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Original Article

Benefits of Coalition Game Theory over Bargain Game Theory to Resolve the Problems of Spectrum Sensing in Cognitive Radio Network

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Abstract - *Coalition Game Theory (CGT) enhances cooperation in a game. To state, examine and discover a key for spectrum sensing and allocation in Cognitive Radio Networks (CRN), collaboration takes a leading role. This paper states game theory's role in resolving the problems present in the spectrum sensing and allocation. The cooperative and non-cooperative game theory is discussed. The major emphasis of this paper is on how the CGT is imperative and cooperates to resolve the problems present in spectrum sensing in CRN. It specifies the merits and demerits of CGT over Bargain Game theory to fix the problems present in CRN. Finally, it is proved that the utility function of Secondary Users enhanced using CGT compared to Bargain Game Theory during spectrum sensing.*

Keywords - *Cognitive Radio Network, Spectrum sensing, Spectrum allocation, Coalition Game Theory, Bargain Game Theory.*

1. Introduction

Cognitive Radio (CR) is a wireless technology having its own trans-receiver. In CR communication, unauthorized users / Secondary Users (SUs) scan the band of authorized users / Primary Users (PUs). SU detects the white spaces and utilizes them for its own benefit without causing interference to PU communication. On arrival of PU's signal, SU relinquishes the white spaces. To establish such a dynamic communication, SUs face various challenges like spectrum sensing, spectrum sharing, spectrum allocation, spectrum mobility, etc. [1 - 6].

While spectrum sensing and allocation, the major problem is identifying the white spaces from the unknown signal and allocating them to a trustworthy SU. In this paper, to resolve this problem, how Coalition Game Theory (CGT) is important and provides a solution is discussed in detail.

In [7], the details of CGT to resolve communication network problems are mentioned. The author presented a detailed mathematical analysis of CGT in the paper. In [8], the authors propose Merge and Split coalition formation rules for wireless networks. In [9], CGT developed a two-step algorithm for resource allocation and load balancing in the Cognitive Radio Network (CRN). In [10], an overview of Game Theory (GT) for CRN is specified. GT is a mathematical tool that analyses and resolves various problems in different fields. It is divided into cooperative and non-cooperative GT. Cooperative GT is more beneficial than non-cooperative GT to resolve the problems of CRN. Cooperative GT is further divided into two categories: Coalition GT and Bargain GT. The detailed analysis of these GTs is mentioned in the paper by the authors. In [11], a study of different game models like Coalition formation, Evolutionary game, and Cournot Game model for Cooperative Spectrum Sensing (CSS) in CRN is done. In [12], an analysis of imperfect reporting channels for CSS is presented. In [13], the utilization of GT for CRN and 5G/6G wireless communication is detailed. The authors discussed cooperative games, non-cooperative games, repeated games, dynamic games, potential games, super-modular games, etc., to resolve the problems in CRN.

After studying the literature for nearly the last 15 years, it is concluded that more research is required to know the best

GT to analyze and resolve the problems present in spectrum sensing and allocation in CRN. Hence, in this paper, the cooperative GTs, i.e. Coalition GT and Bargain GT, are studied rigorously, analyzed and compared in detail.

The Major contributions in this research are mentioned below:

1. To resolve the spectrum sensing and allocation problem, first, the rigorous study of Game Theory (GT) is done. Specially, the GT classifications, such as cooperative and non-cooperative GT, are explored.
2. The cooperative GT, namely Coalition Game Theory (CGT), and non-cooperative GT, namely Bargain Game Theory (BGT), are deliberated in detail.
3. In the analysis, it is understood that CGT can overcome the problems of spectrum sensing and allocation in CRN more swiftly than BGT. To prove this, various CRN scenarios are considered in this research work. Utility function and reliability function are evaluated for SUs during spectrum sensing. Along with the same payoff function $C(f)$, it is evaluated during spectrum allocation.
4. The utility and payoff functions are designed based on the linear optimization method. Whereas the reliability function is designed using the probability of spectrum detection and false alarm.
5. For validation of the results, spectrum sensing and allocation are performed on several CRNs with different scenarios SU is hidden or remotely located from PU or near PU. For every scenario, different coalitions of SUs are formed, and the utility function, reliability function and payoff function are estimated.

This paper is based on our previous work. Hence, the algorithms are provided in [15,16]. The rest of the paper is arranged as follows. Section 2 describes the problem definition. Details of CGT and BGT, along with their merits and demerits, are discussed in section 3. The estimation of the Utility function is included in section 3 as well. Results are specified in the section 4. Moreover, finally, a conclusion is drawn in section 5.

2. Problem Definition

In CRN, SU continuously or repeatedly scans the spectrum of PU to detect the white spaces. In the case of multiple PUs and multiple SUs CRN, white space detection becomes difficult for remotely located or hidden SUs. Instead of a PU signal, they receive a lot of noise. This problem is specified in Figure 1. Whereas the CRN has two PUs and eight SUs. Out of which $\{\boldsymbol{SU_1}, \boldsymbol{SU_3}, \boldsymbol{SU_4}, \boldsymbol{SU_5}, \boldsymbol{SU_7}, \boldsymbol{SU_8}\}$ are directly able to detect the spectrum of either $\boldsymbol{PU_1}$or$\boldsymbol{PU_2}$. However, $\boldsymbol{SU_2}$ it is remotely located and $\boldsymbol{SU_6}$ is hidden form $\boldsymbol{PU_1}$ and $\boldsymbol{PU_2}$. Hence, they are not able to detect white spaces from any PU. This scenario is mathematically specified in equation (1).

$$\boldsymbol{SU_i}(\boldsymbol{y}) = \boldsymbol{PU_j}(\boldsymbol{X}) + \boldsymbol{W}(\boldsymbol{n}) \qquad (1)$$

Where, $\boldsymbol{SU_i}(\boldsymbol{y})$ is signal detected by$\boldsymbol{SU_i}$, $\boldsymbol{PU_j}(\boldsymbol{X})$ is signal transmitted by $\boldsymbol{PU_j}$ and $\boldsymbol{W}(\boldsymbol{n})$ is Additive White Gaussian Noise (AWGN). In the case of $\boldsymbol{SU_{i,RL/H}}$ (i.e. SUs remotely located or hidden from PUs) AWGN is very large. Hence, they are not able to detect white spaces. To resolve this problem of $\boldsymbol{SU_{i,RL/H}}$, cooperation is imperative. So that neighbouring SUs can provide them with information on available white spaces.

Fig. 1 Difficulty in white space detection for remotely located and hidden SUs

In this paper, to tackle the above problem and perform spectrum sensing successfully for distant SUs, GT is utilized. Moreover, the problem is defined as below:

To make available the white spaces information to distantly located SUs and improve the utility payoff function of SUs using CGT in CRN.

3. Game Theory and its Classification

GT is a mathematical tool used to model, analyze and resolve various problems in the fields of Science, Engineering, Commerce, Politics, etc. It is categorized mainly into Cooperative GT and Non-cooperative GT.

In a non-cooperative game, the players do not share the information with neighboring players. In cooperative games, players share information with neighboring players to maximize their benefits [17-18].

To model the specified problem of CR communication (shown in Figure 1), the following assumptions are made, and the game has been formularized:

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1. $G(N, U)$ -
2. $U$is the utility function ($U(f)$) of SUs.
3. $N$is the number of SUs (players). Their task is to acquire white spaces from PUs.
   $N \subset \{SU_{i,}SU_{1,}\ldots\ldots, SU_N\}$
4. M is the number of PUs.
   $M \subset \{PU_{i,}PU_{1,}\ldots\ldots, PU_M\}$
5. Action set $A = \{A_1, A_2\}$
   A_1 = SU acquires white spaces, A_2 = SU head allocates the white spaces among SUs

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3.1. Non-co-operative Game Theory

If the *non-co-operative game* is used to perform the actions A_1 andA_2, the following aspects are need to be considered:

1. SUs may or may not work for the same policies.
2. They may not be shared white space availability with neighboring SUs.
3. The hidden / remotely located SUs may not be acquainted with white space availability.
4. SUs may or may not be able to increase their own payoff.
5. Communication cannot be possible in emergency scenarios.
6. PUs may be unable to take advantage of available white spaces.
7. Hence, overall spectrum utilization reduces.

Instead, more benefits can be achieved by CR communication if cooperative game theory is used to perform A_1 and A_2 actions.

3.2. Cooperative Game Theory

There are two types of cooperative game theory, namely, Bargaining Game Theory and Coalition Game Theory.

3.2.1. Bargain Game Theory (BGT)

Though the BGT is cooperative, if any player disagrees with the same policies, it may spoil the deal/agreement held between PU and Sus, and the player receives disagreement with zero benefits. It may take a longer time to come to a fruitful solution. When BGT is used to resolve the problem specified in section 2, Figure 1, the following aspects need to be considered:

1. All SUs should agree to the same policies to perform the actions $\boldsymbol{A_1}$ and $\boldsymbol{A_2}$in a fraction of the time. Using BGT is quite difficult as multiple PUs and SUs are present in CRN. The finalization of the agreement could be difficult.
2. In CRN, the decision-making either $\boldsymbol{H_0}$ (i.e. PU is ideal) or $\boldsymbol{H_1}$ (i.e. PU is transmitting the signal) needs to be taken swiftly. Hence, during emergency situations, the SUs do not get time to bargain for their own profit during the actions $\boldsymbol{A_1}$and$\boldsymbol{A_2}$.
3. To maintain the trustworthiness to perform the actions $\boldsymbol{A_1}$and$\boldsymbol{A_2}$, in BGT, pre-agreement is required.
4. During the actions $\boldsymbol{A_1}$and$\boldsymbol{A_2}$, if any SU malfunctions, it becomes difficult to maintain the agreement. Moreover, SUs may receive disagreement with zero benefits. This affects their utility function($\boldsymbol{U(f)}$) , and overall spectrum utilization is reduced.

Hence, it is supposed to be difficult to use BGT to perform the actions $\boldsymbol{A_1}$and$\boldsymbol{A_2}$.

3.2.2. Coalition Game Theory (CGT)

Coalition game theory reinforces cooperation among SUs. It forms small temporary groups/coalitions of SUs. SUs are also called Coalition Members (CM). After completing the communication, the coalition can be broken and can be reformed again as per need. The key advantage of CGT is that CMs / SUs of a coalition agree to the same policies. They can share the available white space information with neighboring CM. Moreover, a coalition can share the same information with neighboring coalitions as well. The coalition formation (CF) procedure is explained below:

1. Neighboring SUs form a coalition based on metrics such as distance, number of hops, trustworthiness of SUs, etc.
2. SUs elect a trustworthy SU as a coalition head (CH), who can be an SU directly in the range of PU trans-receiver, as shown in Figure 2.

In Figure 2, three coalitions are formed, and CHs are elected. The Dynamic Coalition Formation (DCF) algorithm is thoroughly explained in [15] *(refer to Algorithm 1)*.

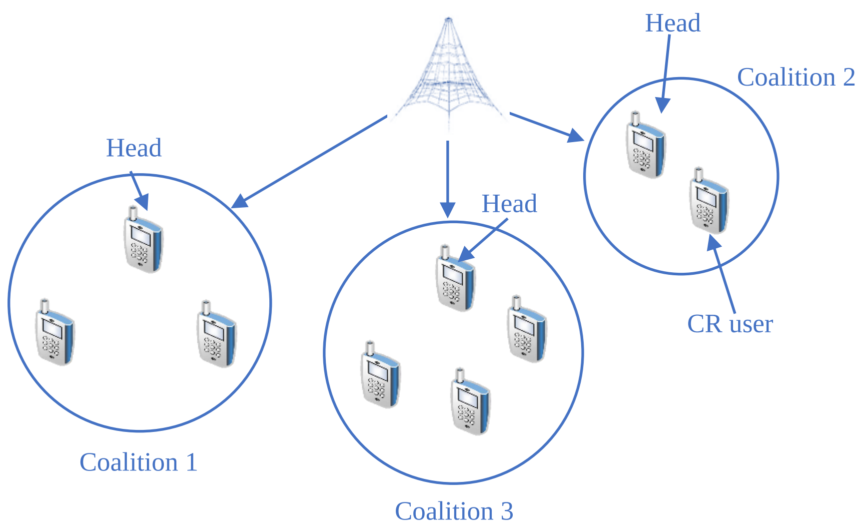

Fig. 2 Coalition game theory approach for the cognitive radio network

After successful decision-making A_2, action, i.e. spectrum allocation, can be performed by CH [16] *(refer to Algorithm for Dynamic Spectrum allocation)*. Due to the above-said merits, the CGT is preferable over BGT and non-cooperative GT to perform the actions of spectrum sensing-$A_1$and spectrum allocationA_2in the Cognitive Radio Network.

3.2.3. Utility Function

The utility function $U(f)$ quantifies the worth of coalition members in a coalition. It is estimated using the Linear Optimization Method as expressed in equation (2).

$$\boldsymbol{U(f) = A * SU_H + B * SU_R + C * SU_N + D * R(f) + E * SU_{FA}} (2)$$

where A, B, C, D and E are weights given to respective specifies. It is total should be one by linear optimization method.

SU_H = Hidden SU

SU_R = Remotely located SU

SU_N = SU near PU

$R(f)$ = reliability function of an SU (3)

SU_{FA} = It is an SU that follows the agreement that happened between PU and SU.

$$R(f) = P_d * (1 - P_f) \quad (3)$$

where,

P_d = probability of detecting white spaces

P_f = probability of false alarm

$R(f)$ defines the reliability of an SU to detect PU white spaces. It should be as high as possible [8].

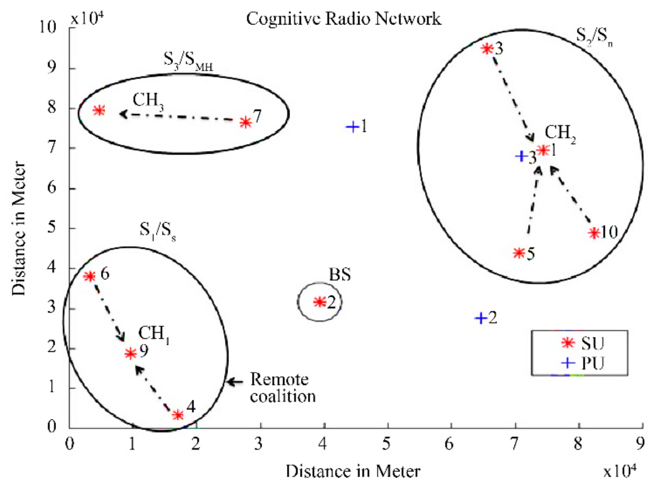

Fig. 3 Coalitions formation in cognitive radio network

4. Results and Discussion

4.1. Importance is given to Agreement and Reliability Policy

4.1.1. Using CGT

To validate the improvement in the $\boldsymbol{U(f)}$, CRN shown in Figure 3 is considered with the following scenario.

N = Number of SUs = 10

M = Number of PUs = 3

A = CRN area = 100km.

For this network, the coalitions are formed using the DCF algorithm. The formed coalitions are shown in Figure 3.

Using DCF [15], three coalitions are formed are $\{S_1, S_2, S_3\}$

Where,

$S_1 = \{SU_9, SU_6, SU_4\}$,

$S_2 = \{SU_{1,}SU_{5,}SU_{10}, SU_3\}$, and

$S_3 = \{SU_{8,}SU_7\}$,

in these coalitions $\{SU_{9,}SU_{1,}SU_8\}$ are coalition heads of S_1, S_2 and S_3 respectively. These SUs/CMs perform the spectrum sensing and submit the report to the respective head. The heads make collective decisions about whether the PU is present or absent. Finally, the white space availability decision is taken collectively by all heads.

Accordingly, the spectrum allocations are executed. In this, for estimating the utility function, importance is given to agreement and reliability with the following assumptions. In equation (2), the weights are assumed as:

$A = 0.15,$

$B = 0.15,$

$C = 0.1,$

$D = 0.2,$

$E = 0.5$

By the linear optimization method, the total weight of all these parameters should be 1.

Here, the maximum weightage/importance is given to E and D, i.e. agreement between PU-SU and reliability of SUs, respectively.

$R(f)$ is dependent on the probability of detection and false alarm of an SU. It ranges from 0 to 1. It should be as high as possible, signifies highly reliable SU. Less importance is given to C, i.e. an SU near PU. According to the CGT property, all SUs agree to the same policies. The $U(f)$ for above-mentioned coalitions are specified in Table 1. $R(f)$ is estimated using equation (3) in ten different spectrum sensing slots.

4.1.2. Using BGT

The same network is considered to estimate coalitions using BGT, and the same assumptions are made. In BGT, it is not mandatory for all SUs to agree to the same policies or agreement between PU and SU. During spectrum sensing, the SU may be malpracticed or disagree with the policies. This affects the overall $\boldsymbol{U(f)}$ of coalitions. Table 1, the last column, specifies the $\boldsymbol{U(f)}$ for mentioned coalitions.

Figure 4 shows the graph of utility function estimation using CGT and BGT. This analysis is performed on ten different CRNs in MATLAB simulation. Every time both the game theories are applied on SUs to estimate the utility function. From Table 1 last two columns and Figure 4, it is predicted that while spectrum sensing, the $\boldsymbol{U(f)}$ of SUs is improved using CGT compared to BGT.

Hence, It is recommended to use CGT to resolve the spectrum sensing problem in CRN. This enhances the $\boldsymbol{U(f)}$ of each SU, which is beneficial to improve overall spectrum utilization using CRN.

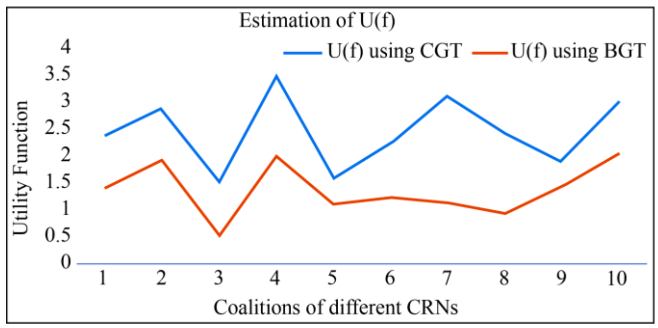

Fig. 4 Estimation of utility function for spectrum sensing

Table 1. Estimation of utility function $U(f)$ using coalition and bargain game theory

Coalitions status	$\boldsymbol{R(f)}$	U(f) **(CGT) (after substituting all the values and weights)**	U(f) **BGT (after substituting all the values and weights)**
S_1 (It is a remote coalition because all Sus in this are away from all PUs.)	$SU_9 = 0.8$ $SU_6 = 0.9$ $SU_4 = 0.7$	SUs status $SU_H = 0, SU_R = 3,$ $SU_N = 0, SU_{FA} = 3$ $U(f) = 2.43$	SUs status $SU_H = 0, SU_R = 3,$ $SU_N = 0, SU_{FA} = 1$ $U(f) = 1.43$
S_2	$SU_1 = 0.5$ $SU_5 = 0.8$ $SU_{10} = 0.9$ $SU_3 = 0.4$	SUs status $SU_H = 0, SU_R = 0,$ $SU_N = 4, SU_{FA} = 4$ $U(f) = 2.92$	SUs status $SU_H = 0, SU_R = 3,$ $SU_N = 4, SU_{FA} = 2$ $U(f) = 1.92$
S_3	$SU_8 = 0.5$ $SU_7 = 0.9$	SUs status $SU_H = 1, SU_R = 0,$ $SU_N = 1, SU_{FA} = 2$ $U(f) = 1.53$	SUs status $SU_H = 1, SU_R = 0,$ $SU_N = 1, SU_{FA} = 0$ $U(f) = 0.53$

Table 2. Relation between utility function and reliability function

Reliability Function	Utility Function
1.1	1.32
1.3	1.41
1.4	1.53
1.8	2.1
2.2	2.43
2.4	2.57
2.5	2.73
2.6	2.92
2.8	2.96
2.9	2.98

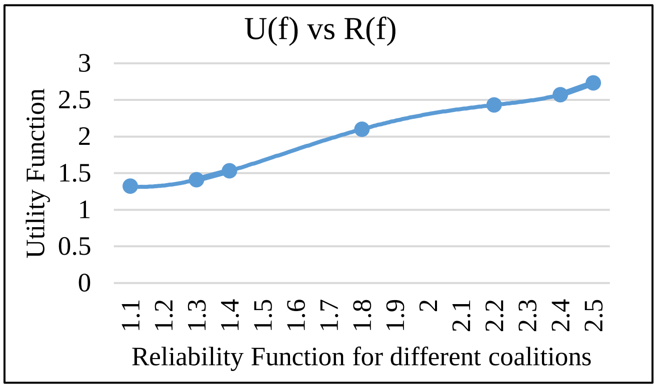

Fig. 5 Relation between tility function and reliability function

Figure 5 shows the relation graph between the utility function $\boldsymbol{U(f)}$ and the reliability function $\boldsymbol{R(f)}$ for various coalitions. Different CRNs are executed in MATLAB for ten separated spectrum sensing slots for this analysis. Table 2 shows the estimation of R(f) and $\boldsymbol{U(f)}$. For this estimation, various coalitions of different sizes are considered. During estimation, it is observed that the range of $\boldsymbol{R(f)}$ is between 1 to 3 and the range of $\boldsymbol{U(f)}$ is between 1 to 3. It is also observed that the $\boldsymbol{U(f)}$ of coalitions depends on the size of the coalition and the reliability function of coalition members, and from the observation, it is concluded that as the size of the coalition and the $\boldsymbol{R(f)}$ of CMs increases, the $\boldsymbol{U(f)}$ increases as well, for spectrum allocation in [14] payoff function is used as specified in equation (4).

$$C(f) = X * R(f) + Y * D(f) + Z * H(f) \quad (4)$$

Where,

$C(f)$ = payoff measured to obtain priority for spectrum allocation,

$R(f)$ = Reliability function,

$D(f)$ = Demand function,

$H(f)$ = Handoff time function, and

X, Y, Z are the weights allocated to the above function.

As per the importance given to different functions, i.e. reliability, demand or handoff function, weights to these functions can be allocated using the liner optimization method. After applying the above payoff function to the coalitions formed using CGT and BGT, it is concluded that the payoff of coalitions for spectrum allocation is increased using CGT compared to BGT. Table 3 shows the Payoff function $(C(f))$ estimation for various coalitions using CGT and BGT; the graphical view is shown in Figure 6.

Table 3. Payoff function $C(f)$ estimation for various coalitions using CGT and BGT

Number of Coalitions	$C(f)$ using BGT	$C(f)$ using CGT
1	0.65	0.9
2	0.62	0.85
3	0.5	0.7
4	0.52	0.75
5	0.5	0.68
6	0.65	0.95
7	0.4	0.78
8	0.35	0.88
9	0.45	0.81
10	0.5	0.75

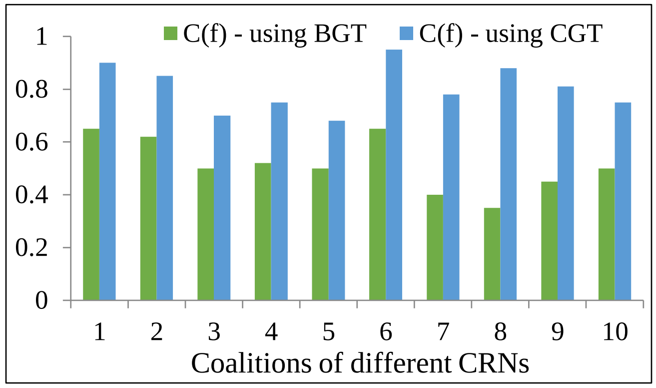

Fig. 6 Estimation of payoff for spectrum allocation

5. Conclusion

This paper discusses the merits and demerits of cooperative and non-co-operative game theory for spectrum sensing in Cognitive Radio Networks. To handle the problem of spectrum sensing, the benefits of Coalition Game Theory over Bargain Game Theory are also focused. To improve the spectrum utilization, the utility function of SUs should be high. In this paper, it has been proved that utility function while spectrum sensing and payoff function while spectrum allocation of SUs/coalitions improves using Coalition Game Theory compared to Bargain Game Theory.

In Coalition Game theory, the utility function depends on the coalition's size and reliability of coalition members, and it enhances with large size coalition and reliable coalition members. Based on the benefits of Coalition Game Theory, utilizing the same for spectrum sensing and allocation in cognitive radio networks is recommended.

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