Energy detection Analysis of Cluster based Cooperative Spectrum Sensing in Cognitive Relay Network

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Abstract— **In this study, we analyzed an intra-cluster based cooperative energy detection between source (S) and destination (D), the network model consisting of one source, one destination and M number of clusters between the source and destination and each cluster consisting of N number of cognitive relays. We analyzed the performance of inter-cluster and intra-cluster cooperative energy detection. We derived the detection probability and false alarm for the improvement of energy detection of the proposed new scheme; we also provided the efficient number of relays in each cluster to improve the performance of the network. For relative comparison, we simulated similar situation like direct (non-cooperative), inter-cluster and intra-cluster communication between source and destination. Simulation results show that the proposed intra-cluster based network improves the network performance in comparison to direct and inter-cluster communication in terms of energy detection.**

Keyword - Cooperative Communication, Cognitive Relay, Energy Detection, Inter-cluster, Intra-cluster.

I. INTRODUCTION

Due to the fast progression of wireless communication engineering, extreme level of competition has emerged for spectrum sensing. Though, Federal Communication Commission (FCC) indicates the research regarding the spectrum usage of all licensed spectrums can be vacant in numerous places at various times [1]. One of the probable solution to fix the problems of the spectrum sensing, cognitive radio has been granted much attention due to its high spectrum efficiency [2, 3].

The cognitive radio systems make a way for the secondary users (Unlicensed Users) to easily share the unused licensed spectrum without creating appreciable interference at some specified time slot and some specified geographical area. Although, whenever the Primary User (PU) returns in the operation, the secondary user (SU) should vacate the spectrum instantly to prevent unwanted interference with the PU. Therefore the incessant spectrum sensing is demanded to observe the presence of the PU. Moreover, while the channel suffers from fading and shadowing the overall result of the sensing for a cognitive user would be falling down. To fix this complication, cooperative spectrum sensing is suggested to make use of multiuser diversity in sensing technique [4]. This is normally carried out in two consecutive sections: *sensing* and *reporting*. Sensing describes about each cognitive user which carries out spectrum sensing one by one and report the entire local sensing experiences to a receiver and later it'll take a final decision in the absence or the presence of the PU. Most of the earlier work deal with the scenario which sensing experiences are revealed to the receiver by using ideal channels. Though, this is unrealistic because the channels in between the users and the receiver are normally dependent to fading [5]. In spectrum sensing method, energy detection is perceived as the most dependable technique when the previous information of the primary message signal isn't known to the secondary user. Indeed the previous information of the PU is always not anticipated. In this article, we'll concentrate on the energy detection sensing strategy for proposed cluster based network.

As mentioned in the theory of energy detection [6], we can get the detection probability (P_d), the false alarm probability (P_f) which are widely utilized to explain the capability of energy detection of a secondary user (Unlicensed) in spectrum sensing. Most of the earlier work concentrates on single relay network, single relay with multiple antenna or multiple relay in a network [8-9].

Our main contributions in this paper are:

a) Introducing a new method for cooperative cognitive radio network that improved the energy detection based on intra-cluster Cooperative Spectrum Sensing.

b) The closed form expression is derived for the detection probability and the false alarm for the improvement of energy detection of the proposed new method.

c) Best-relay selection on the basis of the maximum received energy in relays.

d) Selection of optimal number of relays in each cluster.

e) Simulation results are discussed to compare the performance of the proposed method with existing methods.

The content of this paper is arranged in the following sections. Section II describes the System model for proposed cluster based cooperative communication. The Proposed methodology is discussed in section III. Analytical Result is presented in Section IV. Section V gives the simulation results and the conclusion of this paper is drawn in Section VI.

II. SYSTEM MODEL

In this study, we consider a clustered based wireless network shown in Fig. 1. It consist of one source and one destination node denoted by S and D, respectively in the XY plane. This XY plane is divided into areas of almost equal size. These areas are created by grouping of randomly generated cognitive relays (CR), having single transmitting and receiving antenna. This group of cognitive relays built a cluster. The distance between each cluster to destination is calculated and assuming that the distance between every cluster is almost equal and it is greater than the distance between the intra-cluster cognitive relays. Let us consider an M number of clusters are formed and each cluster consists of N number of cognitive relays (CR) cooperates for spectrum sensing. Let the channels between source (S) and cognitive relays (CR) are Rayleigh faded with AWGN.

Basically our system model works in 2 steps as mentioned below:

A. *Inter-Cluster Communication)*

As the transmission distance is larger among the clusters, the source (S) can primarily broadcast the message signal to the relays of the first cluster. Then the CRs calculate the energy and the relay having the maximum energy is selected as best-relay for communication. Suppose that the elected best-relay in a cluster wants to send the message signal to the elected best-relay of the adjacent cluster, then the best-relay of first cluster will act as a source and the best-relay of second cluster will act as a destination.

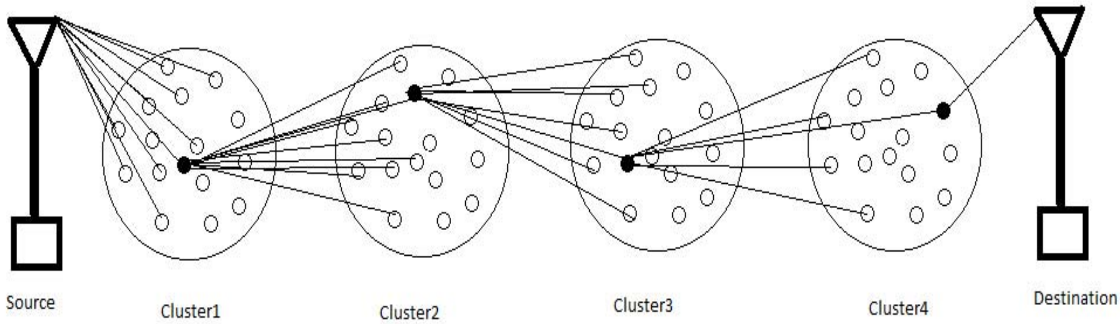

Fig. 1. System model for the Cluster based Communication for cooperative relay selection method

B. *Intra-Cluster Communication*

In Intra cluster communication source (S) broadcasts the message signal or data bits with certain SNR to all CRs of the 1st cluster. Then the relays calculate the energy and the relays having the maximum energy are selected as best-relays. Here we choose two cognitive relays which have received the maximum energy. In 1st hop source (S) transmit the message signal to the 1st best-relay and in 2nd hop, communication 2nd best-relay receives the message signal from the 1st best-relay. Now the 2nd best-relay acts as a source and broadcast to the next cluster.

In this study, we analyze the best-relay selection in terms of detection probability and false-alarm to improve the energy detection in cluster based network for cooperative relay transmission. At 1st time slot, the message signal (x) from source reaches to all the relays of the 1st cluster. The received signal at ith relay is represented by [8],

$$y_{CR,i} = h_{S,CR}\sqrt{px} + n_{S,CR} \qquad (1)$$

The spectrum sensing for ith CR is represented as a binary hypothesis, i.e. [4]

$$y_{CR,i}(t) = \begin{cases} n_{S,CR}(t) \ldots\ldots\ldots\ldots\ldots\ldots H_0 \\ h_{S,CR}\sqrt{px} + n_{S,CR}(t) \ldots\ldots H_1 \end{cases} \qquad (2)$$

Where i=1, 2, 3……, N and $y_{CR,i}(t)$ is a received message signal by a cognitive relay (CR) at its sensing channel input. χ is transmitted message signal from source with zero-mean and $\sigma_S^{\,2}$ is variance Gaussian

Random variable, p is the transmitted power of the message signal. Here, $n_{S,CR}(t)$ is expressed as the noise with zero-mean and variance $\sigma_n^{\ 2}$; $h_{S,CR}$ is represented as the channel coefficient between the source and cognitive relay. The energy detector at CR uses binary hypothesis determines the presence or absence of Source (S).

III. PROPOSED METHODOLOGY

In this section we discuss about the proposed methodology of intra-cluster communication shown in Fig. 2. The energy detection clustering consist of three phases- the broadcasting phase, relay selection phase and received phase.

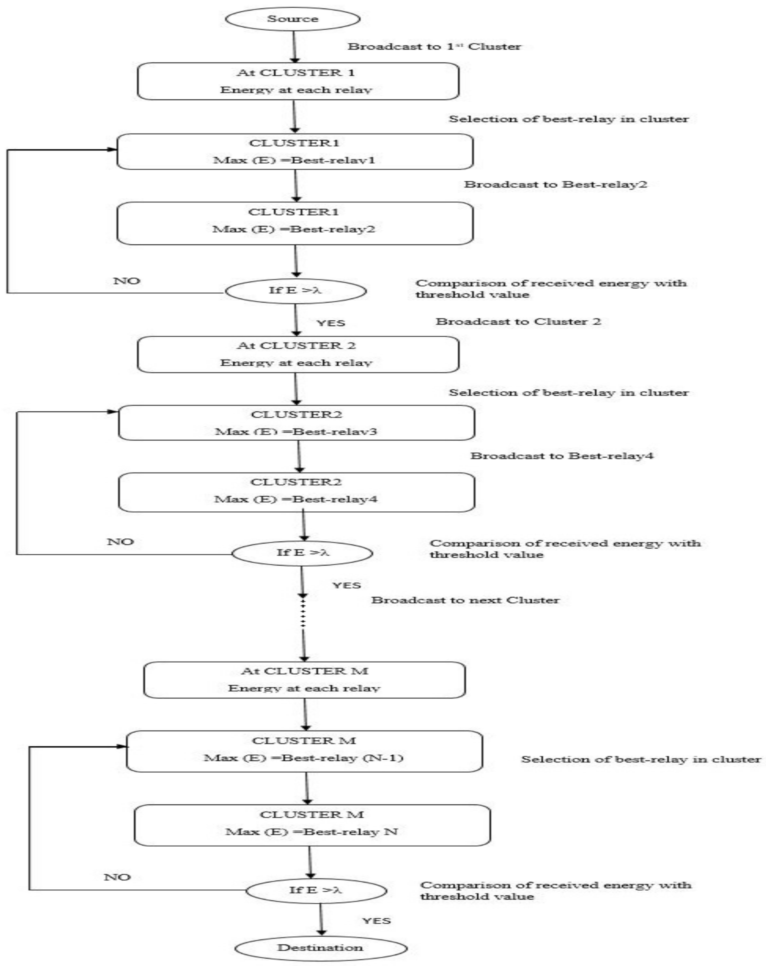

Fig. 2. Flowchart for Proposed Intra-Cluster based Communication Network.

In the broadcasting phase, the source (S) broadcasts the primary message signal to the 1st cluster with certain SNR. In the relay selection phase, the received energy at each relay of 1st cluster is calculated and the relays having the maximum energy is selected as best-relay of a cluster which will send their sensing information to the next cognitive relay. The received energy is represented as,

$$E_{CR,i} = \left|y_{CR,i}\right|^{p} \quad \text{(3)}$$

$$CR_{bestrelay} = \max(E_{CR,i}) \quad \text{(4)}$$

The received energy of the best-relay is compared with a preselected threshold λ at the output of energy detector. If the energy is greater than the preselected threshold, then it broadcasts the message signal to the next cognitive relay (CR) else it sends an acknowledgement to the previous cognitive relay (CR).

$$E_{bestrelay} = \begin{Bmatrix} if \ \left|y_{bestrelay}\right|^{p} > \lambda; \text{ CR broadcast the next CR} \\ if \ \left|y_{bestrelay}\right|^{p} < \lambda; \text{ Send an acknoledgement to previous CR} \end{Bmatrix} \quad \text{(5)}$$

In the received phase, the message signal is received from the cognitive relay of the last cluster in the Network.

IV. ANALYTICAL MODEL OF DETECTION PROBABILITY

The cumulative distribution function (CDF) of an energy detector can be written as [7],

$$F_{E_{bestrelay}}(y)=p\left(\left|y_{bestrelay}\right|^{p}\leq y\right)$$

$$=p\left(\left|y_{bestrelay}\right|\leq y^{1/p}\right) \qquad (6)$$

The probability density function (PDF) can be obtained by differentiating eqn. (6) [7],

$$f_{E_{bestrelay}}(y)=\frac{2}{p}y^{\frac{(1-p)}{p}}.f_{y_{bestrelay}}(y^{1/p}) \qquad (7)$$

Let, $f_{y_{bestrelay}|H_0}(\bullet)$ and $f_{y_{bestrelay}|H_1}(\bullet)$ be the PDF of received message signal under H_0 and H_1 respectively [7],

$$f_{y_{bestrelay}|H_0}(y^{1/p})=\frac{1}{\sqrt{2\Pi\sigma_n^2}}\exp(-\frac{y^{2/p}}{2\sigma_n^2}),y\geq 0 \qquad (8)$$

$$f_{y_{bestrelay}|H_1}(y^{1/p})=\frac{1}{\sqrt{2\Pi(\sigma_S^2+\sigma_n^2)}}\exp(-\frac{y^{2/p}}{2(\sigma_S^2+\sigma_n^2)}),y>0 \qquad (9)$$

Substituting equation (8) and equation (9) in equation (7), the PDF of $E_{bestrelay}$ under hypothesis H_0 and H_1 can be represented as, [7]

$$f_{E_{bestrelay}|H_0}(y)=\frac{\sqrt{2}y^{(1-p)/p}\exp(-\frac{y^{2/p}}{2\sigma_n^2})}{p\sqrt{\Pi\sigma_n^2}},y\geq 0 \qquad (10)$$

$$f_{E_{bestrelay}|H_1}(y)=\frac{\sqrt{2}y^{(1-p)/p}\exp(-\frac{y^{2/p}}{2(\sigma_S^2+\sigma_n^2)})}{p\sqrt{\Pi(\sigma_S^2+\sigma_n^2)}},y>0 \qquad (11)$$

Now, P_d, P_f and P_m can be written as [7],

$$P_d=\int_{\lambda}^{\infty}f_{bestrelay|H_1}(y)dy=\frac{1}{\sqrt{\Pi}}\left[\Gamma\left(1/2,\frac{\lambda^{2/p}}{2\left(\sigma_S^2+\sigma_n^2\right)}\right)\right] \qquad (12)$$

$$P_f=\int_{\lambda}^{\infty}f_{bestrelay|H_0}(y)dy=\frac{1}{\sqrt{\Pi}}\left[\Gamma\left(1/2,\frac{\lambda^{2/p}}{2\sigma_n^2}\right)\right] \qquad (13)$$

$$P_m=1-P_d \qquad (14)$$

The detection probability (P_d) of a cognitive relay over Rayleigh faded channel can be written as [7],

$$P_{d,Ray} = \int_{\gamma} P_d f_{\gamma}(\gamma) d\gamma \qquad (15)$$

Where $f_{\gamma}(\gamma)$ is the PDF of SNR over Rayleigh fading. Hence the detection probability (P_d) over Rayleigh fading can be written as [7],

$$\overline{P_{d,Ray}} = erfc(\sqrt{q}) + \exp(1/\gamma)\left[\exp(-2\sqrt{q/\gamma}) - \sqrt{q/\Pi}\int_0^1 x^{3/2}\exp(-q/x)\exp(-x/\gamma)dx\right] \qquad (16)$$

Where, $q = \lambda^{2/p} / 2\sigma_n^2$.

It is noticed that P_f is independent of fading mechanism. Thus the probability of false-alarm (P_f) under Rayleigh faded can be expressed as [7], $P_{f,Ray} = P_f$.

The selected best-relay of a cluster sends their sensing information under the Rayleigh faded sensing channels to the selected best-relay of the adjacent cluster. Now the previous best-relay acts as a source and present best-relay act as a destination. Thus the message signal is forwarded from source to destination through the clusters in the cooperative cognitive radio network.

V. SIMULATION RESULTS

In this section, we will discuss the performance of the proposed system using MATLAB simulations. A multi-hop cooperative cluster based network with equally spaced M number clusters between the source S and the destination D is considered. Each cluster is equipped with N randomly generated relays. Throughout the simulations the S and the D are located in the XY plane in between 3000 meter area.

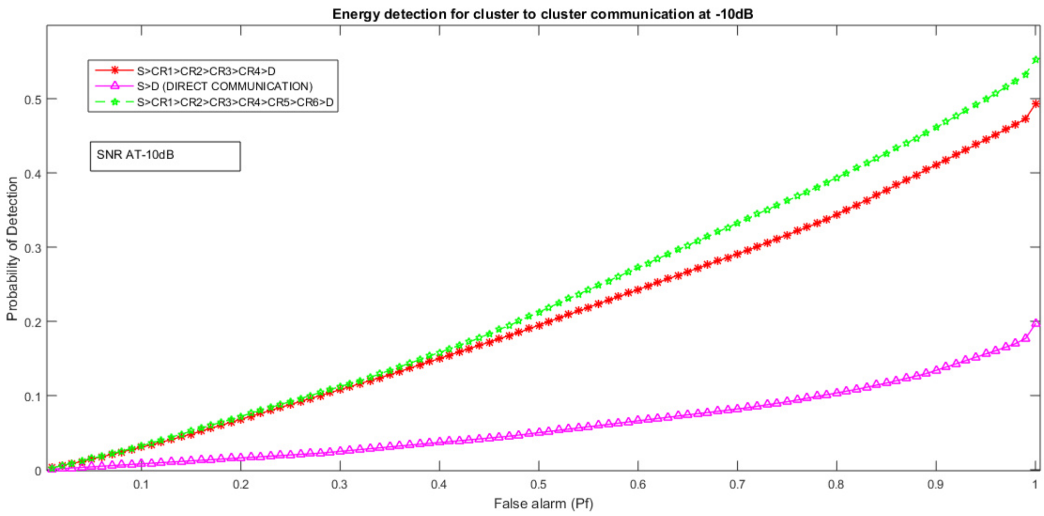

Fig. 3. Energy Detection Analysis for inter-cluster communication at SNR=-10dB

Fig. 3. Shows the energy detection analysis of the proposed system model in terms of detection probability(P_d)and false-alarm probability (P_f) for inter-cluster communication at SNR=-10dB. Here we take M=4 and M=6 in between S and D to compare with direct communication (S→D). We can see that the detection probability (P_d) increases when the number of the cluster increases from M=4 to M=6 and the direct communication from source to destination gives the lowest P_d. So, the energy detection performance can be raised significantly with the increasing number of clusters in the cooperative network.

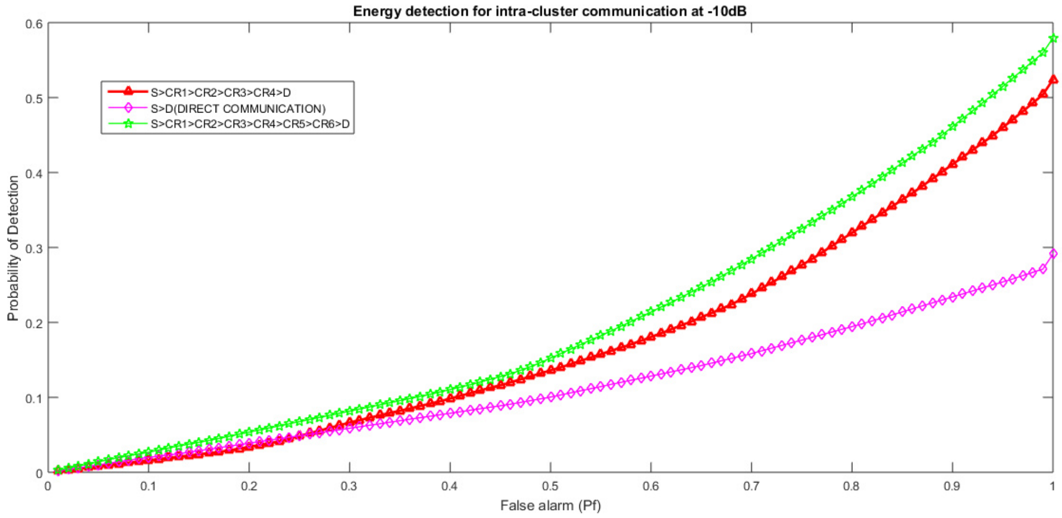

Fig. 4. Energy Detection Analysis for intra-cluster communication at SNR=-10dB

Fig. 4. Shows the energy detection analysis of the proposed system model in terms of detection probability (P_d) and false-alarm probability (P_f) for intra-cluster communication at SNR=-10dB. Here, we take M=4 and M=6 in between S and D to compare with direct communication (S→D). We can notice that the detection probability (P_d) increases when the number of the cluster increases from M=4 to M=6 and the direct communication from source to destination gives the lowest P_d.

Also, it gives better performance in comparison to inter-cluster communication as the communication distance between two cognitive relays are less in case of intra-cluster network. So, the energy detection performance may be enhanced with the increasing number of clusters in the network in case of intra-cluster communication than the inter-cluster communication.

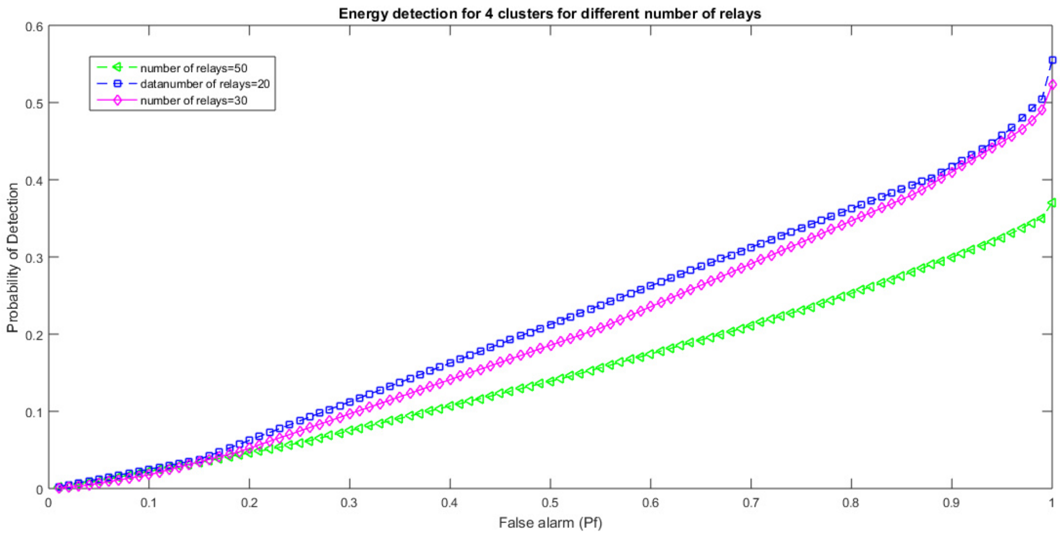

Fig. 5. Energy Detection Analysis for M=4 clusters for different no. of relays (N=20, N=30, N=50) in inter cluster communication.

In Fig. 5. We provide the energy detection performance for different number of relays in each cluster like N=20, N=30, N=50 in between the Source and Destination in 4 inter-cluster communication. We notice that N=20 gives better performance than the N=30 and N=50. So, the optimal number of cognitive relays in each cluster for 4 inter-cluster communication are 20 which gives the better energy detection performance.

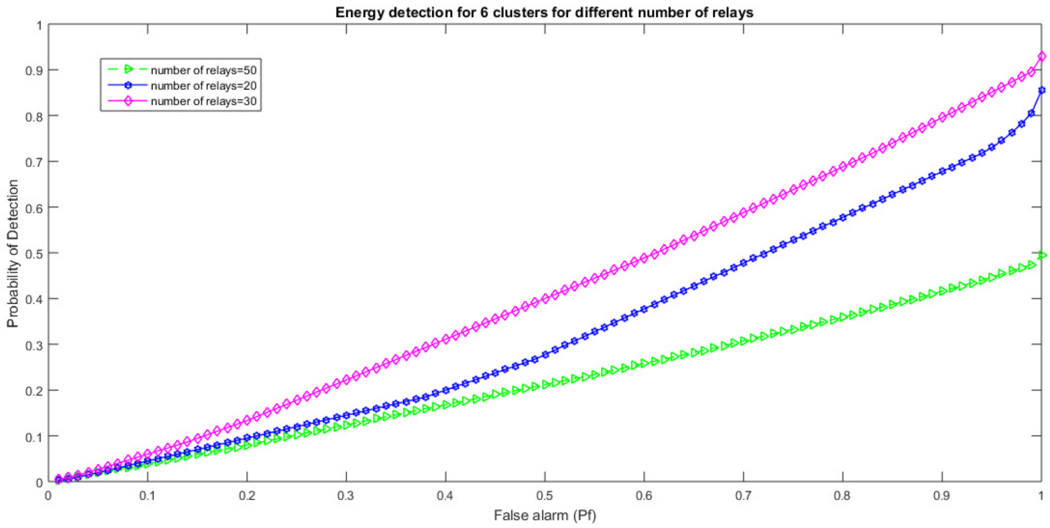

Fig. 6. Energy Detection Analysis for M=6 clusters for different no. of relays (N=20, N=30, N=50) in inter cluster communication

In Fig. 6. We provide the energy detection performance for different number of relays in each cluster like N=20, N=30, N=50 in between the Source and Destination in 6 inter-cluster communication. We notice that N=30 gives better performance than the N=20 and N=50. So, the optimal number of cognitive relays in each cluster for 6 inter-cluster communication are 30 which gives the better energy detection performance.

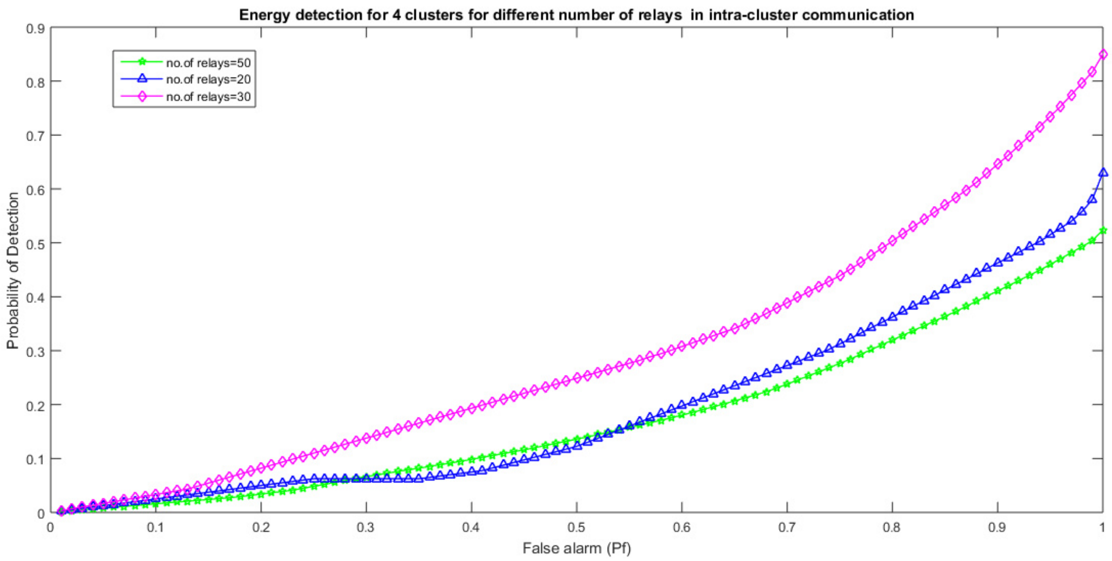

Fig. 7. Energy Detection Analysis for M=4 clusters for different no. of relays (N=20, N=30, N=50) in intra-cluster communication

In Fig. 7, We show the comparison of the energy detection performance for different number of relays in each cluster like N=20, N=30, N=50 in between the Source and Destination in 4 intra-cluster communication. We can see that N=30 gives better performance than the N=20 and N=50. So, the optimal number of cognitive relays in each cluster for 4 intra-cluster communication are 30 which gives the better energy detection performance.

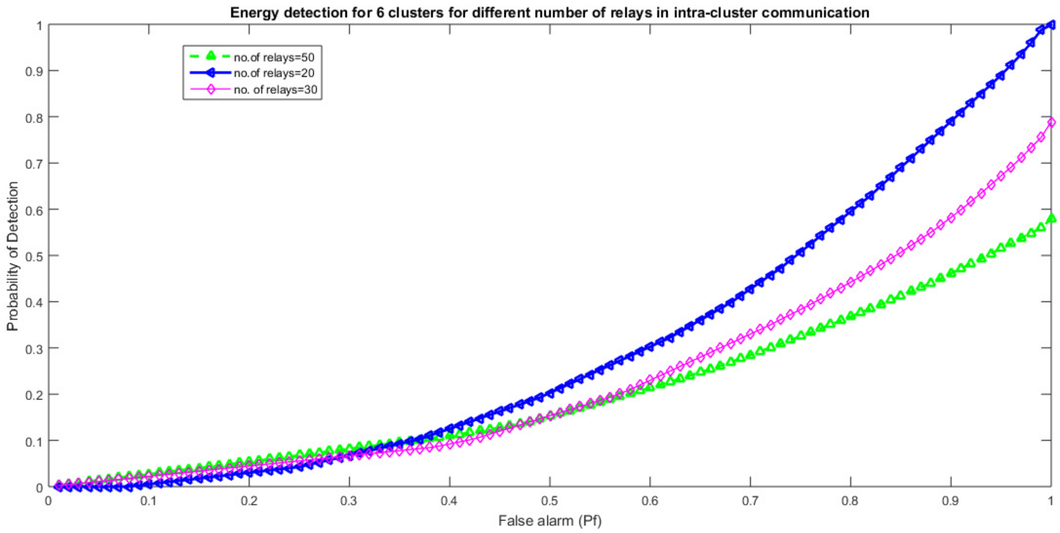

Fig. 8. Energy Detection Analysis for M=6 clusters for different no. of relays (N=20, N=30, N=50) in intra-cluster communication.

In Fig. 8. We give the comparison of the energy detection performance for different number of relays in each cluster like N=20, N=30, N=50 in between the Source and Destination in 6 intra-cluster communication. We can see that N=20 gives better performance than the N=30 and N=50. So, the optimal number of cognitive relays in each cluster for 6 intra-cluster communication are 20 which gives the better energy detection performance. From Fig. 5, Fig6, Fig. 7 and Fig. 8 we can say that optimal number of relay selection increases the energy detection performance.

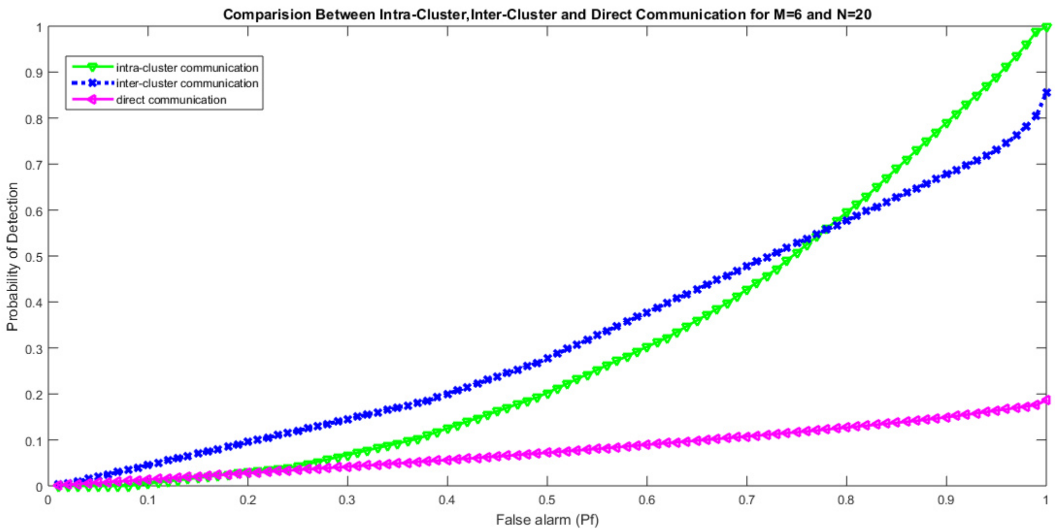

Fig. 9. Comparative Energy Detection Analysis in between intra-cluster, inter-cluster and direct communication for M=6 clusters and N=20 cognitive relays.

In Fig. 9. We give the comparative energy detection analysis in between intra-cluster, inter-cluster and direct communication at SNR=-10dB for M=6 number of clusters in between the source and destination and each cluster consist of N=20 number of relays. Here, we can notice that proposed intra-cluster communication gives a better detection performance than the inter-cluster and direct communication.

VI. CONCLUSION

In this article, we analyzed the energy detection performance of cluster based cooperative communication network for direct communication (non-cooperative), intra-cluster and inter-cluster communication. We proposed an intra-cluster based network for cooperative spectrum sensing based on best-relay selection, comparative results with inter-cluster and direct communication shows that the proposed intra-cluster based communication improves the energy detection performance by increasing the number of clusters in the network. The simulation results also show that the optimal number of relays in each cluster, which improves the performance of the network in terms of detection probability and false-alarm. It has been shown that the all over network performance of the intra-cluster communication network is improved in comparison to the direct communication and inter-cluster communication network.

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