

Performance Analysis of Decode–Amplify-and-Forward Scheme used in Relay-based Cooperative Spectrum Sensing in Cognitive Radio Network

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ABSTRACT

In this paper we have analyzed performance of relay based Cognitive Radio (CR) networks. Later on we present a scheme for cooperative spectrum sensing known as Detect-Amplify-and-Forward (DAF). This technique is having the capacity of sensing over non-identical Nakagami- m fading channels. We have also introduced an advanced statistical approach to derive a new relation in order to calculate the average false alarm probability and average detection probability.

In subsequent section it is also proved that a small number of reliable cognitive radios are enough to achieve practical detection level in cooperative spectrum sensing instead of incorporating all CRs. The simulation results shows improvement in detection accuracy and reduction in bandwidth requirement of the relaying links by abstaining from the heavily faded relays in the DAF scheme

Keywords

Cooperative Spectrum Sensing, Cognitive radio, Energy detection, Decode-Amplify-and-Forward.

1. INTRODUCTION

Spectrum sensing is a major task in cognitive networks. The spectrum sensing efficiency can be improved by cooperative spectrum sensing because fusion center collects the sensing information from many CRs and afterward takes final decision about the presence or absence of PU [1]. When cooperative relay based networks are used; two paths become really important first the sensing paths from the source (primary user) to the relays (CR users), and second the relaying paths from the relays to the receiver [2]. There are two types of protocols generally used in these networks either Amplify Forward (AF) protocol or Decode Forward (DF) protocol. In AF protocol measurements are sent to fusion center and In DF protocol decisions are sent to fusion center. The advantage of DF protocol is that it needs less bandwidth on the other hand AF protocol helps in reducing complexity at the local radios.

Generally two types of gain based relays are used. The relay based on amplifying gain is known as channel state information (CSI)-assisted relay and fixed-gain relay. In (CSI)-assisted relay vary gain according to the sensed power [3]. On the other hand, the fixed-gain relay amplifies and forwards the received signal with a constant gain which results in an output signal with variable power. The fixed-gain relay also reduces the complexity of relay, but CSI assisted relay can perform better when fading channels are used.

It is found by the researchers that Relay-based CR improves the performance of both spectrum sensing and secondary transmissions. It is also found that secondary users with higher detection probabilities constantly act as relays to help those with lower detection probabilities in a distributed network with i.i.d. Rayleigh fading channels is considered .

We analyse the performance DAF relaying scheme that reduces the required bandwidth. We will see that multipath fading on relaying channels yields similar performance degradations as multipath fading on sensing channels.

We will mainly analyse,

- 1) A Detect-Amplify-and-Forward (DAF) relaying scheme for CSS over non-identical Nakagami- m fading channels.
- 2) An error analysis scheme to investigate the truncating infinite series that appear in the closed-form expressions of false alarm probability and detection probability.

2. RELAY SCHEMES

There are three main relay schemes namely as AF, DF and DAF. There are four finite sets X_1 , X_2 , Y_1 , and Y in a single relay channel. Conditional probability distribution $p(y, y_1 | x_1, x_2)$ on these sets, and the probability distribution of the choice of symbols selected by the encoder and the relay encoder is represented by (x_1, x_2)

2.1 Amplify-and-Forward (AF) relay scheme

In this relaying scheme, the relay sends an amplified received signal to the fusion center in last time slot. It requires much less delay because the relay node operates time-slot by time-slot. It also consumes less computing power because decoding or quantizing operation is performed at the relay side [4].

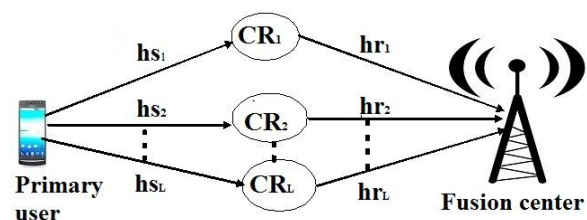


Fig.1 System model

We assume a CR network having L secondary shown in Fig.1. Where decision made by a fusion center. The

secondary users, $\{CR_i\}_{i=1}$, denotes the system relays and shares the same spectrum band with the primary users. The channel fading parameter of the i th sensing link is h_{s_i} and the i th relaying link is h_{r_i} . We also denote by n_{s_i} and n_{r_i} is additive Gaussian noise of sensing channel, It is assumed to be i.i.d with zero mean and variance N_0 [5].

We It is also assumed that channel state information (CSI) is available for all the relays and fusion center has a full knowledge of CSI. it can collect knowledge of sensing and relaying channel gains. The time slot structure used is shown in Fig.2.

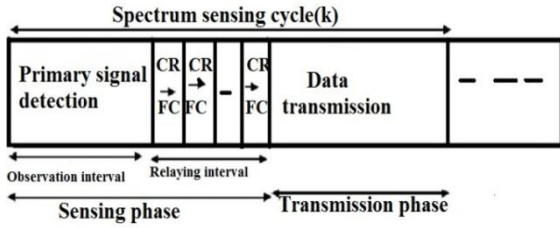


Fig.2 Time slot structure

Let x_p denotes the signal transmitted by the primary radio, then the received signal by the i^{th} CR user, then y_{s_i} , can be expressed as

$$y_{s_i} = \theta h_{s_i} x_p + n_{s_i} \quad (1)$$

Where $\theta = 0$ or 1 denotes the primary user state under two hypotheses H_0 for primary user absence and H_1 for primary user presence.

If Y_{s_i} denotes the power of y_{s_i} , then the mean value of Y_{s_i} can be expressed as

$$E[Y_{s_i}] = \begin{cases} \sigma_{Y_{s_i}} = E_i & H_0 \\ \sigma_{Y_{s_i}} = E_i + N_0 = N_0(1 + \widehat{\gamma}_{s_i}) & H_1 \end{cases} \quad (2)$$

where, $E_i = E\{|h_{s_i} x_p|^2\}$ is the mean value of the signal power as received at the RF front-end of the i th CR receiver and $\widehat{\gamma}_{s_i} = E_i/N_0$ is the average SNR associated with the i th sensing link[6],[7],[8]. For local spectrum sensing, Y_{s_i} is compared with a given threshold λ_i to infer the primary state θ . Hence, the false alarm probability, P_{f_i} , and the detection probability, P_{d_i} , can be expressed as .

$$P_{f_i} = \int_{\delta_i}^{\infty} \left(\frac{m_i}{\sigma_{Y_{s_i0}}} \right)^{m_i} \frac{y^{m_i-1}}{\Gamma(m_i)} e^{\left(-\frac{m_i}{\sigma_{Y_{s_i0}}} \right) y} dy$$

$$= \frac{\Gamma\left(m_i, \frac{m_i \lambda_i}{\sigma_{Y_{s_i0}}} \right)}{\Gamma(m_i)} = \frac{\Gamma\left(m_i, \frac{m_i \lambda_i}{N_0} \right)}{\Gamma(m_i)} \quad (3)$$

and

$$P_{d_i} = \int_{\delta_i}^{\infty} \left(\frac{m_i}{\sigma_{Y_{s_i1}}} \right)^{m_i} \frac{y^{m_i-1}}{\Gamma(m_i)} e^{\left(-\frac{m_i}{\sigma_{Y_{s_i1}}} \right) y} dy$$

$$= \frac{\Gamma\left(m_i, \frac{m_i \lambda_i}{\sigma_{Y_{s_i1}}} \right)}{\Gamma(m_i)} = \frac{\Gamma\left(m_i, \frac{m_i \lambda_i}{N_0(1 + \widehat{\gamma}_{s_i})} \right)}{\Gamma(m_i)} \quad (4)$$

2.1.1 Single relay scheme

In the AF relaying scheme, CR users amplify the received signal and directly relay to the fusion center [9]. It is assumed that each CR relay has a maximum power constraint, P_i . Hence, it measures the average received signal power and scales it appropriately so that the power constraint is satisfied. Accordingly, the signal received at the fusion center takes the form

$$y_i = h_{r_i} \left(\sqrt{A_i} (\theta h_{s_i} x_p + n_{s_i}) \right) + n_{r_i}$$

$$= \theta \sqrt{A_i} h_{r_i} h_{s_i} x_p + \sqrt{A_i} h_{r_i} n_{s_i} + n_{r_i} \quad (5)$$

Where A_i denotes the dimensionless amplification factor of the i th CR relay. According to the maximum power constraint, A_i is selected as

$$A_i = \frac{P_i}{E_i + N_0} \quad (6)$$

In order to accommodate the two hypotheses H_0 and H_1 , we define $g_i = |h_{r_i}|^2$ as the instantaneous channel gain of the i th relaying link and $\bar{g}_i \triangleq E\{|h_{r_i}|^2\}$ as the expected value of g_i . Since h_{r_i} follows a Nakagami- m distribution, it is easy to verify that g_i follows a gamma distribution given by

$$f_{G_i}(g) = \left(\frac{m_i}{\bar{g}_i} \right)^{m_i} \frac{g^{m_i-1}}{\Gamma(m_i)} e^{\left(-\frac{m_i}{\bar{g}_i} \right) g}, \quad g \geq 0 \quad (7)$$

Let Y_i denotes the power of the the relayed signal y_i , then from (5), the mean value of Y_i for a given g can be expressed as

$$E\{Y_i | g\} = \begin{cases} \sigma_{Y_{i0}} = N_0(1 + \widehat{\theta}_i \sqrt{A_i g}) & H_0 \\ \sigma_{Y_{i1}} = N_0(1 + \widehat{\theta}_i (1 + \widehat{\gamma}_{s_i}) \sqrt{A_i g}) & H_1 \end{cases} \quad (8)$$

Therefore, the probability of the false alarm for a given g can be evaluated as

$$P_{f_i}^{AF} = \left(\frac{\beta_i}{A_i} \right) \int_{\delta_i}^{\infty} \left(\frac{m_i}{\sigma_{Y_{s_i0}}} \right)^{m_i} \frac{y^{m_i-1}}{\Gamma(m_i)} e^{\left(-\frac{m_i}{\sigma_{Y_{s_i0}}} \right) y} dy =$$

$$\frac{1}{\Gamma(m_i)} \Gamma\left(m_i, \frac{m_i \lambda_i}{N_0(1 + \widehat{\gamma}_{s_i})} \right) \quad (9)$$

where, the integral in (9) is evaluated with the help of [31, Eq. 3.383.5] and λ denotes the decision threshold used by the fusion center to infer the primary state θ . Now, we remove the condition on g and compute an average false alarm probability P_{f_i} by integrating over the PDF of the channel gain given in (7) as follows

Evaluating the integral in (10) as described in Appendix A.1, $P_{f_i}^{AF}$ can be expressed mathematically as

$$P_{f_i}^{AF} = \left(\frac{\beta_i}{A_i} \right)^{m_i} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i \lambda}{N_0} \right)^q \sum_{n=0}^{\infty} (-1)^n b_n \times$$

$$U\left(m_i; m_i + 1 - q - n; \frac{\beta_i}{A_i}\right) \quad (10)$$

where, $\beta_i = m_i/g_i$, $b_n = (\Gamma/n!)(m_i\lambda/N_0)^n$, and $U(;;;)$ is the confluent hyper geometric function of the second kind defined in [29, Eq. 13.1.3]. Similarly, the average detection probability P_d can be obtained as

$$\bar{P}_{fd}^{AF} = \left(\frac{B_i}{(1+\gamma_{s_i})A_i}\right)^{m_i} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i\lambda}{N_0}\right)^q \sum_{n=0}^{\infty} (-1)^n b_n \times U\left(m_i; m_i + 1 - q - n; \frac{\beta_i}{(1+\gamma_{s_i})A_i}\right) \quad (11)$$

2.1.2 Multi relay scheme

Many performance analysis problems require determination of statistics of the sum of the squared envelopes of the faded signals over several diversity paths [10], which can be achieved through EGC technique. For L inputs, the output of the EGC receiver can be expressed as

$$y = \sum_{i=0}^L \sqrt{A_i} h_{r_i} (\theta h_{s_i} x_p + n_{s_i}) + n_{r_i} = \theta \sum_{i=1}^L \sqrt{A_i} h_{r_i} h_{s_i} x_p + \sum_{i=1}^L \sqrt{A_i} h_{r_i} n_{s_i} + n_{r_i} \quad (12)$$

If Y denotes the power at the output of the EGC receiver, then for given g_i 's, the mean value of Y can be expressed as

$$E\{Y|g_i's\} = \begin{cases} \sigma_{Y_0} = N_0(1 + \sum_{i=1}^L A_i g_i) & H_0 \\ \sigma_{Y_1} = N_0(1 + \sum_{i=1}^L (1 + \gamma_{s_i}) A_i g_i) & H_1 \end{cases} \quad (13)$$

Over Nakagami- m channel fading, the average false alarm probability, P_{fa}^{AF} , for any number of cognitive radio relays, L , in a multi-relay AF system is given by

$$\bar{P}_f^{AF} = \left[\prod_{l=1}^L \left(-\frac{\beta_l}{A_l}\right)^{m_l} \right] \sum_{i=1}^L \sum_{v=1}^{m_i} (-1)^v b_{iv} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i\lambda}{N_0}\right)^q \sum_{n=0}^{\infty} (-1)^n b_n U\left(v; v + 1 - q - n; \frac{\beta_i}{A_i}\right) \quad (14)$$

Where

$$b_{iv} = \left[\frac{\Delta_i}{(m_i-v)!} \sum_{i_1=0}^{m_i-v-1} \binom{m_i-v-1}{i_1} B_i^{m_i-v-1} \sum_{i_2=0}^{i_1-1} \binom{i_1-1}{i_2} B_i^{i_1-1-i_2} \sum_{i_3=0}^{i_2-1} \binom{i_2-1}{i_3} B_i^{i_2-1-i_3} \right] \times \quad (15)$$

$$\Delta_i = \prod_{j=1}^L \left(\frac{\beta_i}{A_i} - \frac{\beta_j}{A_j}\right)^{m_j}$$

and

$$B^t_i = (-1)^{t+1} t! \sum_{j=1}^L m_j \left(\frac{\beta_i}{A_i} - \frac{\beta_j}{A_j}\right)^{-(t+1)}$$

If the diversity paths have i.i.d Nakagami- m fading, then the average false alarm probability P_f and the average detection probability P_d can be expressed as

$$\bar{P}_d^{AF} = \left[\prod_{l=1}^L \left(-\frac{B_l}{(1+\gamma_{s_l})A_l}\right)^{m_l} \right] \sum_{i=1}^L \sum_{v=1}^{m_i} (-1)^v$$

$$\times b_{iv} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i\lambda}{N_0}\right)^q \sum_{n=0}^{\infty} (-1)^n b_n$$

$$\times U\left(v; v + 1 - q - n; \frac{\beta_i}{(1+\gamma_{s_l})A_i}\right) \quad (16)$$

Over Rayleigh fading channels, P_{fRay}^{AF} and P_{dRay}^{AF} is evaluated [11],[12] by setting $m_j = 1, i=1, \dots, L$ in equation (17) and (18) .

$$\bar{P}_{fRay}^{AF} = (-1)^{L+1} \prod_{l=1}^L \frac{1}{A_l \bar{g}_l} \sum_{i=1}^L \bar{\Delta}_i \sum_{n=0}^{\infty} (-1)^n \times \bar{b}_n U\left(1; 2 - n; \frac{1}{A_i \bar{g}_i}\right) \quad (17)$$

$$\bar{P}_{dRay}^{AF} = (-1)^{L+1} \prod_{l=1}^L \frac{1}{(1+\gamma_{s_l})A_l \bar{g}_l} \sum_{i=1}^L \bar{\Delta}_i \sum_{n=0}^{\infty} (-1)^n \times \bar{b}_n U\left(1; 2 - n; \frac{1}{(1+\gamma_{s_l})A_i \bar{g}_i}\right) \quad (18)$$

Where

$$\bar{\Delta}_i = \prod_{j=1}^L \left(\frac{1}{A_i \bar{g}_i} - \frac{1}{A_j \bar{g}_j}\right)$$

2.2 Decode-and-Forward (DF) relay scheme

In this scheme, the relay decodes the message in one block and transmits the re-encoded message in the next block. The achievable rate of DF can be expressed as $\max_{p(x_1, x_2)} \min_{(y_1 | x_2), (x_2 | y_1)} I(x_1, x_2; y)$

2.3 Decode-Amplify-and-Forward (DAF) relay scheme

In this relay scheme CR detects received signal in the observation interval. If the decision is that PU is absent, the CR keeps quiet and transmits only an indicator signal to the fusion center during its relaying time slot. Otherwise, if the PU is present, the CR amplifies the signal and forwards it to the fusion center.

2.4.1. Single relay scheme

According to the DAF scheme, every CR user performs detection and takes its own decision θ_i about the primary user. Then, if $\theta_i = 1$, the CR user amplifies and relays its local sensing to the fusion center. Otherwise, it keeps quiet if $\theta_i = 0$.

The signal received at fusion center at i^{th} link [13]

$$y_i = \hat{\theta}_i h_{r_i} \left(\sqrt{A_i} (\theta h_{s_i} x_p + n_{s_i}) \right) + n_{r_i} = \theta \theta_i \sqrt{A_i} h_{r_i} x_p + \hat{\theta}_i \sqrt{A_i} h_{r_i} h_{s_i} x_p + \hat{\theta}_i \sqrt{A_i} h_{r_i} n_{s_i} + n_{r_i} \quad (19)$$

And

$$E\{Y_i | g\} = \begin{cases} \sigma_{Y_{i0}} = N_0(1 + \hat{\theta}_i \sqrt{A_i} g) H_0 \\ \sigma_{Y_{i1}} = N_0(1 + \hat{\theta}_i (1 + \gamma_{s_i}) \sqrt{A_i} g) H_1 \end{cases} \quad (20)$$

Average false alarm probability over a Nakagami-m channel Under hypothesis H_0 can be given by

$$\bar{P}_{f_i}^{DAF} = \sum_{\hat{\theta}_i=0}^{\hat{\theta}_i=1} P_{(i|H_0)} \left(\frac{\beta_i}{A_i}\right)^{m_i} \sum_{q=0}^{m_i-1} \left(\frac{m_i \lambda_i}{N_0}\right)^q \frac{1}{q!} \times \sum_{n=0}^{\infty} (-1)^n b_n U\left(m_i; m_i + 1 - q - n; \frac{\beta_i}{A_i}\right) \quad (21)$$

Similarly, the average detection probability P_{di}^{DAF} can be expressed as

$$\bar{P}_{d_i}^{DAF} = \sum_{\hat{\theta}_i=0}^{\hat{\theta}_i=1} P_{(i|H_0)} \left(\frac{\beta_i}{(1+\bar{\gamma}_{si})A_i}\right)^{m_i} \sum_{q=0}^{m_i-1} \left(\frac{m_i \lambda_i}{N_0}\right)^q \frac{1}{q!} \times \sum_{n=0}^{\infty} (-1)^n b_n U\left(m_i; m_i + 1 - q - n; \frac{\beta_i}{(1+\bar{\gamma}_{si})A_i}\right) \quad (22)$$

where,

$$P_{(i|H_0)} = P_{f_i} \hat{\theta}_i (1 - P_{f_i})^{1-\hat{\theta}_i}$$

2.4.2. Multi relay scheme

In this scheme CR makes its own decision then amplifies and forwards to the fusion center only when primary user is present. The signal can be expressed as

$$y = \sum_{i=0}^L \bar{\theta}_i \sqrt{A_i h_{ri}} (\theta h_{si} x_p + n_{si}) + n_{r_i}$$

$$= \sum_{i=0}^L \bar{\theta}_i \sqrt{A_i} h_{ri} h_{si} x_p + \sum_{i=0}^L \bar{\theta}_i \sqrt{A_i} h_{ri} n_{si} + n_{r_i} \quad (23)$$

for given g_i 's [14], the mean value of Y can be expressed

$$E\{Y_i|g\} = \begin{cases} \sigma_{Y_{i_0}} = N_0 \left(1 + \sum_{i=1}^L \bar{\theta}_i \sqrt{A_i} g\right) H_0 \\ \sigma_{Y_{i_1}} = N_0 \left(1 + \hat{\theta}_i (1 + \sum_{i=1}^L 1 + \bar{\gamma}_{si}) \theta_i A_i g\right) H_1 \end{cases} \quad (24)$$

Average false alarm probability over a Nakagami-m channel

Under hypothesis H_0 can be given by

$$\bar{P}^{DAF}_f = \sum_{j=1}^{2^L} \left[\prod_{i=1}^L P^j_{(i|H_0)} \right] \left[\prod_{l=1, \hat{\theta}^j_l \neq 0}^L \left(-\frac{\beta_l}{A_l}\right)^{m_l} \right] \times \sum_{i=1, \hat{\theta}^j_i \neq 0}^L \sum_{v=1}^{m_i} (-1)^v b_{iv} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i \lambda}{N_0}\right)^q \sum_{n=0}^{\infty} (-1)^n b_n U\left(v; v + 1 - q - n; \frac{\beta_i}{A_i}\right) \quad (25)$$

Similarly, the average detection probability P_{di}^{DAF} can be expressed as [15]

$$\bar{P}^{DAF}_{di} = \sum_{j=1}^{2^L} \left[\prod_{i=1}^L P^j_{(i|H_0)} \right] \left[\prod_{l=1, \hat{\theta}^j_l \neq 0}^L \left(-\frac{\beta_l}{(1+\bar{\gamma}_{sl})A_l}\right)^{m_l} \right] \times \sum_{i=1, \hat{\theta}^j_i \neq 0}^L \sum_{v=1}^{m_i} (-1)^v b_{iv} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i \lambda}{N_0}\right)^q \sum_{n=0}^{\infty} (-1)^n b_n U\left(v; v + 1 - q - n; \frac{\beta_i}{(1+\bar{\gamma}_{sl})A_i}\right) \quad (26)$$

For Rayleigh fading channels P_{fRay} and P_{dRay} are evaluated by setting $m_i = 1; i = 1; \dots; L$ in (25) and (26)

$$\bar{P}^{DAF}_{fRay} = (-1)^{\sum_{i=1, \hat{\theta}^j_i \neq 0}^L k+1} \times \sum_{j=1}^{2^L} \left[\prod_{i=1}^L P^j_{(i|H_0)} \right] \times \prod_{i=1, \hat{\theta}^j_i \neq 0}^L \frac{1}{A_i \bar{\theta}_i} \sum_{i=1, \hat{\theta}^j_i \neq 0}^L \bar{\Delta}_l \sum_{n=0}^{\infty} (-1)^{n+1} \bar{b}_n U\left(1; 2 - n; \frac{1}{A_i \bar{\theta}_i}\right) \quad (27)$$

$$\bar{P}^{DAF}_{fRay} = (-1)^{\sum_{i=1, \hat{\theta}^j_i \neq 0}^L k+1} \times \sum_{j=1}^{2^L} \left[\prod_{i=1}^L P^j_{(i|H_0)} \right] \times \prod_{i=1, \hat{\theta}^j_i \neq 0}^L \frac{1}{(1 + \bar{\gamma}_{sl}) A_i \bar{\theta}_i} \times \sum_{i=1, \hat{\theta}^j_i \neq 0}^L \bar{\Delta}_l \sum_{n=0}^{\infty} (-1)^{n+1} \bar{b}_n U\left(1; 2 - n; \frac{1}{(1 + \bar{\gamma}_{sl}) A_i \bar{\theta}_i}\right) \quad (28)$$

3. APPROXIMATION OF AVERAGE PROBABILITIES

3.1 Approximated probability of false alarm and detection for AF scheme

Approximated probability of false alarm and probability of detection for AF scheme can be given by [16].

$$\bar{P}^{AF}_f = 2 \left[\prod_{i=1}^L \left(-\frac{\beta_i}{A_i}\right)^{m_i} \right] \sum_{i=1}^L \sum_{v=1}^{m_i} \frac{(-1)^v b_{iv}}{\Gamma(v)} \times \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i \lambda}{N_0}\right)^{v+q} \left(\frac{A_i}{\beta_i}\right)^{\frac{v-q}{2}} K_{q-v} \left(2 \sqrt{\frac{m_i \beta_i \lambda}{N_0 A_i}}\right) \quad (29)$$

$$\bar{P}^{AF}_d = 2 \left[\prod_{i=1}^L \left(-\frac{\beta_i}{(1+\bar{\gamma}_{sl})A_i}\right)^{m_i} \right] \sum_{i=1}^L \sum_{v=1}^{m_i} \frac{(-1)^v b_{iv}}{\Gamma(v)} \times \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i \lambda}{N_0}\right)^{v+q} \left(\frac{(1+\bar{\gamma}_{sl})A_i}{\beta_i}\right)^{\frac{v-q}{2}} K_{q-v} \left(2 \sqrt{\frac{m_i \beta_i \lambda}{N_0 (1+\bar{\gamma}_{sl})A_i}}\right) \quad (30)$$

where, $K_\nu(\cdot)$ is the ν -order modified Bessel function of the second kind.

3.2 Approximated probability of false alarm and detection for DAF scheme

Approximated probability of false alarm and probability of detection for DAF scheme can be given by

$$\bar{P}^{DAF}_f = \sum_{j=1}^{2^L} \left[\prod_{i=1}^L P^j_{(i|H_0)} \right] \left[\prod_{i=1, \hat{\theta}^j_i \neq 0}^L \left(-\frac{\beta_i}{A_i}\right)^{m_i} \right] \times \sum_{i=1, \hat{\theta}^j_i \neq 0}^L \sum_{v=1}^{m_i} \frac{(-1)^v b_{iv}}{\Gamma(v)} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i \lambda}{N_0}\right)^{v+q} \left(\frac{A_i}{\beta_i}\right)^{\frac{v-q}{2}} K_{q-v} \left(2 \sqrt{\frac{m_i \beta_i \lambda}{N_0 A_i}}\right) \quad (31)$$

$$\bar{P}^{DAF}_d = \sum_{j=1}^{2^L} \left[\prod_{i=1}^L P^j_{(i|H_0)} \right] \left[\prod_{i=1, \hat{\theta}^j_i \neq 0}^L \left(-\frac{\beta_i}{(1+\bar{\gamma}_{sl})A_i}\right)^{m_i} \right] \times \sum_{i=1, \hat{\theta}^j_i \neq 0}^L \sum_{v=1}^{m_i} \frac{(-1)^v b_{iv}}{\Gamma(v)} \sum_{q=0}^{m_i-1} \frac{1}{q!} \left(\frac{m_i \lambda}{N_0}\right)^{v+q} \left(\frac{(1+\bar{\gamma}_{sl})A_i}{\beta_i}\right)^{\frac{v-q}{2}} K_{q-v} \left(2 \sqrt{\frac{m_i \beta_i \lambda}{N_0 (1+\bar{\gamma}_{sl})A_i}}\right) \quad (32)$$

4. RESULTS AND PERFORMANCE ANALYSIS

To test the accuracy of the derived expressions and the performance of novel CR network method we perform simulations. The noise variance N_0 and E_i is unity (0 dB) and an upper bound of $P_f \leq 0.1$ and a lower bound of $P_d \geq 0.9$

are considered.

Fig.3 shows probability of missed detection ($1 - P_d$) versus probability of false alarm graph. Variety of diversity paths Are used to plot ROC curves of the energy detector. the values average false alarm probability and the average detection probability are computed from Equations (25) and (26) One can see from Fig. 3 that when the number of cooperative users increases The performance of the energy detector significantly improves. The case with $L = 1$ corresponds to the no-diversity scenario (single-relay system).

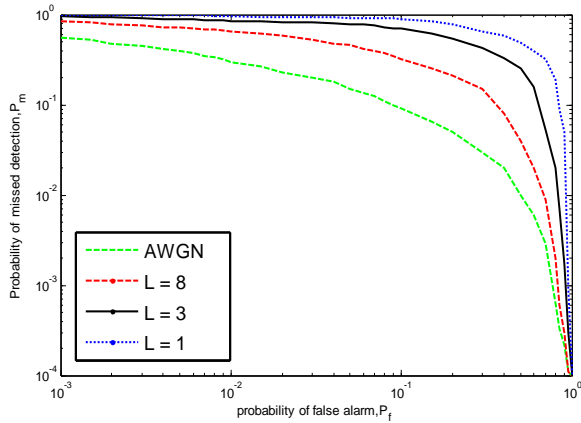


Figure 3: ROC curves of the energy detector with $m = 2$, $P = 5$ dB, and $s = 0$ dB.

In Fig.4 we plot P_d^{AF} and P_d^{DAF} for different number of cooperative users to compare the performance of the diversity system between AF and DAF schemes, we can that the detection accuracy is greatly improved when the number of cooperative users increases for both schemes. But, the DAF scheme performs better than the AF scheme for all the values.

This is because the cooperative users who have reliable detection probability are allowed to forward their local measurements to the fusion center. The difference in the performance of the DAF and AF strategies becomes more visible as the number of cooperative users increases. But if the number of the heavily faded users becomes large enough to induce a missed detection in the final decision the performance of system suffers .

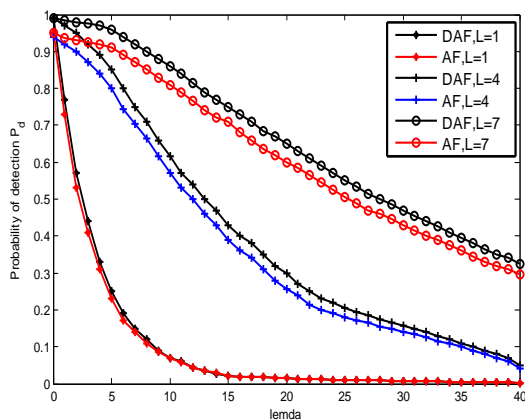


Figure 4: Detection performance of AF and DAF strategies for different diversity scenarios with $m = 2$, $P = 5$ dB, and $s = 0$ dB.

In Fig.5, the average detection probability is plotted versus Nakagami- m fading scenarios with the case $m = 1$ corresponds to Rayleigh fading. Three scenarios are used. For higher values of m performance improves the fading severity is inversely proportional with the fading parameter, m . One can also see that the DAF scheme shows a better performance compared to the AF scheme, specifically at sever fading environments.

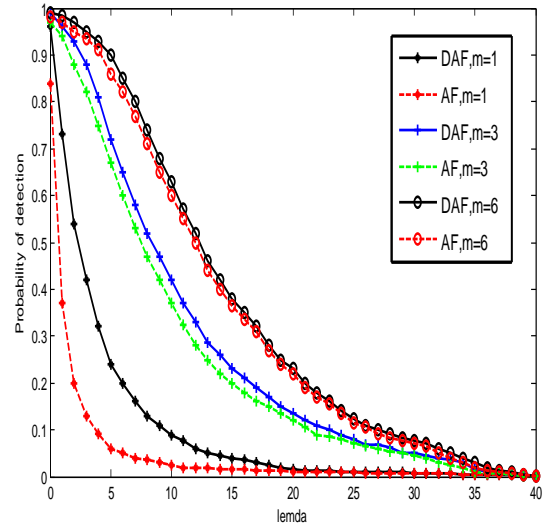


Figure 5: Detection performance of AF and DAF strategies for different fading scenarios with $L = 3$, $P = 5$ dB, and $s = 0$ dB.

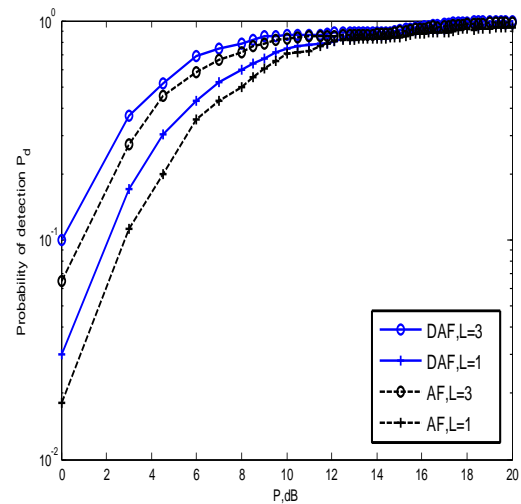


Figure 5: Detection performance of AF and DAF strategies for different power constraints with $P = 5$ dB, $m = 2$, and $s = 0$ dB.

Fig. 6 shows that the detection accuracy is can be improved by increasing the relay power constraint, P . The DAF scheme performs better than AF scheme for all values of the power constraint. This is because the heavily faded relays improve the detection accuracy. At higher values of P the AF performance becomes very close to the DAF performance

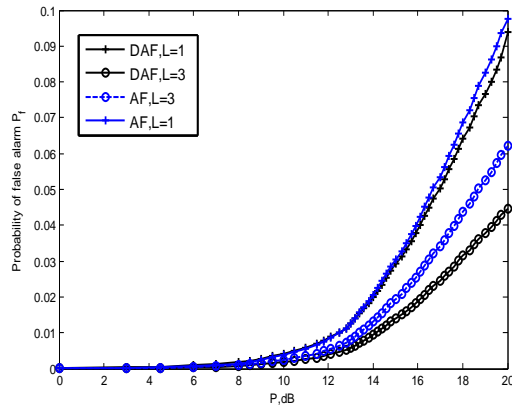


Figure 7: Probability of false alarm performance of AF and DAF strategies for different power constraints with $P = 5$, $m=2$, and $s = 0$ dB.

Fig. 7 shows that an upper bound of $P_f < 0.1$ can be achieved for $\lambda = 5$ over the selected range of the power constraint. For the cooperative case ($L > 1$), the DAF strategy performs better than the AF strategy because it eliminates the negative contributions of the unreliable users.

5. CONCLUSIONS

The above results and analysis shows the importance of including the relaying links and the combining techniques into the performance analysis of CR networks. The novel approach to improve detection accuracy. The derived expressions helps in improving detection accuracy over non identical fading channel because it can be used to determine the energy threshold value, the minimum number of collected energy samples, and the maximum transmission power. The shows that multipath fading heavily contributes to the unreliability of primary user detection

The results also shows that independently faded radios to collectively can achieve robustness to severe fades, multipath fading on relaying channels performs identical degradations as multipath fading on sensing channels, a small number of radios can achieve desired practical detection levels, performance measures strongly depend on the target probability of detection for dealing with fading.

BY analytical and simulation results, we can say that the derived closed-form expressions are accurate. Moreover, we analyzed that detection accuracy varies with the number of diversity branches, the fading severity, and the relay power constraint.

6. FUTURE SCOPE

The results give a basic knowledge upon which more comprehensive models of cooperative sensing can be developed for spectrum sharing in dynamic spectrum access systems.

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