Design an efficient MAC Protocol for Cognitive Radio Systems using Game Theory

Debbrata Kumar Saha, Asaduzzaman, Mohammad Obaidur Rahman
Dept. of CSE, Chittagong University of engineering and Technology, Bangladesh
Email: dev_07_cse@yahoo.com; asad@cuet.ac.bd; obaidur_91@yahoo.com

***Abstract*—In this paper we consider power distribution between cognitive users which is the most crucial problems in cognitive radio systems. To ensure perfect distribution game theory is applied. Conflicting users who are trying to access the same channel are detected first. Targeted signal to noise ratio (SNR) is achieved by iterative fashion which determines the signal strength. Power is calculated for each user by convergence theorem. Power is distributed in such way that it increases system utility. At last Nash equilibrium point is formulated for ensuring the avoidance of selfish behavior of cognitive users. Experimental results show that the proposed strategy achieves the ability to reduce the power consumption in order to increase the system utility.**

Keywords: Cognitive Radio, Conflicted players, Power Distribution, Nash equilibrium, Game Theory.

I. INTRODUCTION

Spectrum scarceness is one of the major challenges that the present world is facing. The efficient use of existing licensed spectrum is becoming most critical because of the growing demand of the radio spectrum. To solve this problem, cognitive radio (CR) has emerged as a leading technology because it can intelligently sense an unused spectrum without creating any harm to authorized users called primary users. In cognitive radio networks the secondary users can borrow the unused spectrum from the primary user for some time but this must be done by creating no harm to the primary user’s communication.

In cognitive radio network there may be multiple secondary users. If there are fixed numbers of channels that are smaller than the total numbers of users then channel distribution among multiple users create severe problems. Suppose a channel is requested by many secondary users. Now the cognitive radio network will have to make a decision to accommodate the secondary user, who is requesting for utilizing the spectrum, specifying its application needs. This Spectrum allocation decision requires some factors or parameters like operating frequency, data rate, transmitting power, modulation scheme, signal bandwidth, error rate etc. for consideration of distribution. To mitigate this problem game theory is applied in this area that perfectly select the proper way of channel distribution.

In game theory, every user is considered as a player and they select their proper role in the channel distribution game. The players who are trying to access the same channel, are called conflicting players. If there is one player in each channel then there is no problem in distributing the channels. But when several players try to access a single channel it is essential to identify the right player who maximizes the spectrum utilization.

Figure 1 represents an example of conflicted players. Here P represents cognitive users (players) and C represents channels. Fig. 1 shows a motivating example where nine players (p1, p2,…,p9) are trying to access five channels (c1, c2,…, c5). Assume that the players first measure the channel-gain in all the available channels and then try to access the channel which has the maximum channel-gain. In fig 1 we see that in channel 2, there are three conflicting players (p6, p8, p9). Because, in this channel, the channel gain for all of these players are maximum among the channels. In channel 3 and 4, there are two conflicting players and in channel 1 and 5 there are only one player. The problem here is to allocate channels 2, 3 and 4 to the best one among the conflicting players so that the overall spectrum utilization is maximized.

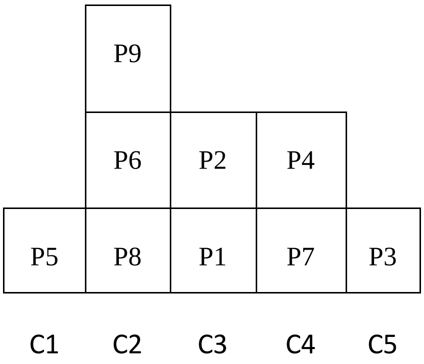

Figure 1. Channels of conflicted players

In this dynamic spectrum sharing case power distribution between conflicted players plays a vital role. A power distribution strategy is used and a utility function is introduced in [3]. A two- step power distribution algorithm based on game theory is proposed in [4]. A Medium Access Control (MAC)

Protocol based on price - based resource allocation algorithm is proposed in [5] for improving system throughput by reducing the average transmission power. A price-based iterative water-filling (PIWF) algorithm is proposed, which allows users to converge to the Nash Equilibrium (NE) that satisfies game theory. On the basis of stated research the power distribution problem between cognitive users is introduced in this paper. First the conflicted users are calculated manually in any channel. Then optimal SNR is calculated in iterative fashion. At last Nash equilibrium point is formulated with the presence of SNR. At this point the optimal power would be found for all conflicted players.

The paper is organized as follows. In section 2, Methodology is represented. Game theoretic model is presented in section 3. In section 4, simulations results are shown. Conclusion is represented in section 5.

II. METHODOLOGY

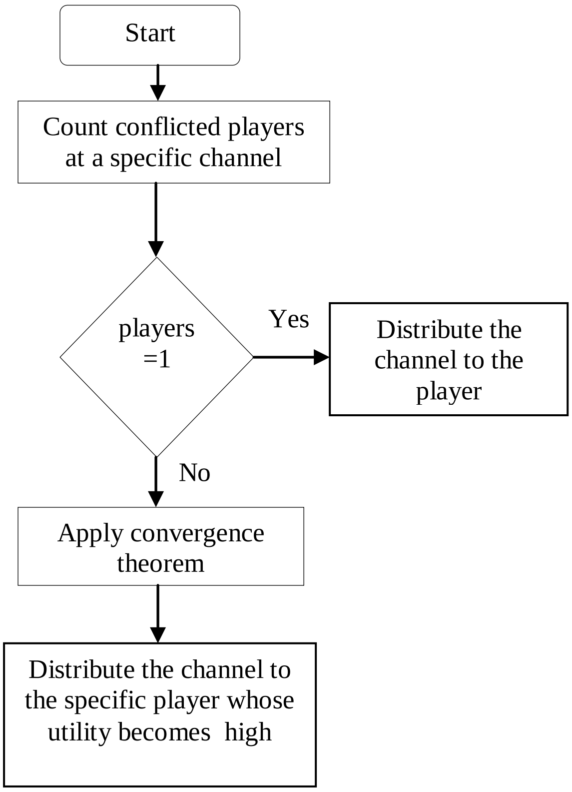

Figure 2. Flow chart for the overall methodology

Figure 2 represents the methodology of the system. At first the system's vital role is to find out the conflicted players at a specific channel. When it exceeds one, it will calculate the convergence point for each player that will represent the power consumption for each player. After this, the system will find out the utility and based on the utility, channel will be distributed.

III. SYSTEM MODEL

We consider a cognitive radio network with *N* radio transmitter-receiver pairs distributed randomly in an area. We assume that in this area, there are *K* frequency channels that are available for transmission between the radio pairs. In the game theoretic model each transmitter is considered as a player. Here all players, individually, try to access the specific channel in which their respective channel-gains are maximum.

Now our role is to find out the equations of those players whose channel-gains are maximum in the same channel. Assume that *Q* transmitters use the same channel c_0. They have power,

$$P : \left(p_0, p_1, p_2, \ldots\ldots\ldots\ldots, p_Q\right)$$

Here, p_i represents the power at the ith transmitter. Where

$$i = 1,2,3,\ldots\ldots\ldots, Q$$

The expression for *SNR* at receiver i is,

$$SNR = \frac{g_{ii} p_i}{\sum_{j=1, j \mp i}^{Q} g_{ij} p_j + n_i} \eta \qquad (1)$$

g_{ij} = link gain

n_i = noise power at receiver i

Now our task is to select power level that exactly meet target SIR. It is denoted by γ_0. *SNR* maintains some criteria. That is,

If $SNR > \gamma_0$, use too much power

If $SNR < \gamma_0$, packets cannot be received correctly

So we can reach in the conclusion that transmitter i is supported if :

$$SNR_i \geq \gamma_0 \text{ , here } \gamma_0 = \text{target } SNR$$

When the targeted *SIR* is obtained then the equation of power can be stated as :

$$p_i \geq \gamma_0 \left(\sum_{j=1, j \mp i}^{Q} \frac{g_{ij} p_j}{g_{ii}} + \frac{n_i}{g_{ii}} \right) \qquad (2)$$

Denote $\frac{g_{ij}}{g_{ii}} = h_{ij}$; $\frac{n_i}{g_{ii}} = \eta_i$

The users adjust their power to meet or exceed target *SNR*. So at last the minimized equation is obtained as-

$$p_1 \geq \gamma_0 \left(h_{12} p_2 + \eta_1 \right) \qquad (3)$$

$$p_2 \geq \gamma_0(h_{21}p_1 + \eta_2) \tag{4}$$

So the Minimum power solution is:

$$p_1 = \gamma_0(h_{12}p_2 + \eta_1)) \tag{5}$$

$$p_2 = \gamma_0(h_{21}p_1 + \eta_2) \tag{6}$$

Here equations 5 and 6 are our concluded state in which players 1 and 2 are conflicted. It implies that here the channel gain is maximum for both players. So game theory is applied here to formulate the minimized solution. At last Nash equilibrium point is calculated by convergence theorem. The same process is applied for multiple players who are trying to access the same channel in order to be maximum channel gain in that channel.

The utility of user j,

$$u_j = \frac{ER}{p_j}(1-e^{-0.5\gamma_j})^L \tag{7}$$

E= energy content of battery

L= packet length

R= data rate

p_j = power at the j^{th} transmitter

A reverse relation exists between power and utility. From equation 7, it is noticeable that if power increases then the user utility decreases. As our vital role is to increase the payoff of the system, so we have to increase utility. If it is somehow possible to decrease the power consumption, then the utility will be easily increased.

IV. SIMULATION RESULTS

In this section we provide our experimental results and the comparison between the existing work. Here we prove the effectiveness of our proposed model. In our experiment we consider the available channels are less than the cognitive users, so that the channels become conflicted between users. The experimental parameters are listed in table 1.

To find out the target SNR is the initial task to our experiment. The number of iterations increases when targeted SNR becomes larger during power calculation.

Figure 3 shows the Experimental results of SNR versus iterations of proposed and existing work [4]. It represents the number of iteration required to reach target SNR for two different models. From this result we can conclude in the discussion that in order to reach in the targeted SNR, initially our proposed model requires a little bit more iterations. But at the end the required iterations for desired SNR is quite similar.

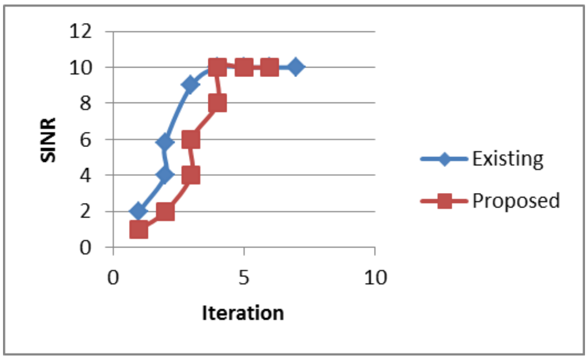

Figure 3. SNR versus iteration

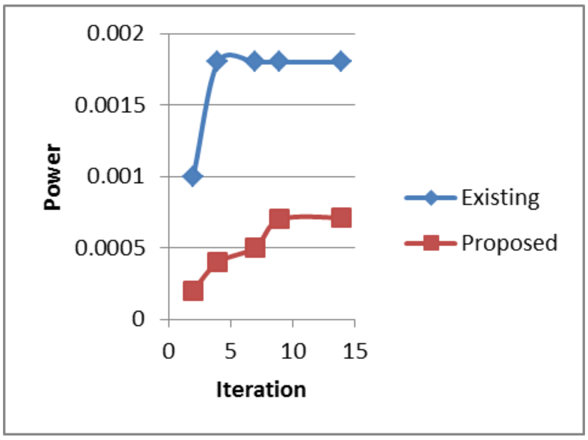

Figure 4. power versus iteration when SNR=10

Power versus iteration curve is shown in Figure 4. It also depends on signal to noise (SNR). Power consumption increases with the increasing order of SNR. Our goal is to keep the SNR in a tolerable limit so that the iterations and the power consumption become low.

In Figure 4 we notice that in our proposed model converging steps (number of iterations) are larger than the existing model [4] to reach in a steady state. But here power consumption is lower than the existing model [4]. As our target is to reduce power consumption, so in this case our proposed model is better than the existing model.

Utility varies reversely with the increasing numbers of conflicted players as stated in equation 6. This relationship implies that the consequences of increasing power consumption decreases utility. Therefore, we can come into conclusion that with the increase of the number of conflicted users, the number of iteration increases and the amount of power is also increased up to a certain stage. Consequently, the utility decreases when the number of conflicted players increases. Figure 5 shows the number of conflicting users versus utility. As we expected, the utility decreases with the increase of the number of conflicting users.

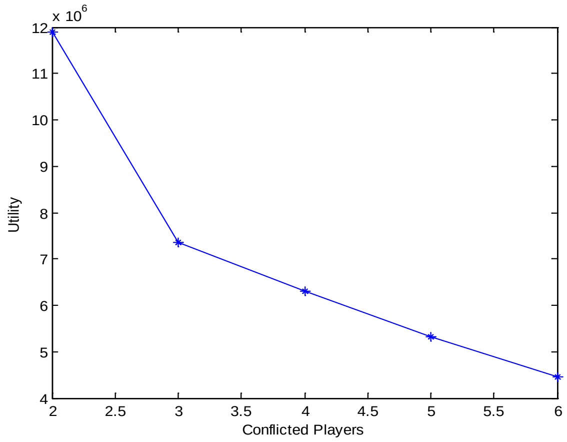

Figure 5. Utility versus conflicting players

Table 1. Experimental Parameters

TRANSMISSION RATE R :	10^3 B/S
LENGTH OF INFORMATION BITS L :	30
NOISE POWER N_0 :	10^{-4} W
MAXIMUM TRANSMISSION POWER :	1W

V. CONCLUSION

The Channel distribution based on power consumption is one of the major challenges in cognitive radio networks. Power sources become more lasting only when the power consumption is low. Here we have reduced power consumption efficiently. Converging steps increase with the increasing order of signal to noise ratio. This ultimately increases power consumption. We have reduced power consumption by slightly increasing in the number of converging steps.

If our proposed model is applied when multiple players try to access the same channel, it will pick up the exact player to give control of the channel with the cooperative manner. So at the end point it can be concluded that the proposed model is a somehow favorable solution for this power distribution problem in a cognitive radio (CR) network. It gives the better solution among the available solutions in existing literature.

When the number of conflicted players becomes very large then sometimes the convergence may not come. But it may happen only in the rare case. Somehow it can be improved in future.

ACKNOWLEDGMENT

I would like to thank my parents for their endless love and support. I am deeply grateful to my thesis supervisor Dr. Asaduzzaman for his valuable suggestions, positive advice, encouragement and sincere guidance through my thesis work.

REFERENCES

[1] I. F. Akyildiz, W. Y. Lee, M. C. Vuran, and S. Mohanty, “A survey on spectrum management in cognitive radio networks," IEEE Communications Magazine, vol. 46, no. 4, pp. 40-48, 2008.

[2] J. Márk Félegyházi, Member, IEEE, Mario ˇ Cagalj, Member,IEEE, ” Efficient MAC in Cognitive Radio Systems: A Game-Theoretic Approach," IEEE transactions on wireless communications, Vol. 8, No. 4, April 2009.

[3] I. F. Wang, M. Krunz, and S. Cui. Price-based spectrum management in cognitive radio networks. IEEE Journal of Selected Topics in Signal Processing, 2(1): 74-86, 2008.

[4] Rui YANG†, Yibing LI, Fang YE, “A Two-Step Power Distribution Algorithm Based on Game Theory in Cognitive Radio Networks," *Journal of Computational Information Systems* 7: 10 (2011) 3585-3590.

[5] Fan Wang,Marwan Krunz,and Shuguang Cui, "Spectrum Sharing in Cognitive Radio Networks Technical Report TR-UA-ECE-2007-1.

[6] Y. C. Yang, J. Li, W. Li, and D. Chen. “Power allocation based on noncooperative game theory in cognitive radio,” Journal of Xidian University,36(1): 1-4, 2009.

[7] S Cheng, Z. Yang, and H. Zhang.Novel,” power control game algorithm for cognitive radios,” Journal of Communications, 28(3):100-106,2007.

[8] C. U. Saraydar, N. B. Mandayam, D. J. Goodman, “Efficient power control via pricing in wireless data networks,” IEEE Transactions on Communications, 50(2): 291-303, 2000