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# Performance Analysis of Cooperative Spectrum Sensing for Cognitive Radios in Nakagami-m Fading Channels

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***Abstract—This paper studies and presents the effect of different hard fusion schemes applied to a cooperative cognitive radio system. The fading channel considered is the Nakagami-m channel. The hard fusion rules are the OR rule, AND rule and the majority fusion rule. Receiver Operating Characteristic (ROC) curves for cooperative sensing using the abovementioned fusion rules are plotted. The simulation results show that the OR fusion scheme gives superior performance compared to other fusion schemes. The paper also studies the effect of different number of co-operating users.***

***Index Terms—spectrum sensing, data fusion, cooperative sensing***

## I. INTRODUCTION

Wireless communication is rapidly growing and evolving in an unpredictable rate and the communication spectrum is almost completely utilized. Entire spectrum will be used up in the near future, which results in the shrinking of vacant spectrum. WRAN IEEE 802.22 standards make it possible to use the unutilized spectrum through a policy by which priorities are already set for different class of users. The users holding the spectrum license is given the access to the channel with the highest priority ie. They can access the channel always without any constraints and are known as Primary Users (PUs) whereas the users designated as the Secondary Users (SUs) can access the channel only in the absence of primary users or by ensuring that their presence does not cause interference to the primary users. Detection of Primary Users is therefore very important in this scenario and it is one of the main tasks of a Cognitive radio (CR) and is known as spectrum sensing. [1]

According to technical literature, there exist many different spectrum sensing techniques. Energy based detector [2] that measures the amount of energy of the received signal in a particular bandwidth is the simplest method of spectrum sensing. But the energy detection method miserably fails in the case of weak signals. Fading and shadowing inherently present in all wireless channels impose challenges to successfully accomplish the spectrum sensing task, using a single cognitive radio. On the other hand, if two or more users participate in the sensing tasks and share their results, it can fetch much more accurate results as put forward by [3-5]. This type of sensing is known as Cooperative Sensing and provides diversity gains against channel fading effects. The relevance of cooperative sensing has been acknowledged in the FCC's recent rules for unlicensed operation in the licensed TV bands.

Once, the users participating in the sensing process makes decision regarding the presence of PU in the desired channel, then it becomes essential to combine these results and arrive at a final conclusion. This is done by an entity called the fusion center. Fusion schemes are broadly classified into two viz. hard decision and soft decision[6]. This paper studies the effect of different hard fusion schemes based on OR, AND and Majority rules in Nakagami-m fading channel.

This paper is organized as follows: Section 2 describes the system model. Section 3 provides an overview of the different fusion schemes under investigation and their theoretical performance.

## II. SYSTEM MODEL

The study assumes a collaborative cognitive radio system which performs the detection of a primary signal embedded in Additive White Gaussian noise by a group of secondary receivers that perform energy estimation and cooperative signal detection. In such a system, N samples of the received signal are gathered by K secondary users in the system, and the signal energy is determined by each user. The users first perform local detection based on the measured energy ie, make a decision regarding the presence of the PU, and send their individual hard decisions to a fusion center for decision combining, or they forward the soft information to be fused at the fusion center to make the final decision. This is finally, a binary hypothesis testing problem where the noise only hypothesis (H0) corresponds to "No PU activity case", and the signal plus noise hypothesis (H1) corresponds to the "Active PU" case:

The binary hypothesis testing problem in a simple energy detection case may be formulated as:

$$H_0: y(t) = n(t)$$
$$H_1: y(t) = x(t) + n(t) \quad (1)$$

where $H_0$ represents the hypothesis corresponding to "no signal transmitted", and $H_1$ to "signal transmitted", $x(t)$ is the unknown deterministic transmitted signal, and $n(t)$ is assumed to be an AWGN with zero mean and an a priori known variance $\sigma_n^2 = N_0W$, where $N_0$ is the power spectral density of AWGN. If the channel model considered is a fading channel whose impulse response is $h(t)$, then equation (1) gets modified as :

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$$H_0: y(t) = n(t)$$
$$H_1: y(t) = h(t) * x(t) + n(t) \qquad (2)$$

Similarly, in the cooperative spectrum sensing scenario, assuming that the whole process takes place on a sampling basis, the equation gets modified as:

$$H_0: y(n) = \sum_{i=1}^{N} \left| n_i \right|^2$$
$$H_1: y(n) = \sum_{i=1}^{N} \left| h_i s_{i+} n_i \right|^2 \qquad (3)$$

When PU is idle ($H_0$), the received signal energy at the CR user follows the Central Chi-Squared distribution with $2m$ degree of freedom. Its probability density function (PDF) can be written as [7,8]:

$$f(y/H_0) = \frac{y^{m-1} e^{y/2}}{\Gamma(m) 2^m} \qquad (4)$$

where$\Gamma(.)$is the gamma function. And, the probability of false alarm can be given as:

$$P_f(\lambda) = \int_{\lambda}^{\infty} f(y/H_0).\,dy$$
$$= \frac{\Gamma\left(m, \lambda/2\right)}{\Gamma(m)} \qquad (5)$$

However, when a PU is active ($H_1$), the received signal energy for a particular instantaneous SNR follows the Non Central Chi-Squared distribution with degree of freedom of $2m$and non-centrality parameter of $2m\gamma$, where $\gamma$ is the instantaneous SNR.

In a non-fading environment, the probability of detection can be expressed as:

$$P_d = Q_m\left(\sqrt{2\gamma}, \lambda\right) \qquad (6)$$

Where $Q_m(.,.)$ is the generalized Marcum Q-function [5].

The average probability of detection ( Pd ) may be derived by averaging (6) over fading statistics[3].

$$P_d = \int_x Q_m\left(\sqrt{2\gamma}, \lambda\right) f_r(x)\, dx \qquad (7)$$

where $f_r(x)\,dx$is the probability density function (pdf) of SNR under fading.

### *A. Nakagami Fading Channel*

Rayleigh and Ricean distributions are the most popularly used for modeling fading channels. However, some empirical results are found to be least fitting with these distributions. Thus, a more general fading distribution called the Nakagami fading distribution is suggested. The Nakagami distributionwas introduced by Nakagami in the early 1940's to characterize rapid fading in long distance HF channels [10].Nakagami-m distribution often gives the best fit to land-mobile and indoor mobile multipath propagation as well as ionospheric radio links [11]. Recent studies also showed that Nakagami-m gives the best fit for satellite-to-indoor and satellite-to-outdoor radio wave propagation. Moreover, Nakagami distribution generalizes many other distributions and thus, it is possible to describe both Rayleigh and Rician fading with the help of a single model using the Nakagami distribution. When m, the Nakagami shape parameter, which takes into account of the degree of fading, is equal to 1, the distributionbecomes the Rayleigh distribution. When m=1/2, it becomesa one-sided Gaussian distribution, and when m=∞thedistribution becomes an impulse (no fading).

Now, if the signal amplitude follows a Nakagami-m distribution then PDF of γ follows a gamma PDF given by [12]

$$f_R(R) = \frac{2m^m R^{2m-1}}{\Omega^m \Gamma(m)} \exp\left(\frac{-mR^2}{\Omega}\right) \qquad (8)$$

Here, $m$ is the Nakagami parameter.

The average $P_d$ in this case can be calculated to be :

$$P_{davg} = \alpha \left[ G_1 + \beta \sum_{n=1}^{u-1} \frac{\frac{\lambda}{2}}{2n!} F\left(m; n+1; \frac{\lambda}{2} \frac{\bar{\gamma}}{\gamma}\right)_1 \right] \qquad (9)$$

where ${}_1F_1(.;.;.;)$ is the confluent hyper geometric function.

$$\beta = \Gamma(m) \left(\frac{\bar{\gamma}}{m+\gamma}\right)^m e^{-\lambda/2} \qquad (10)$$

And

$$G_1 = \int_0^{\infty} x^{2m-1} \exp\left(\frac{-mx^2}{2\bar{\gamma}}\right) Q_u\left(x, \sqrt{\lambda}\right) dx \qquad (11)$$

## III. Fusion Rules

Cooperative Spectrum sensing largely reduces the effect of shadowing and fading [14,15]. A fusion center is required in every cooperative cognitive radio system to combine the decision from different CR's and arrive at a conclusion whether PU is actually present or not. There can be two types of fusions – Soft fusion and hard fusion. In hard fusion, depending on the received energy and the prefixed threshold, the CR receiver will make decision locally as to whether PU is sent or not. If PU is present, the decision is made and is transmitted in the form of 1 and if local the decision is that the PU is absent, then a "0" bit is transmitted. In the second type of data fusion called the hard fusion, the sensing information is directly sent to the fusion center, without the sensing CR getting involved in the decision making process. Based on the received information and the statistics, the fusion center makes a decision. This type of communication process between the Fusion center and the CR nodes requires a control channel. It is very evident that Soft fusion techniques require more bandwidth and the hard decision based fusion requires less bandwidth, since the decisions are locally made and then transmitted to the Fusion Center in the form of bits. Nevertheless, Soft fusion is superior to hard fusion in terms of it its performance, [9]

### *A. Hard Fusion*

Depending on the method in which data is combined at the fusion center, hard fusion strategy is further divided into the following:

- **Logical-OR fusion Rule:**

In this case, if N users are cooperating and at least one of them makes a decision in favor of PU, ie, PU is present, and then the fusion center will also decide that PU activity is there in the channel. In such ascheme, the probability of detection, false alarm and missed detection is expressed as:



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$$Q_{d,OR} = 1 - \prod_{k=1}^{K} 1 - P_{d,k}$$

where $P_{d,k}$ is the detection probability of the k[th] CR user. Similarly, the false alarm probability can be represented as

$$Q_{f,OR} = 1 - \left(1 - \prod_{k=1}^{K} 1 - P_{f,k}\right)$$

Where $P_{f,k}$ is the false alarm probability of the k[th] CR user.

- **Logical AND rule:**

In this scheme, the fusion center will decide that PU is present only if each of the CR users participating in cooperation decides that the PU is present. In that case, the detection probability is given by:[11]

$$Q_{d,AND} = \prod_{k=1}^{K} P_{d,k}$$

The false alarm probability can be represented as

$$Q_{f,AND} = \prod_{k=1}^{K} P_{f,k}$$

- **Majority Fusion Rule:**

This is a special form of N out on N rule in which N =K/2. This means that the fusion center will decide that thePU is present only if K out of N decisions.ie, The decisions from atleast N users must indicate PU activity. It is interesting to notice that the OR rule as well as the AND rules are the specialized cases of K out of N rule where N = 1 in the former and N= K in the latter case.

$$Q_{d,MAJ} = \sum_{k=1}^{\lfloor K/2 \rfloor} \binom{M}{k} P_{d,k}^{k} \left(1 - P_{d,k}\right)^{N-k}$$

### *B. Soft Fusion*

The important class of soft Fusion includes Likelihood Ratio Test (LRT),Soft Linear Combining, Maximal Ratio Combining, Equal Gain Combining etc. In soft combining the test static has to decided accordingly and the probability of detection and false alarm needs to be calculated from the decided test static.

### *C. Quantized Fusion*

In this method, CRs quantize their observations according to their received signal energy and the already set quantization boundaries. Then, the quantized level is forwarded to the fusion center, and the fusion center re-creates the actual spectrum from the received spectrum[13].

## IV. SIMULATION MODEL

In this paper, a cognitive system with N number of secondary users and a single Primary User is considered. The ‘N’ Secondary Users collaboratively participate in the spectrum sensing task. The number of users is allowed to vary from 1(which represents the non-cooperative case) to 10. The channel considered a Nakagami-m fading channel. Spectrum sensing is achieved through energy detection. The following system parameters are assumed: Time-bandwidth product, m = 5, average SNR, γ = -10 dB, number of samples collected = 5000 and probability of false alarm = 0.1. MATLAB is the tool in which Monte Carlo simulations are done.

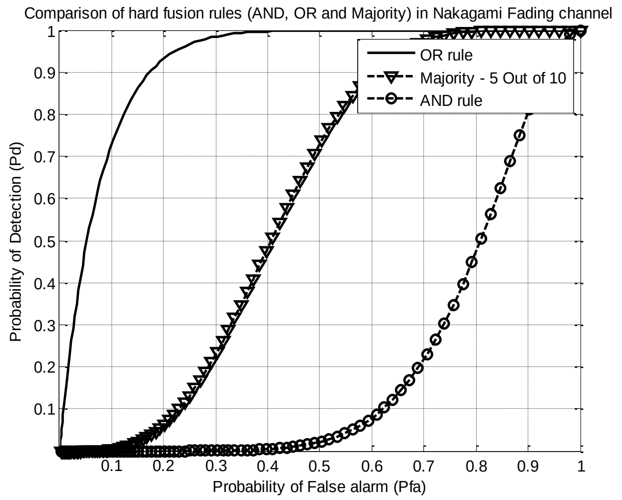


**Figure 1: ROC curve showing the results of AND , OR and Majority fusion in a Nakagami fading channel.**

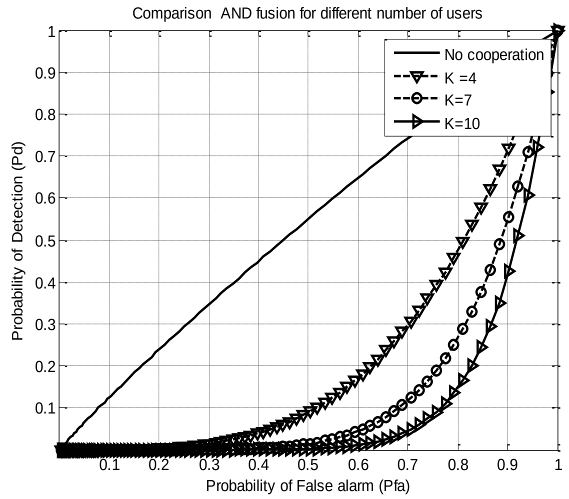


**Figure 2: ROC curve showing the results of AND fusion for different number of users in a Nakagami fading channel**

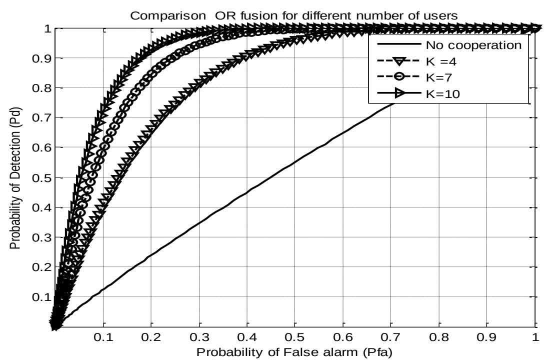


**Figure 3: ROC curve showing the results of OR fusion for different number of users in a Nakagami fading channel**


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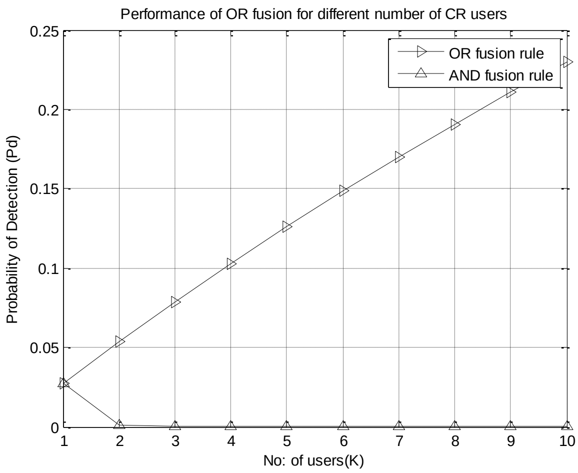


**Figure 4 :Curve showing the performance of OR fusion and AND fusion for different number of users.**

It is clear from the figure that for OR fusion, the detection performance is better for large number of users whereas for AND fusion, the co-operation between too many users might result in no detection at all. The graphs are plotted for a false alarm probability of 0.02.

## V. Conclusion

This paper investigated the performance of different hard fusion schemes in a cooperative spectrum sensing scenario in a Nakagami-m fading channel. The hard fusion schemes that are compared are the OR, AND and majority fusion rules. The comparison shows that OR rule outperforms the other two schemes in terms of the ROC performance. The study of different soft fusion schemes under different fading channels can be considered for future work.

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