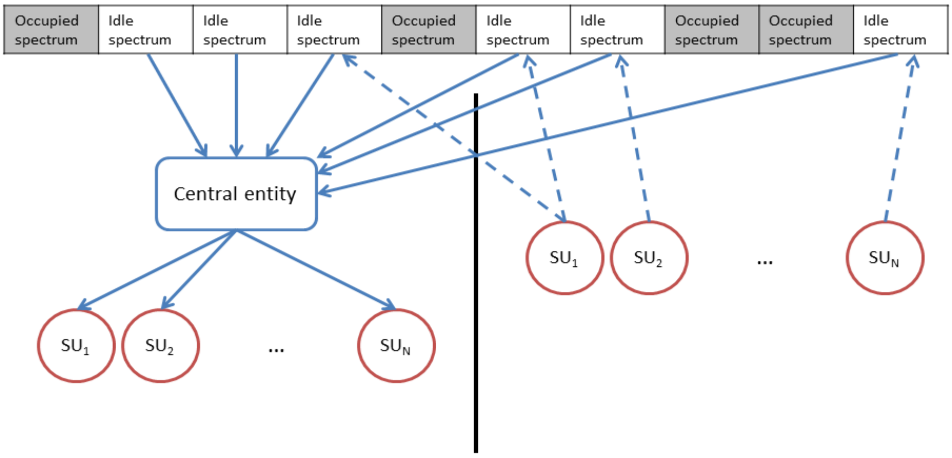

Figure 1. Network access scheme for (a) cooperative game and (b) non-cooperative game

2.1. Cooperative game algorithm (CGA)

CGA considers the quality of service (QoS) demand and the probability of cheating of the SUs. CGA aims at maximizing the total revenue of SUs and providing fairness between SUs. CGA assumes that a spectrum broker (SB) exists and it sets the unit price in the spectrum market. SB has three functions: (1) to provide connection between PUs and SUs, (2) to support smooth transactions between PUs and SUs, and (3) to manage the population of the SUs. CGA defines a satisfaction indicator of SU i as S_i:

$$S_i = \frac{k_i b_i}{Q_i} \tag{1}$$

where k_i is the spectrum efficiency of SU i, b_i is the allocated spectrum size for SU i, and Q_i is the minimum transmission rate required by SU i. Accordingly, k_i is defined as:

$$k_i = \log_2(1 + K \cdot SNR_i) \tag{2}$$

where SNR_i is the received signal-to-noise ratio of SU i and K is a constant related to the target bit error rate (BER) of SU i, defined as:

$$K = \frac{1.5}{\ln\left(0.2 / BER_i^{tar}\right)} \tag{3}$$

where BER_i^{tar} is the target BER required by SU *i*. If the value of S_i is less than 1 ($S_i < 1$), it means that the QoS requirements of SU *i* is not satisfied; otherwise, the QoS requirements is met. Furthermore, the utility function of CGA with *N* SUs is consisted as follows:

$$\max_{B=(b_1,\ldots,b_N)} \Pi_{i=1}^{N} \left(U_i - U_i^{\min}\right) \tag{4a}$$

$$b_i > 0, \forall b_1 \in B \tag{4b}$$

$$\sum_{i=1}^{N} b_i \le W \tag{4c}$$

where $B = (b_1, ..., b_N)$ is the set of allocated spectrum size for *N* SUs or the set of strategies of all the SUs, *W* is the total available spectrum bandwidth, U_i is the profit of SU *i*, and $U_i^{\min}$ is the minimum revenue of SU *i*. The profit of SU *i*, U_i, is defined as:

$$U_i(B) = r_i q_i + \left(r_i k_i b_i - r_i Q_i\right)\frac{Q_i}{Q_i b_i} - b_i c(B) \tag{5}$$

where r_i is the income per transmission rate of SU *i*, and *c(B)* is the pricing function, defined as follows:

$$c(B) = x + y\left(\sum_{b_j \in B} b_j\right)^{\tau} \tag{6}$$

where *x*, *y*, and *τ* are positive constants. The optimal spectrum allocation by CGA is obtained by using the Karush-Kuhn-Tucker (KKT) conditions to the Lagrangian functions given by

$$L(b, \lambda) = \sum_{i=1}^{N} \ln\left(U_i - U_i^{\min}\right) + \lambda_{CGA}\left(W - \sum_{i=1}^{N} b_i\right) \tag{7a}$$

$$\frac{\partial L}{\partial b_i} = \frac{\partial g}{\partial b_i} - \lambda_{CGA} = 0 \tag{7b}$$

where λ_{CGA} is a constant called KKT multiplier and

$$g = \sum_{i=1}^{N} \ln\left(U_i - U_i^{\min}\right) \tag{8}$$

2.2. Demand-matching spectrum sharing (DMSS)

DMSS includes a demand matching factor to the payoff function of the non-cooperative game to improve the spectrum utilization. Moreover, DMSS allows the SUs to access multiple non-contiguous spectrum bands simultaneously. The spectrum bands are assumed to be divided into a number of slots and the access mode assumed is time division multiple access (TDMA). DMSS applies mixed strategy with the matrix defined as

$$\Gamma = [P_1, P_2, ..., P_N] \tag{9}$$

where N is the number of SUs and P_j is the mixed strategy of SU j and defined as

$$P_j = [p_{j,1}, p_{j,2}, ..., p_{j,K}]^T \tag{10}$$

where $p_{j,k}$ is the probability of SU j choosing strategy k, or similarly, the fraction of time slots of channel k occupied by the SU j. A pricing function is included to the utility function and, thus, the utility function of SU j is as follows:

$$U_j(P_i, \Gamma_{-j}) = \sum_{k=1}^{K} \omega_{j,k} p_{j,k} C_k - \lambda_{DMSS} \sum_{k=1}^{K} e^{\delta\left(\sum_{j=1}^{N} p_{j,k} - 1\right)} \tag{11}$$

where K is the number of available strategies, $\omega_{j,k}$ is the overall demand matching factor, C_k is the maximum transmission rate on channel k, λ_{DMSS} is a parameter to adjust the pricing value, and δ is a constant to indicate the effect of collisions. The utility function of SU j depends on the strategies of other SUs, that is, Γ_{-j}. In DSMM, the spectrum sharing solution is achieved by reaching the Nash Equilibrium solved by Nelder-Mead direct search method:

$$\text{minimize: } \sum_{j=1}^{N} \left| P_j - BR_j(\Gamma_{-j}) \right| \tag{12}$$

where $BR_j(\Gamma_{-j})$ is the best response function of user j which depends on the strategies of other SUs.

2.3. Comparison

The utility functions of CGA and DMSS are compared for the different number of SUs. The result of the numerical analysis is shown in Figure 2. As the number of SUs increases, the value of the utility function in the non-cooperative game of DMSS is decreased whereas that in the cooperative game of CGA is increased.

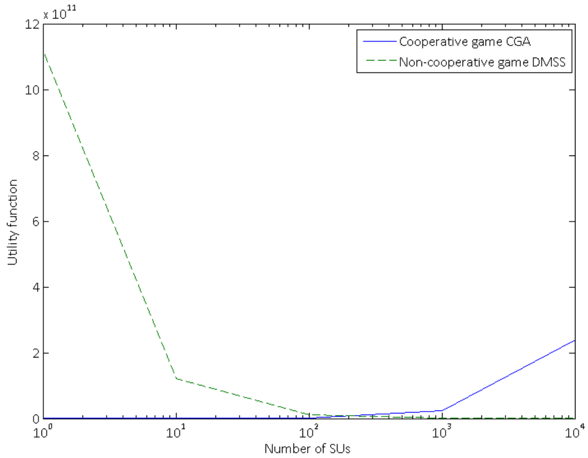

Figure 2. Utility functions of CGA and DMSS

It can be inferred from the numerical results that when the number of SUs is relatively low, the non-cooperative game outperforms the cooperative one, and vice versa. When there are a few SUs, non-cooperative game instructs each SU to act selfishly to maximize its utility function and, thus, its utility function is higher compared to cooperative game. However, as the number of SUs becomes higher, the non-cooperative game suffers from the selfish actions, in terms of mutual interference, while the cooperative game could manage the situation.

3 Conclusions

In this paper, the two spectrum sharing methods of CGA and DSMM, which are based on the cooperative game and the non-cooperative game, respectively, are analyzed and compared. The numerical analysis shows that both games have their own best operation environment. That is, when the number of SUs is relatively low, DMSS outperforms CGA. On the contrary, when the number of SUs is relatively high, CGA outperforms DMSS but it incurs additional overhead of communications between users.

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References

[1] S. Haykin. Cognitive Radio: Brain-Empowered Wireless Communications. *IEEE Journal on Selected Areas in Communications*, **23** (2005), 201 - 220. http://dx.doi.org/10.1109/jsac.2004.839380

[2] R. A. Berry. Network Market Design Part II: Spectrum Markets. *IEEE Communications Magazine*, **50** (2012), 84 - 90. http://dx.doi.org/10.1109/mcom.2012.6353687

[3] S. K. Jayaweera and C. Mosquera. A Dynamic Spectrum Leasing (DSL) Framework for Spectrum Sharing in Cognitive Radio Networks. *Conference Record of the Forty-Third Asilomar Conference on Signals, Systems and Computers*, (2009). http://dx.doi.org/10.1109/acssc.2009.5470212

[4] Q. Yu. A Survey of Cooperative Games for Cognitive Radio Networks. *Wireless Personal Communications*, **73** (2013), 949 - 966. http://dx.doi.org/10.1007/s11277-013-1225-6

[5] B. Wang, Y. Wu, and K. J. Liu. Game Theory for Cognitive Radio Networks: An Overview. *Computer Networks*, **54** (2010), 2537 - 2561. http://dx.doi.org/10.1016/j.comnet.2010.04.004

[6] L. Gao, H. Zhao, X. Mu, Y. Lu. A Joint Design of Spectrum Sharing and Admission Control in Cognitive Radio Networks. *Proceedings of International Conference on Wireless Communications & Signal Processing*, (2012). http://dx.doi.org/10.1109/wcsp.2012.6542794

[7] J. Liu, L. Shen, T. Song, X. Wang. Demand-Matching Spectrum Sharing Game for Non-Cooperative Cognitive Radio Networks. *Proceedings of International Conference on Wireless Communications & Signal Processing*, (2009). http://dx.doi.org/10.1109/wcsp.2009.5371504

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