



# Detection Probability Analysis of Spectrum Sensing over Satellite Fading Channel

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**Abstract.** In this paper, we investigate spectrum sensing relying on multiple satellites, which can achieve global seamless spectrum sensing, due to the feature of wide coverage. We conceive a pair of satellite based spectrum sensing schemes, namely hard combination oriented energy detection based spectrum sensing (HC-EDSS) and semisoft-combination double-threshold oriented energy detection based spectrum sensing (SD-EDSS). In the HC-EDSS scheme, secondary users send their decision results to fusion center in order to get the final decision. By contrast, secondary users not only send their decision results, but also send some individual information to fusion center in the SD-EDSS scheme. We also derive the closed-form of the probability of detection over satellite fading channel. In our performance evaluations, the conceived HC-EDSS and SD-EDSS schemes outperform the conventional single user oriented energy detection based spectrum sensing (SU-EDSS) in terms of its probability of detection. Moreover, the SD-EDSS scheme achieves the best probability of detection among them, demonstrating the advantage of increasing the accuracy of spectrum sensing.

**Keywords:** Spectrum sensing · Satellite communication · Energy detection

## 1 Introduction

Satellite communications [1] is an outgrowth of modern technology to meet the demand of greater capacity and higher communication quality. It is suited to network which has wide coverage because it can overcome the problem of long distances and desolate terrains (desert, ocean, forest, etc.) [2]. For the remote and sparsely populated locations, satellites can actually provide communication access, which may be the cheapest solution in these cases [3]. However, As continuously increasing demand for

broadcast, multimedia and interactive services, the usable satellite spectrum is becoming scarce [4, 5]. Although the spectrum resources is so scarce, many of the licensed spectrum resources are still underutilized, which causes the waste of spectrum resources [6]. It is extremely urgent to improve the spectrum utilization in satellite communications.

In order to raise the spectrum utilization, many wireless communication theories and related technologies have been proposed, such as multi-antenna technology, adaptive technology, etc. Although these technologies have improved the spectrum efficiency to a certain extent, they are far from satisfying the growing demand for spectrum resources. Cognitive radio [7] technology can effectively solve the problem of low spectrum efficiency caused by fixed allocation strategy in satellite communication system. Spectrum sensing is part of cognitive radio, which consists of multi-node cooperative spectrum sensing and single-node spectrum sensing [8]. The aim of spectrum sensing is mainly to detect whether the primary user (PU) occupies a channel to prevent interference with the PU's communication [9]. There are many detection methods in spectrum sensing. Energy detection [10], which is simple and has the characteristics of not requiring priori information about the transmitted signal, is the most widely used spectrum sensing technology.

Although signal often transmits over fading channel in real life, most of existed works are based on non-fading channel [11]. In [12], the author analyses the performance of spectrum sensing system in Rician fading channel and Nakagami channel. In [13], a semisoft combination scheme based on local double-threshold decision has been proposed to improve the probability of detection. In [14], a novel spectrum sensing system is proposed to perform wideband spectrum sensing over fading channel. In [15], author proposed a simple land mobile satellite channel model for the convenience of calculation.

In this paper, the satellite channel is regarded as the Shadowed-Rician fading channel. Theoretical probability of detection under this channel is derived and compared with the simulated value. In addition, cooperative spectrum sensing is introduced in order to improve the probability of detection under Shadowed-Rician fading channel. The satellite performs as secondary user (SU) and sends the decision result to the information fusion center (FC). FC fuses all received information for global decision. In this paper, the SD-EDSS method is applied, which is also compared with some classic cooperative strategy.

The rest of this paper is organized as follows. In Sect. 2, energy detection has been reviewed. In Sect. 3, The system model for Shadowed-Rician fading channel is presented. The simulation results are shown in Sect. 4. Finally, The conclusions are given in Sect. 5.

## 2 System Model

As we can see in Fig. 1, there are  $N$  satellite as SUs in the system model. SUs detect the signal from PU and then send their decision results to FC. FC fuses all the local decision results and makes decision about whether the signal exists.

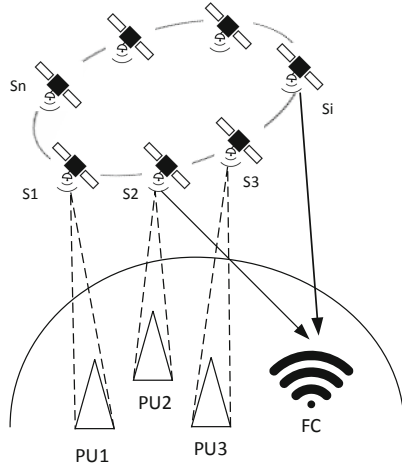


Fig. 1. System model

The aim of spectrum sensing is to determine whether a licensed band is used by the PU or not. The problem can be formulated as [12].

$$x(t) = \begin{cases} n(t) & H_0 \\ hs(t) + n(t) & H_1 \end{cases}, \tag{1}$$

where  $n(t)$  is the additional white Gaussian noise (AWGN),  $s(t)$  represents the signal from PU,  $h$  is the channel gain. Both  $H_1$  and  $H_0$  are the two states of signal, presence or absence.

In local detection, energy detection is used. The essence of energy detection is the accumulation of received signal power on spectrum band, and the accumulated energy is compared with the predefined threshold. The principle of energy detection is shown in Fig. 2.

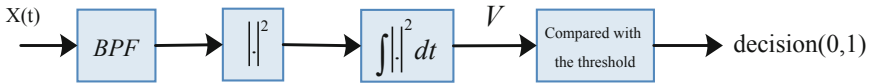


Fig. 2. The principle of energy detection

The energy received by SU can be expressed as  $Y = \sum_{i=1}^{2u} x^2(i)$  and  $Y$  obeys the chi-square distribution as

$$Y \sim \begin{cases} x_{2u}^2 & H_0 \\ x_{2u}^2(2\gamma) & H_1 \end{cases}, \tag{2}$$

where  $\gamma$  is signal-to-noise (SNR). The probability distribution function (PDF) of  $Y$  is given by

$$f_Y(y) = \begin{cases} \frac{1}{2^u \Gamma(u)} y^{u-1} e^{-\frac{y}{2}} & H_0 \\ \frac{1}{2} \left(\frac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{-\frac{2\gamma+y}{2}} I_{u-1}(\sqrt{2\gamma y}) & H_1 \end{cases}, \quad (3)$$

where  $\Gamma(u)$  is the gamma function,  $I_{u-1}(x)$  represents the modified Bessel function of order  $u - 1$ .

### 3 Performance Analysis of the Probability of Detection

#### 3.1 Analysis of the Probability of Detection over AWGN Channel

In this subsection, we analyze the probability of detection of single user oriented energy detection based spectrum sensing (SU-EDSS) over AWGN channel for comparison purpose. If energy detection is applied in a non-fading environment, the probability of detection ( $P_d$ ) and probability of false alarm ( $P_f$ ) for energy detection can be obtained as follows [16]

$$\begin{aligned} P_d &= \Pr(Y > \lambda | H_1) = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \\ P_f &= \Pr(Y > \lambda | H_0) = \frac{\Gamma(u, \frac{\lambda}{2})}{\Gamma(u)}, \end{aligned} \quad (4)$$

where  $\lambda$  is detection threshold,  $Q_u(a, b)$  represents the Marcum-Q function, and  $\Gamma(u, \frac{\lambda}{2})$  refers to incomplete gamma function.

#### 3.2 Analysis of the Probability of Detection over Satellite Fading Channel

**SU-EDSS:** As aforementioned, The content above is based on the AWGN channel. When the signal transmits through satellite channel, instantaneous channel gain  $h$  in the model is varying due to the fading/shadowing of the channel.  $P_d$  for fading channel can be obtained by averaging over fading statistics [17],

$$\overline{P_d} = \int_{\gamma} P_d f(\gamma) d\gamma = \int_{\gamma} Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) f(\gamma) d\gamma, \quad (5)$$

where  $f(\gamma)$  is the probability distribution function (PDF) of SNR under fading/shadowing. However, the  $P_f$  under the fading channel is still the same as that under the AWGN channel due to  $P_f$  is independent of signal-to-noise ratio (SNR).

In this paper, satellite channel can be seen as Shadowed-Rician fading channel, thus, based on [15], the PDF of  $|h|^2$  can be given by

$$f_{|h|^2}(x) = \alpha_0 e^{-\beta_0 x} {}_1F_1(m_0; 1; \delta_0 x), \quad x \geq 0 \tag{6}$$

where  $\alpha_0 = \frac{1}{2b_0} \left( \frac{2b_0 m}{2b_0 m + \Omega} \right)^m$ ,  $\beta_0 = \frac{1}{2b_0}$ ,  $\delta_0 = \frac{\Omega}{2b_0(2b_0 m + \Omega)}$ , the parameter  $\Omega$  represents the average power of the LOS component,  $2b_0$  is the average power of the scatter component, and  $m$  is the Nakagami parameter ranging from 0 to  $\infty$ . For  $m = 0$ , the envelope of  $h$  obeys the Rayleigh distribution, which is associated to urban region with complete obstruction of the LOS. While for  $m = \infty$ , it follows the Rician distribution, which is associated to open region with no obstruction of the LOS.

According to Eq. 5, given  $\gamma$  is the SNR and  $\gamma_s = |h|^2 \gamma$ , the PDF of  $\gamma_s$  can be shown as

$$f_{\gamma_s}(x) = \frac{1}{\gamma} \times f_{|h|^2} \left( \frac{x}{\gamma} \right) = \frac{\alpha_0}{\gamma} e^{-\frac{\beta_0 x}{\gamma}} {}_1F_1(m_0; 1; \frac{\delta_0 x}{\gamma}), \quad x \geq 0 \tag{7}$$

where  ${}_1F_1(m_0; 1; \delta_0 x)$  is the general hypergeometric function.

The closed-form formula for  $P_d$  under Shadowed-Rician fading channel may be obtained (after some manipulation) by substituting  $f_{\gamma_s}(x)$  into Eq. 5.

$$P_d = C_1 \sum_{n=0}^{\infty} C_2 \left\{ \Gamma(n+1) (2b_0 \gamma)^{n+1} - e^{-\frac{\lambda}{2}} \sum_{j=u}^{\infty} \left[ \frac{\lambda^j \Gamma(n+1) 2^{n+1-j} (b_0 \gamma)^{n+1-j}}{(2b_0 \gamma + 1)^{n+1} \Gamma(j+1)} \times {}_1F_1 \left( n+1; j+1; \frac{2\lambda b_0 \gamma}{4b_0 \gamma + 2} \right) \right] \right\}, \tag{8}$$

where  $C_1 = \frac{1}{2\gamma b_0} \left( \frac{2b_0 m}{2b_0 m + \Omega} \right)^m$ ,  $C_2 = \frac{(m)_n \Omega^n}{(1)_n n! (2\gamma b_0)^n (2b_0 m + \Omega)^n}$ , and  $(m)_n = \frac{\Gamma(m+n)}{\Gamma(m)}$  is an incremental factorial whose length is  $n$ .

**HC-EDSS:** To improve  $P_d$ , cooperative spectrum sensing is introduced. ‘K-out-of-N’ rule [18] is used in this paper, which adds all the decision results from SUs and compares the obtained value with a predefined threshold  $K$ . Assuming there are  $N$  spectrum detection nodes detecting the states of the channel, the decision result is as follow.

$$\begin{cases} H_1 : \sum_{i=1}^N D_i \geq K \\ H_0 : \sum_{i=1}^N D_i < K \end{cases} \tag{9}$$

The cooperative detection performance metrics ( $Q_d$  and  $Q_f$ ) for ‘K-out-of-N’ rule are derived as follows

$$\begin{aligned}
 Q_d &= \sum_{i=k}^N \binom{N}{i} \prod_{j=1}^i P_{d,j} \prod_{v=1}^{N-i} (1 - P_{d,v}) \\
 Q_f &= \sum_{i=k}^N \binom{N}{i} \prod_{j=1}^i P_{f,j} \prod_{v=1}^{N-i} (1 - P_{f,v}).
 \end{aligned} \tag{10}$$

**SD-EDSS:** With the aid of double threshold [19], the result of local energy detection transmitted to FC can be shown as

$$\begin{cases} \text{send } 0, & \text{if } Y \leq \lambda_1 \\ \text{send } \frac{Y - \lambda_1}{\lambda_2 - \lambda_1}, & \text{if } \lambda_1 < Y < \lambda_2, \\ \text{send } 1, & \text{if } Y \geq \lambda_2 \end{cases} \tag{11}$$

where  $Y$  is the energy received by each SU.

In FC, weighting factor of each SU is given according to the reliability of its local decision results. In this way, SU not only reports the local decision result through the report channel, but also reports its theoretical  $P_d$  at its received SNR. The weighting factor can be shown as the ratio between the  $P_d$  and the average  $P_d$ . The expression is

$W_i = \frac{P_{d,i}}{\bar{P}_d}$ , where  $\bar{P}_d = \frac{1}{N} \sum_{i=1}^N P_{d,i}$ . FC uses the calculated weighting factors to weight-add all the local decision results as global result, which will then be compared to predefined threshold.

## 4 Simulation Results

In this section, performance evaluations are demonstrated through simulations. The QPSK signal is assumed to be the PU signal, and the satellites are assumed to be the SUs. SUs can accomplish the detection of the wireless spectrum resource to determine the occupancy of the PUs. A cognitive radio network which has one PU and four SUs is considered. The comparison between the theoretical and simulated values under the Shadowed-Rician fading channel are analyzed. In our numerical results, the fading channel parameters are seen as the average shadowing  $(b, m, \Omega) = (0.126, 10.1, 0.835)$ . The threshold at the central node  $K = \frac{N}{2} = 2$ .

Figure 3 shows the comparison of the theoretical  $P_d$  and simulated  $P_d$  under the Shadowed-Rician fading channel. It can be concluded from this picture that the expression derived in this paper is basically consistent with the simulation values, which can prove the correctness of the formula derivation. Furthermore, the performance of the spectrum detection is improved with the increase in SNR.

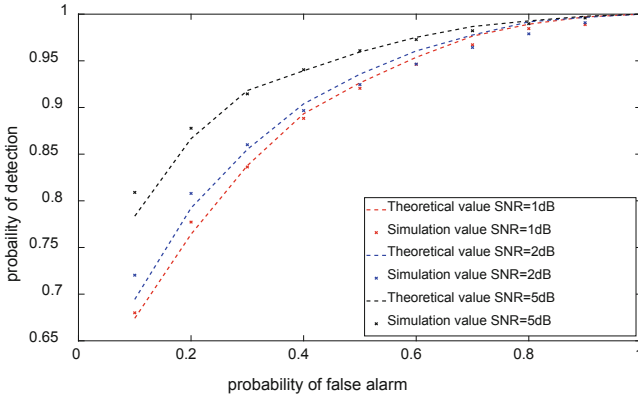


Fig. 3.  $P_d$  vs.  $P_f$  plot of comparison between the theoretical  $P_d$  and simulated  $P_d$

Figure 4 demonstrates  $P_d$  of SU-EDSS, HC-EDSS and SD-EDSS, while  $P_f$  is predefined as 0.1. It is seen that SD-EDSS has better performance than other two methods, which illustrate using SD-EDSS could significantly improve the performance of  $P_d$  under the Shadowed-Rician fading channels as more information is available to FC in SD-EDSS.

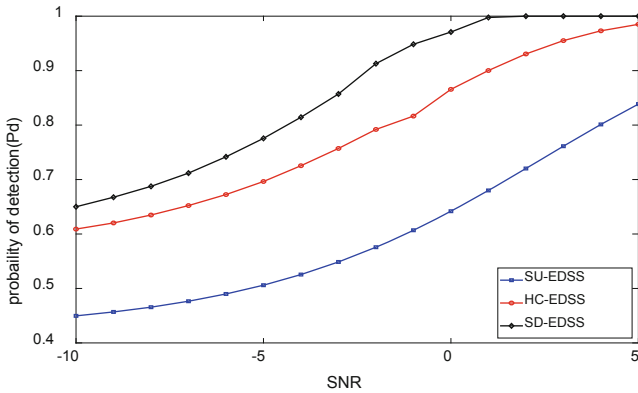


Fig. 4.  $P_d$  vs.  $P_f$  plot of comparison among the SU-EDSS, HC-EDSS and SD-EDSS

## 5 Conclusion

In this paper, we conceived spectrum sensing schemes for a cognitive radio network consisting of multiple satellites. We explored satellite based cooperative spectrum sensing, called HC-EDSS and SD-EDSS, respectively. We also derived the performance of spectrum sensing over satellite fading channel. It was shown that the

probability of detection of the SD-EDSS is better than that of SU-EDSS and HC-EDSS schemes, demonstrating that cooperative spectrum sensing can dramatically improve the probability of detection.

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