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Resource allocation algorithm based on hybrid particle swarm optimization for multiuser cognitive OFDM network

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ABSTRACT

Resource allocation plays a critical role to enhance the performance of cognitive orthogonal frequency division multiplexing (OFDM) network. However, due to lack the cooperation between cognitive network and primary network, the channel state information (CSI) between cognitive radio (CR) user and primary user (PU) could not be estimated precisely. In this work, a resource allocation problem over the power and subcarrier allocation based on chance-constrained programming is formulated to maximize the average weighted sum-rate throughput and guarantee the probabilistic interference constraint condition for PU. In order to solve the above resource allocation problem, the probabilistic interference constraint condition is computed by support vector machine (SVM) and we combine particle swarm optimization (PSO) and SVM to develop hybrid particle swarm optimization (HPSO). Simulation results verify HPSO not only yields the higher average weighted sum-rate throughput than other algorithms, but also satisfies the probabilistic interference constraint condition.

1. Introduction

With the increasement of the multimedia traffic, the emerging crisis of spectrum shortage becomes more and more serious in the future wireless communication (Chen, Liang, Motani, et al., 2011; Cheng, Deng, & Chen, 2012; Deng, Chen, Chau, Sun, et al., 2012; Lei, Li, & Yang., 2014; Stotas & Nallanathan, 2011). In order to solve the above crisis, one promising approach is CR technology and cognitive network as a new communication network is born at the right moment (Andson, Peterson, Kelvin, et al., 2014; Wang, Cheng, & Huang, 2014). So far, there are two scenarios in cognitive network which are overlay scenario and underlay scenario. In overlay scenario, cognitive network focuses on the spectrum hole via spectrum sensing. However, in underlay scenario, cognitive network shares the same spectrum with primary network by carefully controlling the interference at the receiver of primary network. In this work, we are interested in the resource allocation problem of the underlay scenario for cognitive network and select OFDM as an air interface due to the inherent significant advantages of flexibly allocating resource.

Resource allocation algorithms for cognitive OFDM network have been studied widely. Wang, 2010 converts the transmission power and interference threshold constraints to a normalized capacity of each OFDM subcarrier and proposes an efficient resource allocation algorithm for single-user cognitive OFDM network. Zhang and Leung (2009a), Zhang and Leung (2009b) and Zhang and Leung (2009c) study the resource allocation problem with non-real-time applications for multiuser cognitive OFDM network. A resource allocation algorithm based on the max–min criterion is proposed for multiuser cognitive OFDM network (Zhang & Leung, 2009a,b,c). The above resource allocation algorithms enhance the performance of cognitive OFDM network from the perspective of spetral effiency, but they do not consider the energy effiency. Therefore, a resource allocation algorithm with energy efficiency for cognitive OFDM network, which maximizes the system energy efficiency under the consideration of the transmission power budget, the interference threshold and the traffic demand, is proposed (Wang, Ge, & Zhao, 2013).

At the beginning of the study, researchers focus on the physical resource allocation problem for cognitive OFDM network and they do not consider the influence of the upper layer parameters to design the resource allocation algorithm. In order to improve the performance of cognitive OFDM network further, researchers investigate the cross-layer resouce allocaiton problems for cognitive OFDM network. Zhang and Leung (2009a,b,c) propose a

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cross-layer resource allocation algorithm based on mixed services for multiuer cognitive OFDM network. Luan, Gao, and Zhang (2012) investigate the cross-layer resource scheduling problem for relay-assisted cognitive OFDM network. However, Zhang and Leung (2009a,b,c) and Luan et al. (2012) design the spectrum sensing algorithm and the cross-layer scheduling algorithm separately. Therefore, a joint cross-layer scheduling and spetrum sensing problem for cogntive OFDM network is investigated (Wang, Lau, Lv, et al., 2009). Van, Hong, and Lee, (2012) extend the cross-layer resource allocation problem of single-hop cognitive OFDM network to the multi-hop cognitive OFDM network and propose a cross-layer resource allocation algorithm with joint control admission and power control for multi-hop cognitive OFDM network.

With the in-depth study, scientists begin to study the distributed resource allocation algorithm for cognitive OFDM network. Zhang and Leung (2011) propose a distributed resource allocation algorithm with joint subcarrier, bit and power allocation for cognitive OFDM network. A distributed resource allocation algorithm for relay-assisted cognitive OFDM network is investigated (Pan, Nix, & Beach, 2011). Although Zhang and Leung (2011) and Pan et al. (2011) study the distributed resource allocatin algorithms, they focus on the single-hop cognitive OFDM network. Leith, Dong, Alouini, et al. (2012) and Ngo and Tho (2011) investigate the distributed resource allocation algorithms for multi-hop cognitive OFDM network.

In the practical cognitive OFDM network, the cooperation between cognitive network and primary network is not perfect and CSI between CR user and PU could not be estimated precisely. Therefore, the power interference at the receiver of PU which is introduced by CR user could not be estimated precisely. Tailored for this case, Soltani, Kim, and Giannakis (2013) propose a chance-constrained resource allocation algorithm which aims at maximizing the weighted sum-rate over subcarrier and power allocation. However, Soltani et al. (2013) consider only one PU and it is not realistic in 4G network. In this work, we study the resource allocation problem based on the probabilistic interference constraint condition for cognitive OFDM network and more than one PU is considered. The main contributions of this work are as following.

- Model the uplink chance-constrained resource allocation problem.
- We propose HPSO which combines the SVM and PSO.
- Utilize SVM to compute the probabilistic interference constraint condition.

This work is organized as following. Section 2 introduces the network model of cognitive OFDM network and formulates the resource allocation problem based on chance-constrained programming. In Section 3, HPSO is developed and the algorithm complexity is analyzed in Section 4. Simulation results are presented in Section 5 and the conclusion is drawn in Section 5.

2. Network model and optimization problem formulation

2.1. Network model

Consider the uplink resource allocation problem of cognitive OFDM network with M CR users and N PU in a licensed system. The CR users are allowed to access the radio spectrum registered by PU via CR base station (CRBS). Moreover, we assume that CR users in cognitive OFDM network have the perfect CSI between the transmitter of CR users and the receivers of CRBS.

In cognitive OFDM network, the whole available bandwidth W is divided into K subcarriers, denoted by $\mathbf{K} = \{1, 2, \ldots, K\}$. The bandwidth of the kth subcarrier spans from $f_0 + (k-1)W/K$ to $f_0 + kW/K$, where f_0 is the starting frequency and W/K is the bandwidth of every OFDM subcarrier. The nth PU's nominal band ranges from f_n to $f_n + B_n$, where f_n and B_n are the nth PU's starting frequency and bandwidth, respectively. Moreover, $g^n_{m,k}$ represents CSI between the transmitter of the mth CR user and the receiver of the nth PU on the kth subcarrier (Li, Li, Xing, et al., 2013).

In this work, we adopt the underlay scenario for cognitive OFDM network and the interference introduced to the PU must be carefully controlled in a tolerable range (Wang et al., 2013). In order to calculate the interference introduced to the PU, the CSI between the mth CR user and the nth PU must be known. However, only the statistical CSI $g^n_{m,k}$ could be obtained due to lack the cooperation between cognitive network and primary network. To capture the uncertainty of $g^n_{m,k}$, we define the instantaneous channel coefficient between the mth CR user and the nth PU on the kth subcarrier as the complex Gaussian random variables $f^n_{m,k} \sim CN(0, \zeta^2_{m,n})$, where $\zeta_{m,n} = (d_{m,n}/d_0)^{-\gamma} s_{m,n}$ is the long-term average channel gain, d_m is the distance between the mth CR user and the nth PU, d_0 is the reference distance, γ is the amplitude path-loss exponent and $s_{m,n}$ characterizes the shadowing effect between the mth CR user and the nth PU. Hence, $g^n_{m,k} = |f^n_{m,k}|^2$ is an exponential random variable with probability density function (1).

$$f_{g^n_{m,k}}(\eta) = \frac{1}{\sigma_{m,n}} \exp\left(-\frac{\eta}{\sigma_{m,n}}\right) \tag{1}$$

where $\sigma_{m,n}$ is the long-term average CSI between the mth CR user and the nth PU.

2.2. Optimization problem formulation

In this section, we will model the chance-constrained resource allocation problem which maximizes the average weighted sum-rate throughput under the total power constraint and the probabilistic interference constraint for cognitive OFDM network.

Let $c_{m,k}$ denote the subcarrier allocation indicator for the mth CR user on the kth subcarrier. For example, if $c_{m,k} = 1$, the kth subcarrier is allocated to the mth CR user. Moreover, we assume each subcarrier can only be allocated to at most one CR user. Therefore, we could obtain the constraint condition (2).

$$\sum_{m=1}^{M} c_{m,k} \leqslant 1, \quad \text{and } c_{m,k} \geqslant 0, \quad \forall m, k \tag{2}$$

Let $p_{m,k}$ denote the transmission power for the mth CR user on the kth subcarrier, $P^{\max}_m$ denote the maximum transmission power for the mth CR user and $P^{\max}_{m,k}$ denote the maximum transmission power for the mth CR user on the kth subcarrier. In order to guarantee the feasible of power allocation, we add the constraint condition (3).

$$\sum_{m=1}^{M}\sum_{k=1}^{K} c_{m,k} p_{m,k} \leqslant P^{\max}_m, 0 \leqslant p_{m,k} \leqslant P^{\max}_{m,k}, \quad \forall m, k \tag{3}$$

Let $b_{m,k}$ denote the transmission rate for the mth CR user on the kth subcarrier, I_k is the interference power on the kth subcarrier and η is the background noise power. Then, $b_{m,k}$ could be expressed as (4).

$$b_{m,k} = \frac{W}{K} \log_2\left(1 + \frac{p_{m,k} h_{m,k}}{\Gamma(I_k + \eta)}\right) \tag{4}$$