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Performance evolution of ED-based spectrum sensing in CR over Nakagami-m/shadowed fading channel with MRC reception

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ABSTRACT

Internet of things contains the hefty number of devices with diverse types of communication interfaces. Therefore, these devices act as a source of interference to the primary users in the absence of appropriate collision detection technique. Spectrum sensing is the important function of cognitive radio and energy detector is the most popular technique used for spectrum sensing. Detection of the availability of unused spectrum for the secondary user becomes difficult when the channel is affected by composite multipath/shadowed fading. In this paper, analytical expressions of average probability of detection and average area under the receiver operating characteristic over Nakagami-m/log-normal with maximum ratio combining diversity are derived using Gaussian-Hermite integration approximation. In addition, an optimized threshold has been incorporated to overcome the problem of spectrum sensing even at low signal-to-noise ratio. To verify the correctness of exact results and derived analytical expressions, Monte Carlo simulations are incorporated.

1. Introduction

Now a day, internet of things (IoTs) is one of the demanding technologies and is probable to be an indispensable fragment of the next generation 5G technology. IoT comprises number of devices interface to each other. Hence, without suitable detection technique, it is not possible to detect the primary user (PU) signal. Cognitive radio (CR) has emerged as a promising solution to the scarcity of the spectrum problem by exploiting the unused portions of spectrum in an opportunistic manner. Spectrum sensing (SS) is the basic functionality of CR, which monitors the spectrum bands at given time and geographical region. Among SS techniques, energy detector (ED) is the most popular methods addressed in the literature. Non-coherent detection is used in ED and its complexity is lower than other SS techniques [1].

In advance wireless communication systems (AWCS), the performance of ED with non-cooperative and cooperative sensing has been extensively studied in the presence of fading environments for single input single output (SISO) and multiple channel reception. The performance of ED with square law combining (SLC) and square law selection (SLS) over Nakagami-m has been studied [2]. Based on moment generating function (MGF), analytical expressions of the average probability of detection ($\overline{P_D}$) over Rician and Nakagmai-m channels at different diversity has been derived such as maximum ratio combining (MRC), selection combing (SC), equal gain combing (EGC) and SLC [3]. Under Nakagami-m channel with EGC receiver, performance of ED is investigated in terms of receiver operating characteristic (ROC) curve [4]. ED-based performance analysis and threshold optimization with SC over inverse-Gaussian (IG) channel has been discussed [5]. The analytical expressions of average area under the receiver operating characteristic (AUC) curve over Nakagami-m channel with MRC, SLC and SC has been derived [6]. Performance analysis of Wald distribution with SLC is investigated in [7].

Shadowing can considerably reduce the performance of ED in current practical AWCS. Hence, the combination of both multipath and shadowing fading is called composite multipath/shadowing fading channel that occur very frequently in most of the realistic wireless environments, degrade the performance of the channels. Shadowing is modeled by log-normal distribution [8,9]. The performance analysis of SS in CR over Rician/log-normal is studied [10]. In [11,12], log-normal is approximated by Gamma distribution and the performance of ED in K and generalized-K fading channels was discussed. Again log-normal can also be approximated by IG and performance analysis of ED is examined with different diversity [13]. The performance of ED over composite fading channel is measured with mixture Gamma distribution [14]. In order to sense the PUs very quickly, SUs are allocated into multiple clusters then the performance analysis of cooperative spectrum sensing

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(CSS) is examined for multipath/shadowed fading channel [15]. The analytical expressions of $\overline{P_D}$ and average AUC ($\overline{A}$) are derived for different diversity such as MRC, EGC and SC over Gamma/shadowed Rician channels and performances are measured in terms of complementary ROC curves and average complementary AUC curves [16].In fixed threshold method, threshold is fixed at a particular value so when the received signal power fluctuate, SUs are not able to detect the signal as well as it does not work at low signal-to-noise ratio (SNR), optimized threshold is used to overcome this problem. Minimizing the total probability of error is significant parameter to get optimized threshold for better spectrum sensing. Hence, threshold is varied in accordance with the fluctuation of received signal is called optimized threshold. Optimized threshold algorithm has been analyzed, it gave better results in comparison to the conventional one and provide trade-off between the probability of detection (P_D) and probability of false alarm (P_{FA}) [17,18]. The problem of optimized threshold parameter by minimizing the total probability of error for CSS has been consider for Rayleigh channel in [19]. By minimizing the probability of miss detection (P_{MD}) and P_{FA}, optimized threshold algorithm has been discussed [20,21]. Optimized double threshold (ODT) overcomes the problem of sensing failure for CSS. ODT is better in comparison to the conventional threshold, which provides better spectrum sensing even at very low SNR but with multiple EDs [22]. Optimized threshold obtained by minimizing the total probability of error with improved ED and SC is used at each detector [23,24]. The performance analysis and optimize threshold for CR based IoTs devices [25].

In this paper, we present an analytical expression of average probability of detection and average area under the receiver operating characteristic over composite NL fading channel with MRC diversity. MRC gives the best performance among the other diversity techniques. Furthermore, we have optimized the threshold parameter for detection of unknown signal for MRC diversity scheme by minimizing the total probability of error. A significant improvement in the probability of detection is demonstrated the use of optimized threshold parameter for all diversity branches.

The rest of the paper is organized as follow. System and channel model is discussed in Section 2. Energy detection with MRC diversity reception is described mathematically in Section 3. In Section 4, the optimization of threshold parameter is explained. Section 5 gives the results and discussion followed by conclusion in Section 6.

2. System and channel model

2.1. Energy detector

Consider a narrow band composite signal is detected, the received signal $x(t)$, which comprises either noise only or unknown deterministic signal and noise as shown in Fig. 1, can be represented as [1]

$$x(t) = \begin{cases} w(t); & H_0 \\ h\,s(t) + w(t); & H_1 \end{cases} \tag{1}$$

where $s(t)$ denotes unknown deterministic signal, h is the channel gain and $w(t)$ is an AWGN. Furthermore, in the detection of signal either signal is absent or signal is present and it is represented by the hypothesis called H_0, null hypothesis and H_1, alternate hypothesis respectively. In ED, first filter the signal, square it and integrate over the time interval T. The output of the integrator, Λ acts as test statistic that decides whether the received signal energy corresponds to noise energy $w(t)$ or energy of both $s(t)$ and $w(t)$. At the end of ED, Λ compares with the threshold (λ_{th}) and if $\Lambda < \lambda_{th}$, signal is absent otherwise present.

Under H_0, Λ follows a central chi-square distribution with $2d$ degrees of freedom. Similarly, under H_1, Λ follows a non-central chi-square distribution with $2d$ degrees of freedom and 2γ non-centrality parameter [1]. Thus, PDF of Λ can be written as

$$p_\Lambda(y/\gamma) = \begin{cases} \frac{1}{2^d\Gamma(d)} y^{d-1} e^{-y/2}; & H_0 \\ \frac{1}{2}\left(\frac{y}{2\gamma}\right)^{d-1/2} e^{-\left(\frac{y+2\gamma}{2}\right)} I_{d-1}(\sqrt{2y\gamma}); & H_1 \end{cases} \tag{2}$$

where $d = TW$ is the time-bandwidth product and W, bandwidth of the system, $\gamma = |g|^2 E_S^2/N_0\gamma$ is the received SNR with E_S be the signal energy and N_0 is the one-sided power spectral density (PSD). $I_q(.)$, q^{th} order modified Bessel function of first kind. For ED, with λ_{th} as the threshold of detection, the probability of false alarm (P_{FA}) and probability of detection (P_D) are defined [2] by Eqs. (3) and (4) respectively as

$$P_{FA}(\lambda_{th}) = P_r\left(\Lambda > \frac{\lambda_{th}}{H_0}\right) = \frac{\Gamma(d,\lambda_{th}/2)}{\Gamma(d)} \tag{3}$$

$$P_D(\gamma,\lambda_{th}) = P_r(\Lambda > \frac{\lambda_{th}}{H_1}) = Q_d(\sqrt{2\gamma},\sqrt{\lambda_{th}}) \tag{4}$$

$$P_{MD}(\gamma,\lambda_{th}) = 1 - P_D(\gamma,\lambda_{th}) \tag{4-a}$$

where $\Gamma(.,.)$ is the incomplete Gamma function, $\Gamma(.)$ is the Gamma function, $Q_d(.,.)$ is the d^{th} order generalized Marcum Q-function and P_{MD} is the probability of miss-detection. Generalized Marcum Q-function is defined as [26]

$$Q_p(\alpha,\psi) = 1/(\alpha^{p-1}) \int_\psi^\infty \tau^p \exp(-(\alpha^2 + \tau^2)/2) I_{p-1}(\alpha,\tau) d\tau \tag{5}$$

Alternative way to represent generalized Marcum Q-function is given in (4.74) of [8] as

$$Q_d(\sqrt{2\gamma},\sqrt{\lambda_{th}}) = \sum_{k=0}^{\infty} \exp(-\gamma)(\gamma^k/k!) \sum_{l=0}^{k+d-1} (\exp(-\lambda_{th}/2))((\lambda_{th}/2)^l/l!) \tag{6}$$

Eq. (6) can be re-written in (8.352–2) of [26] as

$$\begin{aligned} Q_d(\sqrt{2\gamma},\sqrt{\lambda_{th}}) &= \sum_{k=0}^{\infty} \exp(-\gamma) \frac{\gamma^k}{k!} \frac{\Gamma(k + d,\lambda_{th}/2)}{\Gamma(k + d)} \\ &= \exp(-\gamma) \sum_{k=0}^{\infty} \frac{\gamma^k}{k!} \frac{\Gamma(k + d,\lambda_{th}/2)}{\Gamma(k + d)} \end{aligned} \tag{7}$$

So, Eq. (4), can be written with the help of Eq. (7) as

$$P_D(\gamma,\lambda_{th}) = Q_d(\sqrt{2\gamma},\sqrt{\lambda_{th}}) \approx \sum_{k=0}^{\infty} \frac{\gamma^k}{k!} \frac{\Gamma(d + k,\lambda_{th}/2)}{\Gamma(d + k)} \exp(-\gamma) \tag{8}$$

2.2. Channel model

The composite PDF of received SNR is achieved by averaging the conditional PDF of Nakagami-m distribution over log-normal distribution. The conditional Nakagami-m distribution [8] is given by

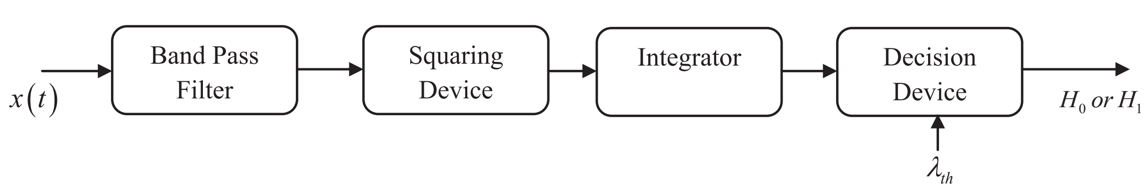

Fig. 1. Block diagram for the determination of test statistic for ED.