Distributed Power Control Algorithm in Orthogonal Frequency Division Multiple Cognitive Radio Systems for Fading Channel

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Abstract—In order to guarantee the quality of service (QoS) for primary users (PUs) and secondary users (SUs) in fading channel, a distributed power control algorithm is proposed based on convex optimization theory in underlay OFDM cognitive radio networks (CRNs). Our purpose obtains the maximum transmit data rate of each SU at all subcarriers under three constraints of the maximum allowable transmission power, the minimum signal to interference plus ratio (SINR) of each SU and the maximum allowable interference generated from SUs to PU at each subcarrier. Simulation results show that the performance of the proposed algorithms (m2) are superior to the geometric programming algorithm (m1) in fading channel environment.

Keywords—Cognitive radio networks, distributed power control algorithm, convex optimization theory

1 Introduction

As the explosive growth of wireless communication services and applications, the limited spectrum resources becomes increasingly crowded and have not satisfied the growing needs of people [1]. In order to dynamically allocate and share spectrum, cognitive radio (CR) [2] is proposed to improve the efficiency of spectrum utilization. Currently, the underlay spectrum sharing mode is most effective where multiple SUs and PUs can use spectrum resource at the same time and satisfy the constraint of the interference temperature (IT) threshold [3]. Thus, we focus on underlay CRNs [4-5] with multiple PUs and multiple SUs to study resource allocation problem.

In CRNs, the distributed power control algorithm can improve the transmission efficiency, reduce message exchange and computational burdens, which is one of the key technologies in resource allocation [6-10]. In [6], a distributed power control algorithm based on a cooperative game theoretic is proposed which satisfied the interference power constraint to protect transmission QoS of PUs. An interference-aware

radio resource allocation based orthogonal frequency division multiple access (OFDMA) in cognitive radio networks is proposed to aim at maximizing secondary users throughput under the interference constraint of PUs in [7]. In [8], it consider the power efficiency optimization problem in the cognitive radio (CR) networks under both the average packet delay constraint of each CR transmitter (CR-Tx) and the interference constraint at primary receiver (PU-Rx). The authors propose a cooperative approach to make each CR-Tx know the interference level at the PU-Rx when there is no central control node in the network and no assistant sensors are deployed to do the interference measuring jobs. In [9], the resource allocation problem, which aims to maximize the weighted sum rate in orthogonal frequency division multiplexing based (OFDM-based) multi-cell cognitive radio networks (CRNs) with multiple description coding multi-cast (MDCM), is investigated. Network-wide optimization of transmit power with the goal of maximizing the total throughput, promises significant system capacity gains in interference-limited data networks, which was proposed in [10]. A large number of the aforementioned distributed power control algorithm are proposed based on perfect channel, and they may be not suitable to actual CR communication environment without taking into the near-far effect on the QoS of PUs and the minimum SINR at SU account.

Based on the above discuss, in this paper, a distributed power control algorithm is proposed to minimum the interference power from SU-Tx to PU-Rx based on convex optimization theory in underlay OFDM CRNs. In order to guarantee communication quality of PUs and SUs in fading channel, our proposed power control scheme not only considers that the transmit power of each SU at all subcarriers should not exceed its maximum power, but also takes the minimum SINR at secondary receivers (SU-Txs) and the interference temperature threshold in each subcarrier into account. The proposed algorithm is well adapt to practical dynamic communication environment. Simulation results show that the proposed algorithm is superior to algorithms (m2) are superior to the geometric programming algorithm (m1) [11] in fading channel environment.

2 System model and problem formulation

In this section, we consider T primary users (PUs) and M secondary users (SUs) in OFDM cognitive network with K subcarriers in underlay scenario.

Owing to the battery capacity, the transmit power of each SU must be lower than is not above its maximum transmit power, i.e.,

$$\sum_{k=1}^{K} p_k^i \le P_{\max}^i \tag{1}$$

where $P_{\max}^i$ is the threshold of the maximum power of the secondary user i in all subcarriers.

In order to make sure the QoS of the PUs and consider near-far effect and reduce exchanging message of the SUs, the interference power generated from each SU in

each subcarriers is lower than the bearable threshold of the PU. Thus, the weighting interference temperature is introduced. It can be defined as follows

$$p_k^i h_k^{it} \le \omega_k^{it} I_k^t \tag{2}$$

where h_k^{it} is the interference gain from the PU t to the SU i at the subcarriers k. I_k^t presents the maximum interference power level of subcarrier k. ω_k^{it} is the weighting factor ,which is proportional to the distance between the SU i and PU t at subcarrier k.

In order to guarantee the reliable QoS of the SUs the signal to interference noise ratio (SINR) at each SU-Rx should exceed the threshold

$$\gamma_{\min}^i \le \gamma_k^i \tag{3}$$

where $\gamma_{\min}^i$ $(\gamma_{\min}^i > 0)$ is the minimum required SINR value at the i SU. γ_k^i denotes the SINR at the i SU in the k subcarrier.

Our optimization objective is to maximize the transmit data rate of each SU at all subcarriers, and simultaneously meet constraints (1), (2) and (3). Thus, the optimization problem can be depicted as

$$\max \sum_{k=1}^{K} \log_2 \left(1 + \gamma_k^i\right)$$

$$\text{s.t.} \begin{cases} \sum_{k=1}^{K} p_k^i \le P_{\max}^i \\ p_k^i \ge 0, \forall k \in \{1,2,\text{L},K\}, i \in \{1,2,\text{L},M\} \\ \gamma_k^i \ge \gamma_{\min}^i \\ p_k^i h_k^{it} \le \omega_k^{it} I_k^t \end{cases} \tag{4}$$

where $\gamma_k^i = \dfrac{g_k^{ii} p_k^i}{N_k + h_k^{it} T_k^t}$. N_k represents the background noise at the k subcarrier. g_k^{ii} is the direct channel gain at the k subcarrier. T_k^t denotes the PU t's transmit power at the subcarriers k.

Obviously, the optimization (4) is a nonlinear programming [12] which is a concave maximization problem. The problem (4) can be converted to a convex function as follows.

$$\min - \sum_{k=1}^{K} \log_2 \left(1 + \gamma_k^i\right)$$

$$\text{s.t.} \begin{cases} \sum_{k=1}^{K} p_k^i \leq P_{\max}^i \\ p_k^i \geq 0, \forall k \in \{1, 2, L, K\}, i \in \{1, 2, L, M\} \\ \log_2(1 + \gamma_k^i) \geq \log_2(1 + \gamma_{\min}^i) \\ p_k^i h_k^{it} / \omega_k^{it} \leq I_k^t \end{cases} \tag{5}$$

3　Distributed power control algorithm

In this section, the distributed power control algorithm is applied to solve the transmit data rate problem of each SU on all subcarriers in OFDM CRNs. The distributed power control algorithm reveals the hidden convexity structure which can be resolved by Lagrange dual principle [13]. Therefore, the Lagrange function of (5) can be given by

$$L(p, \xi, \lambda) = -\sum_{k=1}^{K} \log_2 \left(1 + \gamma_k^i\right) + \xi(\sum_{k=1}^{K} p_k^i - P_{\max}^i)$$
$$+ \sum_k \chi_k [\log_2(1 + \gamma_k^i) - \log_2(1 + \gamma_{\min}^i)] + \sum_k \lambda_k \left(p_k^i h_k^{it} / \omega_k^{it} - I_k^t\right) \tag{6}$$

where $P = \left[p_1, L, p_M\right]^T$ is the transmission power vector. $\xi = [\xi_1, \xi_2, L, \xi_M]^T \geq 0$ denotes vector of dual variable. λ_k represents a Lagrange multiplier.

According to the dual decomposition theory, the Lagrange dual function for (6) is given by

$$D(\xi, \lambda) = \sum_k \min_p L_k(p, \xi, \lambda) + (\xi p_{\max}^i - \sum_k \chi_k \log_2(1 + \gamma_{\min}^i) - \sum_k \lambda_k I_k^i) \tag{7}$$

where

$$L_k(p, \xi, \lambda) = (\chi_k - 1) \log_2 \left(1 + \gamma_k^i\right) + \xi p_k^i + \lambda_k p_k^i h_k^{it} / \omega_k^{it} \tag{8}$$

And, the dual problem (6) is given as

$$\min D(\xi, \lambda)$$
$$\text{subject to} : \xi \geq 0, \lambda \geq 0 \tag{9}$$

According to the KKT condition [14], the optimal transmit power of each SU at each subcarrier can be obtained by the following equation

$$\frac{L_k(p, \xi, \lambda)}{\partial p_k^i} = 0 \tag{10}$$

And the solution is

$$p_k^i = \frac{\omega_k^{it}(1+\chi_k)}{\omega_k^{it}\xi + \lambda_k h_k^{it}} - \frac{N_k + h_k^{ij}T_k^j}{g_k^i} \tag{11}$$

The above problem can be solved by using subgradient method. Thus, we construct the subgradient iteration algorithm to update the Lagrange multipliers as follows

$$\xi(t+1) = \max\left(0, \xi(t) + \phi\left[P_{max}^i - \sum_{k=1}^K p_k^i\right]\right)^+ \tag{12}$$

$$\chi_k(t+1) = \max\left(0, \chi_k(t) + \nu\left[\log_2(1+\gamma_k^i) - \log_2(1+\gamma_{min}^i)\right]\right)^+ \tag{13}$$

$$\lambda_k(t+1) = \max\left(0, \lambda_k(t) + \varphi\left(p_k^i h_k^{it} / \omega_k^{it} - I_k^t\right)\right)^+ \tag{14}$$

where $[X]^+ = \max\{0, X\}$, t represents the iteration time and ϕ, ν, φ are step sizes. The step sizes and multipliers ξ, χ_k and λ_k [15] should be carefully chosen to ensure the fast convergence rate.

The distributed power control algorithm is below:

Step 1: Initialization: Set $t = 0$, $\xi(0) > 0$, $\chi_k(0) > 0$, $\lambda_k(0) > 0$, $\gamma_i^{min} > 0$, $0 \le p_k^i(0) \le p_{max}^i$, $\phi > 0, \nu > 0, \varphi > 0$.

Step 2: Calculate at the SU-Rx of link i: Compute the sum of interference and noise power $N_k + h_k^{ij}T_k^j$. Update Lagrange multiplier ξ by (12). Feedback information $N_k + h_k^{ij}T_k^j$ and ξ to the SU-Tx of link i.

Step 3: Calculate at the SU-Tx of link i: Receive $N_k + h_k^{ij}T_k^j$ and ξ, respectively. Update Lagrange multiplier χ_k and λ_k by (13) and (14).

Step 4: Calculate the transmit power value of SU-Tx by (10).

Step 5: Go to step 2.

4 Simulation results

In this section, the computer simulations are presented to demonstrate the performance of the distributed power control algorithm(m2) by comparison with Geometric Programming algorithm(m1) [11].

In the underlay network, we suppose that there are 3 active cognitive users and 8 subcarriers in OFDMA primary systems, and the bandwidth of each subcarrier is 62.5 kHz. The initial transmission power vector is randomly selected from interval

$(0, 0.01)$ mW. The power budgets P_{max}^i and the background noise levels N_k are randomly chosen from the intervals $(0.9, 1.1)$ and $(0.01, 0.10)$ respectively. The simulation results are shown from Figure 1 to Figure 5.
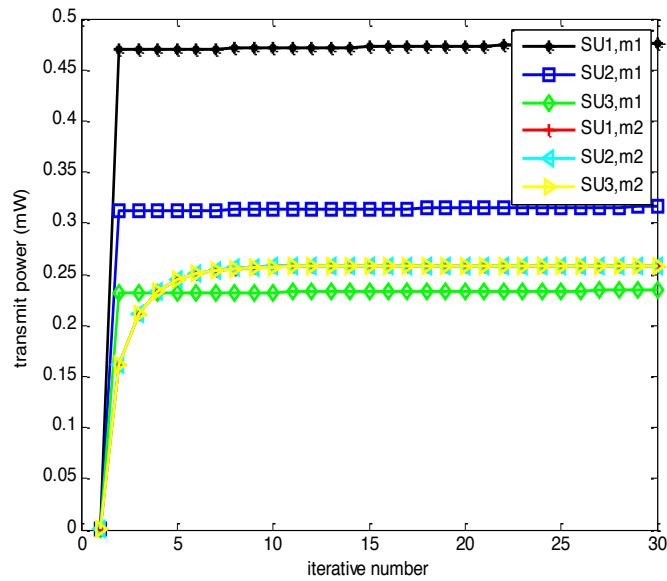

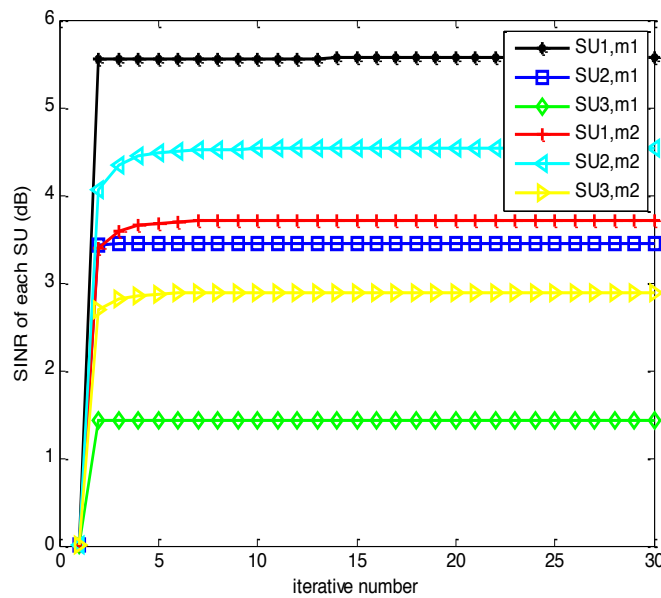**Fig. 1.** The SINR of each SU

Fig. 2. The transmit power of each SU

Fig.1 and Fig.2 present the transmit power and SINR of each SU for m1 and m2. We can clearly see that each SU satisfies the constrain of maximize allowable transmitting power and the minimum SINR in m1 and m2. Through comparing with m1and m2, the transmit power and SINR are larger of SU1 for m1 than that of the proposed algorithm m2. However, the total throughput of m2 is higher than 16.7% that of the m1 in the fading channel. The numerical simulation is given from Fig. 3

According to the principle of the total interference generated from SUs to PU, we can see that m2 is significantly smaller than m1 from Fig. 4. That means m2 has a lower badly effect on PU, which may affect QoS of primary user network.

In Fig.5, we analyze the system performance of the energy under multiple PUs and SUs in underlay CRNs. As expected, the total energy consumption of m2 is less than30% in m1. Thus, we can save a lot of energy in m2, which can improve energy efficiency.

From the above graphs, we can draw a conclusion that the performances of the proposed m2 algorithm is much superior to that of m1 given in [11].
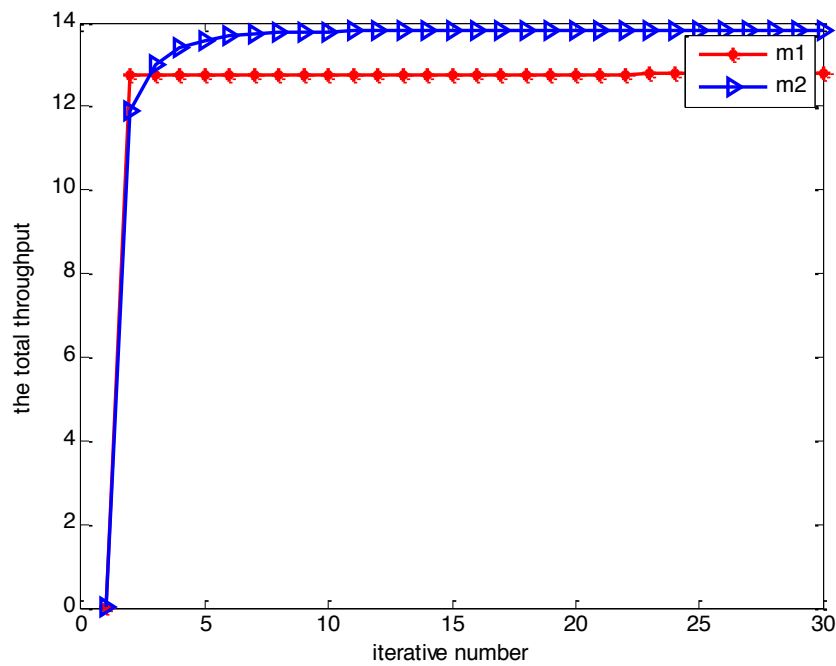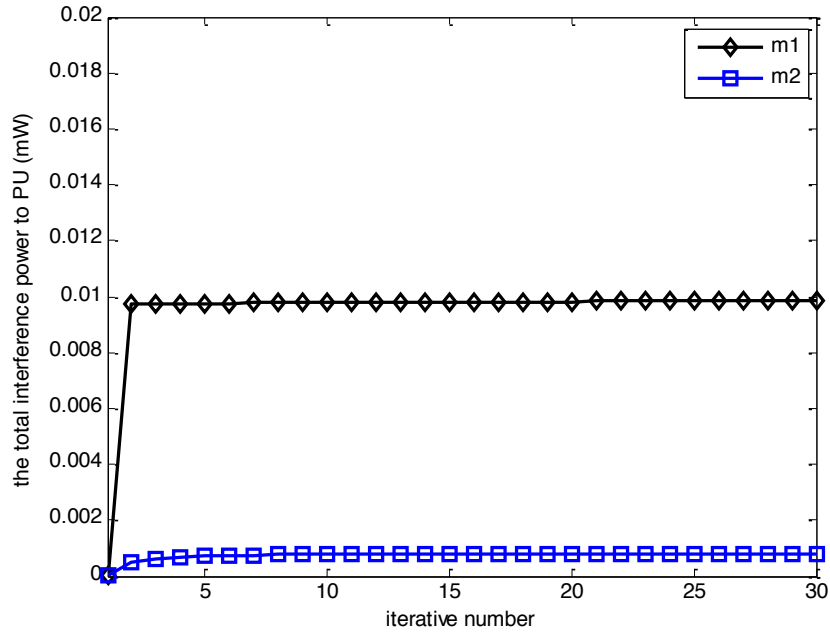

Fig. 3. The total throughput

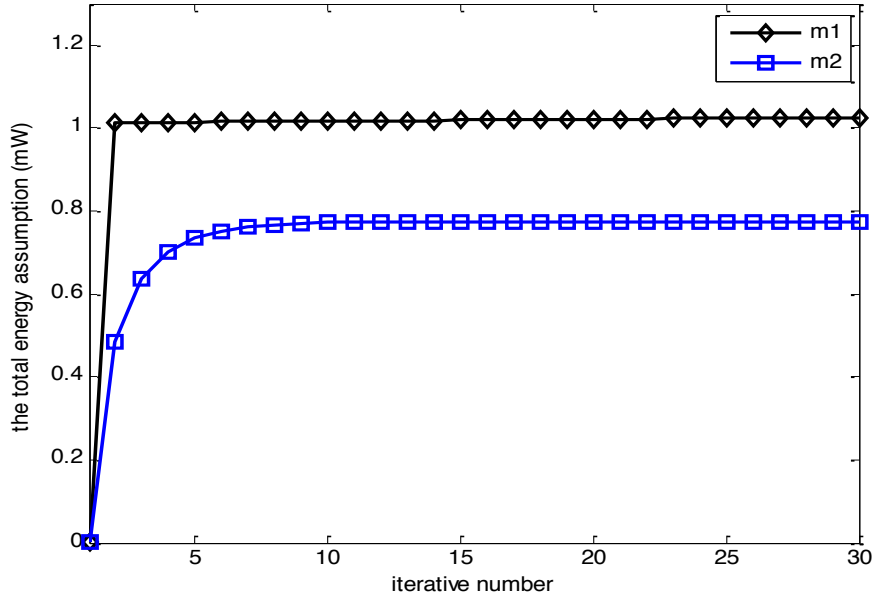**Fig. 4.** The total interference to PU

Fig. 5. The total energy consumption

5 Conclusions

In this study, we solve the transmit data rate of each SU at all subcarriers problem in OFDM cognitive network in underlay scenario. Specifically, considering near-far effect and three major constraints of the minimum accepted SINR, the maximum transmit power of each SU and the bearable threshold of the PU in each subcarrier, a distributed power control algorithm(m2) is proposed based on convex optimization theory. Finally, simulation results demonstrate the performances of the proposed algorithm and prove the performances in m2 is superior to m1 (geometric programming) in fading channel.

6 Acknowledgment

7 References

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