ICEE 2012
20th Iranian Conference on Electrical Engineering
بیستمین کنفرانس
مهندسی برق ایران

Utility-based Joint Power and Admission Control Algorithm in Cognitive Wireless Networks

Roshanak Nasiri Shafti
Ahrar Institute of Technology and Higher Education
Rasht, Iran
rnasirish@gmail.com

Abdorasoul Ghasemi
Faculty of Electrical and Computer Engineering, K. N. Toosi University of Technology, Tehran, Iran
arghasemi@eetd.kntu.ac.ir

Abstract—**Resource allocation is one of the major challenges in wireless communications including cognitive radio networks. In these networks secondary users try to coexist with primary ones. We consider a data communication scenario in which utility obtained by a user measures its quality of service (QoS). This utility is quantified based on success of the user for correct transmission of information bits. To provide primary users protection, a threshold tolerable interference is determined for them. Therefore, transmit powers of secondary users should be controlled in a way that the aggregate interferences for primary users are not exceeded from the predefined extent. A utility-based joint power and admission control (U-JPAC) algorithm is presented for data networks, in order to allocate radio resources in an efficient manner to the requesting links, while the interference constraints are not violated and considering the total utility of secondary users as the objective. Simulation results show that the proposed algorithm performs efficiently in maximizing total utility of cognitive data networks considering primary users protection compared to the similar previous algorithm. However, a small outage increment is occurring. It is illustrated by simulation results that U-JPAC algorithm is efficient in both single and multiple primary user scenarios.**

Keywords-Cognitive radio; underlay spectrum sharing; power and admission control; game theory; optimization problem

I. INTRODUCTION

The recent researches represent that the major reason of inefficient spectrum utilization in wireless networks is applying the static policies for spectrum management [1]. Using Cognitive Radio Technology for dynamic spectrum sharing extremely improves the spectrum efficiency. Cognitive Radio is a wireless communication model in which a wireless user changes its communication parameters to have an efficient communication avoiding interference to the other users. These changes are applied according to different factors inside or outside of the radio environment, including radio frequency spectrum, users' behavior and network status. Game theory and optimization problem are two powerful tools for dynamic resource allocation in wireless networks including cognitive radio networks (CRNs).

Users in a CRN are divided into to two sets; the primary users (PU) and the secondary users (SU) which are equipped with cognitive radio equipment. The former refers to the users with spectrum access license but, they seldom use the available spectrum completely. The underutilized spectrum is called white space. The latter refers to the unlicensed users that are allowed to use the spectrum only when the PUs are provided by their requirements. The most important thing to consider is that SUs are not allowed to degrade the QoS of PUs. There are two modes for spectrum sharing in CRNs. Spectrum overlay is the mode in which the SUs try to find the idle time or frequency slots to avoid conflict to the PUs, whereas in spectrum underlay, which is considered in this paper, the SUs try to control their transmit powers to limit the interference they cause for the primary receivers so that the simultaneous transmissions by PUs and SUs are possible [2].

On the other hand, in wireless communications, it is required to quantify the satisfaction of users by accessing the radio resources. There are different definitions for satisfaction levels of users in wireless networks. Particularly, in the voice networks a user is satisfied when it gets a specific SINR, whereas in data networks there is not a specific SINR satisfaction level for a user. Therefore, users try to achieve the maximum possible number of information bits received correctly at receiving point in data networks [12]. Numerous efficient works are proposed for resource allocation especially power control in voice communication cases considering SINR at receiving point of a user as its QoS measure. In contrast to these works, we propose a power and admission control method based on a game-theoretic approach in [11] to obtain a Pareto optimal net utility (total utility of SUs) for data communications in CRNs. Indeed, we employ a predefined utility function to measure success of a user to transmit information bits correctly as its QoS. Some proposed admission control methods providing maximum possible numbers of SUs by the required QoS are as follows.

In [4], three classes of transmitter removal algorithms; one-by-one removals, multiple removals, and joint power control and link removal, are compared to each other. The admission control algorithms proposed in [5], are designed to be applied with power control jointly in high load network states. These single and multiple removal algorithms provide basic requirements of SUs while the aggregate interference in secondary receivers does not exceed the tolerable threshold. A joint power and admission control for both PUs and SUs in an underlay cognitive scenario is proposed in [6], which considers the interference constraints to guarantee the QoS requirements for PUs and a minimum QoS level for the admitted secondary ones while the maximum possible numbers of SUs are admitted. The authors in [7], proposed a joint power and admission control algorithm for CRNs which achieves a near-optimal performance without exhaustive search. The proposed admission control removes SUs one-by-one and is accomplished jointly with the power control algorithm repeatedly until all remaining SUs satisfy the QoS requirements of both PUs and SUs simultaneously. In [8], two classes of distributed admission control; non-interactive and interactive admission control are considered. The authors studied the mobile admission control problem in a cellular PCS network where transmitter powers are controlled by a distributed constrained power control (DCPC) algorithm. The problem studied in [9] is selecting a subset of cognitive users in a way that results in the maximum total revenue output of network. The authors transformed the original problem into an optimization one that is solved by using a gradient descent based algorithm. An efficient distributed admission control and power allocation algorithm is proposed in [10] with reasonable complexity that provides results close to the optimum solution with no large amount of signaling or wide range of information about the system parameters.

The major vision point in the above works is to maximize the number of QoS satisfied SUs in the network as they achieved a specific extent of SINR. In this paper, we consider the utility of a SU as its QoS. This utility is defined as the number of information bits that the SU can transmit correctly consuming one joule of energy [11]. A utility-based joint power and admission control (U-JPAC) algorithm is proposed that includes two phases; in the first phase, a game is performed between requesting SUs to obtain a Pareto optimal net utility considering interference constraints of PUs. Then, an admission control algorithm is performed to remove the SUs causing intolerable interference for PUs and/or make the net utility lower than the desired extent, in a one-by-one manner. A reducer parameter and a booster one are introduced to be multiplied to power vector in order to reduce the probability of link removal occurrences in next steps. Both phases are performed jointly until a desired level of net utility is achieved, while PUs protection is provided. Simulation results show that the proposed algorithm obtains higher net utility than the maximum value which is obtained by solving an optimization problem. In addition, it is illustrated by simulation results that power allocation for U-JPAC is more efficient as compared to a previous similar method proposed for voice communications.

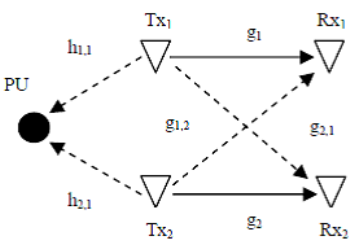

Figure 1. System model for M=1, N=2.

The rest of this paper is organized as follows. System model and problem statement are presented in section II. The proposed U-JPAC algorithm is illustrated in section III; meanwhile a similar previous work is reviewed. In section IV, the simulation results of the proposed algorithm are discussed. Conclusions are presented in section V.

II. System Model and Problem Statement

A. System Model

We consider a coexisting cognitive scenario, including M primary and N secondary transmitters that are communicating with their intended receivers. We call each of these transceiver pairs "a user". Fig. 1, shows the system model for one primary and two SUs. The intended communication links and the interference links between users are shown by solid lines and dotted lines, respectively.

In the above scenario, Tx_i and Rx_i indicate transmitter and receiver number i, respectively. The channel gain for intended communication link i is denoted by g_i. We use $g_{i,j}$ for channel gain of interference link between secondary transmitter number i and secondary receiver number j, and $h_{i,k}$ for channel gain of interference link between secondary transmitter number i and primary receiver number k. For a cellular system as primary system PU is the base station and if the primary system is a WLAN, PU is the access point. The secondary system can be an ad-hoc network including mobile or motionless nodes.

B. Problem Statement

As we mentioned before, a main purpose in underlay spectrum sharing in CRNs is to choose appropriate transmit power vector for SUs providing QoS requirements for both PUs and SUs. Similar to some related works, we apply the QoS requirements of PUs by using interference constraints on primary receiving points. Assume that there are N SUs coexisting with M PUs like that are shown in Fig. 1. As we mentioned before, for data communications, QoS of a secondary receiver is measured by its utility [11]. To define utility for SUs, we employ an efficiency function $f(\gamma_i) = (1-2ber_i)^m$ which is shown in [11] that closely follows the behavior of probability of correct reception of a frame (packet) at secondary receiver i. Using this efficiency function, the utility of a user is defined as,

$$u_i = \frac{LRf(\gamma_i)}{mp_i} = \frac{LR(1-2ber_i)^m}{mp_i}, \qquad i = 1, \dots, N \quad (1)$$

Where, ber_i denotes the bit error rate (BER) for link i which is a function of SINR of link i for various modulation techniques in the case of an additive white Gaussian noise (AWGN) channel m is the size of received packet, p_i is the power of secondary transmitter i, L is the number of information bits in a frame, and R is the transmission rate (bits/sec). Using the Non-coherent FSK modulation technique in this paper, we have $ber_i = \frac{1}{2}e^{-\gamma_i/2}$. Let γ_i denote the SINR on receiving point of secondary link i which can be written as,

$$\gamma_i = \frac{g_i p_i}{\sum_{j=1, j\neq i}^{N} g_{j,i} p_j + P_{N_i}}, \quad i = 1, \dots, N \quad (2)$$

Where, P_{N_i} is the total noise and interference received from PUs on the secondary receiver i. Hence, the utility function for SUs is transformed as,

$$u_i = \frac{LR\left(1 - e^{-\gamma_i/2}\right)^m}{mp_i}, \qquad i = 1, \dots, N \quad (3)$$

Therefore, we can interpret u_i as the number of correct information bits received at receiving point i per one joule consumed energy. To provide SUs by QoS requirements, it is required to maximize sum of their utilities. On the other hand, to provide QoS requirements of PUs it is required to determine some constraints on aggregate interference received by primary receiving points. Therefore, assuming that interference between PUs is negligible, interference constraints of PUs can be expressed as,

$$\sum_{i=1}^{N} h_{i,k} p_i \leq I_k \ , \ \ k = 1, \dots, M \quad (4)$$

Where, I_k is the predefined threshold for aggregate interference on primary receiving point k. The constraints presented in Equation (4) indicate that SUs are allowed to increase their transmit powers and obtain their required QoS while the total interference they create on receiving side of PUs does not exceed the tolerable extent. In most related works the objective is to maximize the number of SUs in network that are achieved to minimum desired SINR while PU protection is provided. Recall that in data communications it is more desired to maximize the net utility; however the number of preserved SUs may be decreased. Therefore, in this paper the objective is to maximize net utility, considering interference constraints of PUs in Equation (4). We transform the selecting problem to an optimization one and solve it to attain a transmit power vector for SUs under a maximum power constraint in a way that PUs protection is provided. We have the optimization problem as,

$$\max U_{total} = \sum_{i=1}^{N} \alpha_i \ln(u_i) = \sum_{i=1}^{N} \alpha_i \ln\left(\frac{LR\left(1 - e^{-\gamma_i/2}\right)^m}{mp_i}\right), \qquad (5)$$

$$subject\ to \sum_{i=1}^{N} p_i h_{i,k} \leq I_k, \qquad k = 1, \dots, M \qquad (5a)$$

$$p_i \leq p_{i,max}, \quad i = 1, \dots, N \qquad (5b)$$

Notice that we transformed the net utility to a weighted sum of all SUs utilities. Employing the weights $\alpha_{i=1,\dots,N}$, we can apply a fairness policy to allocate radio resources to SUs. The solution of this optimization problem provides a power vector for users which results optimized net utility while PUs protection is provided. However, the obtained power control method is centralized. Hence, it is not desired for wireless networks.

In the next section, we will propose an efficient distributed approach which employs a non-cooperative power control game with pricing (NPGP) for power allocation [11].Then, a link removal method will be introduced to optimize the net utility considering interference constraints of PUs.

III. UTILITY-BASED JOINT POWER AND ADMISSION CONTROL ALGORITHM

As we mentioned before, in high load network conditions, in which the exceeded interference between active users may cause QoS degradedness consequences, an admission control method is required to preserve the secondary links that do not make interference constraints violation for any primary receiving points. In [5], interference constraint aware Stepwise Maximum Interference Removal Algorithm (I-SMIRA) which is the most related work of ours is presented to select the appropriate subset with the maximum possible number of satisfied active SUs. The, I-SMIRA is defined based on a related efficient admission control algorithm in [4]. These algorithms employ an efficient DCPC algorithm proposed in [3] for power control phase. Two different cases of violation based on two different kinds of constraints, are considered in [5] as follows,

Case 1: Interference constraints for all PUs are satisfied but QoS requirements of SUs are violated.

In this case, the algorithm removes the link which has the most QoS constraints violation and/or creates the most amount of interference to other links in each removal step.

Case 2: Interference constraints for all PUs are not satisfied.

In this case, I-SMIRA removes the secondary link which creates the most interference for primary receivers and creates or receives the most interference for/from other secondary links in a defined weighted average sense in each removal step [5]. Recall that, I-SMIRA and some other related works consider QoS requirements of SUs as receiving a minimum SINR on the receivers.

We will present an admission control considering cases of violation similar to I-SMIRA but, we discover QoS violation for SUs when the net utility is less than a specific extent.

A. Non-cooperative Power Control Game with Pricing

In [11], an N-player NPGP is proposed as $G_c = [N, \{P_i\}, \{u_i^c(.)\}]$. This game solves a multi-objective optimization problem that is expressed as,

$$(\boldsymbol{NPGP}) max_{p_i \in P_i} u_i^c(\boldsymbol{p_i}, \boldsymbol{P_{-i}}) = u_i(\boldsymbol{P}) - c_i(p_i, \boldsymbol{P_{-i}}), \quad i = 1, \dots N. \qquad (6)$$

Where, P_i is the strategy space of user i that is a convex, compact set as $[0, p_{i,max}]$, $u_i(\boldsymbol{P})$ is the utility function defined in Equation (1), and $c_i(p_i, \boldsymbol{P_{-i}})$ is a pricing function for user i. The existence and uniqueness of equilibrium solution point of the game is proved in [11]. The authors defined the pricing function of a player as a linear function of its transmission power in order to deal with self-optimizing behavior of an individual user that cause QoS degradedness for the others and consequently degrades net utility. In this paper, we introduce another form of pricing function that is defined to apply PUs protection in the CRNs. We define the pricing function as,

$$c_i(p_i, P_{-i}) = p_i \sum_{k=1}^{M} \mu_k h_{i,k}, \qquad i = 1, \dots, N. \quad (7)$$

Where, $\mu_{k=1,\dots,M}$ would be considered as large positive constant factors. In this game, each SU tries to maximize its utility but, it must to pay the price for using recourses proportional to the amount of total interference it causes for PUs. The NPGP is performed between all the SUs requesting to access radio resources in each power control phase of the U-JPAC proposed in this paper. The net utility resulted by the game, may not be the optimized extent that could be obtained. The objective is to select the desired subset of SUs that cause maximum possible net utility.

B. Admission Control

We use two cases mentioned before to choose the secondary link which should be removed in each removal step. To discover the violation case1, we compare the obtained net utility with an optimal extent. Therefore, QoS requirement violation is occurred for SUs if net utility is considerably less thanU_{max}. Let U_{max}denote the objective net utility value for SUs that is resulted by the game with pricing function in [11]. Hence, we employ the utilities of users as the removal criterion. Therefore, our algorithm removes the link that has the minimum utility in each removal step. This is because of channel gain of this link is negligible and/or it receives a large amount of interference from the other SUs. Therefore, we choose the candidate link to be removed as,

$$j^* = argmin_{j \in L}\{u_j\}, \qquad (8)$$

Where Ldenotes the requesting SUs set. In this case, a booster parameter is introduced as,

$$\delta = \frac{u_{j^*,max}}{u_{j^*}}, \qquad (9)$$

Where $u_{j^*,max}$is the desired utility of j^*. The power vector of remaining links is multiplied to this parameter to increase the users' utilities and decrease the probability of removal occurrences in next step. Therefore, the game is performed between the remaining users with the powers increased proportional to the QoS requirement violation occurred in previous step which caused undesired net utility.

On the other hand, to discover the interference constraint violation occurrences we use a definition similar to that defined in [5] to measure the degree of violation at primary receiving points as,

$$\eta_k = I_k - \sum_{i=1}^{N} h_{i,k} p_i \quad , \quad k = 1, \dots, M \qquad (10)$$

In case2, we introduce a removal criterion which measures the aggregate interference each SU creates for PUs and its utility,

$$j^* = argmax_{j \in L}\left\{\sum_{k=1}^{M} p_j h_{j,k} - u_j\right\}, \qquad (11)$$

Therefore, in this case the proposed U-JPAC algorithm removes the link which creates the largest amount of interference for PUs and has the channel with low gain and/or receives a large amount of interference at the receiving point in each removal step. To decrease the probability of removal occurrences in next step a reducer parameter is multiplied to the power vector of remaining links as,

$$\varepsilon = \frac{\sum_{k=1}^{M} p_{j^*} h_{j^*,k}}{\sum_{k=1}^{M} \sum_{i=1}^{N} p_i h_{i,k}}, \quad (12)$$

So that, they perform the game with powers that is reduced proportional to the interference violation occurred in previous step.

IV. Simulation Results

A coexisting scenario similar to Fig. 1 is considered. Secondary transmitters are randomly located in a 1000m×1000m square area. Each secondary receiver is randomly located in a 500m×500m square area in which its intended transmitter is located at the center. The channel gains for communication or interference link between transmitter i and receiver j is calculated by the simple path loss model $c/d_{i,j}^4$, where c=0.097 and $d_{i,j}$ is the distance between transmitter and receiver. The total noise and interference at all secondary receiving points are considered as $P_{N_i} = P_{N_0} = 10^{-10}$ Watt. Maximum transmit powers for all secondary transmitting points are considered as 0.2 Watt. We consider equal weights for all requesting links.

Fig. 2, shows the net utility versus the number of requesting secondary links for algorithms I-SMIRA and U-JPAC as compared with the results of optimization problem solved by MATLAB^{T}, considering single and multiple PU scenarios. As it is evident, when the network load is low, both proposed U-JPAC algorithm and I-SMIRA improve the net utility as compared to the optimization method. The reason is that in low network condition both distributed methods remove successfully the links that have low utilities and cause net utility downfall. Moreover, the figure illustrates that the U-JPAC method improves the net utility in high load network condition as well. In contrast, for the case of I-SMIRA, the net utility dramatically declines as load is increasing.

Fig. 3, indicates the number of admitted links versus number of requesting links for U-JPAC algorithm and I-SMIRA. Evidently, the U-JPAC method results a small outage increment rather than I-SMIRA. This decrement in acceptance capacity of network is negligible, taking into account the significant improvement of net utility

It is illustrated by Fig. 2, and Fig. 3, that the proposed U-JPAC algorithm efficiently works for high load network conditions to preserve the most number of requesting links while the net utility is maximized and interference constraints are not violated.

V. Conclusion

We proposed a distributed joint power and admission control algorithm which is applicable for data communication networks. We use the utility of a user to measure its QoS. The utility function denotes number of information bits which received in receiving point of user correctly consuming one joule of energy. The algorithm includes two phases; in the first phase, a NPGP is performed between requesting links in which the pricing function is defined to allocate users' powers in a way that interference constraints considered for PUs protection are satisfied. Then, a link removal algorithm is performed to optimize the net utility by removing the links which cause intolerable interference for PUs and/or achieves the minimum utility. Both phases are performed jointly until the net utility is maximized while PUs protection is provided.

REFERENCES

[1] FCC, "Spectrum policy task for report", ET Docket No.02-135, Nov. 2002.

[2] Q. Zhao, B. M. Sadler, "A survey of dynamic spectrum access: Signal processing, networking, and regulatory policy", IEEE Signal Processing Mag., Vol. 24, No.3, PP. 79-89, May 2007.

[3] S. A. Grandhi, J. Zander, "Constrained power control in cellular radio systems", IEEE 44th Vehicular Technology conference, pp. 824-828 Jun. 1994.

[4] M. Andersin, Z. Rosberg, and J. Zander, "Gradual removals in cellular PCS with Constrained power control and noise" , 6th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Vol. 1, PP. 56-60, Sep. 1995.

[5] L. B. Le, E. Hossain, "Resource allocation for spectrum underlay in cognitive radio networks", IEEE Trans. on Wireless Communications, Vol. 7, No. 12, PP. 5306-5315, Dec. 2008.

[6] I. Mitliagkas, N. D. Sidiropoulos, A. Swami, "Convex approximation-based joint power and admission control for cognitive underlay networks", International Wireless Communications and Mobile Computing Conference, PP. 28-32, Aug. 2008.

[7] S. Im, W. Kim, Y. Kang, and H. Lee, "Joint power and admission control for underlay spectrum sharing in cognitive radio networks", the 2010 International Conference on advanced Technologies for Communications, PP. 56-61, Oct. 2010.

[8] M. Andersin, Z. Rosberg, and J. Zander, "Soft and Safe admission control in cellular networks", IEEE/ACM Trans. On Networking, Vol. 5, No. 2, PP. 255-265, Apr. 1997.

[9] L. Zhang, Y.-C. Liang, and Y. Xin, "Joint admission control and power allocation for cognitive radio networks", IEEE International Conference on Acoustics, Speech and Signal Processing, Vol. 3, PP. 673-676, Apr. 2007.

[10] J. George, A. Sultan, M. Nafie, "Distributed power and admission control for cognitive radios in spectrum underlay networks", in Proc. IEEE Global Telecommunications Conference, PP. 1-6, Nov.-Dec, 2009.

[11] C. U. Saraydar, N. B. Mandayan, and D. J. Goodman, "Efficient power control via pricing in wireless data networks", IEEE Trans. on Communications,Vol. 50, No. 2, PP. 291-303, Feb. 2002.

[12] V. G. Douros, G. C. Polyzos, "Review of some fundamental approaches for power control in wireless networks", Comput. Commun. (2011), doi:10.1016/j.comcom.2011.03.001.

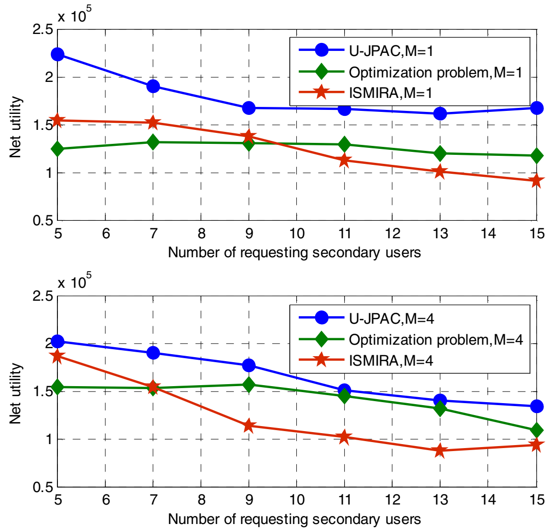

Figure 2. Net utility vs. number of requesting links.

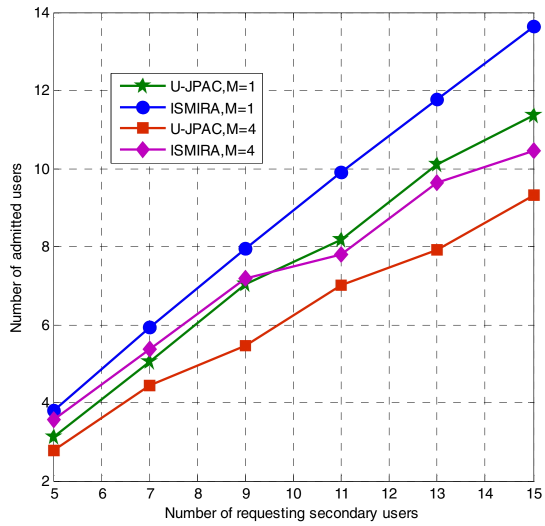

Figure 3. Number of admitted links vs. number of requesting links.