The Mixed Cognitive Frequency Decision for Self-organized Networks

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Abstract. The paper studies the problem of distributed frequency decision problem in cognitive user (CU) network for optimizing satisfaction performance, based on the cognitive radio technology. For cognitive user, it can use both charged and free bands. Charged bands have to be paid and free bands have to be shared among cognitive users. Considering the work bandwidth limit and communication request for each cognitive user, our work is to maximize the network satisfaction performance of the cognitive user network which is defined as the satisfaction degree minus price paid. We propose a mixed cognitive frequency decision algorithm which could improve the network satisfaction performance. According to the experiment results, the proposed approach could work better compared with existing ones.

Keywords: Cognitive radio; Self-organized networks; frequency decision; leaning algorithm, satisfaction performance.

1. Introduction

The evolving 5G networks [1] have been seen as one of the most promising solutions for boosting the capacity and coverage of wireless networks [2] by spatial reuse of frequency spectrum. The CUs are expected to have certain degree of intelligence which can also be defined as cognition [4]. In particular, cognition via spectrum sensing is foreseen as a potential solution for high efficient spectrum use. CU [5] can opportunistically use the free orthogonal frequency via spectrum sensing, i.e., CU can opportunistically use the frequency which is considered free if the power received on that frequency is smaller than the spectrum sensing threshold [3]. For the dense and dynamically deployment of cognitive users, the centralized control in network management will be highly inefficient. Then the importance of self-organization is highlighted [6], and one of the key technical challenges is efficient distributed use management and distributed resource allocation.

A distributed approach is more appropriate for CU to utilize the free spectrum resource effectively. Free spectrum has to be carefully used to avoid severe interference. Otherwise, the service in the free bands will suffer. References [7]~[9] show their concerns on coexistence of LTE-U and WiFi in the free spectrum.

In our work, we assume each CU can acquire frequencies in both charged and free bands to satisfy its communication request by taking operating bandwidth limit into consideration. The objective is to maximize the satisfaction performance of CU network. We propose a mixed cognitive frequency decision algorithm which could improve the network satisfaction performance. According to the experiment results, the proposed approach could work better compared with existing ones.

The remainder of paper is organized as follows. System model is depicted in section 2. The mixed cognitive frequency decision algorithm is proposed in section 3. Experiment results and discussion are presented in section 4. Finally, we draw a conclusion in section 5.

2. The System Model

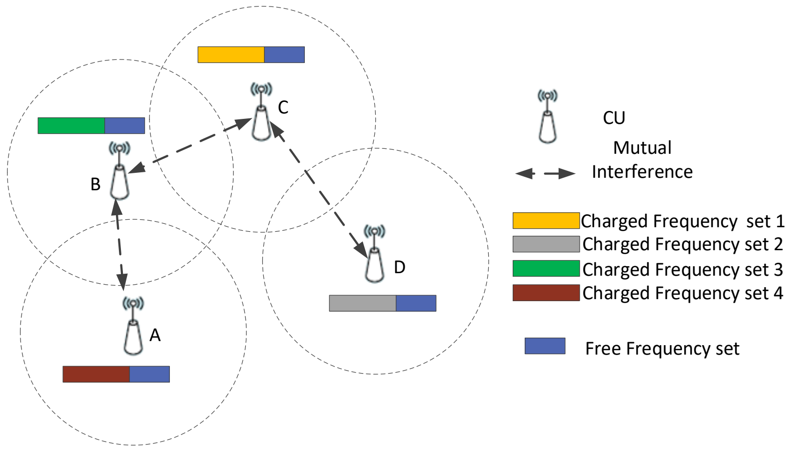

Fig.1 System model

The system model in our work is depicted in figure 1. The cellular network consists of M cognitive users (CU) which can use both charged and free bands. Denote the set of CU as $\mathbf{M}$,i.e. $\mathbf{M}=\{1,2,\cdots,M\}$. To avoid mutual interference among neighboring CUs, the charged frequencys admitted by MBS for CU are orthogonal with its neighbors. As shown in the figure, the orthogonal charged frequency set for cognitive user *A, B, C, D* is marked with different colors. Circle in dotted line indicates the coverage area for CU. A potential interference exists when their coverage area intersects with each other, such as (A,B) , (B,C) and (C,D). In the sequel, we call X and Y in (X,Y) neighbors. Actually, *A* can reuse the allocated charged frequencys for *C* far away. The same situation also holds for *B* and *D*. Nevertheless, the free bands are shared by all CUs. For each CU, the same size N_L of charged frequency set are reserved. And all CUs compete for N_U free frequencys. Denote $\mathbf{N_U}$ as the free frequency set and we have $\mathbf{N_U}=\{1,2,\cdots,N_U\}$.

Note that CU only make a decision about the number of selected charged frequencys n_L . After deciding the value of n_L , CU selects frequencys from the reserved charged frequency set randomly and transmits on them. These selected charged frequencys work in "ON" mode, while the rest charged frequencys in "OFF" mode. Unlikely, CU has to decide which free frequencys should be adopted carefully to avoid heavy interference. Denote the number of selected free frequencys as n_U which satisfies $n_U + n_L \le N_B$.

3. The Mixed Cognitive Frequency Decision Algorithm

We try to design the mixed cognitive frequency decision algorithm to improve the network performance. In the algorithm, a randomly selected CU will update its action while all other CUs repeat their actions. The process is repeated until some stop criterion is met. As shown in Step 3, CU's action decision is updated with the probability distribution which depends on its performance with previous action and its neighbors' action. Action which creates larger performance value will be selected with a higher probability. After multiple iterations, CU will converge to its optimal action with a probability arbitrarily close to 1 which will be proved in the following subsection. In the game, neighboring players will exchange information about their performance value and action decision with each other.

Algorithm 1: mixed cognitive frequency decision algorithm

Step 1. Initially, set $k=0$ and let each CU $m \in \mathbf{M}$ selects an action $a_m(0)$ from its available action set $\mathbf{A_m}$ with equal probability.

Step 2. CUs exchange the information with their neighbors.

Step 3. A CU i is selected randomly from $\mathbf{M}$. All other CUs will repeat their actions as $a_{-i}(k+1)=a_{-i}(k)$. And for CU i, we will decide the probability distribution of decision for action $a_i(k+1)$. If CU i selects action $a_i(k+1)=a_i$, it will obtain its performance as $U_i\left(a_i,a_{J_i}(k)\right)$ according to the information from neighbors. Then, we could acquire the probability for selecting $a_i(k+1)=a_i$ as follows

$$p_i^{a_i}(k+1)=\frac{\exp\left\{\gamma U_i\left(a_i,a_{J_i}(k)\right)\right\}}{\sum_{\bar{a}_i\in\mathbf{A_i}}\exp\left\{\gamma U_i\left(\bar{a}_i,a_{J_i}(k)\right)\right\}}$$

Where γ is a learning factor. $\sum_{\bar{a}_i\in\mathbf{A_i}}\exp\left\{\gamma U_i\left(\bar{a}_i,a_{J_i}(k)\right)\right\}$ represents the aggregate performance for CU i performing all actions in $\mathbf{A_i}$. Then, CU i decides its action $a_i(k+1)$ with the probability distribution $\left\{p_i^{a_i}(k+1)\right\}_{a_i\in\mathbf{A_i}}$.

Step 4. If the predefined maximum number if iteration is achieved, stop; else go to Step 2.

Fig.2 The proposed algorithm

In the algorithm, the learning factor γ should be designed carefully. If γ is too small, converge speed will slow down. Oppositely, the algorithm may converge to some suboptimal point if γ is too large.

4. Experiment and the Result Discussion

In the experiment, we consider a network consists of 6 CUs which are deployed densely or sparsely. We call any two CUs neighbors when they locate in the other's interference region. For each charged or free frequency, $\alpha=4Mbps$ can be supported. We note that the operating bandwidth limit and the reserved charged frequency for each CU are given as $B=3$ and $N_L=3$ respectively. CU will transmit on the free frequency which is also utilized by other CUs with probability $p=0.5$. To verify the performance of the proposed algorithm, we compare the performance with capacity aware frequency decision approach in the figure 3. In the capacity aware frequency decision Approach, the objective is to maximize the total network capacity. We simulate in both a dense network and a sparse network. Compared to the sparse network, CU has more neighbors in the dense network and endures a heavier potential interference. Meanwhile, three cases about communication request are considered: 1) heterogeneous request $\mathbf{D_1}=\{10Mbps,6Mbps,8Mbps,11Mbps,5Mbps,9Mbps\}$; 2) approximate homogeneous high request $\mathbf{D_2}=\{10Mbps,12Mbps,12Mbps,11Mbps,10Mbps,11Mbps\}$; 3) approximate homogeneous low request $\mathbf{D_3}=\{6Mbps,7Mbps,7Mbps,6Mbps,6Mbps,7Mbps\}$. Obviously, we can learn from the figure that demand aware (DA) is more favorable than capacity aware (CA) Approach since the resource allocation has a higher matched-degree. Moreover, with the same available resources and communication request CU always obtain a higher satisfaction performance in the sparse network than the dense network. This can be explained by the less capacity loss due to interference. When CU has a growing communication request, its performance will decrease as shown in the figure. CU has the highest request in *case 2* where network satisfaction performance is the lowest.

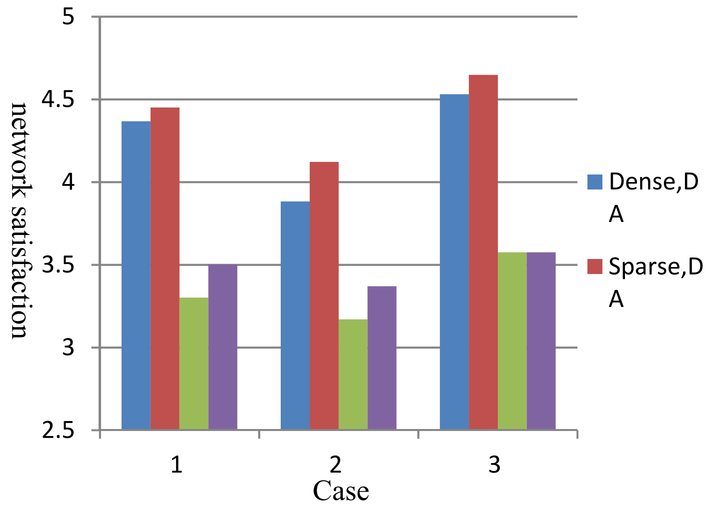

Fig.3 Performance comparison under different network circumstances

5. Conclusion

In this paper, we studies the problem of distributed frequency decision problem in cognitive user (CU) network for optimizing satisfaction performance, based on the cognitive radio technology. Considering the work bandwidth limit and communication request for each cognitive user, our work is to maximize the network satisfaction performance of the cognitive user network which is defined as the satisfaction degree minus price paid. We propose a mixed cognitive frequency decision algorithm which could improve the network satisfaction performance. According to the experiment results, the proposed approach could work better compared with existing ones. Under the same available resources and communication request CU always obtain a higher satisfaction performance in the sparse network than the dense network.

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