A Reliable Spectrum Sensing Strategy Based on Multiple-Antenna Technique

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Abstract. In this paper, we propose a *reliable spectrum sensing* strategy based on *multiple-antenna technique*, called RSS-MAT, to combat the channel uncertainties. We derive the closed-form expressions of the false alarm probability and detection probability for RSS-MAT. Finally, we present simulation results to validate our performance analysis. As expected, the simulation results show that RSS-MAT outperforms the spectrum sensing strategy with single antenna.

Introduction

Spectrum sensing is a fundamental task for cognitive radio (CR). Generally, there are three sensing methods widely used in application: matched filtering detection, cyclostationary feature detection and energy detection [1, 2, 3]. However, the performances of these methods will be severely degraded by the uncertainties in wireless environments [4]. The multiple-antenna technique is an effective method to combat the channel uncertainties [5]. In [6], the authors showed the benefit of spectrum sensing using the multiple-antenna technique.

In this paper, we propose a *reliable spectrum sensing* strategy based on *multiple-antenna technique*, referred to as RSS-MAT to mitigate the effects of channel uncertainties. In RSS-MAT, the power of the signal from primary user (PU) received at each antenna is independently compared with a predefined threshold. The received signals whose powers are no less than the threshold will be amplified and added together. Finally, the secondary user (SU) uses the resultant signal to make a final decision by energy detection. We give performance analysis for RSS-MAT and derive the closed-form expressions of the false alarm and detection probabilities. Finally, simulations are presented to show that RSS-MAT achieves better performance than the single-antenna based spectrum sensing.

System Model

We consider the CR system consists of a PU P and a SU S equipped with N antennas. The channels are modeled as independent Rayleigh fading. To improve the detection performance of S, RSS-MAT is proposed. Specifically, each antenna of S calculates the received power from P and compares it with a predefined threshold T_0. Next, S amplifies the received signals whose powers are no less than T_0. Then, the amplified signals are added together at S. Finally, S uses the resultant signal to make a final decision via energy detection.

Performance Analysis

We assume that P transmits signal x_P ($E\left\{\left|x_P\right|^2\right\}=1$) with power E_P. The signal to noise ratio (SNR) of E_P is denoted as γ_P. We let θ denote P's state, i.e., $\theta=0$ means that P is absent and $\theta=1$ means that P is present. Then, the signal received at the i th antenna is

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$$y_i = \theta\sqrt{E_P}h_i x_p + n_i \tag{1}$$

where h_i is the channel coefficient from P to the i th antenna and n_i is the additive white Gaussian noise (AWGN) with zero mean and variance σ_0 . Clearly, $Y_i = |y_i|^2$ follows an exponential distribution and its expected value is given as

$$\begin{cases} \lambda_{i0} = \sigma_0, H_0 \\ \lambda_{i1} = E_P\sigma_i + \sigma_0, H_1 \end{cases} \tag{2}$$

where H_0 (i.e., $\theta = 0$) and H_1 (i.e., $\theta = 1$) are two standard test hypotheses, and σ_i is the average gain of the channel h_i . According to energy detection, the false alarm and detection probabilities are

$$P_{if} = \Pr\{Y_i \geq T_i \mid H_0\} = \int_{T_i}^{\infty} \mathrm{e}^{-x/\lambda_{i0}} / \lambda_{i0} dx = \mathrm{e}^{-T_i/\lambda_{i0}} \tag{3}$$

$$P_{id} = \Pr\{Y_i \geq T_i \mid H_1\} = \int_{T_i}^{\infty} \mathrm{e}^{-x/\lambda_{i1}} / \lambda_{i1} dx = \mathrm{e}^{-T_i\lambda_{i1}} \tag{4}$$

where T_i is the power threshold. Assuming $P_{if} = \alpha$, we have $T_i = -\sigma_0 \ln(\alpha)$.

In RSS-MAT, the amplification factor is chosen as $\beta_i = E_i / (E_P\sigma_i + \sigma_0)$, where E_i is set by the i th antenna. The SNR of E_i is denoted as γ_i . The received signal after amplified and added together is

$$y_S = \sum_{i=1}^{N}\theta_i\sqrt{\beta_i}y_i = \theta\sum_{i=1}^{N}\theta_i\sqrt{\beta_i}\sqrt{E_P}h_i x_p + \sum_{i=1}^{N}\theta_i\sqrt{\beta_i}n_i \tag{5}$$

where θ_i denotes the estimated value of θ made at the i th antenna. In this case, the power $Y_S = |y_S|^2$ obeys an exponential distribution and its expected value is

$$\begin{cases} \lambda_0 = \sum_{i=1}^{N}\theta_i\beta_i\sigma_0, H_0 \\ \lambda_1 = \sum_{i=1}^{N}\theta_i\beta_i(E_P\sigma_i + \sigma_0), H_1 \end{cases} \tag{6}$$

Then, the false alarm and detection probabilities of RSS-MAT are respectively calculated as

$$P_f = \Pr\{Y_S \geq T_S \mid H_0\} = \sum_{j=1}^{2^N-1}\left\{\left(\prod_{i\in\Phi_j}\alpha\right)\left(\prod_{i\in\bar{\Phi}_j}(1-\alpha)\right)\mathrm{e}^{-T_S/\left(\sum_{i\in\bar{\Phi}_j}\beta_i\sigma_0\right)}\right\} \tag{7}$$

$$P_d = \Pr\{Y_S \geq T_S \mid H_1\} = \sum_{j=1}^{2^N-1}\left\{\left(\prod_{i\in\Phi_j}P_{id}\right)\left(\prod_{i\in\bar{\Phi}_j}(1-P_{id})\right)\mathrm{e}^{-T_S/\left[\sum_{i\in\bar{\Phi}_j}\beta_i(E_P\sigma_i+\sigma_0)\right]}\right\} \tag{8}$$

where T_S is power threshold used by S , Φ_j is the j th sub-collection of the set $\{1,\cdots,N\}$ and $\bar{\Phi}_j$ is its complementary set. Assuming $P_f = \alpha$, we have

$$T_S = P_f^{-1}(\alpha) \tag{12}$$

where P_f^{-1} is the inverse function of P_f.

Simulation Results

In this section, the false alarm probability α is set as 0.1. First, we consider the detection probability P_d versus the primary transmit SNR γ_P for RSS-MAT under $\sigma_i = 0.5$ and $\sigma_i = 1$ for $i = 1, 2, \cdots, N$, which are respectively illustrated in Fig. 1 and Fig. 2. Meanwhile, we choose $\gamma_i = 1$ for $i = 1, 2, \cdots, N$. In Fig. 1 and Fig. 2, we also plot P_d for the single-antenna (i.e., $N = 1$) strategy.

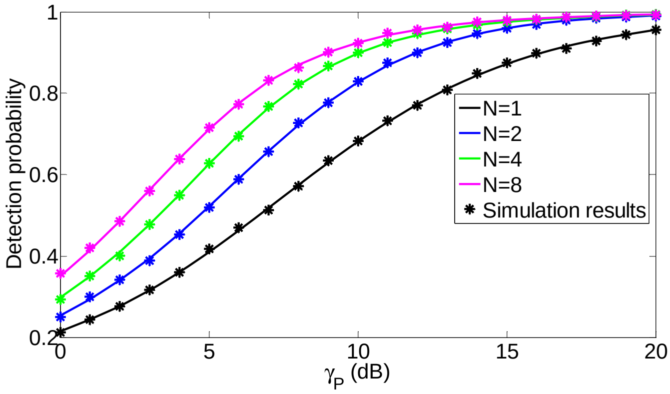

Fig. 1. P_d versus γ_P under $\sigma_i = 0.5$.

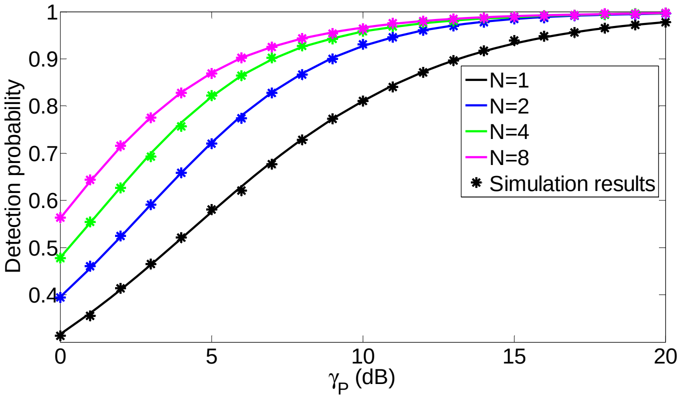

Fig. 2 P_d versus γ_P under $\sigma_i = 1$.

From Fig. 1 and Fig. 2, we can observe that RSS-MAT has higher detection probability than the single-antenna case. The detection probability of RSS-MAT increases with increasing γ_P. Besides, the detection performance of RSS-MAT can be improved by increasing the antenna number. Comparing Fig. 1 with Fig. 2, we also can see that better channel condition results in higher detection probability for RSS-MAT, i.e., the detection probability of RSS-MAT is higher under $\sigma_i = 1$ than under $\sigma_i = 0.5$.

Second, we depict P_d versus γ_i under $\sigma_i = 0.5$ and $\sigma_i = 1$ in Fig. 3 and Fig. 4, respectively, where we assume that $\gamma_P = 10$ dB. The simulation results also show that RSS-MAT has better detection performance than the single-antenna case. Besides, from Fig. 3 and Fig. 4, we know that increasing γ_i can not improve the detection performance of RSS-MAT significantly.

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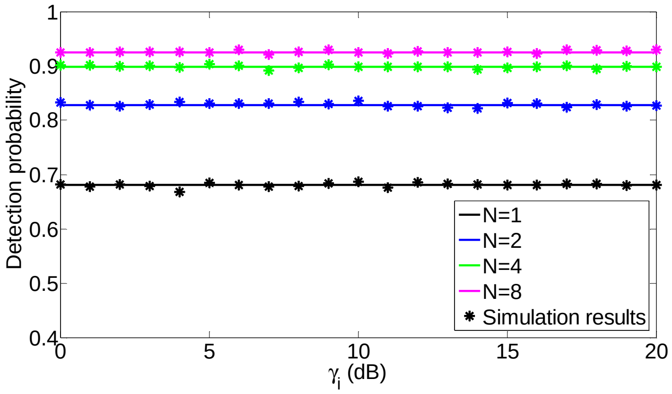

Fig. 3. P_d versus γ_i under $\sigma_i = 0.5$.

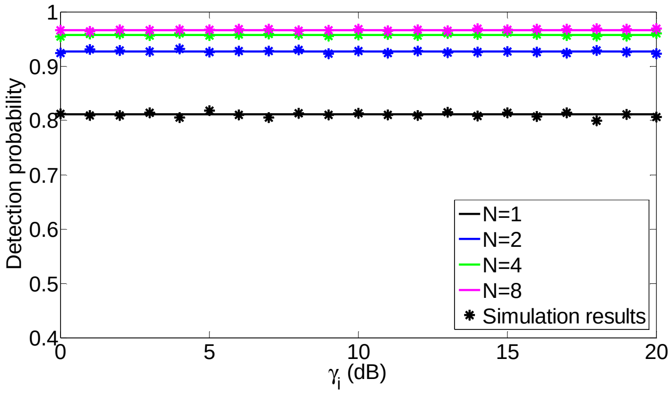

Fig. 4. P_d versus γ_i under $\sigma_i = 1$.

Summary

In this paper, we proposed a multiple-antenna based spectrum sensing strategy, called RSS-MAT, to combat the channel uncertainties. We derive the closed-form expressions of the false alarm and detection probabilities for both the RSS-MAT and single-antenna strategies. Finally, numerical and simulation results are presented to validate the effectiveness of RSS-MAT. It is shown that RSS-MAT can achieve better detection performance than the single-antenna case. In this end, since the proposed RSS-MAT strategy has low computational complexity, it can be easily applied in practice.

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