An Eigenvalue Based Cooperative Spectrum Sensing for Multiuser MIMO Cognitive Radio Networks Under Correlated Fading Scenario

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Abstract. In this work, the performance of an eigenvalue-based cooperative spectrum sensing for multiuser multiple-input multiple-output (MIMO) cognitive radio networks is investigated under a correlated fading scenario. The secondary user (SU) is modeled as a MIMO system to detect the presence of primary user signal under incomplete channel state information (CSI) and Rayleigh faded channel model. At each SU, an energy detector is used to obtain the local decision statistic. Next, SU's local decision is sent to the fusion center (FC) via numerous transmit antennas in order to get the transmitting diversity gain to combat the hidden node problem. Further, FC received the local decision statistic with multiple antennas under Racine faded correlated channel with perfect CSI. Finally, a global decision is made at FC based on an eigenvalue-based detection algorithm. The closed-form expression for the detection probabilities is derived at both SUs and FC. A simulation study shows that the target detection probability $P_d \geq 0.95$ is achieved even at a very low signal to noise ratio value of -5 dB.

Keywords: Cognitive radio · Cooperative spectrum sensing · Multiple input multiple output · Eigenvalue based detection

1 Introduction

The continuous development of new technologies and wireless communication systems applications increases the demand for high data rates and bandwidth for individual users. Consequently, the frequency spectrum band is getting crowded

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day by day [1]. According to an FCC analysis, the current fixed spectrum allocation strategy results in inefficient use of the licensed spectrum band [2]. Cognitive radio (CR) is a promising technology that enables the secondary users (SUs) to utilize the available spectrum resources of the licensed/primary users (PUs) opportunistically [3]. SU must ensure the minimum interference to PUs by dynamically changing the value of transmit power, carrier frequency, modulation, and other parameters while accessing the PU band opportunistically [1]. To access PU band opportunistically, spectrum sensing techniques are employed to exploits the wireless spectrum and find the spectrum white spaces band [4]. Thus, it is important to perform the spectrum white space detection accurately for the efficient operation of CR systems. Ambient noise and channel defects, on the other hand, have a significant impact on white space recognition, resulting in detection mistakes and PU interference [1,4,5].

Recently, cooperative spectrum sensing (CSS) and multiple input multiple output (MIMO) antenna systems is attracted researcher attention to exploit spatial diversity the spectrum white spaces by combating wireless channel defects to find spectrum [1,6]. In CSS, each cooperating CR network (CRN) user performs local sensing to determine the availability of spectrum white spaces and then sends the local sensed decision value to the fusion center (FC) to make a global decision on white space availability. Specifically, the FC receives the locally sensed energy information in soft combining (SC) and local hard decisions information in hard combining (HC) schemes from SUs [3,6]. Finally, FC aggregates the data from the SUs to arrive at a global sensing decision [6]. Due to numerous advantages such as energy efficiency, better reliability, fault tolerance, low cost, scalability, and restricted bandwidth requirements, it is preferable to communicate the local hard decision to FC rather than sending real sensed data [7].

In [8], author proposed a CSS scheme which incorporate multiple antennas at the FC and single antennas at each SUs to sense the PU signal, this configuration minimize the sensing error by exploiting the spatial diversity in reporting channel. However, MIMO configuration at individual SUs is not examined, which is critical for combating the fading imperfection effect in local sensing channels. A multiuser MIMO CR network in which SUs sends local hard decisions to the FC via multiple transmit antennas and the FC receives them via multiple receive antennas is presented in [9]. The installation of numerous reception antennas at FC aids in the reduction of fading and noise in the reporting channel [9–11]. It's worth noting that multi-antenna sensing at SUs could improve performance even more by combating the imperfect channel conditions of the sensing channel as well. In [9–11], the energy detection based spectrum sensing technique is performed at both SUs and FC for ease of implementation. Recent study shows that the eigenvalue based spectrum sensing in MIMO scenario outperforms the energy detection with the cost of slightly higher computation complexity [12,13]. To the best of authors' knowledge eigenvalue based multiuser MIMO CSS with SUs equipped with multiple antenna for the PU signal sensing is not reported so far.

Further, multiuser MIMO CSS is practically feasible as most of the SUs/end user equipment for sixth generation (6G) cellular technology will have multi antenna system [14,15].

Motivated by the above, in this paper, we propose a novel eigenvalue based multiuser MIMO CSS for CRNs in fading scenario. Here, at each SU, an energy detector is used to obtain the local decision statistic under uncertain channel state information (CSI). Next, SU send the obtained local hard decision to the FC via numerous transmit antennas in order to get the transmitting diversity gain to combat the hidden node problem. Further, FC received the local decision statistic with multiple antennas under Racine faded correlated channel with perfect CSI. Finally, a global decision is made at FC based on an eigenvalue-based detection algorithm. The main contributions of this paper are listed below:

- An energy detection is adopted at the SUs for local sensing decision and eigenvalue based detection at FC for global sensing decision, as SUs are assumed to have a low computation capability and FC is assumed to have higher computation complexity.
- A more realistic scenario is assumed, where the sensing channel is modelled as a Rayleigh faded channel and reporting channel is modelled as a correlated MIMO channel with Rician fading as the CRNs users are placed in a close proximity area.
- The closed form expressions are derived at both SU for local sensing performance and at FC global sensing performance.
- The receiver operating characteristic (ROC) plot is obtained, which shows that the proposed spectrum sensing technique achieve the target detection probability (P_d) $P_d \geq 0.95$ is achieved even at a very low signal to noise (SNR) value of -5 dB with the proposed scheme.

2 System Description

A multiuser MIMO CSS architecture for the detection performance analysis of SUs and FC is shown in Fig. 1. The spectrum sensing technique is modeled as the binary hypothesis detection problem at both SUs and FC [6,9]. Let, assume that the m^{th} SU senses the PU signal with the N_r antenna, then the corresponding received signal vector, $\mathbf{y}_m(k) \in \mathbb{C}^{N_r \times 1}$ at k^{th} observation is given by;

$$\mathbf{y}_m(k) = \mathbf{h}_m x(k) + \mathbf{w}_m(k), \tag{1}$$

here, $x(k) \in \mathbb{C}^{1\times 1}$ is the PU signal at k^{th} interval, $\mathbf{h}_m \in \mathbb{C}^{N_r \times 1}$ is the sensing channel vector, and $\mathbf{w}_m(k) \in \mathbb{C}^{N_r \times 1}$ is additive white Gaussian noise (AWGN) $\mathcal{N}(0, \sigma^2)$. $\hat{\mathbf{h}}_m$ is imperfect minimum mean square estimation (MMSE) of $\mathbf{h}_m$, which is known to SU. Thus, $\mathbf{h}_m$ is given by [16],

$$\mathbf{h}_m = \hat{\mathbf{h}}_m + \mathbf{e} \tag{2}$$

where, $\mathbf{e}$ is an error vector, and $\sigma^2_{\mathbf{h}_m} = \sigma^2_{\hat{\mathbf{h}}_m} + \sigma^2_e$, here $\sigma^2_{\mathbf{h}_m}$ denotes the variance of $\mathbf{h}_m$, $\sigma^2_{\hat{\mathbf{h}}_m}$ denotes the variance of . The distribution of $\hat{\mathbf{h}}_m$ and $\mathbf{e}$ are $\hat{\mathbf{h}}_m \approx$

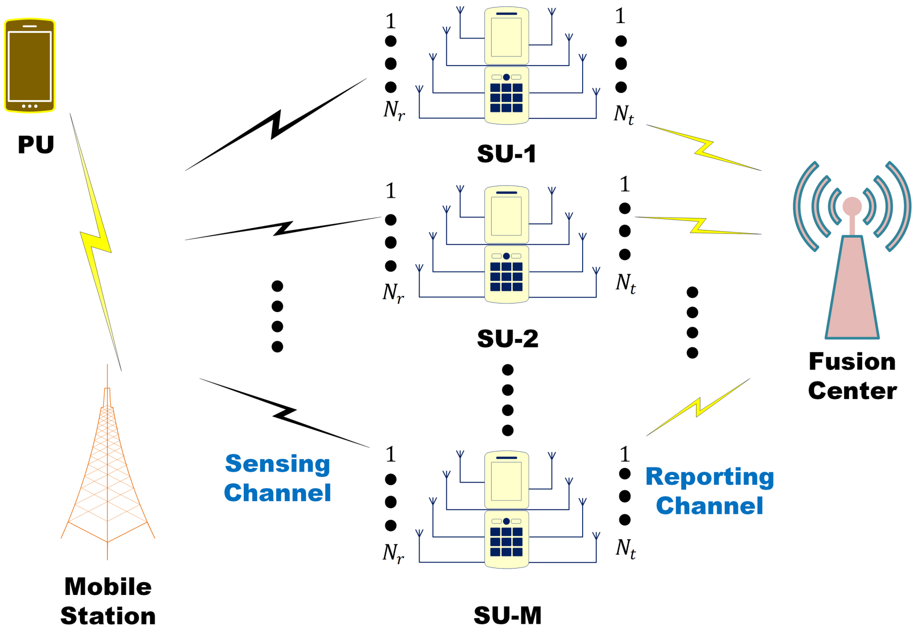

Fig. 1. A multiuser MIMO cooperative CRN architecture

$\mathcal{CN}(0,1)$ and $\mathbf{e} \approx \mathcal{CN}(0,\sigma_e^2)$ respectively [17]. Now, the received signal at m^{th} SU is rewritten as:

$$\mathbf{y}_m(k) = (\hat{\mathbf{h}}_m + \mathbf{e})x(k) + \mathbf{w}_m(k). \tag{3}$$

In the absence of PU signal the (3) is given by;

$$\mathbf{y}_m(k) = (\hat{\mathbf{h}}_m + \mathbf{e})x(k) + \mathbf{w}_m(k). \tag{4}$$

The hypotheses H_1 and H_0 is correspond to the presence and absence of the PU signal which is the case (3) and (4). The likelihood ratio test (LRT) $\Lambda_m = p(\mathbf{y}_m(k)|H_1)/p(\mathbf{y}_m(k)|H_0)$ for the energy detection is performed at each SU to obtained the local decision. The obtained local decision at m^{th} SU gives the local decision $d_m(k)$, which is given by,

$$d_m(k) = \begin{cases} 0 & \Lambda_m \leq \eta_m \;\; H_0 \\ 1 & \Lambda_m \geq \eta_m \;\; H_1 \end{cases} . \tag{5}$$

Here, η_m is the given LRT threshold value, and $d_m(k) \in D = [0,1]$ is the obtained local decision.

η_m is determined using Neyman Pearson criteria where,

$$P_{fa} = \int_{\eta_m}^{\infty} p(\mathbf{y}_m(k)|H_0)dy \leq \alpha_m \tag{6}$$

where, α_m is the upper bound of $P_{m,fa}$. $d_m(k)$ is further transmitted to FC through N_t transmit antennas to combat the hidden node problem. The received signal at FC from m^{th} SU for k^{th} observation at j^{th} antenna is given as:

$$y_{j,m}(k) = \mathbf{h}_{j,m}^{h}\mathbf{d}_m(k) + w(k). \tag{7}$$

Here, $\mathbf{d}_m(k) \in \mathbb{C}^{N_t \times 1}$ is the local decision of m^{th} SU transmitted via N_t antennas, $\mathbf{h}_{j,m} \in \mathbb{C}^{N_t \times 1}$ is the reporting channel vector between m^{th} SU and j^{th} antenna of FC. Next, by concatenating the all K observations, the received signal at FC from j^{th} receive antenna is given as:

$$\mathbf{y}_{j,m} = \mathbf{D}_m\ \mathbf{h}_{j,m} + \mathbf{w}_{j,m}, \tag{8}$$

here, $\mathbf{D}_m = [\mathbf{d}_m(1), \mathbf{d}_m(2), \cdots, \mathbf{d}_m(K)] \in \mathbb{C}^{N_t \times 1}$ denotes the decision vector of m^{th} SU, $\mathbf{w}_{j,m} \in \mathbb{C}^{K \times 1}$ denotes AWGN vector, and $\mathbf{y}_{f_m} = \left[\mathbf{y}_{f_{1,m}}^T, \mathbf{y}_{f_{2,m}}^T, \cdots, \mathbf{y}_{f_{N_{rf},m}}^T\right] \in \mathbb{C}^{N_{rf}K \times 1}$ denotes received signal at FC from the m^{th} SU.

Now, the received signal at FC from all M SUs for all K observations, is given by;

$$\mathbf{y}_f = \mathbf{H}_r\mathbf{d} + \mathbf{w}, \tag{9}$$

where, $\mathbf{y}_f \in \mathbb{C}^{MKN_{rf} \times 1}$, $\mathbf{H}_r \in \mathbb{C}^{MKN_{rf} \times N_t}$ is the reporting channel matrix, and $\mathbf{w} \in \mathbb{C}^{MKN_{rf} \times 1}$ is AWGN vector.

2.1 A Correlated Reporting Channel Model

An antenna correlation at SU's transmit antennas as well as at FC's receive antennas are considered for the sensing performance evaluation at FC. $\mathbf{H}_r$ is the correlated channel matrix between SUs and FC, and given by [18]:

$$\mathbf{H}_r = \frac{1}{\sqrt{tr\left(\mathbf{R}_{Rx}\right)}}\mathbf{R}_{Rx}^{\frac{1}{2}}\mathbf{H}_u\mathbf{R}_{Tx}^{\frac{1}{2}}. \tag{10}$$

Here, the transmit antenna covariance matrix is $\mathbf{R}_{Tx} = \frac{1}{N_t}\mathbb{E}\left[\mathbf{H}^H\mathbf{H}\right] \in \mathbb{C}^{N_t \times N_t}$, the receive antenna covariance matrix is $\mathbf{R}_{Rx} = \frac{1}{N_{rf}}\mathbb{E}\left[\mathbf{H}\mathbf{H}^H\right] \in \mathbb{C}^{N_{rf} \times N_{rf}}$, and $\mathbf{H}_u$ denotes the uncorrelated channel matrix, which contains independent identically distributed (i.i.d) complex fading channel coefficients [19]. $\mathbf{R}(i,j) = \rho_0^{\left|\frac{(d_i - d_j)}{\lambda/2}\right|}$ denotes the correlation between i^{th} and j^{th} antennas, where ρ_0 signifies the correlation between two co-located antennas and λ is the wavelength. Due to pattern/polarization diversity, the correlation coefficient value is $\|\rho_0\| \leq 1$.

3 Analytical Study of the CSS for Multiuser MIMO CRNs

A novel multiuser MIMO CSS for CRNs is proposed in this section. First, multiple sensing antennas are used to perform LRT-based PU link detection at each

SU in order to get a local hard decision over a Rayleigh faded channel with imperfect CSI situation. Then, through multiple transmit antenna, each SU sends its obtained local decision to FC to achieve transmit diversity and address the hidden node problem at FC. In addition, eigenvalue detection is used at FC to obtain the global decision. The assumptions to employ energy detection technique at SUs and eigenvalue detection at FC are more suitable to implement the CRN practically as the SUs are user equipment, which is less computational efficient and FC have high computation capacity [9,18]. The closed form expression for P_{fa} and P_d have been derived in both cases.

3.1 MIMO Energy Detection Based Local Spectrum Sensing at SU over Rayleigh Faded Scenario

In this subsection, each SU used the maximal ratio combining (MRC) and LRT detection to find the availability of spectrum white spaces with multiple sensing antennas to resist the fading/shadowing impact in sensing channels with imperfect CSI. The LRT test of the PU's signal for k^{th} observation at m^{th} SU is given by;

$$T(\mathbf{y}_m(k)) = \Lambda_m = \frac{p(\mathbf{y}_m(k), H_1)}{p(\mathbf{y}_m(k), H_0)}. \tag{11}$$

The PDF of the received signal at m^{th} SU under H_1 and H_0 are $p(\mathbf{y}_m(k), H_1)$ and $p(\mathbf{y}_m(k), H_0)$, respectively. The test statistic could be further obtained by approximating these PDFs with Gaussian distribution and is given by;

$$T(\mathbf{y}_m(k)) = \frac{\left(\frac{1}{2\pi\sigma^2}\right)^{\frac{1}{2}} \exp\left[\frac{-1}{2\sigma^2}\left(\mathbf{y}_m(k) - \mathbf{h}_m x(k)\right)^2\right]}{\left(\frac{1}{2\pi\sigma^2}\right)^{\frac{1}{2}} \exp\left[\frac{-1}{2\sigma^2}\left(\mathbf{y}_m(k)\right)^2\right]}. \tag{12}$$

$$= \exp\left[\frac{-1}{2\sigma^2}\mathbf{h}_{s,m}^2 x^2(k) - 2\mathbf{h}_{s,m} x(k)\mathbf{y}_{s,m}(k)\right]. \tag{13}$$

The test statistic is further reduced to by calculating logarithm on both sides and excluding the data independent factors,

$$T'(\mathbf{y}_m(k)) = ln(T(\mathbf{y}_m(k))) = \mathbf{h}_m x(k)\mathbf{y}_m(k). \tag{14}$$

By incorporating all the sensing antennas (N_r) in the above equation, the $T'(\mathbf{y}_m(k))$ is given by;

$$T'(\mathbf{y}_m(k)) = \sum_{n=1}^{N_r} \mathbf{h}_m x(k)\mathbf{y}_m(k). \tag{15}$$

In case of imperfect CSI of the sensing channel, (15) is given by;

$$T'(\mathbf{y}_m(k)) = \sum_{n=1}^{N_r} \hat{\mathbf{h}}_m x(k)\mathbf{y}_m(k). \tag{16}$$

The mean and variance of $T'(\mathbf{y}_m(k))$ under H_1 is obtained as $\mu_{T'(\mathbf{y}_m(k))|H_1} = N_r|\hat{\mathbf{h}}_m|^2 x^2(k)$ and $\sigma^2_{T'(\mathbf{y}_m(k))|H_1} = N_r|\hat{\mathbf{h}}_m|^2 x^2(k)\left[\sigma_e^2 x^2(k) + \sigma^2\right]$ respectively. Further, the local hard decision $d_m(k)$ for the k^{th} observation of the PU signal is then given by m^{th} SU as:

$$d_m(k) = \begin{cases} 1 & T'(\mathbf{y}_m(k)) \geq \lambda_m \\ 0 & T'(\mathbf{y}_m(k)) \leq \lambda_m. \end{cases} \tag{17}$$

$d_m(k) \in [0, 1]$ depending upon the value of $T'(\mathbf{y}_m(k))$ and λ_m. The probability of detection $(P_{d,m})$ and probability of false alarm $(P_{fa,m})$ at m^{th} SU is given by [9]:

$$P_{d,m} = Q\left(\frac{\lambda - \mu_{T'(\mathbf{y}_m(k))|H_1}}{\sigma^2_{T'(\mathbf{y}_m(k))|H_1}}\right), \tag{18}$$

and

$$P_{fa,m} = Q\left(\frac{\lambda - \mu_{T'(\mathbf{y}_m(k))|H_0}}{\sigma^2_{T'(\mathbf{y}_m(k))|H_0}}\right). \tag{19}$$

Here, $\mu_{T'(\mathbf{y}_m(k))|H_1}$ is the mean and $\sigma^2_{T'(\mathbf{y}_m(k))|H_1}$ is the variance of $\mathbf{y}_m(k)$ under H_1, and similarly $\mu_{T'(\mathbf{y}_m(k))|H_0}$ is the mean and $\sigma^2_{T'(\mathbf{y}_m(k))|H_0}$ is the variance of $\mathbf{y}_m(k)$ under H_0.

3.2 Eigenvalue Based Spectrum Sensing at FC Under Correlated Rician Faded MIMO Reporting Channel

The analysis of the global decision at FC is presented in this subsection, where correlated MIMO reporting channel is considered between SUs and FC with perfect CSI. Perfect CSI and Rician fading channel is considered by assuming that there is at least one line of sight (LOS) link is present between each SU and FC in case of cooperative CRNs. The received signal at FC from M SUs for K observations is concatenated and given by, $\mathbf{y}_{fc} = [\mathbf{y}^T_{fc,1}, \mathbf{y}^T_{fc,2}, \cdots \mathbf{y}^T_{fc,M}]^T \in \mathbb{C}^{MKN_{rf} \times N_t}$. Here, $\mathbf{y}^T_{fc,m} \in \mathbb{C}^{KN_{rf} \times N_t}$ is the received K decision vector at FC by m^{th} SU. The ratio of maximum eigenvalue to the average eigenvalue is considered as the decision test statistic owing to its advantage presented in [13] and the corresponding detection performance metric at FC is derived. The block implementation of eigenvalue based spectrum sensing at FC is presented in Fig. 2. The L consecutive sub samples of the received signal $(\hat{\mathbf{y}}_{fc}(n))$ is given by,

$$\hat{\mathbf{y}}_{fc}(n) = \mathbf{H}_r\hat{\mathbf{D}}(n) + \hat{\mathbf{w}}(n), \tag{20}$$

here, $\mathbf{H}_r \in \mathbb{C}^{L\times(N+L)}$ is the correlated reporting channel matrix, and is given as:

$$\mathbf{H}_r = \begin{bmatrix} h_r(0) & \cdots & h_r(N) & \cdots & h_r(0) \\ & \ddots & & \ddots & \\ h_r(N) & \cdots & h_r(0) & \cdots & h_r(N) \end{bmatrix}. \tag{21}$$

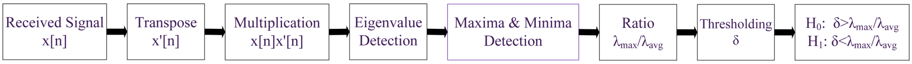

Fig. 2. A schematic model of eigenvalue based detection at FC

Thus, the covariance matrix ($\mathbf{R}_{y_{fc}}$) of $\hat{\mathbf{y}}_{fc}(n)$ is:

$$\mathbf{R}_{y_{fc}} = \mathbb{E}\left[\mathbf{y}_{fc}[n]\mathbf{y}_{fc}^{H}[n]\right],$$
$$\mathbf{R}_{y_{fc}} = \frac{1}{N}\sum_{n=L}^{L-1+N} \mathbf{y}_{fc}[n]\ \mathbf{y}_{fc}^{H}[n]. \tag{22}$$

Next, the covariance matrix of SUs decision is given as:

$$\mathbf{R}_{d} = \mathbb{E}\left[\mathbf{d}[n]\mathbf{d}^{H}[n]\right],$$
$$\mathbf{R}_{d} = \frac{1}{N}\sum_{n} \mathbf{d}[n]\mathbf{d}^{H}[n], \tag{23}$$

and the noise covariance matrix is given by;

$$\mathbf{R}_{w} = \mathbf{E}\left[\mathbf{w}[n]\mathbf{w}^{H}[n]\right],$$
$$\mathbf{R}_{w} = \frac{1}{N}\sum_{n=L}^{L-1+N} \mathbf{w}[n]\mathbf{w}^{H}[n] = \sigma_w^2\mathbf{I}_L. \tag{24}$$

Here, $\mathbf{I}_L \in \mathbb{C}^{L\times L}$ is the identity matrix, σ_w^2 is the noise variance. Next, for large N, the relationship among covariance matrices is given by;

$$\mathbf{R}_{y_{fc}} = \mathbf{H}\mathbf{R}_d\mathbf{H}^H + \sigma_w^2\mathbf{I}_L. \tag{25}$$

It is inferred that, if there is absence of primary signal corresponding to H_0 then $\mathbf{R}_d = 0$, which means that the off-diagonal elements of the received signal covariance matrix $\mathbf{R}_y$ are zero. Further, the maximum eigenvalue (λ_{max}) and average eigenvalue (λ_{avg}) of the covariance matrix $R_{y_{fc}}$ are obtained, and the global decision test statistic at FC is given by;

$$T(y_{fc}) = \frac{\lambda_{max}}{\lambda_{avg}} \underset{H_0}{\overset{H_1}{\gtrless}} \delta. \tag{26}$$

The approximated value of the λ_{max} and λ_{min} is given by [20],

$$\lambda_{max} = \frac{\sigma_w^2}{K}\left(\sqrt{K}+\sqrt{P}\right)^2, \tag{27}$$

and

$$\lambda_{min} = \frac{\sigma_w^2}{K}\left(\sqrt{K}-\sqrt{P}\right)^2, \tag{28}$$

where, $K = N - 1$ and $P = N_{rf}L$, where N_{rf} is total number of receiving antennas at FC. Thus, λ_{avg} is given by;

$$\begin{aligned}\lambda_{avg} &= \frac{\lambda_{max} + \lambda_{min}}{2}, \\ &= \frac{\frac{\sigma_w^2}{K}\left(\sqrt{K}+\sqrt{P}\right)^2 + \frac{\sigma_w^2}{K}\left(\sqrt{K}-\sqrt{P}\right)^2}{2}, \\ &= \frac{\sigma_w^2}{K}\left(K+P\right). \end{aligned} \tag{29}$$

In case of random matrices the distribution of the λ_{max} is the Tracy-Widom distribution of the second order and given by [21]:

$$\mathbf{Q} = \frac{N}{\sigma_w^2}\mathbf{R}_w, \tag{30}$$

$$\mu = \left(\sqrt{K}+\sqrt{P}\right)^2,$$

and

$$\nu = \left(\sqrt{K}+\sqrt{P}\right)\left(\frac{1}{\sqrt{K}}+\frac{1}{\sqrt{P}}\right)^{\frac{1}{3}}. \tag{31}$$

Here, μ and ν are the mean and variance of distribution of λ_{max} respectively. The probability of false alarm P_{fa} for the global decision is give as [20]:

$$\begin{aligned}P_{fa} &= P\left(\lambda_{max} \geq \delta\lambda_{avg}\right) \qquad : H_0, \\ &\approx 1 - F_2\left(\frac{\delta\left(K+P\right)-\mu}{\nu}\right). \end{aligned} \tag{32}$$

Thus, the threshold value is given by;

$$\delta = \frac{\nu F_2^{-1}\left(1-P_{fa}\right)+\mu}{\left(K+P\right)}, \tag{33}$$

by putting the value of μ and ν in (33) the threshold value is given by;

$$\delta = \frac{1}{\left(K+P\right)}\left(\left(\sqrt{K}+\sqrt{P}\right)\left(\frac{1}{\sqrt{K}}+\frac{1}{\sqrt{P}}\right)^{\frac{1}{3}} F_2^{-1}\left(1-P_{fa}\right) + \left(\sqrt{K}+\sqrt{P}\right)^2\right). \tag{34}$$

Similar to the derivation presented in [22,23], the probability of detection (P_d) of the global sensing is given by;

$$P_d = 1 - F_1\left(\frac{\delta K + \frac{K\left(\delta\lambda_{avg}-\lambda_{max}\right)}{\sigma_w^2} - \left(\sqrt{K}+\sqrt{P}\right)^2}{\left(\sqrt{K}+\sqrt{P}\right)^2\left(\frac{1}{\sqrt{K}}+\frac{1}{\sqrt{P}}\right)^{\frac{1}{3}}}\right). \tag{35}$$

4 Performance Evaluation

In this section, detection performance of the proposed eigenvalue based multiuser MIMO CSS for CRNs is evaluated in fading scenario. In the proposed system architecture presented in Fig. 1, is considered where the sensing antenna at each SU is ($2 \leq N_r \leq 6$), and transmitting antenna at each SU is ($N_t = 2$), is taken to evaluate the sensing performance. Next, receiving antenna at FC is ($2 \leq N_{fc} \leq 4$) and $\rho_0 = 0.15$ is considered for correlated reporting channel, 10000 Monte-Carlo simulation is performed to obtained the ROC plot at both SU and FC. Thus, the sensing scenario at each SU is modeled as MIMO system and the decision reporting scenario at the FC is modeled as SIMO system as presented in Fig. 1. The detection performance at SU for local decision is presented in Fig. 3. Next, the detection performance for global decision at FC is depicted in Fig. 4.

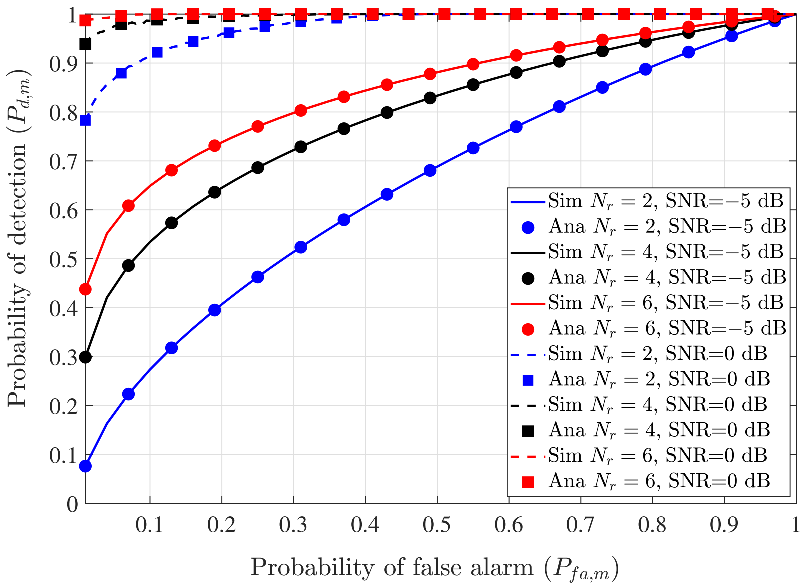

Fig. 3. A $P_{d,m}$ vs. $P_{fa,m}$ plot at m^{th} SU. (Color figure online)

The ROC plot for local sensing performance at each SU is presented in Fig. 3. It has been observed that as the number of sensing antennas grows, so does the sensing diversity, resulting in improved sensing performance.

The ROC plot for global decision at FC is depicted in Fig. 4. In Fig. 4, it is shown that the global decision at FC imposes a better performance compared to the individual performance of each SU, because of the cooperative gain at FC, which enhances the overall detection performance. It has also been observed that the detection performance is almost equal to 1 under correlated MIMO reporting channel model at FC with $SNR = 0\ dB$, $N_t = 2$ and $N_{rf} = 4$.

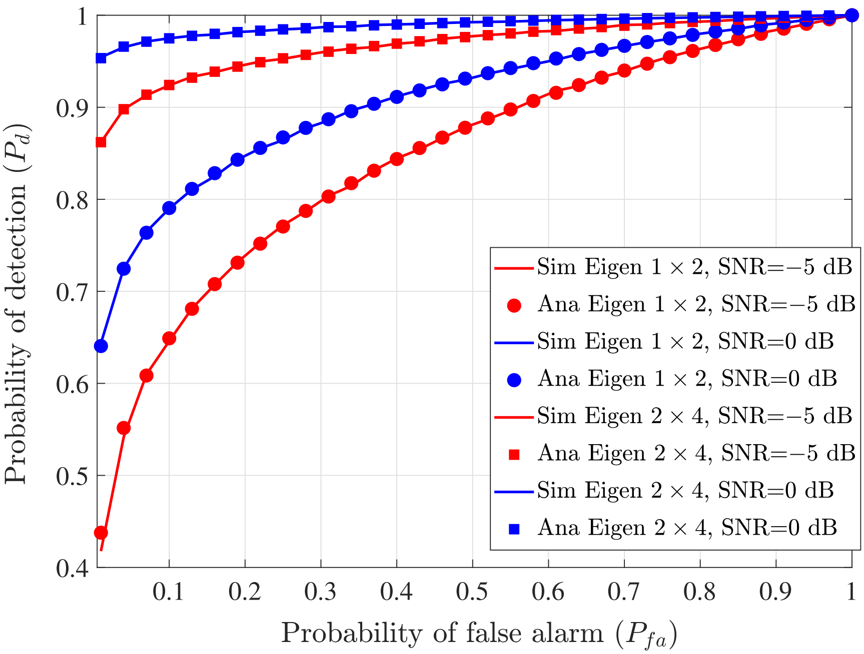

Fig. 4. P_d vs. P_f plot for both eigenvalue based detect at FC. (Color figure online)

5 Conclusion

In this work, the multiuser MIMO CSS technique for CRNs is presented, where each SU is model as MIMO system. First, the local decision performance is obtained at each SU by employing energy detection over Rayleigh faded sensing channel. Further, we obtained the global decision performance at FC by employing eigenvalue detection over MIMO correlated reporting channel. Finally, the performance evaluations at FC show that the detection performance is almost equal to 1 under correlated MIMO reporting channel model at FC with $SNR = 0\ dB$, $N_t = 2$ and $N_{rf} = 4$.

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