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Short communication

SU throughput enhancement in a decision fusion based cooperative sensing system

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ABSTRACT

Wireless communication systems primarily depend on the availability of bandwidth. Cognitive radio has been realized as an effective means to maximize the bandwidth for internet and other communication applications. Multiple cognitive radios perform spectrum sensing in cooperation to mitigate the effects of fading. A specific number of cooperating cognitive radio users are responsible to form the decision at the fusion center for spectrum occupancy and is called the global decision threshold. In this letter, we find the global threshold which maximizes the throughput of the cognitive radio users while keeping a constraint on the interference to the licensed primary user. It is observed that for every interference value below the constraint, the throughput of the cognitive radio users maximizes at a particular value of the global decision threshold.

1. Introduction

The constantly growing demand for the frequency spectrum has resulted in the development of Cognitive Radio (CR) based spectrum sensing systems. The secondary user (SU) senses the primary user (PU) band with the help of CR technology [1–4]. If the PU band is found vacant, it can be used by the SUs. However, there are certain issues in CR based spectrum sensing. One major problem is the hidden terminal problem, which arises because of obstacles obstructing the path of the PU signal, resulting into a wrong detection by the SU [5]. To counter this issue, more than one SUs may cooperatively sense the PU spectrum. The process is called cooperative spectrum sensing (CSS) [6]. CSS enables the detection process to benefit from the diversity in the environmental space. At a given instant in an area, one cooperating CR may be in deep fade while the other may be having a good channel condition. The detection process can rely on the latter for robustness.

CSS can be performed in a centralized as well as decentralized manner [6–12]. Centralized CSS systems are based on the fusion while decentralized CSS systems on the sharing of the SU energy data or decisions. The focus of this paper is on the centralized decision fusion CSS systems. In these systems, individual SU decisions are made by comparing the received statistic to the local thresholds. These individual decisions are fused at the fusion center (FC) and compared to a global threshold to form the decision about the spectrum occupancy. In the landmark paper [13], the authors found the particular values of global decision thresholds where the *total error rate* was minimum over different values of individual threshold. In this paper, we evaluate the system in [13] for maximization of the SU throughput. We evaluate different SU threshold values over the values of the interference to the PUs. We aim to maximize the SU throughput while keeping a constraint on its interference to the PU. For different values of the interference below the constraint, the throughput values are obtained over different global threshold values. We show that when the SU throughput maximization is concerned, the optimal global threshold is different from that obtained with for error minimization in [13].

The rest part of the paper is as follows: Section 2 presents the system model under consideration. In Section 3, the expressions for throughput and interference have been derived. Section 4 presents the problem formulation and in Section 5, the algorithm for solving it has been presented and the experimental results are shown. Finally in Section 6, the conclusions have been drawn for the work.

2. System model

Consider a CSS system with K cooperating SUs, as shown in Fig. 1. Let $y_i(k)$ is the signal received at the ith SU from the PU band. Depending on the absence and the presence of the PU, the hypotheses H_0 and H_1 are formulated as [3],

$$y_i(k) = \begin{cases} h_i x(k) + w(k) & H_0 \\ w(k) & H_1 \end{cases} \tag{1}$$

where $x(k)$ represents the PU transmitted signal, $w(k)$ is an AWGN

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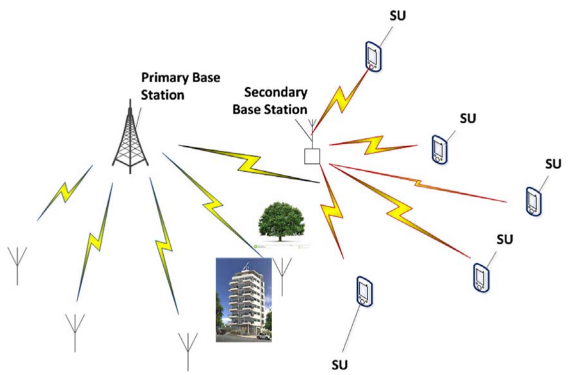

Fig. 1. Cooperative spectrum sensing.

sample, h is fading channel coefficient. Since we have considered slow fading here, h will remain constant throughout the sensing period. The SUs use the energy detection method to make their individual decisions. The individual SU energy (IE_i) of the incoming signal from the licensed band at the ith SU is calculated as [14],

$$IE_i = \frac{1}{N}\sum_{k=1}^{N} |y_i(k)|^2 \tag{2}$$

where N is the number of samples in which the sensing time is divided.

Each of the cooperating SUs make local decisions regarding spectrum occupancy by comparing the calculated energy to a predetermined threshold (τ) as,

$$IE_i\begin{cases}\geqslant \tau \; L_{d_i} = 1\\ <\tau \; L_{d_i} = 0\end{cases} \tag{3}$$

where L_{d_i} is the local decision of the ith SU having value 1 when the PU is present and 0 when it is absent.

$x(k)$ in (1) is assumed to be BPSK modulated. Hence, under both the hypotheses, the received signal $y(k)$ will be Gaussian. The number of samples (N) over which sensing process is carried out is assumed to be large. Therefore, $y(k)$ will approximately follow the Gaussian distribution with means and variances $(\gamma_i + 1)\sigma_w^2$ and $\frac{2}{N}(2\gamma_i + 1)\sigma_w^4$ under H_1, and σ_w^2 and $\frac{2}{N}\sigma_w^4$ under H_0 respectively, where, σ_w^2 is the AWGN variance and γ_i is the instantaneous SNR of the ith SU.

Considering the parameters derived above, the individual SUs P_{f_i} and P_{m_i} are obtained as,

$$P_{f_i} = Q\left(\sqrt{\frac{N}{2}}\left(\frac{\tau}{\sigma_w^2}-1\right)\right) \tag{4}$$

$$P_{m_i} = 1-Q\left(\sqrt{\frac{N}{2}}\left(\frac{\tau-(\gamma_i+1)\sigma_w^2}{\sqrt{(2\gamma_i+1)\sigma_w^4}}\right)\right) \tag{5}$$

where $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty \exp\left(\frac{-u^2}{2}\right)du$. The calculations of P_{f_i} and P_{m_i} have been shown in Appendix A and B. The individual local decisions are sent to the FC. The FC combines the local decisions and forms a global decision (G_d). G_d is made by the following expression,

$$\sum_{i=1}^{K} L_{d_i}\begin{cases}\geqslant D_t \quad G_d \text{ favours } H_1\\ <D_t \quad G_d \text{ favours } H_0\end{cases} \tag{6}$$

where D_t is the discrete threshold deciding the hypothesis G_d must agree with. Various methods to form the global decision may result from the different values of D_t. However, the significant schemes are: The AND rule, the OR rule, the 'n out of K' rule and the Majority rule. The AND rule makes $D_t = K$, which means, G_d favours H_1 only when all the cooperating SUs give positive decisions about spectrum occupancy. For the OR rule, $D_t = 1$, which means if even one SU decides the spectrum to be occupied, G_d goes in the favour of H_1. The 'n out of K' rule anticipates a prior value 'n' for D_t between 1 and K. The sum of the local decisions must be greater than n. The majority rule makes $n = \left\lceil \frac{K}{2} \right\rceil$. A general assumption as made in [15,13] to be noted is, the SUs are located close to each other compared to their distances from the PU. Therefore, the path through which the PU signal travels to each of them plausibly experiences similar pathloss. Hence we assume the instantaneous SNRs to be equal for all the SUs. Let $\gamma_1 = \gamma_2 = \ldots = \gamma_K = \gamma$. We make an assumption that the individual thresholds are equal. This brings us to a conclusion that all the cooperating users will have equal P_f and P_m.

Our work mainly focuses on the n out of K scheme. We aim to find the optimal value of n which maximizes SU throughput while keeping its interference to the PU under a constraint. Before proceeding, for the sake of completeness, the 'n out of K' scheme has been briefed about.

For the n out of K scheme, (6) becomes,

$$\sum_{i=1}^{K} L_{d_i}\begin{cases}\geqslant n \quad G_d \text{ favours } H_1\\ <n \quad G_d \text{ favours } H_0\end{cases} \tag{7}$$

As told above, the different SUs are sending binary '1's and '0's to the FC indicating H_1 and H_0. A positive global decision about spectrum occupancy is made when the sum of the binary decisions is greater than 'n'. Therefore, the probability of false alarm ($P_{f_{FC}}$) and miss detection (P_{mFC}) at the FC will be given as,

$$P_{f_{FC}}(n) = \sum_{j=n}^{K}\binom{K}{j}P_f^j(1-P_f)^{K-j} \tag{8}$$

and

$$P_{mFC}(n) = 1-\sum_{j=n}^{K}\binom{K}{j}P_d^j(1-P_d)^{K-j} \tag{9}$$

3. SU Throughput and Interference to the PU

3.1. SU system throughput analysis

Once a PU band is found unoccupied, it is allotted to an SU. The SU transmitter then transmits information to the SU receiver. It would be reasonable to consider the Shannon capacity formula to calculate SU throughput. The effective throughput of the ith SU is [16],

$$Thpt(n) = \frac{T_1}{T+T_1}C_{0_i}(1-P_{f_{FC}}(n))P(H_0) \tag{10}$$

where T and T_1 are the sensing and transmission times for the SU which together make a time frame allotted to the SU ($T + T_1$), C_{0_i} is the capacity of the SU channel under the hypothesis H_0, given as $C_{0_i} = \log_2(1 + |h_i|^2\gamma_{\sec})$,$h_i$ is the channel coefficient between the ith SU transmitter and receiver and N_0 is the AWGN power spectral density. The transmission time is likely to be more than the coherence time of h_i [16]. For calculations, one needs to calculate the average throughput. It is given by,

$$\overline{Thpt(n)} = \frac{T_1}{T+T_1}\overline{C_{0_i}}(1-P_{f_{FC}}(n))P(H_0) \tag{11}$$

where $\overline{C_{0_i}}$ is the average capacity given as, $\overline{C_{0_i}} = \int_0^\infty C_{0_i}f(h_i)dh_i$. Assuming h_i to follow Rayleigh distribution, $\overline{C_{0_i}}$ comes out to be,

$$\overline{C_{0_i}} = e^{1/\gamma_{\sec}}E_i\left(-\frac{1}{\gamma_{\sec}}\right)\frac{1}{\log 2} \tag{12}$$

where $E_i(x)$ is the exponential integral given by, $E_i(x) = -\int_{-x}^\infty \frac{e^{-t}}{t}dt$.

3.2. Characterization of interference to the PU

The individual binary decisions are sent to the FC. Then the FC makes a global decision regarding the spectrum occupancy. SUs cause