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# Performance Analysis of Hard Combing Schemes in Cooperative Spectrum Sensing for Cognitive Radio Networks

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***Abstract***— ***The basic idea of cognitive radio is to reuse the spectrum whenever it finds the spectrum holes in wireless environment. However, detection performance in practice is often compromised with multipath fading, shadowing, receiver uncertainty and even hidden node problem due to primary users activity that is not spatially localized. To mitigate the impact of these issues, cooperative spectrum sensing has been shown to be an effective method to improve the probability of detection by exploiting spatial diversity by collaborating.This paper studies cooperative spectrum sensing and signal detection in cognitive radio system by implementing hard combining in data fusion centre using energy detector to observe the presence of primary user signal.In this paper, we analyzed the detector performance exploiting TV white space by employing OR and AND rules as decision combining under AWGN, Rayleigh time varying fading channel by setting probabilities of false alarm and measuring probability of detection.The simulation results show that cooperative spectrum sensing employing OR rule has better performance than non-cooperative.The performance of signal detection degrades in time varying fading Rayleigh channel compared to flat fading Rayleigh channel.***

***Index Terms***— ***IEEE 802.11af, energy detection, fading channels, spectrum sensing, cognitive radio, cooperative sensing, hard decision.***

## I. INTRODUCTION

Although spectrum is seen as a scarce natural resource, measurements show that often there are moments in time and space where the spectrum is not being utilized by the services that have allocated it and therefore is being used inefficiently thus demanding dynamic allocation of spectrum instead of static [1][2]. Recently, there have been growing interests in cognitive radio(CR), where secondary opportunistic radio exploits opportunistically spectrum left-overs- or so-called “White Spaces”, by means of knowledge of the environment and cognition capability, and adapts their radio parameters accordingly, [3][4] so that higher bandwidth can be given to secondary user through dynamic management of the unused spectrum. The upcoming IEEE 802.11af standard (known as “super-Wi-Fi”) is based on cognitive radio (CR)[5], exploiting the bandwidth within TV broadcast stations[6]-[8].

CR makes opportunistic use of the spectrum by allowing unlicensed or secondary user (SU) to reuse the spectrum whenever the licensed or primary user (PU) is inactive[6]. The SUs are required to perform the frequent spectrum sensing for detecting the presence of PUs with a high probability of detection and vacant the channel or reduce transmit power. For upcoming IEEE 802.11af standard, time to vacate band after PUs detection is 2s with 90% of probability of detection and 10% of probability of false alarm at Signal-Noise-Ratio (SNR) level as low as -20dB along with geo-location accuracy of +/-50m [9][10].But in CR ,sensing a spectrum is a crucial task. The performance of single CR spectrum sensing is always degraded due to receiver uncertainty, fading and shadowing effect of PU [11]. To overcome this problem, cooperative spectrum sensing have been proposed for improving the detection performance of single CR user by exploiting spatial diversity[11]. Based on how cooperating CR users share the sensing data in the network, the cooperative sensing is divided into three categories [11]: Centralized /partial cooperative, Distributed /total cooperative and relay–assisted. The cooperative spectrum sensing based on SNR comparison was studied in [11], where in CR with better SNR are selected to forward their detection results to CR base station (CRBS) also called as Fusion Center (FC). By this way, probability of detection can be greatly increased reducing number of nodes required for final decision in data FC. The excellent survey of cooperative spectrum sensing can be found in [12].

In this paper, we model CR user populated in the area of PU transmitter to detect PU signal. The distances between CR users to primary transmitter and FC are not considered. Each CR user detects PU signal and forwards their local decision to the FC. Since we discuss cooperative spectrum sensing under communication bandwidth constraints, we focus on two decision rules- OR and AND for final decision [13]-[16]. Probability of detection, SNR and also probability of false alarm are used as metrics to evaluate the performance of cooperative spectrum sensing.

The rest of this paper is organized as follows. In section II framework of cooperative spectrum sensing are discussed with priority given to data fusion scheme. System model for non-cooperative and cooperative signal detection is described in section III.

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Section IV deals with performance analysis of non-cooperative and cooperative model, OR and AND rule in AWGN, flat fading and time varying Rayleigh channel. Finally, we draw the conclusion in section V.

## II. CLASSIFICATION OF COOPERATIVE SPECTRUM SENSING

In the following the primary signal detection is described before studying cooperative spectrum sensing.

### *A. Primary Signal Detection*

The process of cooperative sensing starts with spectrum sensing performed individually at each cognitive radio called as local sensing. The Neyman-Pearson criteria say that the spectrum detection is a binary hypothesis sensing problem [11] given by,

$$H_0: y(n) = \eta(n) \qquad n = 1,2,3, \dots \dots \qquad (1)$$
$$H_1: y(n) = h(n).s(n) + \eta(n) \quad n = 1,2,3, \dots \dots$$

where $s(n)$ indicates the PU , $h(n)$ is channel gain, and $\eta(n)$ is the additive white Gaussian noise which is assumed to be independent and identically distributed random variable with zero mean and variance $\sigma_\eta^2$. Here, the hypothesis $H_0$ means the absence of signal and $H_1$ its presence. Performance of spectrum sensing algorithm is indicated by two metrics: by a probability of detection, $P_d$, which is the probability of the algorithm correctly detecting the presence of the PU and by a probability of false alarm, $P_{fa}$which defines probability of the algorithm mistakenly declaring the presence of PU. Hence leads to inefficient use of available spectrum opportunities.

### *B. Classification of Cooperative Spectrum Sensing*

Cooperative spectrum sensing methods are classified based on how CR share the sensing data in the network: centralized, distributed and relay-assisted [11]-[16].In centralized cooperative sensing, a central identity-FC, combines the received local sensing information, determines the presence of PUs, and diffuses the decision back to cooperating CR users. For data reporting, all CR users send the sensing results to FC through reporting channel. Note that partial cooperative sensing can occur in either centralized or distributed CR networks [12].In Distributed cooperative sensing, there is no FC for making the cooperative decision. In this case, CR users communicate among themselves and converge to a unified decision on the presence or absence of PUs by iterations. In centralized CR networks, CRBS is naturally the FC. Alternatively, in CR ad-hoc networks (CRAHNs) where CRBS is not present, any CR user can act as a FC to coordinate cooperative sensing and combine the sensing information from the cooperating neighbours. The sensing results can be improve by relaying local spectrum sensing result of one CR having not good channel state to other CRs having good channel state. For example, [11] uses relaying based on the Amplify-and-Forward (AF) cooperation protocol in order to reduce the detection time. Further the distributed cooperative sensing can be classified based on various mathematical transformations [12] of the received data. In [18], multiple SUs are used to infer on the structure of the received signals using Random Matrix Theory (RMT). The SUs share information among them making the scheme not dependable on the knowledge of the noise statistics or its variance, but relying on the behaviour of the largest and the smallest eigenvalue of random matrices.

### *C. Data Fusion*

Out of various data fusion schemes like soft combining, quantized soft combining and hard combining [11][12], we are focusing on hard combining since we discuss cooperative spectrum sensing under communication bandwidth constraints, all CRs send their one-bit decision on spectrum sensing to FC based on their local observations. As shown in Fig.1, hard combining is the one in which the individual CR makes the one-bit decision regarding the existence of the PU signal. The bit $1\,(H_1)$ indicates that PU uses spectrum channel, so that CR user cannot access. Spectrum channel is available to be accessed if CR makes bit $0\,(H_0)$. After observing the PU signal, the local detection forwards them to FC which takes final decision by combining all local detection /observations and sends determines the presence of PUs, and diffuses the decision back to cooperating CRs.The two simple rules of hard decision are OR and AND rule.

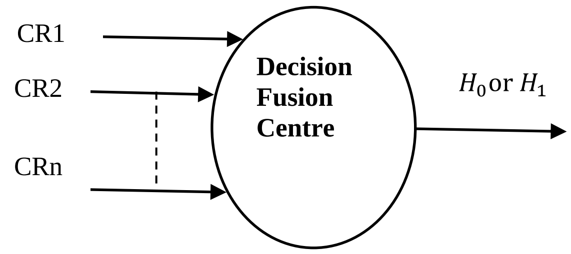


**Figure1.** Decision fusion centre in Hard Combining

In OR rule, at least one of the CRs involved in sensing decides that PU is present that is $H_1$. Whereas AND rule decides PU is present when primary signal is detected by all CRs or in other word that all local decision of CR is $H_1$.

## III. SYSTEM MODEL

System model in non-cooperative and cooperative spectrum sensing is as follows.

### *A. Non-cooperative sensing*

In non-cooperative sensing, PUs signal are detected independently by CR. Each CR determines the presence $H_1$ and absence $H_0$ of PUs individually and acts accordingly. As shown in Fig.2, CRs detect primary signal and decide whether signal is present or not by themselves.

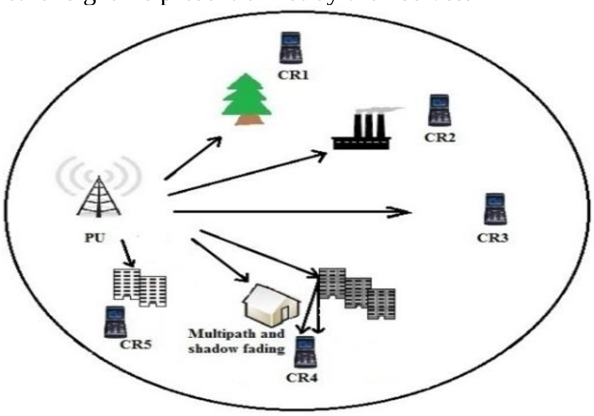


**Figure 2.**Non-cooperative spectrum sensing


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In Fig. 2, multipath fading, shadowing are shown. Due to multiple attenuated copies of the PU signal and the blocking of a house, CR4 experiences multipath and shadow fading such that the PU's signal may not be correctly detected. CR3 can detect primary transmitter signal more accurately than the other users because CR3 detects signal in line of sight (LOS) condition.

### *B. Energy Detection Method*

Out of various spectrum sensing methods like energy detector, covariance absolute value and hybrid detection method etc.[8]-[10] for identifying the presence of PU signal, Energy detector requires no prior knowledge of the signal and is less complex than the other detectors. Energy detection method compares the energy of the received waveform over a specified time with a threshold $\beta_{ED}$ obtained for a given $P_{fa}$ limit to decide whether primary signal exists or not. Note that for a given signal bandwidth $B$, a pre-filter matched to the bandwidth of the signal needs to be applied as shown in Fig.3.

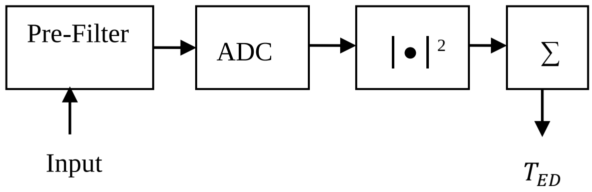


**Figure 3.** Energy Detection

The decision statistic for energy detector is [8]-[10]:

$$T_{ED} = \frac{1}{N}\sum_{n=0}^{N-1} (|y(n)|)^2 \tag{2}$$

where N is the total number of taken signal samples. This decision statistic is compared with a threshold $\beta_{ED}$. If $T_{ED} > \beta_{ED}$, the signal is assumed to be present; otherwise it is assumed to be absent. For large value of N, according to Central Limit Theorem (CLT), the probability distribution function of $T_{ED}$ can be approximated by Gaussian distribution. The expressions for probability of detection and false alarm can be obtained as

$$P_d = Q\left(\frac{\sqrt{N}\,(\beta_{ED}-(\sigma_s^2+\sigma_\eta^2))}{\sigma_s^2+\sigma_\eta^2}\right) \tag{3}$$

$$P_{fa} = Q\left(\frac{\sqrt{N}\,(\beta_{ED}-\sigma_\eta^2)}{\sigma_\eta^2}\right) \tag{4}$$

where $\sigma_s^2$ is primary user signal variance, $\sigma_\eta^2$ is noise variance and Q(t) is Q function given by:

$$Q(t) = \frac{1}{\sqrt{2\pi}} \int_t^{+\infty} e^{-\frac{u^2}{2}}\, du \tag{5}$$

However, energy detection has a limit on the required amount of signal SNR (SNRwall) [9] [10].

### C. Cooperative Spectrum Sensing

In most of the cases it unlikely happen that all spatially distributed CR users in a CR network to concurrently experience the fading or shadowing problem which is as shown in Fig.2. The CR3 detects signal in line of sight (LOS) condition, can cooperate to improve the detection probability. Hence the modified version of Fig.2 in cooperative spectrum sensing is as shown in Fig.4. The CRs send their individual decision to FC (CRBS) which takes final decision ($H_1$ *or* $H_0$) by combining all local detection /observations and sends decision back to cooperating CRs. Hard decision fusion based on OR ,AND, voting rule shares individual CR's final binary bit to minimize communication overhead.

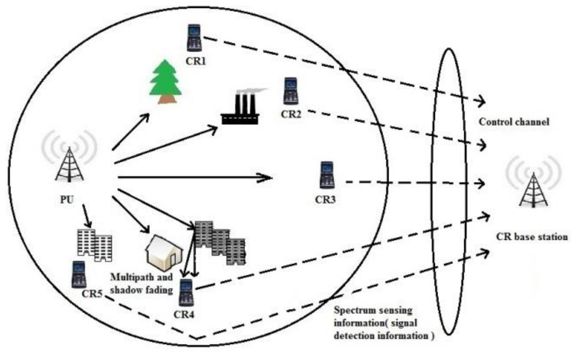


**Figure 4.** Cooperative spectrum sensing

Thus, cooperative spectrum sensing is an attractive and effective approach to combat multipath fading and shadowing and receiver uncertainty and even hidden primary problem. The performance improvement due to spatial diversity is called cooperative gain.

The probability of detection, $P_d$ and probability of false alarm, $P_{fa}$ for hard decision based cooperative spectrum sensing for OR and AND rule [10] is:

For OR rule:

$$C_d = 1 - \prod_1^q (1 - P_{d,m}) \tag{6}$$

$$C_{fa} = 1 - \prod_1^q (1 - P_{fa,m}) \tag{7}$$

For AND rule:

$$C_d = \prod_1^q (1 - P_{d,m}) \tag{8}$$

$$C_{fa} = \prod_1^q (1 - P_{fa,m}) \tag{9}$$

where q is number of CR, $P_{d,m}$ and $P_{fa,m}$ are probability of detection and probability of false alarm of the m$^{th}$ CR respectively which can be calculated using (3) and (4).

## IV. SIMULATION RESULTS

In the following, the simulation results of cooperative spectrum sensing using hard combining for energy detection method has been shown. The primary signal - Digital Video Broadcast–Terrestrial (DVB–T) is generated using MATLAB according to the European Telecommunications Standards Institute (ETSI) specifications given in [19] intended for mobile reception of standard definition TV in 2K mode with 8 MHz bandwidth. The received signal is sampled at the rate 36 times sampling rate at the transmitter. The Signal-to- Noise ratio (SNR) of the received signal is unknown. In order to use the signals for simulating the algorithms at very low SNR, we need to add white noise to obtain various SNR levels [20]. The DVB-T signal and the added white noise are passed through a raised cosine filter with bandwidth 8MHz, rolling factor 0.5 with 217 taps.

The simulation is performed by using probability of detection $P_d$ as a metric at different SNR values. In Fig. 5, the $P_{fa}$ for each CR is set as 0.1 and by varying SNR from -20 to 4 dB the $P_d$ is evaluated for OR and AND rule in AWGN channel with number of samples as 5000.


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We have different probability of detection which is nearly 0 for SNR value from -20 to -11 dB and reaches to 1 for OR rule at -9dB, for AND rule at -6dB and for single user -7.5dB.This values increased as SNR improved. However, when SNR greater than and equal -6dB, detection probability relatively close and equal to one for both of cooperative using OR rule and non cooperative. It means that cooperative technique using OR rule can be effectively and efficiently implemented when SNR lower than -6dB. In these values, cooperative technique using OR rule has better values significantly than non cooperative one. The cooperative technique using AND rule underperforms than non-cooperative scheme.

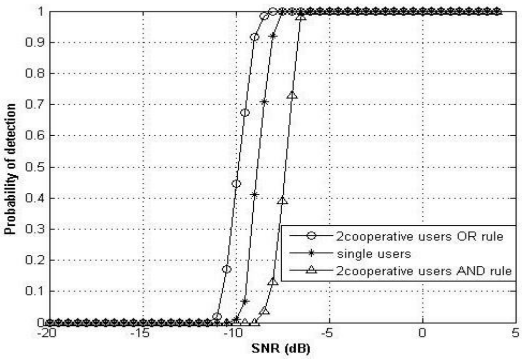


**Figure 5.** Probability of detection versus SNR in AWGN channel with N=5000 and $P_{fa}$ = 0.1

In Fig. 6, 2 to 5 collaborated users are considered for OR rule in AWGN channel. In case of low SNR, number of 5 collaborated users gives better value than the others. The low SNR is caused by propagation loss such as fading and shadowing. If we compare the single user performance in Fig.5 with Fig. 6 for SNR value is of -15dB, probability of detection which was 0 in case of single user reaches to 0.95 for 5 cooperative users using OR rule.

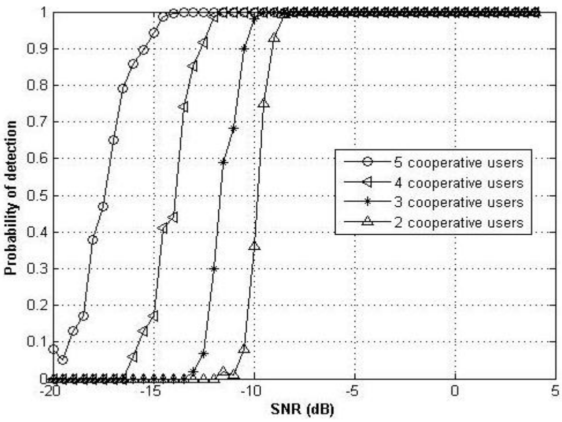


**Figure 6.** Probability of detection versus SNR for OR rule in AWGN channel with N=5000, $P_{fa}$ = 0.1

The evaluation of detection probability by employing AND rule in AWGN channel is shown in Fig. 7 for 2 to 5 collaborated users and is compared to non-cooperative signal detection as shown in Fig.5. When employing AND rule, non-cooperative case has better probability of detection values than the others. Increasing number of collaborated user using AND rule causes probability of detection values become low in comparison with non-cooperative case. When SNR value is greater than -6dB, probability of detection achieves an optimal and equal value relatively which gives 100% detection for PU signal.

Furthermore, improvement of detection probability by increasing number of collaborated user is shown in Fig. 8. The simulation is conducted by varying number of cooperative users. We adopt OR rule and vary SNR values -10dB, -8dB, and -6dB, respectively. The result shows that increasing number of collaborated users that are populated in the range of primary transmitter can improve probability of detection in CR system.

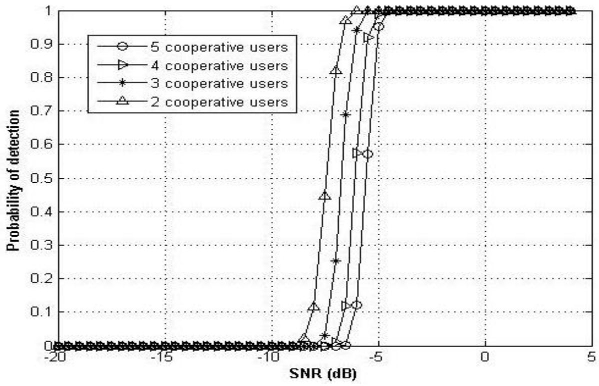


**Figure 7**. Probability of detection versus SNR for AND rule in AWGN channel with N=5000 and $P_{fa}$ = 0.1

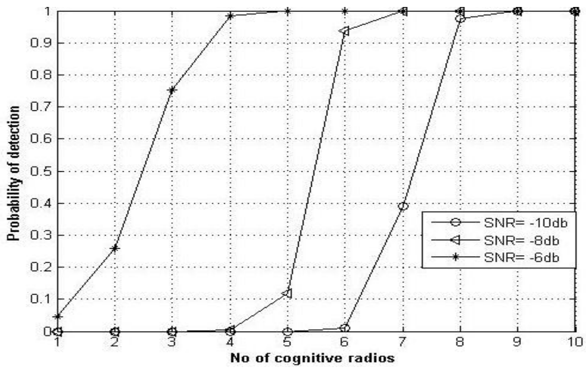


**Figure 8.** Probability of detection versus numbers CRs for OR rule in AWGN channel with N=5000 and $P_{fa}$ = 0.1

The receiver operating characteristic (ROC) curve is plotted in Fig.9 for AWGN channel which reveals that there is performance improvement for 5 and 4 collaborated users compared to single user which is not able to detect PU at SNR -14dB.

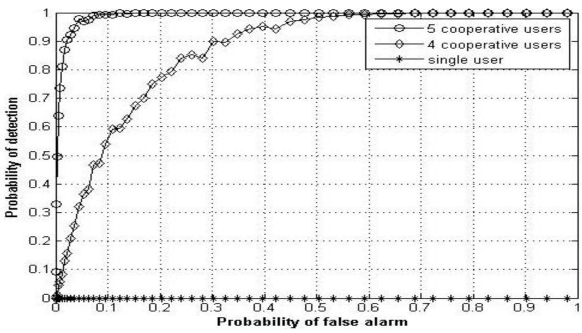


**Figure 9.** ROC for OR rule in AWGN channel with N=5000 and SNR= -14dB


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In order to study the effect of Rayleigh fading, we assume that TV signal detection in indoor environment, the distance between PU transmitter and CR users are assumed to be tens of meter. a multi path Rayleigh fading channel is sufficient to model the indoor environment. Assuming the user speed is $v$ =0.6m/s i.e walking velocity with maximum carrier frequency of 802MHz, the Doppler frequency is evaluated as 1.604Hz.Since maximum Doppler shift is very small it can be neglected.

$$f_d = f_c \frac{v}{c} \tag{10}$$

where $f_d$ =Doppler shift, $v$ =velocity, $c$ =speed of light, $f_c$ =maximum carrier frequency.

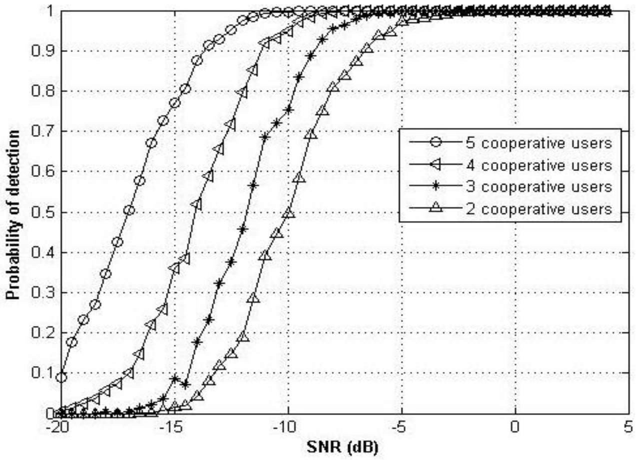


**Figure 10.** Probability of detection versus SNR for OR rule in Rayleigh channel with N=5000 and $P_{fa}$ = 0.1

The performance of cooperative sensing in Rayleigh channel is analyzed with $P_{fa}$ = 0.1 in Fig 10 to 13. Fig.10 and Fig.11 show the probability of detection as a function of SNR for N=5000 and 10000 using OR rule for different collaborated users (2 to 5).

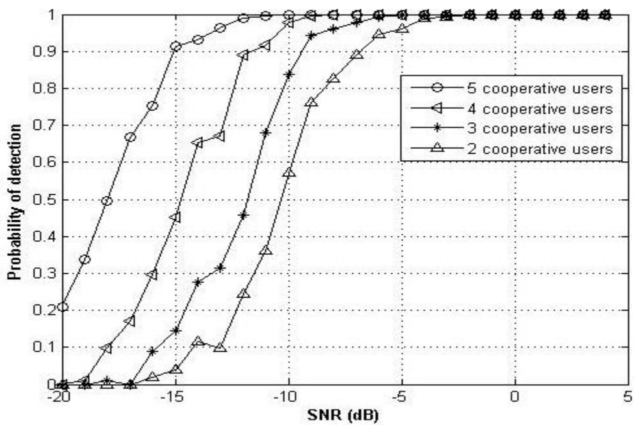


**Figure 11.** Probability of detection versus SNR for OR rule in Rayleigh channel with N=10000 and $P_{fa}$ = 0.1

It clearly reveals that as the number of samples increases the probability of detection in collaboration improves. Also the performance improvement is observed for OR rule compared to single user when number of samples are taken as 10000 as shown in Fig.12.

In Fig.13, the performance of cooperative sensing in Rayleigh channel is analyzed with N=10000 when employing AND rule. Increasing number of collaborated user in AND rule causes probability of detection values become low in comparison with non-cooperative case as shown in Fig.12.The non-cooperative case which shows probability of detection as 0.78 at SNR of -5dB decreases to 0.55 if 5 collaborated users are considered. The non-cooperative case has better probability of detection values than the cooperative AND rule.

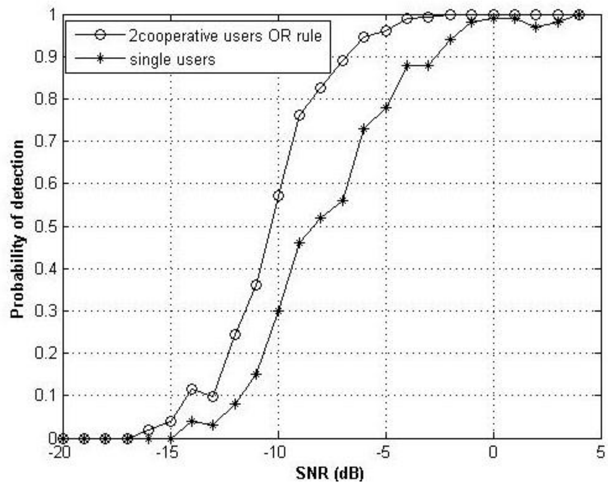


**Figure 12.** Probability of detection versus SNR in Rayleigh channel with N=10000 and $P_{fa}$ = 0.1

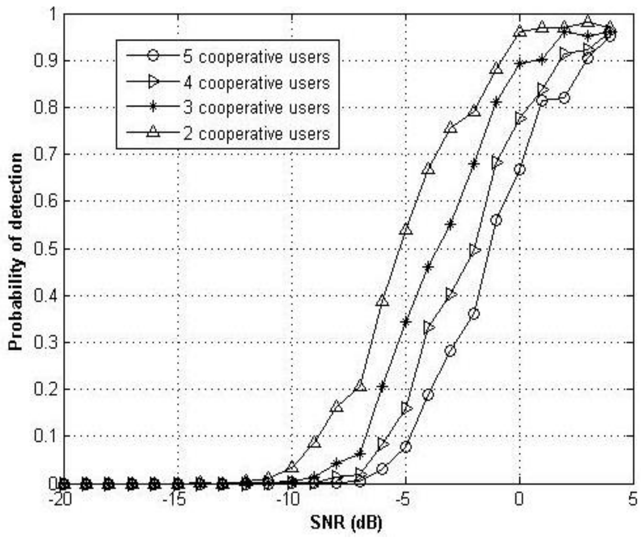


**Figure 13.** Probability of detection versus SNR for AND rule in Rayleigh channel with N=10000 and $P_{fa}$ = 0.1

In Fig.14, the performance of cooperative sensing under time-varying Rayleigh channel is analyzed. The time varying channel is generated using the simplified Jakes' model with Doppler frequency of 20Hz with velocity of $v$ =7.24m/s. The multipath Rayleigh channel is considered. Fig.14 shows that there is degradation in performance under time varying channel.


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The probability of detection which was 0.2 for SNR of -20dB under Rayleigh channel without doppler shift for 5 cooperative users drops to 0.08 under time varying Rayleigh channel. Similarly at SNR of -15dB for 4 cooperative users probability of detection which was 0.48 drops to 0.3 under time varying Rayleigh channel.

Fig.15 clearly reflects that under time varying channel, the cooperative spectrum sensing with AND rule shows poor performance compared to cooperative one without Doppler shift. The probability of detection for all cooperative user which was zero upto SNR of -10dB without Doppler shift in Rayleigh channel extends upto SNR of -8dB in time varying Rayleigh channel.

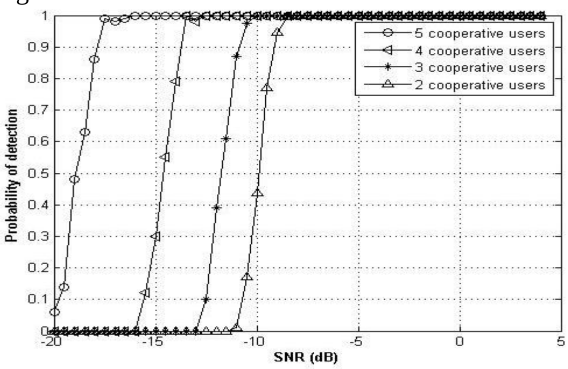


**Figure 14.** Probability of detection versus SNR for OR rule in time varying Rayleigh channel with N=10000 and $P_{fa}$ = 0.1

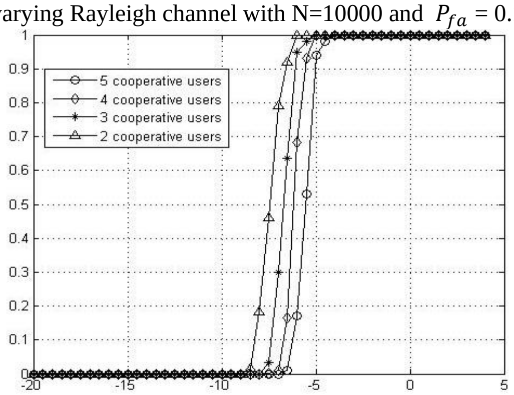


**Figure15.** Probability of detection versus SNR for AND rule in time varying Rayleigh channel with N=10000 and $P_{fa}$ = 0.1

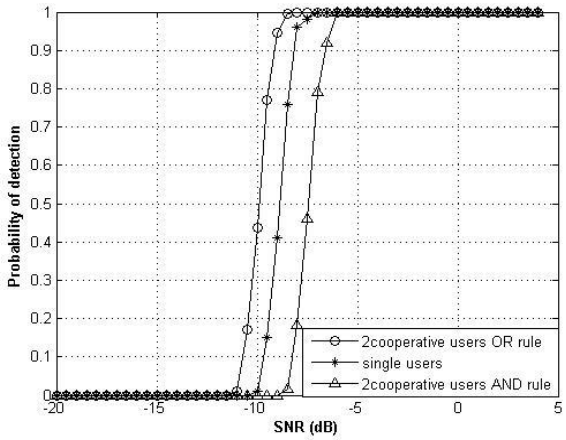


**Figure 16.** Probability of detection versus SNR for OR, AND rule in time varying Rayleigh channel with N=10000 and $P_{fa}$ = 0.1

Fig.16 shows performance of energy detection in time varying fading Rayleigh channel for single user, 2 cooperative users employing OR and AND rule .There is degradation in performance if compared with Fig.10 to Fig.13.

## V. CONCLUSION

The numerical results show that cooperative technique has better performance compared with non cooperative. The performance of cooperative spectrum sensing under AWGN, flat fading Rayleigh channel and time varying fading Rayleigh channel employing OR rule outperforms AND rule and non cooperative signal detection at different SNR values. The receiver operating characteristics curve shows better performance for 5 cooperative users than single user in AWGN channel. In cooperative spectrum sensing as the number of sample increases, probability of detection improves to 0.2 for 5 cooperative users at SNR of -20dB in flat fading Rayleigh channel. Also a minimum of 10 collaborated users relatively in cognitive radio system can achieve optimal value of detection probability. Further degradation in performance under time-varying fading Rayleigh channel with Doppler shift of 20Hz has been analysed for non cooperative ,cooperative spectrum sensing employing OR, AND rule . The simulation results presented in this paper can be applied for IEEE 802.11 af standard for dynamic spectrum access in CR networks.

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