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Deflection coefficient maximization criterion based optimal cooperative spectrum sensing

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Abstract

This paper proposes an optimal cooperative spectrum sensing scheme, based on the criterion of deflection coefficient maximization of the global decision statistic. Multiple cooperative secondary users serve in the cognitive radio network to provide space diversity for spectrum sensing. After the fusion center acquires the optimal fusion weights, an optimal global threshold setting strategy is utilized to obtain the final global decision. Since the proposed optimal cooperative sensing scheme requires precise estimations of primary user signal strengths and the noise variances at different cooperative secondary users, a recursive estimate algorithm is also proposed. Simulations illustrate the proposed optimal soft fusion scheme can significantly improve the spectrum sensing performance and outperform the conventional maximal-ratio combining and equal gain combining schemes. The recursive estimate algorithm can effectively approach the ideal performance of the proposed sensing scheme.

Keywords: Deflection coefficient maximization; Energy detection; Optimal soft fusion; Cooperative spectrum sensing; Cognitive radio

1. Introduction

Cognitive radio (CR) has been proposed in recent years as a promising paradigm for exploiting the precious spectrum opportunities, which are wasted by the current fixed spectrum allocation scheme, to solve the spectrum scarcity problem in nowadays [1,2]. Being inherently lower priority or secondary users (SU), the fundamental requirement for CR is to avoid interference to the primary users (PU) in the vicinity. In order to detect the PU signal with unknown location, structure and strength, energy detection (ED) serves as the optimal spectrum sensing scheme when the detector only knows the power of the received signal. Moreover, ED is also the most commonly used strategy in spectrum sensing due to its implementation simplicity [3,4]. However, there are several factors that prevent the energy detector from operating in a reliable manner, such as multipath fading/shadowing and noise power fluctuating [5,6]. These factors suggest the necessity of secondary users' cooperation in the CR networks [7–12].

In a centralized user cooperation scenario, several deflection coefficient (DC) based soft fusion algorithms have been proposed in the literature to improve the overall sensing performance in the CR network. In [9], a soft fusion solution is obtained by tackling the problem of maximizing the modified deflection coefficient (MDC). Based on the Rayleigh–Ritz inequality, this solution is actually a maximum eigenvector based soft fusion scheme. In [10], a linear-quadratic fusion strategy is proposed, on the basis of deflection criterion, to study its performance in correlated log-normal shadowing environments. Therein, the conventional ED sensing scheme has been rebuilt by introducing the covariance matrix of the received signal into the sensing statistic. In [11], an optimal soft fusion weight vector is derived in a likelihood ratio test. It is thereby proved to be a

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conventional maximal ratio combination (MRC) scheme. In [12], a blindly combined energy detection (BCED) for spectrum sensing is proposed. The blind combining weights are derived based on the covariance matrix of the signal samples received by multiple antennas of the fusion center (FC). Assuming the signa-to-noise ratios (SNR) of the received PU signals at the cooperative SUs are known, the proposed scheme in [9] is a special case of the BCED.

In this paper, an ED based optimal cooperative spectrum sensing scheme is developed, based on the optimality criterion of deflection coefficient maximization (DCM) of the global test statistic at the FC. The DCM based cooperative spectrum sensing scheme is categorized into the normal DCM (NDCM) soft fusion and the modified DCM (MDCM) one. We prove that the NDCM and MDCM based soft fusions have the same theoretical performance in cooperative spectrum sensing. To implement the proposed optimal sensing scheme, an optimal global threshold setting method and a simple yet effective recursive estimate algorithm are also proposed. Using this estimate algorithm, NDCM and MDCM only have trivial performance difference in practice. Analysis and simulations verify the superior performance of our proposed cooperative spectrum sensing scheme, compared to the conventional maximal-ratio combining (MRC) and equal gain combining (EGC) schemes.

The rest of the paper is organized as follows. In Section 2, the system model of spectrum sensing observation relaying and energy measuring is given. In Section 3, the DCM based cooperative spectrum sensing is investigated with two different fusion methods, namely the NCDM and MDCM. Implementation of the DCM based cooperative spectrum sensing scheme is then presented in Section 4. Conclusions are finally given in Section 5.

2. System model

2.1. Spectrum sensing observation relaying

We consider that M cooperative SUs (denoted as $\{R_i\}_{i=1}^{M}$) are deployed over a certain geographical area of the CR network by some upper layer algorithms and they simply serve as relays in the network to provide space diversity.

In the first phase, the signal received at the i-th relay R_i is

$$x_i(k) = \begin{cases} n_i(k), & \mathscr{H}_0, k \in \{1, 2, \ldots, K\}, \\ \sqrt{E_{PU}} h_i s(k) + n_i(k), & \mathscr{H}_1, i \in \{1, 2, \ldots, M\}, \end{cases} \tag{1}$$

where $s(k)$ is the transmitted signal of the PU transmitter at time k with unit power, $\sqrt{E_{PU}}$ is the amplitude of the PU signal yielding a transmitting power of E_{PU}, and h_i is the channel gain between the PU and R_i, which accommodates the effects of channel shadowing, channel loss and fading, etc. $n_i(k)$ is the complex additive white Gaussian noise (AWGN) with zero mean and variance σ_i^2, and it is assumed that $n_i(k)$ and $s(k)$ are mutually independent. $\mathscr{H}_0$ and $\mathscr{H}_1$ are the hypotheses of the PU signal being absent and present, respectively. K is the time-bandwidth product $2T_S W$, where T_S is the effective spectrum sensing interval and W is the bandwidth of the licensed spectrum of interest.

Upon receiving signals in the first phase, each relay will simply acts in an amplify-and-forward (AAF) manner, and the signal received by the FC from R_i is

$$\begin{aligned} y_i(k) &= \sqrt{E_i}\bar{h}_i x_i(k) + n_{\mathrm{FC}}(k), \\ &= \begin{cases} \sqrt{E_i}\bar{h}_i n_i(k) + n_{\mathrm{FC}}(k), & \mathscr{H}_0, \\ \sqrt{E_{PU}E_i} h_i \bar{h}_i s(k) + \tilde{n}_{\mathrm{FC},i}(k), & \mathscr{H}_1, \end{cases} \end{aligned} \tag{2}$$

where $\bar{h}_i$ is the channel gain between the FC and R_i, $n_{\mathrm{FC}}(k)$ is the complex AWGN noise at the FC with zero mean and variance σ_{FC}^2, and E_i is the transmit power of R_i. Here, E_i has two physical meanings. First, it represents the supplied power that R_i can provide, for instance, in a battery-supported scenario; second, it functions as an adjustable parameter that can be controlled by the FC to optimize the power allocation in the CR network [13].

As for the noise and signal components at the FC, again, it is assumed that:

(1) $n_{\mathrm{FC}}(k)$ is independent with both $n_i(k)$ and $s(k)$;
(2) $n_{\mathrm{FC}}(k)$ is statistically the same for each of the relays;
(3) the individual sensing observations are relayed to the FC in a space orthogonal manner that the FC can easily discern the M observations captured at different R_i.

Consequently, the equivalent noise variance of $\tilde{n}_{\mathrm{FC},i}(k)$ is

$$\tilde{\sigma}_{\mathrm{FC},i}^2 = E_i |\bar{h}_i|^2 \sigma_i^2 + \sigma_{\mathrm{FC}}^2, \quad i \in \{1, 2, \ldots, M\}. \tag{3}$$

We can now write the received signals by the FC at time k in a more compact form

$$\mathbf{y}(k) = \begin{cases} \mathbf{\Pi}_0 \times \mathbf{n}(k) + n_{\mathrm{FC}}(k)\mathbf{1}, & \mathscr{H}_0, \\ \mathbf{\Pi}_1 \times s(k)\mathbf{1} + \tilde{\mathbf{n}}_{\mathrm{FC}}(k), & \mathscr{H}_1, \end{cases} \tag{4}$$

where the signals $\mathbf{y}(k) = [y_1(k), y_2(k), \ldots, y_M(k)]^T$ are received by the FC, $\mathbf{n}(k) = [n_1(k), n_2(k), \ldots, n_M(k)]^T$ are the noise components at the M cooperative relays, $\tilde{\mathbf{n}}_{\mathrm{FC}}(k) = [\tilde{n}_{\mathrm{FC},1}(k), \tilde{n}_{\mathrm{FC},2}(k), \ldots, \tilde{n}_{\mathrm{FC},M}(k)]^T$ are the equivalently combined M noise components at the FC, and $\mathbf{1}$ is the column vector of all ones. $\mathbf{\Pi}_0$ and $\mathbf{\Pi}_1$ are diagonal matrices with $\boldsymbol{\pi}_0 = [\sqrt{E_1}\bar{h}_1, \sqrt{E_2}\bar{h}_2, \ldots, \sqrt{E_M}\bar{h}_M]^T$ and $\boldsymbol{\pi}_1 = [\sqrt{E_{PU}E_1}h_1\bar{h}_1, \sqrt{E_{PU}E_2}h_2\bar{h}_2, \ldots, \sqrt{E_{PU}E_M}h_M\bar{h}_M]^T$ on their diagonals, respectively. The aggregate spectrum sensing observations at the FC are hence $\mathbf{Y} = [\mathbf{y}(1), \mathbf{y}(2), \ldots, \mathbf{y}(K)]^T$.

2.2. Energy measuring and soft fusing

Soft fusion of the collected sensing observations is carried out at the FC. The FC first measures the received signal