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SIMO-Based Cooperative Spectrum Sensing for Cognitive Radio Network

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Abstract
Cooperative spectrum sensing has a great impact to increase the performance for detecting the Primary User (PU) signal over single node sensing. Recent developments in multiple antenna techniques adjoin a new dimension in spectrum sensing. In this paper, we have proposed multi antenna based signal detection considering cooperative approach to minimize sensing and reporting time. The simulation is accomplished in Rayleigh fading channel with different combining methods to obtain local decision where every cognitive radio user contains multiple antennas. In addition, decision fusion of cognitive radio users is considered in the simulation, where fusion is done with general fusion rule for showing global probability of detection. The significance and efficiency of the proposed method is justified through analysis and simulation for both local as well as global sensing in term of probability of detection or miss detection, false alarm, sensing time and reporting time. The experimental results demonstrate that the proposed method improves the performance maintaining quality of service as compared with the conventional system.

Keywords
Cognitive Radio, Cooperative Spectrum Sensing, Decision Fusion, Fading, SIMO, MIMO

I. Introduction
Cognitive Radios (CRs) [1-2] are being considered as a promising solution that can maximize the utilization of the frequency resources by allowing Cognitive Radio Users (CRUs) to access the allocated spectrum bands, which are temporally idle. In traditional cases, the energy detection can be achieved by a CRU, at where primary signal does not deal with the hidden terminal problem [3], which is occurred due to the multi-path fading and shadowing effects. Cooperative spectrum sensing provides an outstanding performance over single node sensing method [4-5]. The concept of Multiple-Input Multiple-Output (MIMO) has drawn a lot of interest in the CR research, which can mitigate fading, and shadowing effects. With the emergence of MIMO system, multipath is effectively converted into benefit for communication system. Therefore, multiple antennas can provide outstanding performance for detecting the Primary User (PU) signal over single antenna system, which is treated as cooperative as well. A number of papers have investigated the application of multiple antennas with energy detection for spectrum sensing [6-8]. But minimizing sensing and reporting time as well as channel overhead in common control channel is yet to observe by multiple antennas in cooperative spectrum sensing.

Previously, several works have reported in the aspects of single antenna cooperative spectrum sensing and decision/data fusion [9-10]. To implement conventional cooperative spectrum sensing, each CRU makes a local decision and those decisions are reported to a fusion center to give a final decision according to some fusion rules (e.g. OR, AND, Half Voting, Majority Voting rule, etc.). As the energy detection relies on the knowledge of noise power, inaccurate estimation of the noise power leads to high probability of false alarm as well as miss detection for single antenna cooperative spectrum sensing [11]. Recently IEEE 802.22 [12] approved an amendment which includes the target probability of false alarm and detection in Wireless Regional Area Network (WRAN) with low Signal to Noise Ratio (SNR). However, the impact of multi-antenna can recover the problem of noise power and highly decrease the probability of false alarm and miss detection. For single antenna, it is noticeably true that higher sensing performance can be achieved by higher number of sensing nodes. Conversely, increased number of nodes requires more reporting time as well as bandwidth for reporting to fusion center [13-14]. In addition, it increases network intricacy to the common receiver [15-16]. Therefore, replacing the multiple antennas for every CRU, higher probability of detection can be attained by the small amount of nodes, which intuitively reduce the ambiguity of reporting while maintaining quality of service.

In this paper, we have proposed multi-antenna based spectrum sensing with Rayleigh fading channel. We have considered that every CRU uses multiple antennas for a single PU signal to calculate local decision, where the approach can be expressed as Single Input Multiple Output (SIMO). Moreover, energy of each antenna is combined with Equal Gain Combining (EGC) and Maximum Ratio Combining (MRC) to obtain local decision of every CRU which is sent to FC which has single antenna. The comparative performance of EGC and MRC is shown. In addition, a comparative result of hard data fusion (1 bit decision) to the fusion center (FC) for single antenna and multiple antennas CRU for Half Voting (HV) and Majority Voting (MV) decision fusion rule is shown for global decision. Taking the advantages of cooperation among the CRU's and multiple antennas, the signal detection has a high dimension of improvement. It is also clarified that the target performance level of probability of false alarm and detection set by IEEE 802.22 WRAN standard is easily satisfied with small number of nodes having multiple antennas. At the end, based on the simulation results, it is elucidated that the cooperative detection of probability with multiple antennas has outperformance over conventional single antenna based cooperative methods in term of probability of detection, false alarm improvement and sensing time and reporting time reduction.

The rest of the paper is organized as follows: In Section II system model is explained. The proposed scheme is provided in Section III. Moreover, performance evaluation is demonstrated in Section IV. And in Section V, Conclusion is drawn.

II. System Model
We consider a cognitive radio network with N_T users and each user having M antenna individually, and a FC that has a single antenna which associates global decision upon obtaining from each CRU. Thus, the received signal in any receiver antenna is composed of two components: the signal of the transmitter multiplied by the channel coefficient, and the other is Additive White Gaussian Noise (AWGN). Signals received from the multiple antennas goes

through the energy detectors and the local decision is made at every CRU. The received samples are represented by Y with a sample index n where, $n = 1,2,...N$. The local spectrum sensing problem can be formulated as binary hypothesis problem:

$$Y_i^j(n) = \begin{cases} \eta_i^j(n) : H_o \\ h_i^j s(n) + \eta_i^j : H_1 \end{cases} \quad (1)$$

where, H_0 and H_1 represent the signal absent and signal present, respectively. And $Y_i^j(n)$ is the signal from CRU i with j antenna that has N samples; where, $i = 1,2,...N_T$, $j = 1,2,...,M$ and $n = 1,2,...,N$. h_i^j is the fading channel coefficient of the i'th CRU at antenna j which is unity for AWGN channel, $s(n)$ is the primary user signal, $\eta_i^j(n)$ is the noise of the i'th CRU at antenna j. If the CRU knows nothing about the waveform transmitted by the PUs in a frequency band of interest, energy detection is an optimal detection method [10]. Since, it only based on the measured energy of the received signal in that band. If no PU is present, the CRU measures only thermal noise energy. Otherwise, the CRU measures the signal-plus-noise energy. The principle of energy detection [17-18] is based on the difference between the energy of PU transmission signal and the noise. In order to measure the energy of the signal in the frequency band of interest, a Band-Pass Filter (BPF) is first applied to the received signal, later it is converted into discrete samples with an Analog-to-Digital (A/D) converter. In the energy detection process, the energy of the received signal measured in a fixed bandwidth S over an observation time period T. A CRU with single antenna Y is the sum of the squares of N Gaussian random variables. The observed energy of a CRU:

$$E_y = \sum_{n=1}^{N} |Y(n)|^2 \quad (2)$$

Suppose that, the noise in each sample is a Gaussian random variable with mean zero and variance σ_η^2 and the signal variance is σ_y^2 . As a result, if the PU is absent, $\frac{Y}{\sigma_\eta^2}$ follows a central chi-square distribution with N degree of freedom. Otherwise, $\frac{Y}{\sigma_\eta^2}$ follows a non-central chi-square distribution with N degree of freedom and a non-centrally parameter [18]:

$$\frac{Y}{\sigma_\eta^2} \sim \begin{cases} X_N^2, H_0 \\ X_N^2(N\gamma), H_1 \end{cases} \quad (3)$$

where, $\gamma = \frac{E_y|h|}{N\sigma_\eta^2}$ is the SNR. By the central limit theorem, the test statistic can be approximated as a Gaussian distribution.

$$H_0 : E_y \sim Normal(N\sigma_\eta^2, 2N\sigma_\eta^4)$$
$$H_1 : E_y \sim Normal(N(\sigma_\eta^2 + \sigma_y^2), 2N(\sigma_\eta^4 + \sigma_y^4)^2) \quad (4)$$

The performance of detection is measured by two parameters probability of detection, P_d and probability of false alarm, P_f . Each pair is associated with a particular threshold α that tests the decision statistic:

$$E_y > \alpha : signal\ present$$
$$E_y < \alpha : signal\ absent$$

The Rayleigh fading occurs when a signal experiences a Non-Line-of-Sight multipath [19]. Due to Rayleigh fading, the signal amplitude follows a Rayleigh distribution, and the SNR of the PU signal at each CRU follows an exponential distribution whose Probability Density Function (PDF) is given by:

$$f_\gamma(\gamma) = \frac{1}{\gamma} e^{\frac{-\gamma}{\hat{\gamma}}}, \gamma > 0 \quad (5)$$

where, $\hat{\gamma}$ is the mean SNR value. Assuming that, all CRUs have the same energy threshold. This results in all CRUs having the same average key metric probabilities, i.e., false alarm, detection, and missed detection probabilities [10], which are given respectively for Rayleigh fading as [10]:

$$P_d = e^{-\alpha/2} \sum_{\eta=0}^{u-2} (\alpha/2)^\eta / \eta! + \left(\frac{1+\bar{\gamma}}{\gamma}\right)^{u-1} \left[e^{\frac{-\alpha}{2(1+\bar{\gamma})}} - e^{-\alpha/2} \sum_{\eta=0}^{u-2} \frac{1}{\eta!} \frac{\alpha\bar{\gamma}}{2(1+\bar{\gamma})} \right] \quad (6)$$

$$P_f = \frac{\Gamma(u, \alpha/2)}{\Gamma(u)} \quad (7)$$

And $P_m = 1 - P_d$. Where, P_m is the probability of miss detection and u=ST. And $\Gamma(.)$ and $\Gamma(.,.)$ are the complete and incomplete gamma function respectively. Finally, for a given pair of target probabilities the number of required samples to achieve these targets can be determined. The minimum number of samples is given by [18]:

$$N = \frac{1}{\gamma}[Q^{-1}(\hat{P}_f) - Q^{-1}(\hat{P}_d)\sqrt{2\gamma + 1}]^2 \quad (8)$$

where, $\hat{P}_d$ is the target probability of detection; and $\hat{P}_f$ is the target probability of false alarm.

III. Proposed Multiple Antenna-Based Spectrum Sensing

A. Multi Antenna-Based Local Sensing

As the potentiality of energy detection relies on SNR, the multiple antennas method can augment the SNR of the received signal by exploiting receive diversity. There are different combining methods e.g. EGC, MRC, Selection Combining etc. for uniting multiple antenna signals in order to boost the signal SNR of every CRU, where every rule has ability to perform in different situation (e.g. antenna, signal, etc.) with different class of complexity by the detection algorithm. In this paper, it is assumed that, the multiple antennas are uncorrelated or isolated. In the multiple antenna system, sum of the signal and noise from each antenna is multiplied by a weight factor g and added in a linear combiner from all antennas. The energy of received signal at each antenna is calculated independently and the energy is added to perform detection. The fig. 1 shows the multiple antenna based signal detection and energy combining process.

Pre-detection diversity signal output Y of a CR can be written as:

$$Y^j(n) = g^j[S^j(n) + \eta^j(n)] \quad (9)$$

where, g^j is the weight factor from antenna j ($j = 1,2,...,M$)and $S^j(n) = h^j s(n)$.

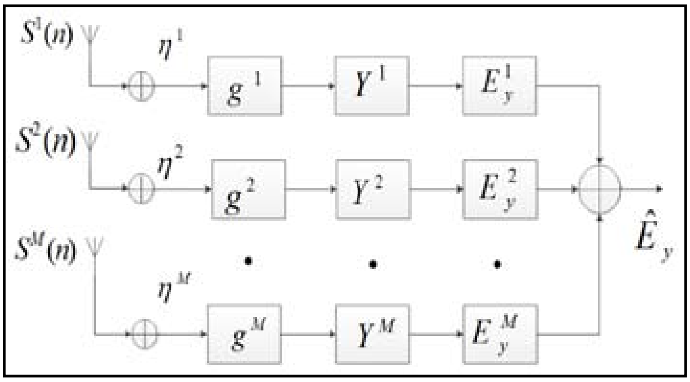

Fig. 1: Block Diagram of Pre-Detection Energy Combining Scheme for Multiple Antennas

Generally, the combined energy from multiple antennas is denoted by $\hat{E}_y$ and defined in term of EGC and MRC:

Equal Gain Combining

For multiple bands, it is required to minimize processing complexity to reduce time and energy cost. The EGC method has relative lower complexity order for processing as compared to other methods complexity, but it has lower efficiency. For EGC, the branch weights are all set to unity, i.e. $g^j = 1$. The energy for antenna j with EGC is:

$$E^j_{y\_EGC} = \sum_{n=1}^{N} | Y^j(n) |^2 \tag{10}$$

The total energy for EGC case is denoted by $\hat{E}_{y\_EGC}$ and written as:

$$\hat{E}_{y\_EGC} = \sum_{j=1}^{M} E^j_{y\_EGC} \tag{11}$$

Maximum Ratio Combining

Although the MRC has higher complexity but it has better approach to increase efficiency of signal detection. An additional time is required for channel estimation and multiplication of the weight with the signal. The calculated energy for antenna j becomes:

$$E^j_{y\_MRC} = \sum_{n=1}^{N} g^j . | Y^j(n) |^2 \tag{12}$$

The weight is calculated from channel gain which is calculated simply, $g^j = \left|h^j\right|^2$. However, the observed energy of the CRU by M antennas is denoted by $\hat{E}_{y\_MRC}$ and defined as:

$$\hat{E}_{y\_MRC} = \sum_{j=1}^{M} E^j_{y\_MRC} \tag{13}$$

Signal, Noise Hypothesis and Decision

The chi square distribution for multiple antenna case:

$$\frac{Y}{\sigma_\eta^2} \sim \begin{cases} X^2_{MN}, H_0 \\ X^2_{MN}(MN\gamma), H_1 \end{cases} \tag{14}$$

Moreover, H_0 and H_1 hypothesis for multiple antennas case can be expressed as:

$$\begin{aligned} H_0 &: \hat{E}_y \sim Normal\,(MN\sigma_\eta^2, 2MN\sigma_\eta^4) \\ H_1 &: \hat{E}_y \sim Normal\,(MN(\sigma_\eta^2 + \sigma_y^2), 2MN(\sigma_\eta^4 + \sigma_y^4)^2) \end{aligned} \tag{15}$$

where, $\hat{E}_y$ is the energy calculated by multiple antennas for either EGC or MRC. As in multiple antenna case the number of sample is increased by the factor M, the SNR is increased significantly. Let us denote the SNR for multiple antennas as γ_c and it is logical to be written: $\gamma_c > \gamma$. The required numbers of samples in the case of multiple antennas for target probabilities of $\hat{P}_d$ and $\hat{P}_f$ are obtained by:

$$N_m = \frac{1}{\gamma_c}\left(Q^{-1}(\hat{P}_f) - Q^{-1}(\hat{P}_d)\sqrt{2\gamma_c + 1}\right)^2 \tag{16}$$

It is admittedly true that, as the number of antenna is increased, the SNR is increased. And every antenna performs parallel sensing (i.e. every antenna sensing time is independent of another and also can do in parallel way). Interestingly enough, the sensing time is almost equal to the single antenna. However, combining energy from multiple antennas requires very small time which increases when number of multiple antennas is increased significantly. It should be chosen small number of antennas (M) such that, energy combining time from multiple antennas is negligible. Therefore, in this paper it is assumed small number of antennas so that energy combining time is negligible. From that equation (8 and 16) it is evident that, the required number of samples (N) for single antenna is admittedly more than that (N_m) of multiple antennas which can be expressed as: $N_m \approx MN$ to obtain target performance. Therefore, to obtain target detection $\hat{P}_d$ and false alarm probability $\hat{P}_f$ required number of time for fine sensing is minimized as compared with single antenna.

B. Global Decision

After making a binary decision (hard decision), each CRU forwards 1 bit decision (either 1 or 0) to the FC. At the FC, all of the signals from the CRUs will be decoded to obtain the binary local decisions. Let $\mu_i (i = 1,2,..., N_T)$ be the local decision of thei-th CRU and $\mu_i \in \{0,1\}$. The decision can be denoted as $D(Y)$ and defined by:

$$D(Y) = \sum_{i=1}^{N_T} \mu_i \begin{cases} \geq k, H_1 \\ < k, H_0 \end{cases} \tag{17}$$

Where, the integer K represents the q-out-of-K fusion rule, which is a general form of all (AND, OR, HV, MV) rules. The AND rule refers to the FC determines, if $\mu_i = 1, \forall i$. Similarly, the OR rule refers to $D(Y) = 1$, if $\mu_i = 1$, for any i. However, the detection probability of OR rule is always largest, but its probability of false alarm is always largest as well. The false alarm probability of AND rule is always smallest but its probability of detection is similar too. It can be said that both AND andOR rule have relatively poor performance. Thus, the HV rule and MV rule has better accuracy than the OR and AND rule, which requires exactly half and more than a half of the CRUs to report 1, respectively. Under this voting rule, the FC declares H_1 if q-out-of-K CRUs report 1. If all CRUs have the same local false alarm probability P_f and the same local detection probability P_d, the global false alarm and detection probabilities for cooperative sensing under this rule for decision fusion are given by [20]:

$$Q_f(K) = \Pr\{Decision = H_1 \mid H_0\} = \sum_{l=q}^{K} \binom{K}{q} P_f^{\,l}(1-P_f)^{K-l} \quad (18)$$

$$Q_d(K) = \Pr\{Decision = H_1 \mid H_1\} = \sum_{l=q}^{K} \binom{K}{q} P_d^{\,l}(1-P_d)^{K-l} \quad (19)$$

When q is taken as 1 and K, the q out of K rule becomes OR and AND rules, respectively. The HV and MV rule can be obtained from the q out of K rule under the condition of $q=\frac{K}{2}$ and $q>\frac{K}{2}$ respectively. And the probability of miss detection for global sensing $Q_m = 1 - Q_d$. The main objective is to justify minimum number of CRU to obtain target performance. Thus, total number of CRU to obtain target performance is defined as the optimization problem and defined as:

$$K_{\min} = \min(K)$$

$$s.t.\ Q_d(K) \geq 0.9$$

$$Q_f(K) \leq 0.1 \quad (20)$$

The optimization problem simply indicates minimum number of CRU to obtain the target global probability of detection and false alarm.

C. Time Consumption

1. Sensing Time

Number of sample to obtain target performance is given in (8). The sensing time is calculated by the number of sample and time required to sense a sample. Let us denote the sensing time for a single bitas τ_b. Therefore, total sensing time for single antenna is denoted as T_s and defined as:

$$T_s = N\tau_b \quad (21)$$

And for multiple antennas total sensing time consists of sensing and combining time which is defined as:

$$T_s = N\tau_b + \hat{\tau}_c \quad (22)$$

Where, $\hat{\tau}_c$ is the time for adding energy from multiple antennas.

2. Reporting Time

The reporting mechanism is shown in fig. 2 and given in the following steps:

Step1: After sensing period the FC sends reporting request to CRU in turn of its specific order during requesting time which is denoted by t_{req}.

Step2: Upon getting the request from FC, the CRU sends their sensed decision and this time is denoted by t_{send} and defined as sending time.

Step3: The FC justifies the decision performance to obtain the global performance $Q_d \geq 0.9$ and $Q_f \leq 0.1$ and send message to CRUs to stop reporting.

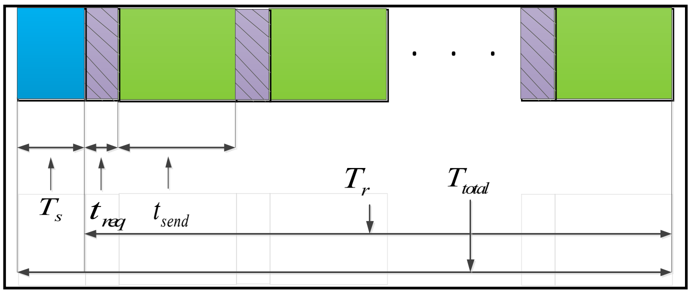

Fig. 2: Sensing and Reporting Time Method for Cooperative Spectrum Sensing

The total reporting time is the requesting time(t_{req}) from FC and decision sending time of every CRU to FC. Therefore total reporting time for single antenna becomes:

$$T_r = K_{\min}(t_{req} + t_{send}) \quad (23)$$

where $K_{\min}$ is the number of CRU to obtain global target probability of detection and false alarm for single antenna. And for multiple antennas total reporting time is as follows:

$$T_r = \hat{K}_{\min}(t_{req} + t_{send}) \quad (24)$$

where, $\hat{K}_{\min}$ is the number of CRU to obtain global target probability of detection and false alarm for multiple antennas and it is evident that $K_{\min} > \hat{K}_{\min}$.

Total time for sensing and reporting is denoted by T_{total} and defined as:

$$T_{total} = T_s + T_r \quad (25)$$

IV. Performance Evaluation

In order to evaluate the proposed scheme for local as well as global detection, the simulation results have been experienced under different conditions. For the performance shown in fig. 3 to fig. 7, the following general parameters are considered; the signal passed through the Rayleigh flat fading channel, the sampling frequency is 300 KHz, the signal is BPSK modulated, and the number of samples is 100. We have tested total 500 Monte-Carlo simulations for fig. 3 and 10000 Monte-Carlo simulations for fig. 4 to fig. 7. Note that, the EGC and/or MRC are performed at local decision and the hard decision is sent to FC for global decision.

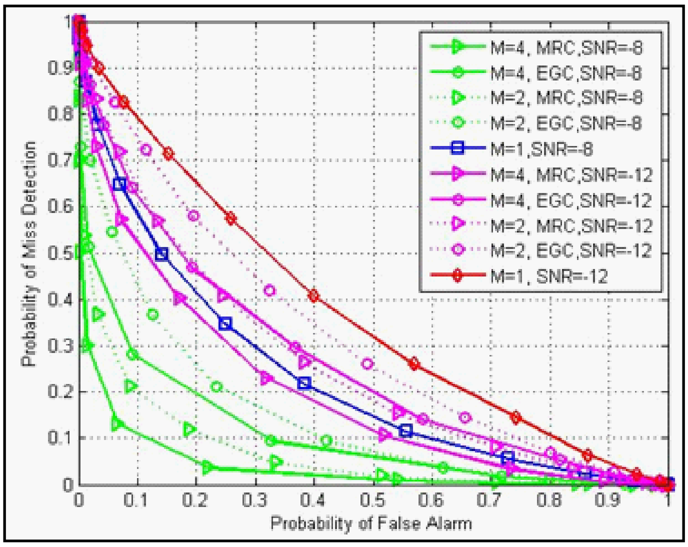

Fig. 3: The ROC Curve for Probability of False Alarm and Miss Detection for Local Sensing

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The local sensing performance is shown in the fig. 3. The performance is justified with two different average SNRs which are -8 dB and -12 dB respectively. Overall, it is clear that, for the high SNR (-8 dB) the performance is better as compared with relatively low SNR (-12 dB). From the ROC (Receiver Operating Characteristics) curves (Figure 3) it is clarified the comparative P_f and P_m with single antenna (M=1) and multiple antennas (M=2, 4). The P_f and P_m decrease as the number of antennas increase. Moreover, the MRC has lower P_f and P_m as compared with EGC for $M > 1$. The Figure 3 demonstrates that a CRU with four antennas has higher performances i.e. lower probability of false alarm and miss detection as compared with single antenna for the local sensing. The same is factual for a CRU with two antennas as compared with the single antenna which has the lowest sensing performance.

In fig. 4 the comparative global probability of detection and false alarm is performed by HV and MV fusion rule. We have justified the result exploiting 10 CRU and different number of antennas (M=1, 2 and 4) for every CRU. Firstly, the probability of detection is higher for both multiple antennas case as compared with single antenna and vice versa for probability of false alarm. Moreover, the probability of detection for HV rule is higher but false alarm is higher and vice versa for MV rule in both single and multiple antennas. In general, from all the global detection it is clarified that, if the numbers of antennas for every CRU are increased then the performance is increased significantly.

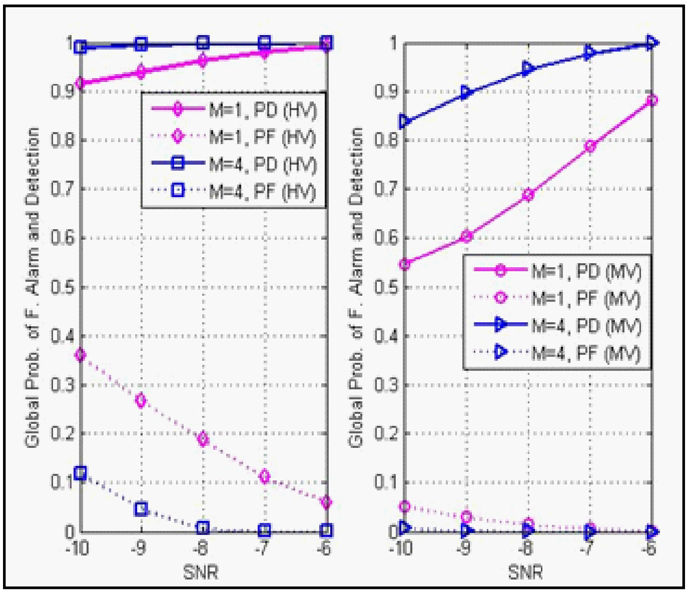

Fig. 4: The ROC Curve for Global Probability of False Alarm and Detection for HV and MV and CV rule with 10 CRU

The comparative global probability of detection and false alarm by EGC and MRC with HV fusion rule is shown in fig. 5. For single antenna case the probability of false alarm is higher as compared with multiple antennas and probability of detection is lower as compared with multiple antennas. Particularly, the CRUs having 4 antennas have higher Q_d and lower Q_f as compared with single antenna and 2 antennas.

In the fig. 6, the required number of CRU to achieve target $Q_d \geq 0.9$ and $Q_f \leq 0.1$ is demonstrated. As evident from the fig. 6, single antenna based CRU has higher number of nodes to obtain target global probability of detection and false alarm. Particularly, for SNR=-10, single antenna based CRU requires 27 CRU's reporting to obtain $Q_d \geq 0.9$ and $Q_f \leq 0.1$ and CRU's having multiple antennas need very small number of reporting. Moreover, for 4 antennas with MRC and 4 antennas with EGC need 3 and 6 node's reporting respectively where 4 antennas with MRC and 2 antennas with EGC need 11 and 17 nodes' reporting respectively to obtain $Q_d \geq 0.9$ and $Q_f \leq 0.1$. And the similar trends are observed for other SNRs.

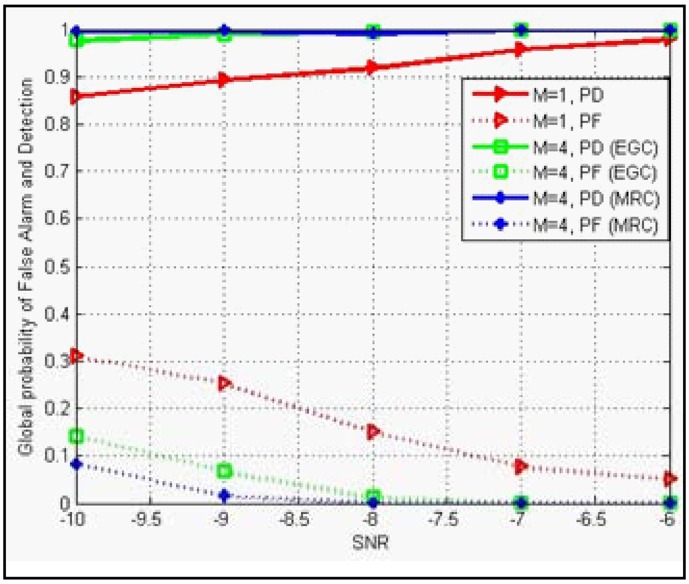

Fig. 5: The ROC Curve for Global Probability of False Alarm and Detection for EGC and MRC by HV Rule With 8 CRUs

The fig. 7 calculates the sensing and reporting time for cooperative decision. For sensing every bit, the sensing time is 1 micro second ($\tau_b = 1\mu$ sec.) for single antenna and for multiple antenna with EGC. However since MRC method needs time for channel estimation to calculate channel gain, therefore we apply numerical method to calculate sensing time as $\tau_b = 1.5\mu$ sec. Moreover, energy combining time ($\hat{\tau}_c$) for multiple antennas is assumed as negligible. As it is the time to add maximum 4(M=4)energy values only, therefore it is logical to be assumed as negligible.

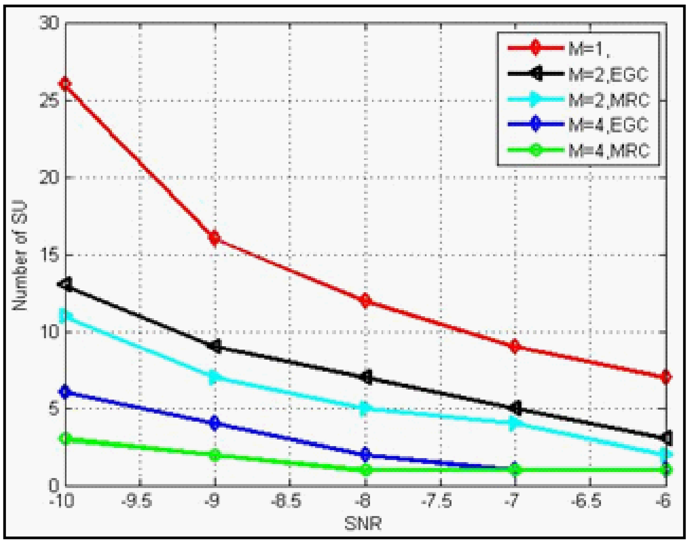

Fig. 6: The Required Number of CRU to oobtain $Q_d \geq 0.9$ and $Q_f \leq 0.1$ by HV Rule

Cognitive radio utilizes the equivalent parameters of IEEE 802.11. Therefore based on the fig. 2, to send 1 bit decision by every CRU the following parameters are assumed to calculate reporting time:

Table 1: Parameters and Time Value for Reporting

Parameters	Values
Slot time	20 μ sec
Request time ($t_{req} = 5 \times Slot\ \ time$)	100 μ sec
Sending time ($t_{send} = 5 \times t_{req}$)	500 μ sec

From the fig. 7 in general it is apparent that single antenna based sensing has the highest time (sensing and reporting) as compared with multiple antennas. For both antenna 2 and 4 cases, MRC has the lower time and the opposite trend is true for EGC. Although MRC based sensing require complexity nevertheless it shows the highest time gain. And as the number of antennas increase the time gain increases i.e. require less time for sensing and reporting. Thus the proposed multiple antenna schemes for cooperative spectrum sensing have the ability to significantly improve the probability of detection with small number of nodes. Overall, sensing and reporting with small number of nodes indicates low bandwidth, low reporting time, and fewer channels overhead in common control channel.

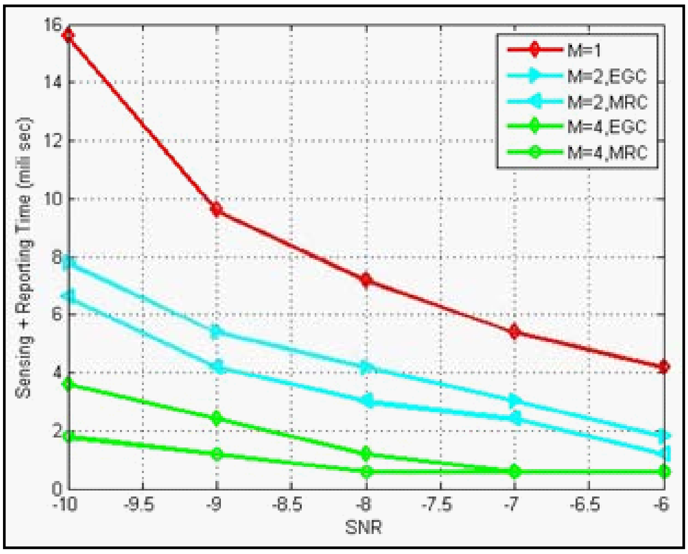

Fig. 7: Sensing and Reporting Time Versus SNR to Obtain $Q_d \geq 0.9$ and $Q_f \leq 0.1$ by HV Rule

V. Conclusion

In this paper, we have proposed multiple antennas based cooperative spectrum sensing for cognitive radio network to reduce sensing and reporting time. The efficiency of relative performance for local and global sensing by single and multiple antennas with different combining methods is demonstrated. The simulation for the local sensing result shows that utilizing multiple antennas ensure lower probability of miss detection and false alarm. It is observed that the proposed multiple antennas have higher efficiency over single antenna based sensing for deciding in cooperative communication with lower number of nodes to achieve target probability of detection for Rayleigh fading channels. However, one drawback of multiple antennas is higher power consumption which is our further research issue for making tradeoff between the better performances and the required energy consumption. We expect that, our work contribute towards the development of spectrum sensing in cognitive radio network.

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