

# Performance Evaluation of Cooperative Spectrum Sensing in Cognitive Radio

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**Abstract**— Energy detection is a challenging problem in several applications in cognitive radio communications. In cognitive radio the spectrum is under-utilized. Proper employment of these channels are needed. This work determines the various effects of multipath fading on energy detection and their performance evaluation. For detecting energy Rayleigh channels and additive white real Gaussian signal and noise is used. It has been observed that detection performance is degraded by increasing multipath and cascading channels. Further the optimization of cooperative spectrum sensing with energy detection to minimize the total error rate is considered. An optimal voting rule for optimal value of cognitive radios is used. The different error levels are founded by varying the SNR values to find the optimal number of CRs for minimizing the error levels.

**Key words:** Cognitive Radio, Spectrum Sensing, Optimization, Cooperative Spectrum Sensing

## I. INTRODUCTION

The frequency band detection is an emerging technology in cognitive radio network. The various techniques are compared in this paper. The ability to detect with less priori knowledge and the simple structure of the energy detector motivate the further exploration of the detector performance.

## II. PROPOSED WORK

### A. N\*Rayleigh Fading

It is multiplicative fading models are capable of accounting for fading phenomena holistically. Physically, these models consider received signals generated by the product of a large number of rays reflected via N scatterers [20], [21]. Based on this, a generic cascaded fading model, When m = 1, this model reduces to the N\*Rayleigh distribution with probability density function (PDF)(1)

$$p_{\gamma}(\gamma) = \frac{1}{\gamma} G_{0,N}^{N,0} \left[ \frac{\gamma}{\bar{\gamma}} \mid \underbrace{1, 1, \dots, 1}_N \right] \quad (1)$$

Where  $\gamma$  and  $\bar{\gamma}$  denote the instantenious and average signal to noise ratio respectively and  $G(\cdot)$  is the Meijer G-function.

### B. Energy Detection of Unknown Signals

The detection of unknown signals can be modeled as a binary hypothesis-testing problem, where H<sub>0</sub> and H<sub>1</sub> correspond to the cases that a signal is absent or present, respectively. Based on this, the received signal can be expressed as

$$y(t) = \begin{cases} n(t) & : H_0 \\ hs(t) + n(t) & : H_1 \end{cases} \quad (2)$$

where h and s (t) denote the wireless channel gain and the transmitted information signal with average power E<sub>s</sub>, respectively, and n (t) is the zero-mean complex additive white Gaussian noise (AWGN) with single-sided power spectral density N<sub>0</sub>. The received signal is firstly band-pass filtered at bandwidth B (Hz) and the output of the filter is subsequently squared and integrated over time duration T. This generates the test statistic Y which is typically formulated as

$$Y \sim \begin{cases} \chi_{2u}^2 & : H_0 \\ \chi_{2u}^2(2\gamma) & : H_1 \end{cases} \quad (3)$$

where  $\chi_{2u}^2$  is a central chi-square distribution with 2u degrees of freedom with u denoting the corresponding time-bandwidth product. In the case of AWGN, the probability of false alarm and probability of detection are represented as follows

$$P_f = \Pr(Y > \lambda | H_0) = G\left(u, \frac{\lambda}{2}\right) \quad (4)$$

$$P_d = \Pr(Y > \lambda | H_1) = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \quad (5)$$

respectively, where G(a, b) and Qu (a, b) are the regularized upper incomplete gamma function and the Marcum Q-function, respectively.

### C. Minimising total error rate

H<sub>0</sub>: The primary user is absent.

H<sub>1</sub>: The primary user is in operation.

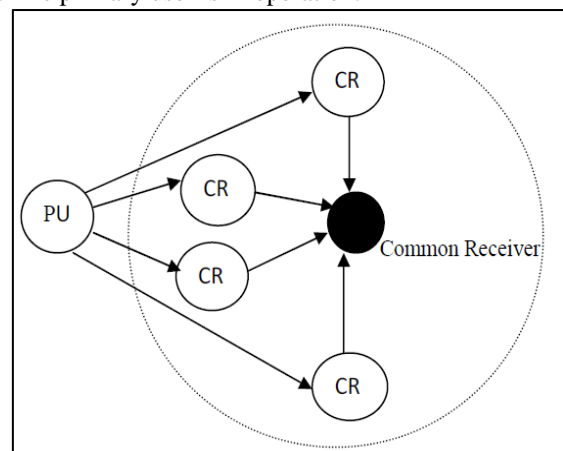


Fig. 1: Cooperative Spectrum Sensing  
When the signal is received at each *i*th CR, it follows two hypotheses as above. Then the received signal will be;

$$x_i(t) = \begin{cases} w_i(t), & H_0 \\ h_i(t)s(t) + w_i(t), & H_1 \end{cases} \quad (6)$$

Where  $x_i(t)$  is the received signal at the  $i$ th CR time slot  $t$ ,  $s_i(t)$  is the PU signal. The  $h_i(t)$  indicate the complex channel gain of the sensing channel between PU and  $i$ th CR.  $w_i(t)$  is the Additive White Gaussian Noise(AWGN). For each  $i$ th CR by energy detection missed detection and false alarm over AWGN channel is computed by equation

$$P_{f,i} = \frac{\Gamma\left(u, \frac{\lambda_i}{2}\right)}{\Gamma(u)} \quad (7)$$

$$P_{d,i} = Q_u(\sqrt{2\gamma_i}, \sqrt{\lambda_i}) \quad (8)$$

$$P_{m,i} = 1 - P_{d,i} \quad (9)$$

Where,  $\lambda_i$  is the energy detection threshold and  $\gamma_i$  is the instantaneous signal to noise ratio at the  $i$ th CR. Also  $u$  is the time bandwidth product of the energy detector.  $\Gamma(a)$  is the Gamma function and the incomplete gamma function is equal to

$$Q_u(a, x) = \frac{1}{a^{u-1}} \int_x^\infty t^u e^{-\frac{t^2+a^2}{2}} I_{u-1}(at) dt \quad (10)$$

$$\Gamma(a, x) = \int_x^\infty t^{a-1} e^{-t} dt \quad (11)$$

Where  $I_{u-1}(\cdot)$  is the first kind and order  $u-1$  modified Bessel Function. The cooperative spectrum sensing, where number of CR takes binary decisions based in decision  $D_i$  to common receiver.

$$Y = \sum_{i=1}^K D_i \begin{cases} \geq n, & H_1 \\ < n, & H_0 \end{cases} \quad (12)$$

In this  $n$  is the threshold representing  $n$  out of  $k$  rule. The common receiver calculates false alarm probability and missed detection probability with the help of average probability of each CR. The false alarm probability is given by,

$$Q_f = \sum_{l=n}^k \binom{k}{l} p_f^l (1-p_f)^{k-l} = \text{Prob}\{H_1 / H_0\} \quad (13)$$

$$Q_m = 1 - \sum_{l=n}^k \binom{k}{l} p_d^l (1-p_d)^{k-l} = \text{Prob}\{H_0 / H_1\} \quad (14)$$

#### D. Optimization of Cooperative Spectrum Sensing

In this section, we analyse optimal voting rule, optimization of number of CR and detection threshold with cooperative spectrum sensing.

##### 1) Optimal Voting Rule

Let,  $K$  is fixed then what is will be optimal value of  $n$  so that we get minimum error rate  $(Q_f + Q_m)$ , this is the optimal voting rule and optimal value of  $n$  is called as  $opt n$ . We have plotted graph for  $n=1$  to  $n=10$ . For each  $n$ , for different

threshold values, we calculated error rate. For small threshold value, we get more error rate and optimal rule AND rule (i.e.  $n=10$ ). For large threshold value, optimal rule is OR rule. But when  $n=5$ , we get more error rate for medium threshold values. To find  $opt n$  value for minimum error rate following equations are used.

$$n_{opt} = \min\left(K, \left\lceil \frac{K}{1+\alpha} \right\rceil\right) \quad (15)$$

$$\text{where, } \alpha = \frac{\ln \frac{P_f}{1-P_m}}{\ln \frac{P_m}{1-P_f}} \text{ and } \lceil \cdot \rceil \text{ denotes the ceiling function} \quad (16)$$

#### 2. Optimal Energy Detection Threshold

Here we consider that  $K$ ,  $n$  and SNR are known then what will be optimum threshold  $\lambda^*$  such that total error rate minimum. We have plotted in figure 1 total error rate curve with different threshold values. For only one threshold value, figure has the low error rate for given  $n$ . i.e. there will be one and only value of  $\lambda$  for which  $(Q_f + Q_m)$  is minimum.

$$\lambda^* = \arg\{\min(Q_f + Q_m)\} \quad (17)$$

#### 2) Optimal Number of Cognitive Radios

In cooperative spectrum sensing, large number of CR's used, but it increases the time slot and becomes impractical. As only one CR should send its local decision at a time to the fusion centre so it may take whole sensing time intolerably long. This problem can be solved by permitting CR's to send the decision concurrently but this is difficult for common receiver to separate each decision. There is another way to send decisions using orthogonal frequency bands, but large bandwidth requirement is the problem. So we proposed efficient sensing algorithm, in which we define some error bound and calculated optimal number of CR's. Also each CR sends decision in one time slot. By this method we get required error rate with use of few CR's only. Let, SNR and threshold values are known then we calculated least number CR's in cooperative spectrum sensing to achieve target error bound. i.e.  $(Q_f + Q_m) \leq \epsilon$ , where  $\epsilon$  is the target error bound. As we have stated earlier for optimal voting rule [1],

$$n_{K^*}^{opt} = \min\left(K^*, \left\lceil \frac{K^*}{1+\alpha} \right\rceil\right) \quad (18)$$

Here,  $K^*$  ( $1 \leq K^* \leq K$ ) is the least number of CR's to satisfy target error bound  $(Q_f + Q_m) \leq \epsilon$  and  $\alpha$  is calculated from  $P_f$ ,  $P_m$  and known SNR and  $l$  values. We define the function.

#### E. System Modelling with Energy Detection of Signal

Here, the energy of signal is calculated and probability of false alarm and detection is calculated.[2-4] For AWGN channel, first we define different threshold values and calculate the energy of received signal. If energy of received signal is  $1x(t) = s(t) + w(t)$ , then the energy of  $1x(t)$  is calculated, also if received signal is  $2x(t) = w(t)$ , then energy of  $2x(t)$  is calculated. If energy of  $1x(t)$  is greater

than threshold value then that would be probability of detection and if energy of  $2x(t)$  is greater than threshold value then that would be probability of false alarm.

$$E_1 = \frac{1}{N_{02}} \sum_n (s(n) + w(n))^2 \quad (19)$$

$$E_2 = \frac{1}{N_{02}} \sum_n (w(n))^2 \quad (20)$$

where  $2N$  is the two sided noise power spectral density [2] and is given by;

$$N_{02} = \frac{\sum_n (s(n))^2}{(2 \times SNR)} \quad (21)$$

For Rayleigh Fading Channel, the SNR values are exponentially distributed. We consider SNR values as exponential random number with same mean. To determine Rayleigh fading channel gain we have used [3]

$$h = \sqrt{\frac{(2 \times SNR)}{\sum_n (s(n))^2}} \quad (22)$$

Then we find the two sided noise power by [3]

$$N_{02} = \frac{\left\{ h^2 \times \sum_n (s(n))^2 \right\}}{(2 \times SNR)} \quad (23)$$

Then using this value of  $2N$  and equation (11) we calculated the energy of the received signal and find probability of false alarm and detection using threshold values. The energy becomes in Rayleigh Fading Channel;

$$E_1 = \frac{1}{N_{02}} \sum_n (h \times s(n) + w(n))^2 \quad (24)$$

### III. RESULTS & DISCUSSIONS

The Figure 2 shown below depicts the Complementary ROC of Rayleigh Channel.

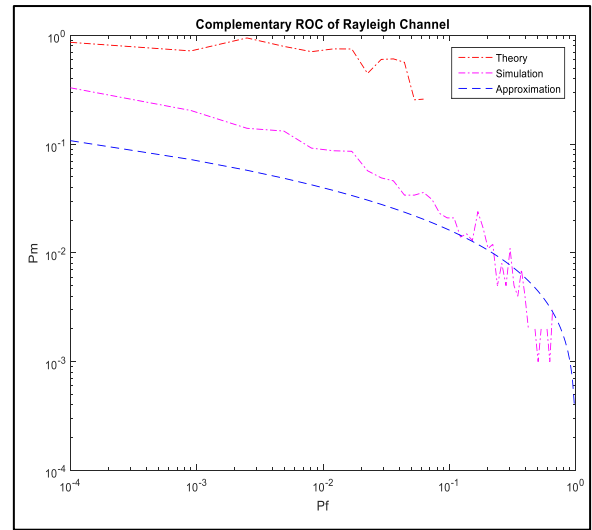


Fig. 2: Complementary ROC of Rayleigh Channel

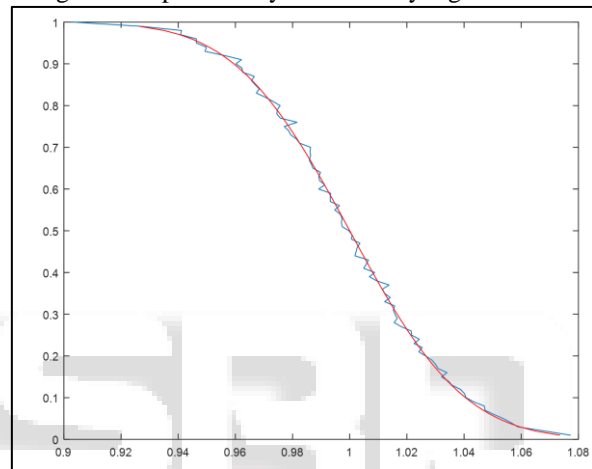


Fig. 3: Threshold in energy detection

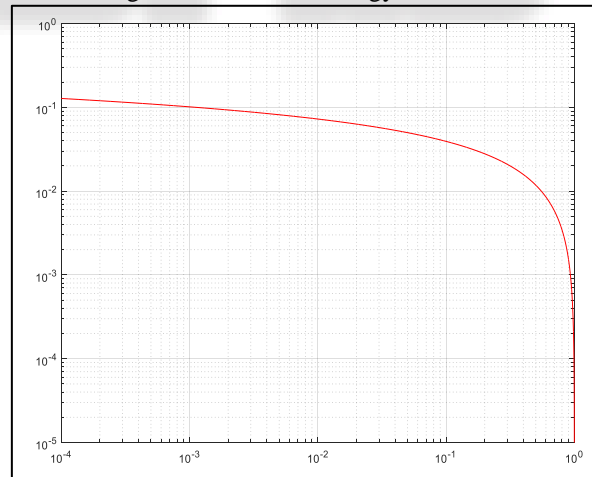


Fig. 4: Rayleigh channel energy detection

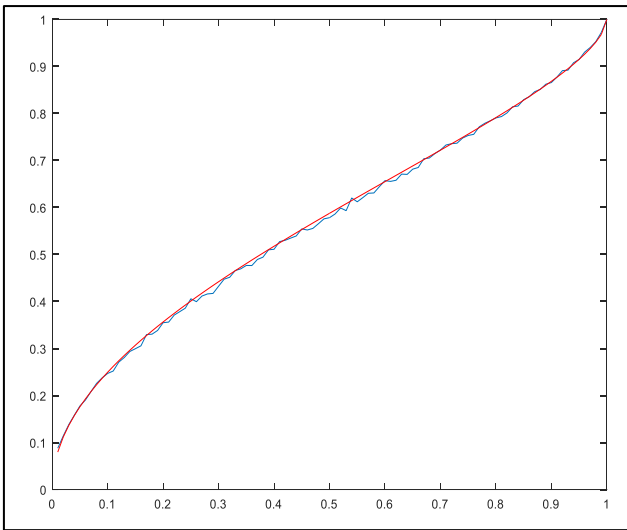


Fig. 5: AWGN Channel Energy detection

Simple energy detection, when the primary signal is real Gaussian signal and noise is % additive white real Gaussian

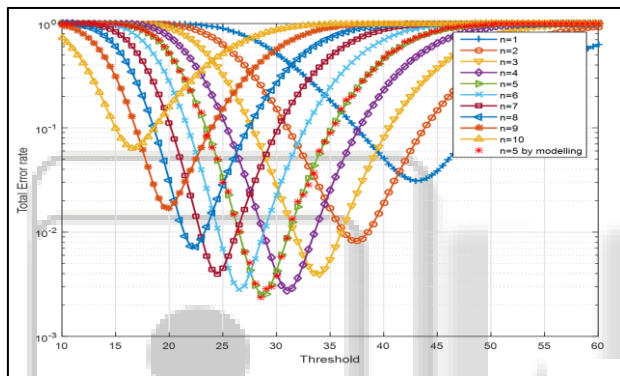


Fig. 6: Total Error Rate Vs Threshold

#### IV. CONCLUSION

In this paper the problem of detecting an unknown deterministic signal through energy detection systems has been analyzed. The decision variable of a selection of combined energy detection was constructed and experimented. Optimisation of cooperative spectrum energy improved energy detector. It is also shown that the total error rate minimization criteria is possible to achieve good utilization of spectrum hole and low interference level for PU at very low SNR.

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