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A general framework for multiuser de-centralized cooperative spectrum sensing game

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ABSTRACT

Over recent years, cognitive radio technology has been paid enormous attention as this innovatory communication archetype can utilize existing wireless spectrum resources more competently. Spectrum sensing is considered to be primary and most essential task for cognitive radio network operators. It has been acknowledged that cooperative spectrum sensing improves the overall sensing performance of the network. But selfish users be likely to act greedily to access the channel without involving in spectrum sensing. In this paper, we considered multiuser de-centralized cooperative spectrum sensing scenario and game theory is used to analyze the cognitive interaction process. A comprehensive expression is derived for throughput and it is, then, maximized through strategic interaction between cognitive users. Simulation result shows that taking part in sensing is not always good in terms of throughput. This work also evaluates network conditions to determine when to contribute in sensing to maximize throughput.

1. Introduction

As huge number of wireless applications and devices appeared in the market, in last decade. An exaggerated demand of RF spectrum has been observed. Early method of static spectrum allocation is being proven to be inefficient, because after allocating spectrum to the licensed band users, insufficient amount of spectrum left for a huge number of unlicensed band users. Thus, scarcity of unlicensed band become a major issue for government regulatory bodies, such as the Federal Communications Commission (FCC). Contrasted with the situation, allotted spectrum remains unutilized for quite a long time by licensed band users. This inefficient utilization of spectrum leads to wastage of resource. In order to get rid of this problem, FCC introduced Cognitive Radio (CR) [1,2] and decided to open the under-utilized band for the unlicensed band users to use opportunistically. When the licensed spectrum holders, also called Primary Users (PUs), are not transmitting or sensed as inactive, the unlicensed band users i.e. Secondary Users (SUs) or CRs may use the licensed spectrum dynamically, without interfering to the PUs [3]. This new spectrum allocation scheme is known as dynamic spectrum allocation.

To detect available spectrum and to protect PUs from interference caused by SUs, CRs must sense the Radio Frequency (RF) spectrum. Several algorithms for spectrum sensing have been proposed in the literature [4–9]. Waveform based detection and energy detection methods of sensing have been projected in [5,6]. How to combine individual spectrum sensed result, to improve the performance of sensing in cooperative spectrum sensing, is discussed in [8]. The authors of [9], contributed towards deriving closed form expressions of detection probability and false alarm probability for cooperative sensing of spectrum. In [7], authors demonstrated that cooperative spectrum sensing can minimize detection time of PUs and thus improves overall capability. Which SU is to be chosen for cooperation is examined in the literature [8]. Maximization of throughput by designing of sensing time slot duration, is explored in [9]. Authors of [10], [11] and [12] used Evolutionary Game theory to study behavior of users in communication network. In [13], authors used Bayesian approach with suitable prior distributions to elaborate the availability analysis of frequency band. Effect of SUs' mobility on the probability of intra-cell spectrum handoff is investigated in [14]. Authors of [15] estimated a probabilistic spectrum access which gives a transmission probability for CR over individual primary sub-bands. Authors of [16] have considered issues of robust cooperative spectrum sensing with crowd of low end personal spectrum sensor and proposed a robust spectrum sensing scheme to eliminate adverse effect of abnormal data. Considering the energy consumption in channel sensing and switching, authors of [17] have proposed the conditions of sensing and accessing licensed channels for

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potential energy consumption reduction. In [18] it is shown that the number of spectrum sensing nodes and related global decision rule have major impacts on the accuracy of collaborative sensing results for CR network.

In most of the existing cooperative spectrum schemes, it is assumed, that all SUs are cooperative during spectrum sensing, and their detection results are sent to the central controller (fusion center) for making final decision [19,20]. However, sensing of spectrum in every time slot and sending the detected result to the fusion center consumes a certain amount of energy and time, which can be alternatively used for data transmission. To achieve maximum throughput, it is not optimal to sense the spectrum in every time slot by every SUs. Again, SUs, those are mostly unregulated users, may be selfish and may not contribute towards common objective. They may take advantage of others' sensing outcomes and reserve their timeslots and power for their own data transmission only, hoping for higher throughput. On the contrary, if no SU is participating in spectrum sensing then interference and data collision to PU is almost obvious. This will lead to decrement of throughput. Hence, it is substantial to explore the dynamic and co-operative behavior of such selfish user in cooperative atmosphere while enhancing the system performance all together.

In this paper, SUs' cooperative spectrum sensing strategy [21] is analyzed, while optimizing overall throughput of individual users. If very few or no SUs are cooperating in sensing of spectrum, then it lend to high false alarm probability, resulting low throughput. Again, when all SUs are cooperating, a lot of channel bandwidth is utilized for sensing, provides low throughput to individual SUs. Therefore, it is important for each SU to dynamically regulate its strategy of cooperation according to the knowledge obtained from strategic interaction with other SUs. The optimal strategy, to maximize throughput, in different RF environment and system configuration, is verified by MATLAB simulation.

2. System model

2.1. Cognitive radio network

For analysis, a cognitive radio network with one PU and K number of SUs, has been considered, as shown in Fig. 1. The PU has utmost priority to access the channel for transmission. While, SUs may access the channel only when it is not being used by PU or at least preserving the quality of service for PU. SUs sense the channel to check its availability and to share the result through narrow band signaling channel. SUs are considered to be working in half duplex mode, which implies they cannot execute spectrum sensing and data transmission simultaneously.

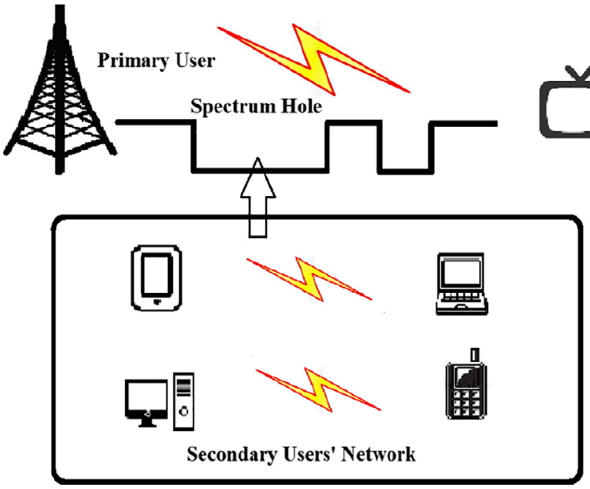

Fig. 1. System model.

2.2. Channel sensing

Two hypothesis, H_1 and H_0, representing presence and absence of the PU, respectively, on the sensed channel. Let $x(t)$ is the received signal by the SU, under H_1 and H_0, can be expressed as

$$x(t) = \begin{cases} g\ s(t) + n(t); & for\ H_1 \\ n(t); & for\ H_0 \end{cases} \tag{1}$$

g denotes the channel gain from PU's transmitter to SU's receiver; $s(t)$ is representing transmitted signal from PU; which is independent and identically distributed (i.i.d) random process with zero mean and σ^2 variance; and $n(t)$ is Additive White Gaussian Noise (AWGN) with zero mean, and variance σ_n^2 and independent of transmitted signal $s(t)$. Considering, energy detection is being adopted by all SUs as a detection technique in which energy of N samples of $x(t)$ are summed in a single time interval, i.e.

$$X(t) = \frac{1}{N}\sum_{t=1}^{N} |x(t)|^2 \tag{2}$$

SU, therefore, compare X with a predefined threshold value X_{th} to determine the existence of PU,

(i) $X < X_{th}$; The SU detects PU is absent.
(ii) $X > X_{th}$; The SU detects PU is present.

Spectrum sensing performance is measured by two probabilities. Probability of detection P_D and probability of false alarm P_F. Probability of detecting the transmission of PU when actually PU is transmitting, i.e. under the hypothesis H_1, is known as probability of detection. Probability of false alarm P_F is the probability of detecting the transmission of PU when PU is not transmitting, i.e. under hypothesis H_0. Higher P_D guarantees, better protection of PU from the interference with SUs, whereas, lower P_F ensures, higher spectrum opportunity for SUs.

Probability of false alarm is given by [9]

$$P_F(X_{th}) = \frac{1}{2}erfc\left(\left(\frac{X_{th}}{\sigma_n^2}-1\right)\sqrt{\frac{N}{2}}\right) \tag{3}$$

Similarly probability of detection is represented by [9,22–27].

$$P_D(X_{th}) = \frac{1}{2}erfc\left(\left(\frac{X_{th}}{\sigma_n^2}-SNR-1\right)\sqrt{\frac{N}{2(SNR+1)}}\right) \tag{4}$$

SNR denotes the received signal to noise ratio of the PU signal, under the hypothesis H_1 and $erfc(.)$ is the complementary error function, i.e. $erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^{\infty} e^{-t^2}dt$.

2.3. Illustration of Throughput of Secondary Users

Let's denote the sampling frequency and duration of frame by f_s and T, respectively. Sensing duration is considered as $T_s(N) = \frac{N}{f_s}$. SUs, which are participating in spectrum sensing, has to spent $T_s(N)$ amount of time for sensing out of total frame duration T. Sensing duration $T_s(N)$ is considered as cost of sensing, which is not imposed on nonparticipating SUs. Therefore, after sensing, the remaining time i.e. $T-T_s(N)$, can be mentioned as free slot for data transmission. Considering full utilization of the free slot, the average throughput of the SU is under the hypothesis H_0,

$$R_{H_0}(N) = \frac{T-T_s(N)}{T}(1-P_F)r_{H_0} \tag{5}$$

r_{H_0} is the data rate of SUs, when PU is not transmitting i.e. under hypothesis H_0. When PU is actually present, but not detected by SU, then the average throughput of the SUs is,