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Optimal soft combination for multiple antenna energy detection under primary user emulation attacks

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ABSTRACT

One of common threats imposed to the cognitive radio (CR) network is primary user emulation attack (PUEA), where some *malicious* users try to mimic the primary signal and deceive secondary users to prevent them from accessing the vacant frequency. Here, we propose a cooperative spectrum sensing scheme based on energy detection for CR networks in the presence of multiple *smart* PUEAs with spectrum sensing capability. In particular, we assume that the CR receiver has a number of L antennas and the CR transmitter sends combined information to the fusion center using beamforming with a single antenna. Soft combination of the observed energies from different CR users is investigated. By employing the Neyman–Pearson criterion, an optimal soft combination scheme is designed to maximize the cognitive signal-to-interference-plus-noise ratio (CSINR) for a given false alarm probability. Comparative simulation results validate the superiority of our proposed method in terms of detection accuracy compared to conventional methods.

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1. Introduction

Cognitive radio (CR) technology has been proposed as an approach for improving spectrum efficiency by allowing dynamic spectrum access of vacant bands through spectrum sensing process [1]. Spectrum sensing is a fundamental functionality of CR systems where CR or secondary users can intelligently monitor the frequency spectrum and detect vacant channels to use [2]. Spectrum sensing can basically be classified into non-cooperative sensing, cooperative sensing and interference-based sensing. Cooperative spectrum sensing is well known to be an effective method to improve the detection performance [2].

In cooperative spectrum sensing, CR users can share their information for making a combined decision about the presence or absence of the primary user. In [3], a hard combination scheme is considered that a fusion center (FC) made final decision about presence or absence of primary user based on combined CR binary sensing results with OR fusion rule. In [4], an optimal soft combination scheme, similar to maximal ratio combining (MRC), is proposed to maximize the probability of detection for a given probability of false alarm. It is shown that soft combination scheme, even based on a simple equal gain combination (EGC), provides a higher performance once compared to conventional hard combination.

Multiple input multiple output (MIMO) [5] signaling that provides significant performance improvement, can be utilized in order to combat the co-channel interference by enhancing the signal-to-interference-plus-noise ratio (SINR) in wireless systems via techniques such as beamforming that exploits channel knowledge at the transmitter. More precisely, beamforming maximizes the SINR at the receiver by transmitting in the direction of the eigenvector corresponding to the largest eigenvalue of the channel [6]. In [7–9], the authors consider that CR users are equipped with multiple independent antennas, where in [8,9], beamforming is applied to reduce the interference and noise of the CR network.

As the CR technology becomes mature, security issues pose new challenges to the implementation of this emerging transmission technology. One entire new suite of threats in the security issues of CR networks is referred to as primary user emulation attack (PUEA), which is first identified in [10]. PUEA in fact, mimics the primary user's signal with the aim of competing the well-behaving CR users. A variety of research efforts have been directed on detection and defense schemes of CR under PUEA, as explained in what follows. In [11], an analytical model for the probability of successful PUEA based on energy detection was proposed and a lower bound on the probability of a successful PUEA is obtained using Markov inequality. In [12], the authors proposed a received signal strength (RSS)-based defense technique to operate against PUEA, where

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attackers can be identified by comparing the received primary signal's power and the suspect attacker. In [13], Wald's sequential probability ratio test (WSPRT) was presented to detect PUEA based on the received signal power whereas in [14], the authors proposed a transmitter verification localization-based scheme to detect PUEA. In [15], the authors have considered a cooperative spectrum sensing scheme in the presence of PUEA, but the PUEA is assumed to be always present, which is not a practical assumption. To overcome this weakness, the authors in [16,17] have considered a smart PUEA in which malicious users choose their attack strategy in a smart manner so as to impose a more destructive effect. In [17], we have recently derived optimal parameters involved in cooperative energy detection spectrum sensing, such as voting rule, number of samples used for making the decision and the detection threshold so as to minimize the probability of error when energy detection is corrupted by malicious users attack. Also, in [18], we have recently derived optimal strategy for cooperative energy detection spectrum sensing based on the Neyman–Pearson criterion with the aim of maximizing the channel throughput. In [19], a single antenna CR network is likely to face threats incoming from multiple attackers that are not always present during the primary transmission time slot.

In this paper, we consider *multiple smart* malicious users and investigate how the performance of cooperative spectrum sensing is influenced by the presence of multiple PUEAs in the CR network. Based on Neyman–Pearson criterion, we derive an optimal soft combining scheme to be used among different CR user observations at the FC so as to maximize the received signal power to the interference plus noise as cognitive signal-to-interference-plus-noise ratio (CSINR) for a given probability of false alarm. Our proposed soft combining scheme is also extended to the case of multiple input single output (MISO), where the CR receivers are using multiple antennas. Moreover, our scheme mitigates the impact of malicious users that degrade the CR user sensing performance.

The rest of this paper is organized as follows. Our considered system model is described in Section 2. In Section 3, we formulate our cooperative spectrum sensing in the presence of multiple smart PUEAs. In Section 4, optimal soft combining scheme for cooperative spectrum sensing in the presence of multiple smart PUEAs is described. Discussion along with comparative simulation results and complexity analysis is presented in Section 5, and finally, Section 6 draws our conclusions.

2. System model

We consider cooperative spectrum sensing in a centralized CR network composed of N CR users and a FC in the presence of Q smart PUEAs, as shown in Fig. 1. Each CR receiver is equipped with L antennas whereas the CR transmitter is equipped with a single antenna. This assumption is motivated by the fact that power consumption and complexity should be kept as low as possible in distributed CR terminals for practical considerations as in [7,9]. Similarly, the primary user and each attacker has a single antenna. In this network, each CR user sends its combined sensing information from L receiver antennas multiplied by a beamforming coefficient to the FC that makes a global decision about the presence or absence of primary signal. The received signal at the CR receiver during the kth time-slot in the circumstance of PUEAs writes:

$$\mathbf{r}_i^k = \upsilon\sqrt{P_P}\mathbf{h}_{\mathbf{P},i}^k x_P^k + \omega\sum_{m=1}^{Q}\sqrt{P_E}\mathbf{h}_{\mathbf{E}m,i}^k x_{Em}^k + \mathbf{n}_i^k, \tag{1}$$

where x_P^k and x_{Em}^k are the signal transmitted by primary user and the mth PUEA with transmitting power P_P and P_E, respectively.

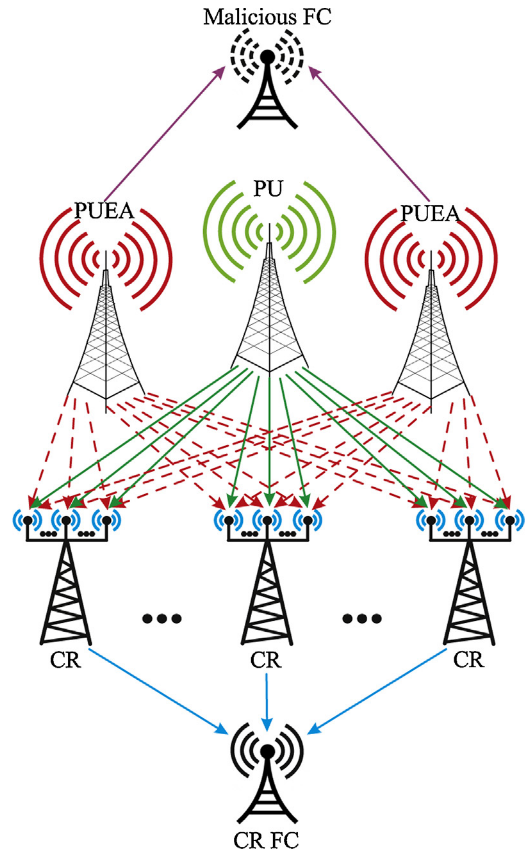

Fig. 1. Considered system model for the CR network.

Note that $\mathbf{h}_{\mathbf{P},i}^k$ and $\mathbf{h}_{\mathbf{E}m,i}^k$ are the channel between the primary user and the ith CR receiver and between the mth PUEA and the ith CR receiver, which are assumed to follow a block fading channel model. $\mathbf{n}_i^k$ is the additive white Gaussian noise on the ith CR receiver with zero mean and variance σ_n^2. υ and ω are two binary indicators to specify the absence or presence of primary user and PUEA, respectively. Hypothesis $\mathcal{H}_1$ and $\mathcal{E}_1$ indicate the presence of primary user and PUEAs, and $\mathcal{H}_0$ and $\mathcal{E}_0$ implies their absence, to decide whether the channel is occupied or not by primary user and PUEAs. Hence, we would have the quad hypotheses, $\mathcal{S}_1 = \{\mathcal{H}_1, \mathcal{E}_1\}$, $\mathcal{S}_2 = \{\mathcal{H}_1, \mathcal{E}_0\}$, $\mathcal{S}_3 = \{\mathcal{H}_0, \mathcal{E}_1\}$ and $\mathcal{S}_4 = \{\mathcal{H}_0, \mathcal{E}_0\}$. Then, (1) can be rewritten as:

$$\mathbf{r}_i^k = \begin{cases} \sqrt{P_P}\mathbf{h}_{\mathbf{P},i}^k x_P^k + \sum_{m=1}^{Q}\sqrt{P_E}\mathbf{h}_{\mathbf{E}m,i}^k x_{Em}^k + \mathbf{n}_i^k, & \mathcal{S}_1 \\ \sqrt{P_P}\mathbf{h}_{\mathbf{P},i}^k x_P^k + \mathbf{n}_i^k, & \mathcal{S}_2 \\ \sum_{m=1}^{Q}\sqrt{P_E}\mathbf{h}_{\mathbf{E}m,i}^k x_{Em}^k + \mathbf{n}_i^k, & \mathcal{S}_3 \\ \mathbf{n}_i^k, & \mathcal{S}_4 \end{cases} \tag{2}$$

Let us denote the weight vector corresponding to the antennas of ith CR receiver to be $\mathbf{w}_{\mathbf{A},i}$, then the combined signal at each CR user is:

$$y_i^k = \mathbf{w}_{\mathbf{A},i}\mathbf{r}_i^k, \tag{3}$$

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