International Symposium on Advances in Science and Technology
Bandar-Abbas | Iran
7-8 March 2013
7th SASTech
Hosted by: Hormozgan University
Organised by: Khavaran Institute of Higher Education

A Low Computational Method in Maximizing the Throughput of An OFDM based Cognitive Radio System

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Paper Reference Number: 07-06-6552

Abstract

Computation reduction in resource allocation of those cognitive radio systems which employ orthogonally frequency division multiple access[1], is the aim of this paper. When the secondary user is permitted to capture any portion of the band which holds its interference with the primary user[2]'s below a given threshold level, and efforts are to maximize the throughput under power budget and interference constraint, a very simple method with low complexity for resource allocation is proposed. Comparison between the proposed method and previous works shows the performance of the proposed method.

Key words: resource allocation, cognitive radio, OFDMA.

1. Introduction

The radio spectrum in wireless communication systems is a scarce source. This topic is a reason for using spectrum in opportunistic manner. Cognitive radio is a partly new paradigm to solve the above problem. Spectrum sensing and dynamic spectrum access are two principle concepts in cognitive radio[3]. CR users sense the licensed bands which occupied by PUs,and opportunistically utilize anyvacant holes. Simultaneously the CR user must maintain its interference on PUs under a given interference threshold.

Recently much has been done on resource allocation in the context of CR and dynamic spectrum access.ByAttar A., Holland O. Nakhai, Aghvami A.H. (2008) a novel resource allocation scheme is developed fororthogonal frequency-division multiplexing[4]networks, designed to maximize the performance and limit the received interference at each user. Resource allocation in cognitive radio and cooperative networks have been extensively studied. For the former, most work Mitran P., Le L. B., and Rosenberg C. (2010)consider maximizing SUs' throughput with constrained interference to PUs. Power allocation was also studied by Zhang Y. and Leung C.(2009)where the CR user formulates the resource allocation problem as a 0–1 multidimensional knapsack problem and utilizes a heuristic solution to solve the problem. Although Zhang and Leung considered multiple PUs, they only considered a single-user CR network. The bit and power allocation problem is formulated as a

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[1] OFDMA
[2] PU
[3] CR
[4] OFDM

multidimensional knapsack problem, which is NP-hard. An optimal scheme is derived via the Lagrangian technique by Ngo D. T., Tellambura D. T., and Nguyen H. H. (2010).Radio resource allocation in the context of CR and dynamic spectrum access has received much attention in the recent literature, and a good summary of the state of the art is provided byBy Zhang R., Liang Y. C., and Cui S.,(2010).Hoang, A. T. Liang, Y. C. and Islam, M. (2010) consider the problem of power control and channel allocation in a CR network, assuming some kind of PU cooperation.Almalfouh S. M.,Stber G. L. (2011) have proposed four strategies for power and band allocation in an OFDM cognitive radio based system.

In this paper and using the system model of Almalfouh S. M.,Stber G. L. (2011), we will propose a very simple strategy in band and power allocation. Accordingly the paper is orgonized as follows. In section 2 the system model and the four strategies of Almalfouh S. M.,Stber G. L. (2011) is given, briefely. Section 3 contains the proposed method. Comparison between the results of the proposed and previous works is given in section 4 and finally section 5 gives the conclusion.

2. System Model

Consider a cognitive radio access point[5],K cognitive radio users,one PU base,and PU receivers as shown in fig. 1. The PUs employ orthogonal frequency division multiple access scheme, where their bands are divided into subbands,with N subcarrier in each subband. The CR AP senses the spectrum through periodic energy detection and detects N_v vacant subbands. The CRs utilize only the vacant subbands and the occupied subcarriers aren't used by them explicitly.Assume the CR AP has a maximum transmit power budget of p_t .The channel-gain-to-noise ratio[6] between the CR AP and the CR user k on subcarrier $n \in N_v$ is denoted by $\gamma_{kn} = h_{kn}^d / \sigma_{kn}^2$, where h_{kn}^d is the channel gain, and σ_{kn}^2 is the receiver noise power.

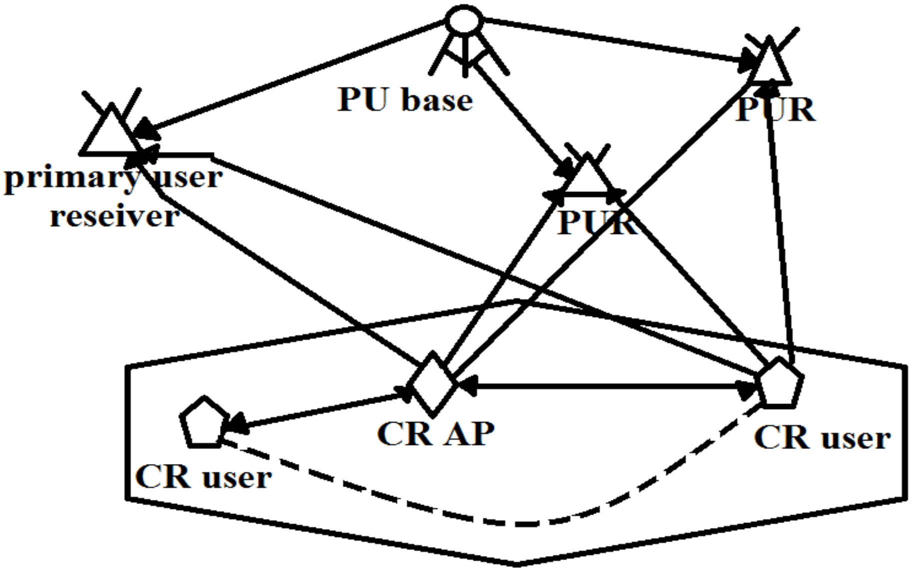

Figure 1: system model

Based on the above assumptions, the resource allocation problem can be formulate as follows Almalfouh S. M.,Stber G. L. (2011):

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[5] CR AP

[6] CNR

$$\max_{x_{kn},p_{kn}} \sum_{k=1}^{K} \sum_{n\in N_v} x_{kn} w_n \log_2 \left(1 + p_{kn}\gamma_{kn}\right) \qquad (1)$$

Subject to:

$$\sum_{k=1}^{K} \sum_{n\in N_v} x_{kn} p_{kn} \le p_t \qquad (2)$$

$$\sum_{k=1}^{K} \sum_{n\in N_v} x_{kn} p_{kn} \tilde{I}_n \le I_{th} \qquad (3)$$

$$\sum_{k=1}^{K} x_{kn} \le 1 \forall n \in N_v \qquad (4)$$

$$p_{kn} \ge 0 \ \forall n \in N_v, \forall k \qquad (5)$$

$$x_{kn} \in \{0,1\} \ \forall n \in N_v, \forall k \qquad (6)$$

x_{kn} is a binary parameter. When the subcarrier *n* allocated to CR user k, then x_{kn} =1. In this case p_{kn} will be the allocated power to CR user k in subcarrier *n*, otherwise x_{kn} =0. Equation 4 implies that each subcarrier at most will be allocated to only one CR user. The weight variable w_n in Equation 1 can be viewed as the CR AP confidence level in its decision that subcarrier *n* is vacant and available for CR transmission. $\tilde{I}_n$, the threshold factor, is the average interference, introduced by the CR AP in subcarrier $n \in N_v$, on all PU subcarriers. I_{th} is the interference threshold and p_t is the maximum transmitting power of CR AP. Hence the purpose of the maximization is to find p_{kn} and x_{kn} where maximize relation 1 (the throughput), subject to constraints 2-5.For $K > 1$, there is not a closed form solution for (1). By dividing the resource allocation problem into two parts of power and subcarrier allocation problems separately, Almalfouh S. M.,Stber G. L. (2011) solved the problem through three steps: power allocation, subcarrier allocation, and power enhancement.

The first step at algorithm of Almalfouh S. M.,Stber G. L. (2011) four strategies have been applied for initial power achievement. The first strategy allocates equal powers to all vacant subcarrier:

$$\bar{p}_{kn} = \frac{P_t}{N_v} \qquad (7)$$

In the second strategy the initial power level allocated to subcarrier *n*, if assigned to CR user *k*, is inversely proportional to its interference factor $\tilde{I}_n$ i.e., $\bar{p}_{kn} \propto 1/\tilde{I}_n$. The result is given by:

$$\bar{p}_{kn} = \frac{I_{th}^{n}}{\tilde{I}_n} \qquad (8)$$

in which:

$$I_{th}^{n} = \frac{\sum_{k=1}^{K} \frac{\gamma_{kn}}{\tilde{I}_n}}{\sum_{k=1}^{K} \sum_{n\in N_v} \frac{\gamma_{kn}}{\tilde{I}_n}} I_{th} \qquad (9)$$

In the third strategy, the restriction (2) and in the fourth strategy the restriction (3) at first is omitted and it is assumed:

$$x_{kn} = 1 \ \forall n \in N_v, \forall k \qquad (10)$$

Having the rest relations, the result of initial power allocation for the third strategy, will be:

$$\bar{p}_{kn} = \left[\frac{w_n}{\mu \tilde{I}} - \frac{1}{\gamma_{kn}} \right]^+ \qquad (11)$$

where $[\theta]^+ = \max(0, \theta)$ and μ can be obtained from inequality (3), using equation (11).
For the forth strategy, the result will be:

$$\bar{p}_{kn} = \left[\frac{w_n}{\lambda} - \frac{1}{\gamma_n} \right]^+ \quad (12)$$

where λ can be obtained from inequality (2), using equation (12).
The second step of all strategies is the following optimization:

$$\max_{x_{kn}} \sum_{k=1}^{K} \sum_{n \in N_v} x_{kn} w_n \log_2 (1 + \bar{p}_{kn} \gamma_{kn}) \ (13)$$

subject to equations(2) to (4) and(6). These optimization is a modified form of multiple-choice knapsack problem which its complexity has an exponential order.
Finally at the third step, according to a given algorithm, the initial power, assigned at the first step, is revised to enhance the throughput.Steps 2 and 3 of the four mentioned strategies are very complex. In the next section we will propose a very simple method which contains only two steps. The first step is in common with the above methods. However the second step is very simple and different.

3. The proposed method

The proposed solution for resource allocation problem is explained in this section. We start by the following definition:

$$\alpha_{kn} = \frac{\log_2 (1 + p_{kn} \gamma_{kn})}{p_{kn} \gamma_{kn}} \ (14)$$

Hence, from definition (14) the relation (1) changes to:

$$\max_{x_{kn}, p_{kn}} \sum_{k=1}^{K} \sum_{n \in N_v} w_n \alpha_{kn} \gamma_{kn} x_{kn} p_{kn} \qquad (15)$$

For $\gamma_{kn} \ll 1$ (low CNR). from:

$$\lim_{\theta \to 0} \frac{\log_2 (1 + \theta)}{\theta} = 1.44 \qquad (16)$$

we will have α_{kn} =1.44. Otherwise p_{kn}, is necessary to find α_{kn}.

Assuming $p_{kn} \approx \bar{p}_{kn}$, where $\bar{p}_{kn}$ is the initial power allocation given from (7), (8) , (11) or (12) , the following approximation is made to compute α_{kn}:

$$\alpha_{kn} \approx \frac{\log_2 (1 + \bar{p}_{kn} \gamma_{kn})}{\bar{p}_{kn} \gamma_{kn}} \qquad (17)$$

Now define $\eta_{kn} = \omega_n \gamma_{kn} \alpha_{kn}$ where using equation (17), η_{kn} is known. Also define $z_{kn} = p_{kn} x_{kn}$. Rewriting the optimization problem (1) we will have:

$$\max_{z_{kn}} \sum_{k=1}^{K}\sum_{n\in N_v}\eta_{kn} z_{kn} \qquad (18)$$

Subject to:

$$\sum_{k=1}^{K}\sum_{n\in N_v} z_{kn} \le p_t \qquad (19)$$

$$\sum_{k=1}^{K}\sum_{n\in N_v} \tilde{I}_n z_{kn} \le I_{th} \qquad (20)$$

$$z_{kn} \ge 0 \qquad (21)$$

and:

$$H([z_{1n}, z_{2n},..., z_{Kn}]) \le 1 \qquad (22)$$

where $H([\theta_1,\theta_2,...,\theta_K])$ is the number of nonzero elements of vector$[\theta_1,\theta_2,...,\theta_k]$.

Define

$$\eta_{n_M n} = \max(\eta_{1n},\eta_{2n},...,\eta_{Kn}) \qquad (23)$$

In maximizing (18) between K values $z_{1n}, z_{2n},..., z_{kn}$, because of inequality (22), at most $z_{n_M n}$, can be nonzero.Hence the optimization problem is simplified to:

$$\max_{z_{n_M}} \sum_{n\in N_v}\eta_{n_M n} z_{n_M n} \qquad (24)$$

Subject to:

$$\sum_{n\in N_v} z_{n_M n} \le p_t \qquad (25)$$

$$\sum_{n\in N_v} \tilde{I}_n z_{n_M n} \le I_{th} \qquad (26)$$

$$z_{n_M n} \ge 0 \qquad (27)$$

Comparison between (24) and (1) shows that while dimensionof unknown variables ($\{z_{n_M n}\}$) in(24) is N_v, dimension of unknown variables in ($\{p_{kn}\},\{x_{kn}\}$) is KN_v. There is also no logarithm term in (24).The optimization problem in equations24-27can be solved using polynomial time methods such as simplex algorithm by Dantzig G. B.,(1951).

It is explicit that the relation between the outcome values of (1) and (24) is:

$$x_{kn} = \begin{cases} 1 & if \quad k = n_M \\ 0 & if \quad k \ne n_M \end{cases} \qquad (28)$$

$$p_{kn} = \begin{cases} z_{kn} & if \quad k = n_M \\ 0 & if \quad k \ne n_M \end{cases} \qquad (29)$$

4. result and simulations

The optimized solution of (24)(the proposed optimization problem) i.e. $z_{n_M n}$is obtainedand equations (28) and (29)are applied to find x_{kn}, p_{kn}. The results are placed in maximization (1) to find the throughput. Two cases have been considered: 1- Throughput comparison to interference threshold variations in fixed power transmit budget of CR AP and 2- Throughput comparison to power transmit budget of CR AP variations in fixed interference thresholds.

To make a comparison between the previous works and the proposed method, for each point also the result of one of the four strategies of Almalfouh S. M.,Stber G. L. (2011) which gives the best result for throughput (relation (1)) is given. Figures 1 and 2show the outcomes.The figures demonstrate appropriate performance of the proposed method in low power transmit and interference threshold,specially; because in low p_t, I_{th} the approximation (17)is near to actual values.

Table 1: the best strategy at each p_t , I_{th}

$p_t \backslash I_{th}$	10	0	-10	-20
0	3	3	4	2
10	3	4	2	2
20	4	1	2	1
30	4	3	4	1

5. Conclusion

In this paper, simple method in power and subcarrier allocation of cognitive radio system based on OFDMA was proposed. By collation of it with the methods of Almalfouh S. M.,Stber G. L. (2011), the proposed method has low computational complication and by subtraction of throughput determiner variables, distribution of power and frequency band was performed. Results comparison between the proposed and previous methods indicates suitable performance of proposed method in low p_t, I_{th} specially and acceptable performance in high p_t, I_{th} .

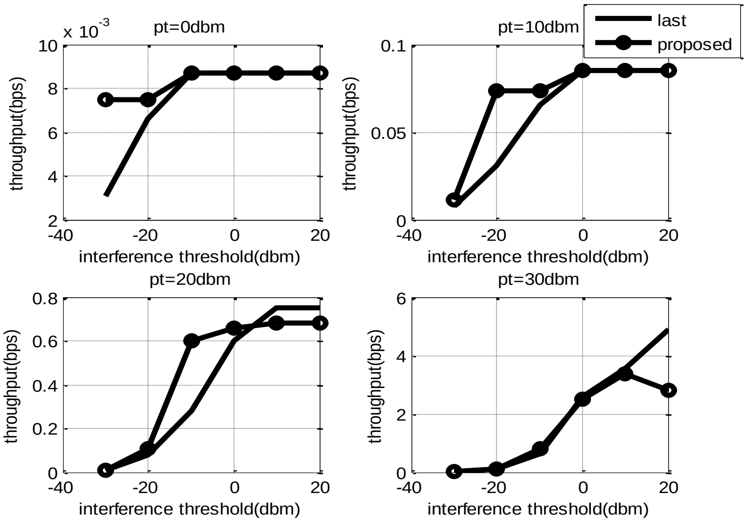

Figure 2: network throughput compared to the interference threshold with fixed maximum transmit power budget

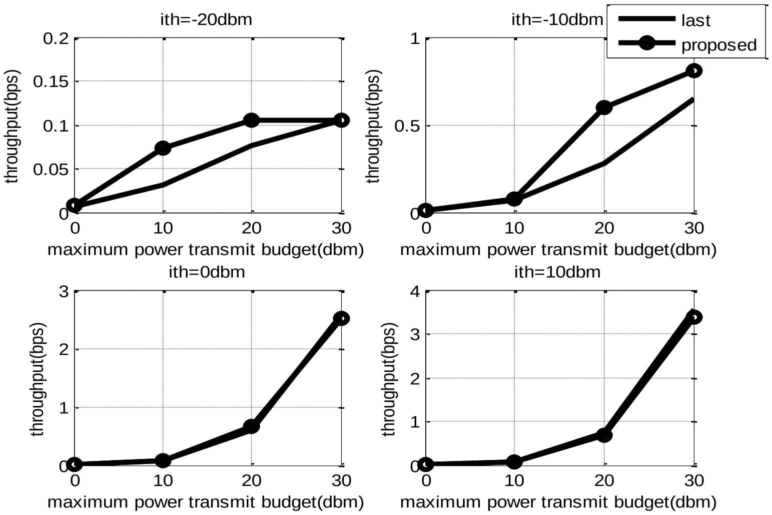

Figure 3: network throughput compared to the maximum transmit power budget with fixed interference threshold

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