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Analysis of Detection Performance in Cognitive Radio Using Cooperative Spectrum Sensing Technique with Different Channel

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ABSTRACT: Cognitive radio is the Dynamic Spectrum Allocation (DSA) technology. In CR networks, secondary user can sense the spectrum and make decision for presence of primary user. Due to shadowing effect, spectrum sensing information at single terminal is not accurate. In that case cooperative approach is useful where multiple secondary users share their spectrum sensing information. In this paper we analyzed detection performance of cooperative spectrum sensing with different channel. In our algorithm we simulate for AND/OR rule. We consider here different channels like Additive White Gaussian Noise (AWGN) channel, Rayleigh and Rician channel. We compare their results and shows reporting channel is the one of the element of cooperative sensing that affects on the result. In this paper, we reduced the miss detection probability with false alarm probability and increase the detection probability.

KEYWORDS: Cognitive radio(CR), Cooperative spectrum sensing, Additive white Gaussian noise (AWGN), Rayleigh channel, Rician channel, Probability of detection (P_d), Probability of false alarm (P_{fa}), Probability of missed detection (P_m)

I. INTRODUCTION

Wirelss networks mostly uses static spectrum allocation policy. In SSA license users have been assigned the fixed spectrum by agencies. Recently, for the spectrum below 3 GHz, critical competition has been arisen for spectrum usage. Report from the Federal Communication Commission (FCC) show that the utilization of licensed spectrum only ranges from 15% to 85%. IEEE 802.22 Wireless Region Area Network (WRAN) Group is established to utilize the spectrum between 54 MHz and 862 MHz [1] to make full use of these spectrums. Cognitive radio is a dynamic spectrum allocation (DSA)technology which allows secondary user to use spectrum of primary user when it is free. This can help to overcome the lack of available spectrum in wireless communication and achieve significant improvements over services offered by current wireless networks. This is a very critical feature of CR networks which allow unlicensed user to operate in licensed bands without license. In addition, primary user network have no requirement to change their configuration for spectrum sharing with cognitive radios. Therefore, secondary user should be able to independently detect the presence of primary user through continuous spectrum sensing. Such spectrum sensing can be conducted either individually (or locally) or cooperatively. Each secondary user sense spectrum and make decision by itself in individually sensing while in cooperative sensing, group of secondary users perform spectrum sensing by collaboration.

Some research activities have been conducted in cooperative spectrum sensing, most of them use a common receiver (fusion center) to perform data fusion for the final decision that determines primary user is present or not. Common receiver may not be available in some CR-based networks, such as mobile ad hoc networks. Moreover, as indicated in [9], gathering the entire received data in one place may be very difficult under practical communication constraints. In addition, Sun et al. [10] studied the reporting channels between the cognitive users and the fusion center. The results showed that there are limitations in the performance of cooperation when the reporting channels to the common receiver are under deep fading.

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Rician fading is also a stochastic model for radio propagation. The signal reaches at the receiver by different paths. Rician fading can be defined as a line of sight condition.

In Rician fading, receiving signal is much stronger than other fading. If huge building, towers, mountains are available on receiving path then signal propagated through various path because of reflections. This is called multipath fading as well as Rayleigh fading.

In section II system model is presented, Parameters of the system is also given section III. In Section IV different multipath channels are represented. Section V represents simulation results of various decision rules and effect of SNR on detection probability. Comparison and conclusion are given in section V.

II. RELATED WORK

In a paper [2], the survey of cooperative sensing is provided to address the issues of cooperation method, cooperative gain, and cooperation overhead. Spectrum sensing is a main function of cognitive radio to prevent the harmful interference with licensed users and identify the available spectrum for improving the spectrum's utilization. However, detection performance is affected by multipath fading, shadowing and receiver uncertainty issues. To mitigate the impact of these issues, cooperative spectrum sensing has been shown to be an effective method to improve the detection performance by exploiting spatial diversity. Various rules are used to measure the detection probability.

III. SYSTEM MODEL

For describing the system model, we should first list the main notations which are going to be used in this paper.

- s(t) : signal waveform.
- $n_1(t)$: noise waveform which is modelled as a zero-mean white Gaussian random process.
- Pd : Probability of detection.
- Pf : Probability of false alarm.
- Pm = 1− Pd : Probability of miss detection.
- H0 :Hypothesis 0 ;Noise is present
- H1:Hypothesis 1; Primary signal is transmitted
- λ : Energy threshold of the energy detector.
- T : observation time interval, seconds.
- Fc: Carrier Frequency
- W : Bandwidth(one sided) (Hz)
- N_{01} : one-sided noise power spectral density

The energy detection is done under the test of the following two hypotheses:

$$H_0 : r_0(t) = n_1(t) \tag{1}$$

$$H_1 : r_0(t) = h(t) \cdot s_1(t) + n_1(t) \tag{2}$$

$r_0(t)$ is the signal received by unlicensed user, $h_1(t)$ is the transmitted signal by licensed user and $n_1(t)$ indicates the additive white Gaussian noise, h(t) is the response of the channel. Under H_0, the input $r_0(t)$ is only the noise . Under H1, the input $r_0(t)$ is signal with noise. The probability of detection and probability of false alarm are generally expressed as:

$$P_d = \mathrm{P}\ (Y > \lambda / H_1) \tag{3}$$

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$$P_f = P\,(Y > \lambda / H_0) \tag{4}$$

Where λ is the threshold [13] Presents exact closed form expressions for both and P_f :

$$P_d = Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \tag{5}$$

$$P_f = \frac{\Gamma(m, \frac{\lambda}{2})}{\Gamma(m)} \tag{6}$$

where m is the integer number which is denoted by half of the
degrees of freedom m. Q (., .) is the generalized Marcum Q function defined as Γ(.) and Γ(., .) are complete and incomplete gamma functions respectively.

$$Q_m(a,b) = \int_b^{\infty} \frac{x^m}{a^{m-1}} e^{-\frac{x^2+a^2}{2}} I_{m-1}(ax)\,dx \tag{7}$$

where is the modified Bessel function of (m − 1) th order. γ denotes the SNR, $\bar{\gamma}$ is the average SNR. Since P_f is considered for the case of no signal transmission, it is independent of SNR, we only consider in this paper. (5) gives the P_d under ideal environment based on the instantaneous Signal to Noise Ratio, where h(t) is deterministic. However, when h(t) is changing due to various fading, corresponding
must be calculated by [14],

$$P_d = \int_x Q_m\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) f(x)\,dx \tag{8}$$

Where $f(x)$ is the probability distribution function (PDF) of SNR under fading. When the signal experiences Rayleigh fading, γ follows an exponential PDF given by [13],

now received signal is in the form

$$r(t) = hs(t) + n_1(t), \tag{9}$$

Where h=0 or 1 under hypotheses H0 or H1, respectively. As described in [15], the received signal is first pre-filtered by an ideal band pass filter with transfer function

$$H(f) = \begin{cases} \frac{2}{\sqrt{N_{01}}} \left| f - f_c \right| \le W \\ 0, \left| f - f_c \right| > W \end{cases} \tag{10}$$

to limit the average noise power and also normalize the noise variance. After that, the output of this filter is squared and integrated over a time interval T to produce a value of the energy of the received waveform. The integrator's output denoted by Y will act as the test statistic to test the two hypotheses H_0 and H_1.As this process is band-pass type, we can still deal with its low-pass equivalent form and eventually translate it back to its band-pass type [9]. Besides, it has been verified in [16] that both low-pass and band-pass processes are equivalent from the decision statistics perspective which is our main concern. So, for convenience, we address the low-pass process problem in this paper. According to the sampling theorem, the noise can be expressed as

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$$n_1(t) = \sum_{i=-\infty}^{\infty} n_i \sin c(2w_t - i) \tag{11}$$

Where $\sin c(x) = \dfrac{\sin(\pi x)}{\pi x}$,

$$n(i) = n\left(\frac{i}{2w}\right)$$

one can easily check that

$$n_i = N(0, N_{01} w), \tag{12}$$

For all i, Over time interval (0, T), the noise energy can be approximated as [7]

$$\int_0^T n_1^2(t)dt = \frac{1}{2w}\sum_{i=1}^{2u} n_i^2 \tag{13}$$

Where u=Tw. We assume that T and w are chosen to restrict u to integer values. If

$$n_i' = \frac{n_i}{\sqrt{N_{01} w}} \tag{14}$$

Then the of decision statistic Y can be written as [17]

$$Y = \sum_{i=1}^{2u} n_i'^2 \tag{15}$$

Y can be viewed as the sum of the squares of 2u standard Gaussian variables with zero mean and unit variance. Y follows a central chi-square (χ^2) distribution with 2u degrees of freedom. The same approach is applied when the signal $S_1(t)$ is present with the replacement of each n_i by $n_i + S_i$ where $S_i = s_1\left(\frac{i}{2w}\right)$. The decision statistic Y in this case will have a non-central χ^2 distribution with 2u degrees of freedom and a non centrality parameter 2γ [16]. Following the short-hand notations mentioned in the beginning of this section, we can determine the decision statistic as

$$Y \sim \begin{cases} \chi_{2u}^2, & H0 \\ \chi_{2u}^2(2\gamma), & H1 \end{cases} \tag{16}$$

The probability density function (PDF) of Y can then be written as

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$$f_Y(r) = \begin{cases} \frac{1}{2^u \Gamma(u)} r^{u-1} e^{-\frac{r}{2}}, H0 \\ \frac{1}{2}\left(\frac{r}{2\gamma}\right)^{\frac{u-1}{2}} e^{\frac{-2\gamma+r}{2}} I_{u-1}\left(\sqrt{2\gamma r}\right), H1 \end{cases} \quad (17)$$

Where Γ (.) is the gamma function I_v(.) is the v^{th} order modified Bessel function.

IV. DIFFERENT MULTIPATH CHANNEL

The physical phenomenon is the reflection of radio waves (that are transmitted from an antenna) off structures like buildings, mountains, trees, what not..Thus the received signal is a sum of several reflections with various delays, phase changes and amplitude attenuations.

A. *Types of Channels*

There are three different types of channels which are mentioned below:

1) Rayleigh channel

If we consider a Rayleigh distribution as the signal amplitude, then the SNR follows an exponential PDF given by[17]

$$f(\gamma) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right), \qquad \gamma \geq 0 \quad (18)$$

The P_{dRay}, can now be evaluated by averaging (5) over (18).It is an average P_d .

$$P_{dRay} = e^{-\frac{\lambda}{2}} \sum_{n=0}^{u-2} \frac{1}{n!}\left(\frac{\lambda}{2}\right)^n + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{u-1}\left[e^{-\frac{\lambda}{2(1+\bar{\gamma})}} - e^{-\frac{\lambda}{2}} \sum_{n=0}^{u-2} \frac{1}{n!} \frac{\lambda\bar{\gamma}}{2(1+\bar{\gamma})}\right] \quad (19)$$

2) Rician Channel

If the signal strength follows a Rician distribution, the PDF of *will* be[17]

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$$f(y) = \frac{K+1}{\bar{\gamma}} \exp\left(-K - \frac{(K+1)\gamma}{\bar{\gamma}}\right) I_0\left(2\sqrt{\frac{K(K+1)\gamma}{\bar{\gamma}}}\right) \quad (20)$$

γ ≥ 0, where *K* is the Rician factor. The average *Pd* in the case of a Rician channel, *PdRic*, is then obtained by averaging (14) over (20) and substituting *x* for $\sqrt{2\gamma}$. The resulting expression can be solved for *u* = 1

$$\overline{P_d Ric} /_{u=1} = Q\left(\sqrt{\frac{2K\bar{\gamma}}{K+1+\bar{\gamma}}}, \sqrt{\frac{\lambda(K+1)}{K+1+\bar{\gamma}}}\right) \quad (21)$$

For *K* = 0, this expression reduces to the Rayleigh expression with *u* = 1.

3) Nakagami Channel

If the signal amplitude follows a Nakagami distribution, then the PDF of follows a gamma PDF given by [17]

$$f(\gamma) = \frac{1}{\Gamma m}\left(\frac{m}{\bar{\gamma}}\right)^m \gamma^{m-1} \exp\left(\frac{m}{\bar{\gamma}}\gamma\right), \; \gamma \ge 0 \quad (22)$$

Where m is Nakagami parameter. The average *Pd* in the case of Nakagami channels P_{dNak} can now be obtained by averaging (5) over (19)

$$\overline{P_{dNak}} = \alpha \int_0^\infty x^{2m-1} \exp\left(-\frac{mx^2}{2\bar{\gamma}}\right) Qu\left(x, \sqrt{\lambda}\right) dx \quad (23)$$

Where

$$\alpha = \frac{1}{\Gamma(m) 2^{m-1}}\left(\frac{m}{\bar{\gamma}}\right)^m$$

V. SIMULATION RESULTS

I. Probability of Detection of different users

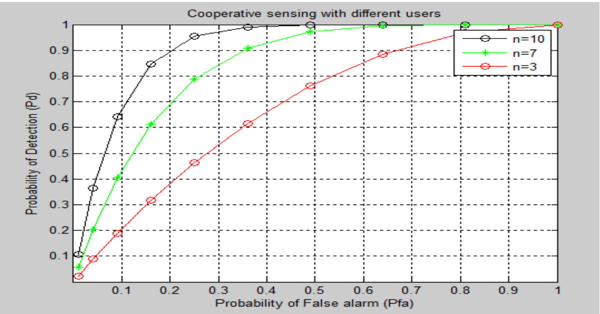

Figure.1 Probability of detection with different users

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Figure 1 shows graph of detection probability versus probability of false alarm with different number of users n. We plot this result in terms of theoretical calculation.

II. Simulation results of AND rule with different channels

AND rule is the one the decision making rule in cognitive radio.In AND rule,if one of the secondary user takes the decision in favour of absence of primary user then final decision will be taken as 'primary user is not present'.

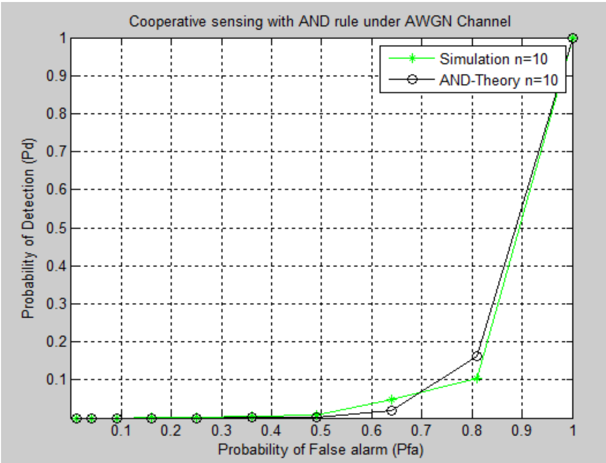

Figure.2 Probability of false alarm detection Vs Probability of detection for AND rule under AWGN channel

Fig 2.shows plot of probability of false alarm detection Vs probability of detection for AND rule under AWGN channel. In ideal scenario theoretical and simulation result will be same.

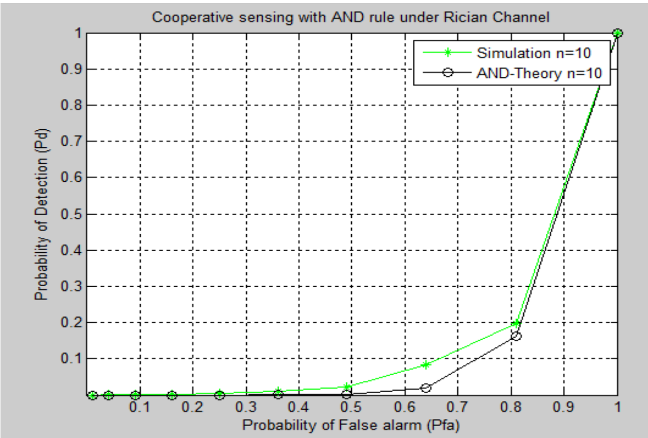

Figure.3 Probability of false alarm detection Vs Probability of detection for AND rule under Rician channel

Fig 3.shows plot of probability of false alarm detection Vs probability of detection for AND rule under rician channel. Rician fading consider as a line of sight condition. so results at receiver terminal for it are much better than other fading.

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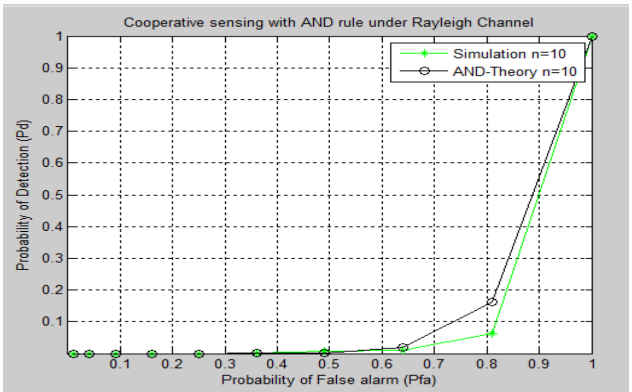

Figure.4 Probability of false alarm detection Vs Probability of detection for AND rule under Rayleigh channel

Fig 4.shows plot of probability of false alarm detection Vs probability of detection for AND rule under Rayleigh channel. If no of obstacles like large building, tower, mountain are available in the receiving path then multipath fading is occurred. so result becomes poor.

III. Simulation results of OR rule with different channels

In OR rule, if all secondary users take the decision in favour of absence of primary user then final decision will be taken as ‘primary user is not present’.

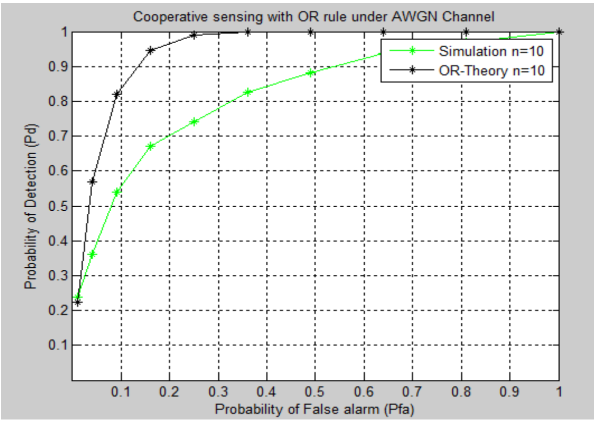

Figure.5 Probability of false alarm detection Vs Probability of detection for OR rule under AWGN channel

Fig 5.shows plot of probability of false alarm detection Vs probability of detection for OR rule under AWGN channel. It shows results nearer to theoretical values.

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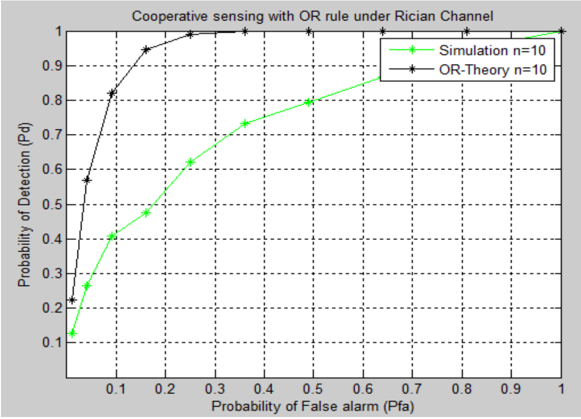

Figure.6 Probability of false alarm detection Vs Probability of detection for OR rule under RICIAN channel

Fig 6.shows plot of probability of false alarm detection Vs probability of detection for OR rule under rician channel. It shows results better than other fading.

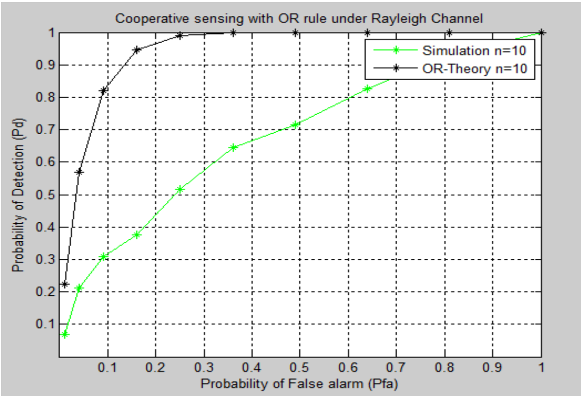

Figure.7 Probability of false alarm detection Vs Probability of detection for OR rule under Rayleigh channel

Fig 7.shows plot of probability of false alarm detection Vs probability of detection for OR rule under rayleigh channel. It has poor results because of fading.

V. CONCLUSION

From this paper we conclude that, we increase detection probability as increase the no, of secondary users. As we increase the probability of false alarm, the probability of miss detection is decreased and probability of detection is increased in a exponential manner. We use the AWGN channel and also Rician and Rayleigh fading channel. We conclude that in a fading environment the results are not as good as compared to AWGN channel. Here, we also compared the theoretical results with the simulated results.

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