International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

# Implementation of Enhanced Energy Detector in Cluster Based Multistage Relaying Cooperative Spectrum Sensing

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***Abstract:*** *This paper explains the improved performance of spectrum sensing in cognitive radio networks using cluster based multistage relaying. It depicts that use of an enhanced energy detector instead of conventional energy detector results in better total error rate and optimizes the number of CR nodes. Enhanced energy detector is based on increased positive power as compared to the conventional energy detector whose decision statistics is based on square of signal amplitude. Further, the number of detection stages is optimized by using an expression derived for reducing the total error rate. On the contrary, to reduce the trade off sensing time, the required number of diversity branches is optimized. Clustering approach help to optimize the voting rule at every cluster head with objective to reduce the error probability. With the help of simulations, it is derived that use of MIMO systems achieves better reliability in detecting the vacant spectrum without interfering the primary user.*

***Keywords:*** *Cognitive radio, cooperative spectrum sensing, enhanced energy detector, MIMO systems, detection probability*

## I. Introduction

The Energy Detection technique has been the most widely adopted technique for spectrum sensing in cognitive radio networks because of its simplicity and ease of practical implementation [1]. Due to the fact, many researchers have been continuously improvising the performance of the energy detection technique. Urkowitz [2] was the first to introduce the energy detection of unknown signals by determining the signal noise. Later this detector was used to detect random signals with Gaussian noise [3], [4]. Further the conventional energy detector was improved by using an arbitrary positive value of power in place of square operation to calculate the received noise signal energy, which is generally not '2' [5].

As we know cooperative spectrum sensing always increases the reliability of the detection of spectrum hole [6], [7]. Cooperative spectrum sensing with multiple antennas based on enhanced energy detection outperforms the single antenna systems based on enhanced energy detection technique [8] [9]. Multiple antenna based MIMO systems with multiple samples were deployed to increase the data rate and better detection range [10]. Latest studies show that the linearly combined multiple sample based systems results in the improved performance of energy detection techniques with reduced error probability [11].

In this paper the performance of cluster based multistage relaying network is analysed which utilises the enhanced energy detector. The performance parameter is the total error rate which is the addition of the probability of detection and probability of false alarm. Several researchers have studied the performance of cooperative spectrum sensing under various conditions considering both the probabilities individually as well as jointly [12], [13]. As per our best knowledge cluster based cooperative spectrum sensing network deploying MIMO system with multistage relaying has not been studied in literature till date. The rest of the paper follows section II which describes the system model assumed for the performance analysis of cluster based multistage relaying in cognitive radio networks. The performance analysis of the proposed system model based on cooperative spectrum sensing cognitive radio network is done in section III. It includes the results based on performance parameters like probability of false alarm and probability of missed detection and total error rate. At last, the conclusions gathered from the implementation and simulations are discussed.

## II. System Model

The system model based on cooperative spectrum sensing network consists of one primary user, 'u' number of secondary users and a fusion centre. The PU has single antenna while each secondary user is equipped with 'L' number of antennas and relaying network consists of 'f' number of FCR clusters as shown in figure 1.

The two hypotheses used to test the received signal in the $L^{th}$ antenna is the binary hypothesis [1], i.e.

$$H_0 : r_i(t) = n_i(t), \quad \text{if PU is absent}$$
$$H_1 : r_i(t) = h_i(t)s + n_i(t), \quad \text{if PU is present} \quad (1)$$

where i denotes the antenna index (i = 1,2,....,L); s is the transmitted signal; $n_i(t)$ represents the noise introduced in the received signal. It is assumed that the primary user characteristics remains constant in the sensing duration and each sample undergoes fading independently. Each antenna is equipped with an advanced energy detector [6] which works to detect PU based on the following test statistic:

$$T_i = \sum_{t=1}^{k} \left(\frac{|y_i(t)|}{\sigma_n}\right)^a, \quad a > 0 \quad (2)$$

where k denotes total number of samples. Here, 'a' represents the arbitrary positive value of power in place of square operation of the conventional energy detection method to calculate the received noise signal energy [5]. For a=2, $T_i$ simplifies to test statistics of the conventional energy detector



Vatsala Sharma and Kamal Nayanam, "Implementation of Enhanced Energy Detector in Cluster Based Multistage Relaying Cooperative Spectrum Sensing," *International Research Journal of Advanced Engineering and Science*, Volume 9, Issue 1, pp. 40-44, 2024.

[1].

$$T_i = \sum_{j=1}^{k} \left(\frac{y_i(j)}{\sigma_n}\right)^2 \quad (3)$$

where $i = 1,2,......,L$, $j = 1,2,......,k$

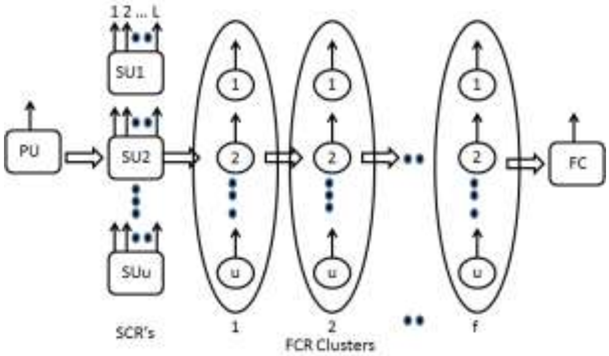


Figure 1. Cluster based Multistage relaying model with multiple antenna system.

The system is divided into two parts: Spectrum sensing part & Relaying part. Sensing performed is cooperative in nature based on hard combination. First of all, each antenna gives the decision statistics based on (2) and selection combining gives a binary decision, which is sent to fusion centre. At last optimal voting rule is applied to get the final result of the binary hypothesis. In the relaying part FCR clusters adopts multistage amplify and forward relay network, its analysis is done in [14]. Performance of decode and forward relay networks is analysed in [15]. The error probability performance of amplify and forward multistage cooperative sensing CR network with enhanced energy detector was improved compared to that of decode and forward relay network as discussed in [16] [18]. Decision variable test statistic at each secondary cognitive radio (SCR):

$$R = \sum_{i=1}^{L} T_i = \sum_{i=1}^{L} \sum_{j=1}^{k} \frac{|y_i(j)|^a}{\sigma_n^a} \underset{0}{\overset{1}{\gtrless}} \lambda \quad (4)$$

where L represents the number of antennas in each secondary cognitive radio, R=1 denotes PU is present and R=0 denotes absence of PU.

## III. Performance Analysis of Cluster Based Multistage CR Network

If the number of antennas in each secondary cognitive radio (L) and the number of samples at the receiver (k) are large, as a result we obtain a normally distributed decision variable R in each SCR with [10]

$$\text{Mean} = \begin{Bmatrix} \mu_0 = Lk\Gamma\left(1+\frac{a}{2}\right): & H_0 \\ \mu_1 = (1+\gamma)^{\frac{a}{2}}\mu_0: & H_1 \end{Bmatrix} \quad (5)$$

and

$$\text{variance} = \begin{cases} \sigma_0^2 = Lk\Gamma(1+a) & \\ +(k^2-k-Lk^2)\Gamma^2\left(1+\frac{a}{2}\right): & H_0 \\ \sigma_1^2 = (1+\gamma)^a\sigma_0^2: & H_1 \end{cases} \quad (6)$$

where $\gamma$ is the parameter to represent PU-CR link signal to noise ratio average. The probability of false alarm $P_{fscr}$ can be calculated as

$$P_{fscr} = Q\left(\frac{\lambda-\mu_0}{\sigma_0}\right) \quad (7)$$

where Q(.) denotes the Q-function [14]. In the same manner the probability of miss detection $P_{mscr}$ of every SCR is given by

$$P_{mscr} = 1 - Q\left(\frac{\mu_1}{\sigma_1}\right) - Q\left(\frac{\lambda-\mu_1}{\sigma_1}\right) \quad (8)$$

The channel that reports from cognitive radio to fusion centre is assumed to be binary symmetric channel whose error probability is e. The total error rate at each CR is the addition of the probability of detection and probability of false alarm

$$P_{e,scr} = b_0 P_{fscr} + b_1 P_{mscr} \quad (9)$$

where $b_0$ and $b_1$ are the weighting factors for $P_{fscr}$ and $P_{mscr}$ respectively.

Let us first consider a dual stage network, in this case the total error rate will be

$$P_{ter} = b_0 P_{fscr}(1-e) + b_0(1-P_{fscr})e + b_1 P_{mscr}(1-e) + b_1(1-P_{mscr})e \quad (10)$$

By equating the optimal threshold at each SCR to 0 i.e. $\frac{d(P_{e,scr})}{d\lambda} = 0$ and by manipulating some equations [15], we get the optimized value of threshold in closed form expression as derived by the author in [16]

$$\lambda^* = \frac{\frac{\mu_1}{\sigma_1^2}-\frac{\mu_0}{\sigma_0^2}}{\frac{1}{\sigma_1^2}-\frac{1}{\sigma_0^2}} \pm \sqrt{\frac{\left(\frac{\mu_1}{\sigma_1^2}-\frac{\mu_0}{\sigma_0^2}\right)^2}{\left(\frac{1}{\sigma_1^2}-\frac{1}{\sigma_0^2}\right)^2} - \left(\frac{\left(\frac{\mu_1}{\sigma_1^2}-\frac{\mu_0}{\sigma_0^2}\right)^2 - ln\left(\frac{P_1\sigma_1}{P_0\sigma_0}\right)^2}{\left(\frac{1}{\sigma_1^2}-\frac{1}{\sigma_0^2}\right)^2}\right)} \quad (11)$$

Threshold value is optimized to reduce the total error rate as shown in Figure 2.

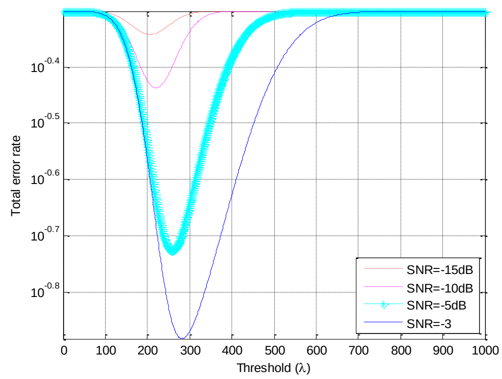


Figure 2: Total error rate vs threshold in CR network with dual stage at different SNR with a=4; k=10 and L=10.

Figure 2 shows total error rate vs threshold plot for CR network with dual stage at different SNR values $\gamma$ = -15, -10, -5, -3; with k=10; L=10 and a=4. The convex downward curve relates the total error rate with the threshold whose optimal value is obtained from (11). It represents that as the value of SNR for the channel between PU-CR is increased eventually the value of the total error rate is decreased. Now, multistage relay based cognitive radio networks are prevailing in case of long-distance communications [17]. Here, multistage relay based cognitive network is considered for enhanced energy detection with MIMO systems. We assume that there is H number of stages modelled with H-1 number of SCR's. The probability of missed detection as $P_{mscrh}$ and the probability of false alarm as $P_{fscrh}$ are given by



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$$P_{fscrh} = \left(\frac{1}{2} - \frac{1}{2}\prod_{q=1}^{H-1}(1-2e_q)\right)\left[1 - Q\left(\frac{\lambda-\mu_0}{\sigma_0}\right)\right] + \left(\frac{1}{2} + \frac{1}{2}\prod_{q=1}^{H-1}(1-2e_q)\right)Q\left(\frac{\lambda-\mu_0}{\sigma_0}\right) \quad (12)$$

$$P_{mscrh} = \prod_{q=1}^{H-1}(1-2e_q)\left[1 - Q\left(\frac{\mu_1}{\sigma_1}\right) - Q\left(\frac{\lambda-\mu_1}{\sigma_1}\right)\right] + \frac{1}{2}\left(1 - \prod_{q=1}^{H-1}(1-2e_q)\right) \quad (13)$$

Where $e_q$ defines the probability of error for $q^{th}$, q=1,...,H-1. The total error in a multistage cognitive relay network is the addition of the probabilities of detection and the probabilities of false alarm in a multistage CR network given by

$$G = b_0 P_{fscr} + b_1 P_{mscr} + \frac{1}{2}\left(1 - \prod_{q=1}^{H-1}(1-2e_q)\right) \times \left(1 - 2b_0 P_{fscr} - 2b_1 P_{mscr}\right) \quad (14)$$

Where $P_{fscr}$ and $P_{mscr}$ are defined by (7) and (8), respectively. The equation (14) concludes that if multiple stages are assumed to be identical, as the value of H increases the error rate also increases. The relation between the total error rate and decision threshold in case of multistage cognitive radio network is represented by the plots in Figure 3.

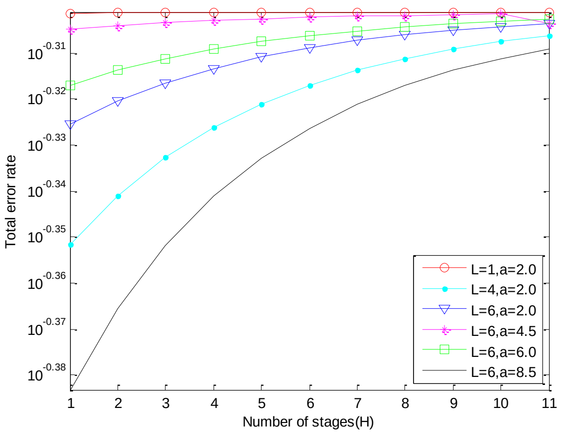


Figure 3: Total error rate vs number of stages in a cognitive radio network with SNR=-10dB; k=10 and e=0.1.

The error performance gets worsen with the increase in the number of stages. On the contrary the error performance is significantly improved with the increase in number of antennas. Fig. 3 depicts the same by using the value of a=8.5 in place of a=2.0 improves the error performance of the multi stage cognitive radio network. Further, it concludes that using an enhanced energy detector with MIMO antenna improves the error performance of the multistage relay based cognitive radio network.

Now, we consider cluster based CR network with multistage relaying where V is the number of diversity branch clusters. Each branch has H number of relay stages within PU and FC. Let C be the optimal number of diversity branches required to reduce the total error rate in cluster based CR network. The decision statistics that depend on the binary decision received at FC from all he cluster heads of SCR clusters is given by

$$R = \sum_{n=1}^{V} d_n \underset{0}{\overset{1}{\gtrless}} C \quad (15)$$

Based on the optimal voting rule [19] used by the fusion centre on the binary decisions from all the cluster heads, the probability of false alarm for the proposed system model is given as

$$P_{fc} = \sum_{n=C}^{V}\binom{V}{n}\left(P_{fscrh}\right)^n\left(1-P_{mscrh}\right)^{V-n} \quad (16)$$

On the similar grounds, the probability of missed detection for the proposed system model is given by

$$P_{mc} = 1 - \sum_{n=C}^{V}\binom{V}{n}\left(1-P_{mscrh}\right)^n\left(P_{mscrh}\right)^{V-n} \quad (17)$$

Let the total error rate of the proposed cluster based multistage relaying CR network be the sum $b_0P_{fc}+b_1P_{mc}$, where $b_0$ & $b_1$ are the weighting factors for $P_{fc}$ & $P_{mc}$ respectively [20]. Now, the optimal number of diversity branch cluster heads C for particular number of cooperative multistage diversity branches V in order to minimize the total error rate is to be calculated. Using (16) & (17) in order to reduce the total error rate, assume the first order derivative with respect to v, we obtain

$$G(c) = b_0\sum_{n=C}^{V}\binom{V}{n}\left(P_{fscrh}\right)^n\left(1-P_{mscrh}\right)^{V-n} + b_1 - b_1\sum_{n=C}^{V}\binom{V}{n}\left(1P_{mscrh}\right)^n\left(P_{mscrh}\right)^{V-n} \quad (18)$$

Optimal value of C is derived by equating differential of (18) w.r.t. C to zero and simplying we get,

$$C = \left\lceil \frac{V}{1+\alpha} + \frac{\ln\frac{b_1}{b_0}}{\ln\frac{P_{fscr}}{P_{mscr}} + \ln\frac{P_{mscr}}{1-P_{fscr}}} \right\rceil \quad (19)$$

Where ⌈.⌉ is the ceil operator & $\alpha=\ln\frac{P_{fscr}}{P_{mscr}} / \ln\frac{P_{mscr}}{1-P_{fscr}}$. In a very special case for dual stage network, considering equal role of weighing factors $b_0=b_1=0.5$, then the expression for C is reduced to

$$C = \left\lceil \frac{V}{1+\alpha} \right\rceil \quad (20)$$

In order to analyse the proposed cluster based multistage relaying CR network with enhanced energy detector as compared to conventional energy detector based CR network we plot some semi log curves between number of SCR clusters vs total error rate at cluster head.

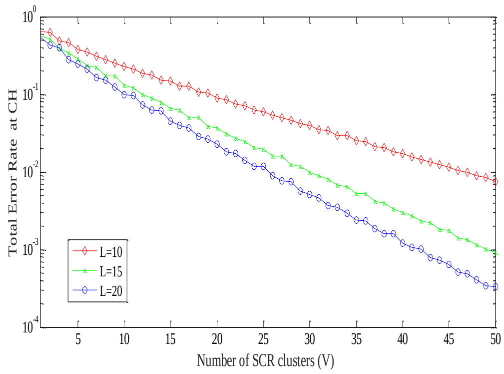


Figure 4: Total error rate vs number of cluster heads to compare the enhanced energy detector with the conventional energy detector based on the proposed MIMO based cooperative spectrum sensing with SNR=- 10db; k=10; e=0.1; $b_0=b_1=0.5$ and a=2.

We analyse the error performance of the proposed system model in presence of enhanced energy detector as compared to that of conventional energy detector [21] with reference to the number of clusters with an optimal threshold to get the minimum number of clusters required to reduce the total error rate. It is shown in fig. 4 that when proposed sensing model is implemented with enhanced energy detector in multistage CR networks with 50 diversity branch clusters, the minimum number of SCR clusters to get reduced error rate is 10.

The error performance of dual stage CR network, Multistage CR network and cluster based multistage CR network is analysed in fig.5. It depicts the total error rate on the basis of SNR for L=10, C=30, k=10, H=5, e=0.1, $b_0=b_1=0.5$ and a=3.5 along with the optimal decision threshold and optimal voting rule applied. It concludes that the total error rate is significantly reduced in multistage sensing CR network with analysed system parameters.

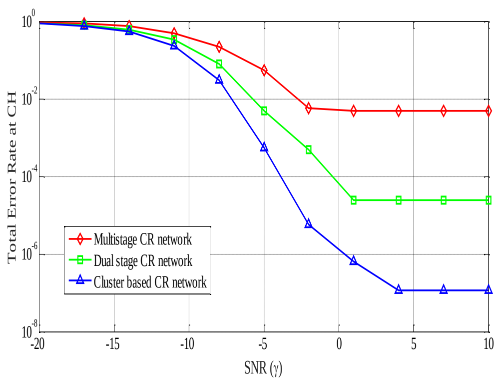


Figure 5: Total error rate vs SNR plots for Dual stage, Multistage & cluster based multistage CR networks with C=30; H=5; k=10; L=10; e=0.1; $b_0=b_1=0.5$; & a=3.5.

## IV. CONCLUSIONS

The error performance of cluster based multistage relaying in cooperative spectrum sensing CR networks is significantly reduced by using enhanced energy detector as compared to conventional energy detector as verified in figure 4. To preserve other parameters like sensing time and other CR resources, we calculated optimal threshold value as well as optimal number of SCR clusters. Implementation of reduced closed form of expression (18) prove that the proposed cluster based sensing technique with diversity of MIMO antennas outperforms the conventional sensing techniques with a single antenna when enhanced energy detector is implemented in terms of total bit error rate as depicted in Figure 5.

## ACKNOWLEDGMENT

I am grateful to all of those with whom I have had the pleasure to work during this research. There was no funding agency involved. There is no conflict of interests and author confirms that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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