Outage Performance Enhancement of Cognitive Radio UnderNakagami Fading

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Abstract—
The cognitive network allows the unlicensed user to access the licensed spectrum to enhance spectrum utilization. In this paper we make an attempt to enhance the outage performance of the cognitive user by incorporating multiple antenna and maximal ratio combining (MRC) scheme at the cognitive user and relays in the wireless environment to detect the presence of the primary user. The wireless environment is assumed to be characterized by Nakagami fading as it provides a single model for Rayleigh and Rician fading. Mathematical expression for outage probability is derived from the test statistics at the fusion center which receives the signal from the cognitive user through MRC scheme and relays. The outage performance is analyzed in terms of probability of false alarm and probability of detection for different receiving and fading conditions. Throughput performance of the entire system is also investigated through numerical analysis by implementing different numbers of receiving antenna and relays. Simulation results provided at the end validates the various numerical analysis discussed above.
***Keywords* – Cognitive radio, maximal ratio combining, Nakagami fading, outage probability.**

I. INTRODUCTION

Effective spectrum sharing through cognitive radio can significantly enhance the spectrum utilization in a wireless environment. Cognitive technology allows the unlicensed user to opportunistically utilize the licensed spectrum. [1] The objective of this technology is to allow universal augmentation of the spectrum utilization with the constraint that unlicensed users do not degrade the performance of the licensed users. To assure this unlicensed user also called cognitive or secondary user continuously monitors the spectrum activities to find a suitable spectrum hole for possible utilization and to avoid possible interference to the licensed users. Licensed users are otherwise called primary users. As the primary users have the priority of service, the above spectrum sensing by cognitive users includes detection of possible collision when a primary user becomes active in the spectrum momentarily occupied by a cognitive user and relocation of the communication channels. The spectrum sensing is of significant importance in cognitiveradio as the secondary user can start transmitting its data uponsensing a white spot and it should vacate the channel withincertain duration once the primary user is found active on thatband. Therefore, spectrum sensing should be periodicallyperformed to efficiently recognize the operation of primary usersystems and other CR systems

In this paper, the methods of improving the performance of the secondary user without outage and satisfying the constraint on the primary user are being investigated. This is done by equipping the cognitive receiver with more number of antennas and exploiting relays in the wireless environment to improve the system performance. The paper is organized as follows: Section II depicts the system and channel models. Section III provides the outage analysis. Simulation results are presented in section IV and is finally concluded.

II. SYSTEM MODEL

We consider a wireless cognitive radio system where in each cognitive user is incorporated with multiple antenna and maximal ratio combining scheme is adopted for the detection of spectrum pool and data transmission. Relays are also exploited in the cognitive environment to aid the spectrum sensing and to transmit and receive the cognitive user's data. The complete system model is depicted in fig 1. There are M relays present in the wireless environment and K antenna in the cognitive receiver. r_1, r_2 till r_M represent the M relays and 1, 2, till K represents the K antenna. The combination of the above two helps in the enhancement of detection performance of the cognitive user. The array of antennas in the cognitive user contends with multipath fading of the desired signal and tends to reduce the interference at the receiver. The cognitive user uses an array of K antennas to sense the spectrum. The relay nodes use only one antenna. The spectrum sensing technique at the cognitive user and at the relay node is assumed to be energy detection because of its low computational complexity. Relay based spectrum sensing utilizes the relay nodes to carry the signal transmitted from primary users to a cognitive receiver which is sent to the fusion center wherein the decision about the presence or absence of primary activities is made. Relay nodes use amplify-and- forward protocol.Decision at the fusion center is made through maximal ratio combining (MRC) scheme.

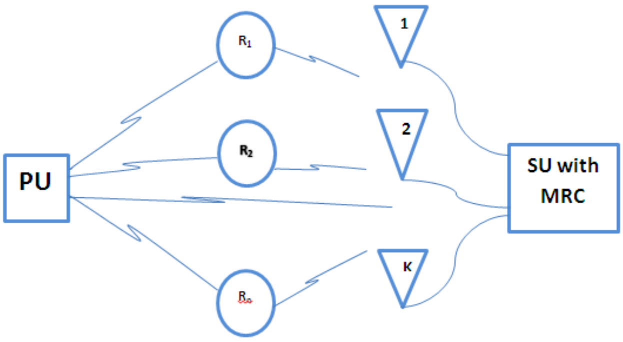

Fig.1. System Model

The spectrum sensing at any of the antenna in the array and in the relay node is based on the following hypotheses which is formulated by comparing the received signal strength with a predefined threshold,τ.

$$H_0 : x_k(n) = w_k(n)$$
$$H_1 : x_k(n) = h_k s(n) + w_k(n)$$

(1)

The hypotheses H_0 and H_1 correspond to absence and presence of primary user respectively. $x_k(n)$ is the sample to analyzed periodically and $w_k(n)$ is the noise with variance σ^2. s(n) represents the primary user's signal and $h_k$represents the channel gains at the k^{th} antenna of the cognitive user, which are uncorrelated Nakagami-m distributed random variables.With N samples used for sensing the spectrum, it is seen from [1] that under hypothesis H_0, the global test statisticis modeled as a Gaussian distributed random variable with mean $\mu_0 = \sigma^2$ and variance $\sigma_0{}^2 = \frac{\sigma^4}{KN}$.

In relay based spectrum sensing the relay nodes listen to the primary user and the data received by the relay network is sent to the fusion center where the decision regarding the presence or absence of primary user is made. The signal received from the primary user s(n) by the relay station is passed on to the fusion center. If there are M relays in the system, the signal received at the i^{th} relay station $y_r(n)$ is given by$y_r(n)=\sigma h_{sri} s(n)+w_i(n)$, where i=1,2,3,…M and h_{sri} is the fading coefficient. The parameter σ specifies the presence or absence of the primary. If σ=1, the primary user is present and is not present otherwise.The relays use amplify and forward scheme to pass on the received signal to the cognitive user.

The amplification factor is given by

$$A_r = \sqrt{\frac{E_p}{E_p |h_{sri}|^2 + N_0}}$$

(2)

whereE_p is the average signal energy from primary user to the i_{th} relay station.

III. CHANNEL MODEL

From [2], as Nakagami fading represents various fading conditions in a wireless channel, it is assumed that the analysis sounds good upon choosing a Nakagami fading channel. Nakagami distribution provides single model which better describes both Rayleigh and Rician fading. The fading model proposed byNakagami distribution has the pdf given by

$$f(y:m,\Omega) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m y^{2m-1} \exp\left(-\frac{my^2}{\Omega}\right) U(z) \quad (3)$$

where m is the shape factor also called Nakagami parameter of fading depth with the constraint that m≥0.5 given by

$$m = \frac{E^2[y^2]}{E[\{y^2 - E(y^2)\}]}$$

(4)

$\Omega = E[y^2]$ controls the spread of distribution, Γ(.) is the gamma function defined by

$$\Gamma(z) = \int_0^\infty e^{-t} t^{z-1} dt$$

(5)

and U(z) is the step function.

[4] When *m* = 1, Nakagami reduces to Rayleigh distribution. For *m* > 1, the fluctuations of the signal strength reduce compared to Rayleigh fading, and Nakagami tends to Rician, while the case *m* < 0.5 corresponds to the unilateral Gauss distribution. The case $m = \infty$ describes the channel without fading. The Nakagami distribution seems to be a good fit for Rayleigh fading with an average value of the parameter *m*= 1. It also seemed to fit the Rician distribution between 1 <*m* <2.

IV. OUTAGE ANALYSIS

The two major performance parameters important for outage analysis are probability of false alarm and probability of detection. Probability of detection defines the accurate detection indicating protection to primary user and probability of false alarm defines higher spectrum utilization. The expressions for these two terms can be derived by analyzing the statiscal properties of the decision threshold under the two hypotheses discussed in section II. In a cognitive receiver with K antennas and N samples used for sensing the spectrum and, it is seen from [1] that under hypothesis H_0, the global test statistics modeled as a Gaussian distributed random variable with mean $\mu_0 = \sigma^2$ and variance $\sigma_0^2 = \frac{\sigma^4}{KN}$. From [2], the global probability of false alarm is given by:

$$P_{FA}(\tau, N) = erfc\left(\left(\frac{\tau}{\sigma^2} - 1\right)\sqrt{KN}\right)$$

(6)

On the other hand, under hypothesis $\mathcal{H}1$, the global test statistic T is Gaussian distributed with mean $\mu_1 = \sigma^2 + \frac{\sigma_s^2}{K}\sum_k h_k^2$ and variance $\sigma_1^2 = \frac{\sigma^4}{KN} + \frac{2\sigma^2\sigma_s^2}{K^2 N}\sum_k h_k^2$ where σ_s^2 is the variance of the primary user's signal $s[n]$. The global probability of detection is thus given by

$$P_D(\tau, N) = erfc\left(\sqrt{\frac{KN}{1+\frac{2\gamma}{K}}}\left(\frac{\tau}{\sigma^2} - 1 - \frac{\gamma}{K}\right)\right)$$

(7)

where γ denotes the instantaneous signal to noise ratio of the wireless system.

[5] The instantaneous SNR with MRC scheme is expressed as

$$\gamma_{MRC} = \sum_{k=1}^{K}\gamma_k = \frac{P}{N_0}\sum_{k=1}^{K} h_k^2$$

(8)

Where P is the transmitted power and N_0 is the noise power spectral density.

For Nakagami m fading channel, the pdf of the instantaneous SNR is given by

$$f_{\gamma MRC}(x) = \left(\frac{m}{\Omega}\right)^{km}\frac{x^{Km-1}}{\Gamma(Km)}e^{-\frac{mx}{\Omega}}u(x)$$

(9)

where x denotes the random variable representing the SNR of the received signal and u(x) denotes the step signal. When $\gamma_{MRC} < \frac{R}{N_0}$ the pdf of SNR corresponds to the outage probability of the cognitive user. Here R is the power constraint of the interference. The outage probability under the above power constraint is given by

$$P_{out} = 1 - \frac{\Gamma\left(Km, \left(\frac{m.INR}{\Omega\gamma}\right)\right)}{\Gamma(Km)}$$

(10)

where INR denotes the interference to noise ratio.

The end to end SNR in a relay based cognitive system is given by

$$\gamma_R = \frac{1}{N_0}\left(\sum_{i=1}^{M}\frac{E_{pri}E_{rid}\left|h_{pri}\right|^2\left|h_{rid}\right|^2}{\Omega_{pri}E_{pri} + N_0\;\frac{E_{rid}}{\Omega_{pri}E_{pri} + N_0}\left|h_{rid}\right|^2 + 1}\right)$$

(11)

where $\left|h_{pri}\right|^2$ and $\left|h_{rid}\right|^2$ are the channel gain coefficients from primary user to relay stations and from relay stations to cognitive center. The probability of false alarm is given by

$$P_{FA} = P\left(y < \frac{\lambda}{H_0}\right)$$

(12)

$$P_{FA} = \frac{\Gamma\left(u, \frac{\lambda}{2}\right)}{\Gamma(u)}$$

(13)

And the probability of detection is given by

$$P_D = P\left(y > \frac{\lambda}{H_1}\right)$$

(14)

$$P_D = Q_M\left(\sqrt{2\gamma_R}, \sqrt{\lambda}\right)$$

(15)

Q_M is the Marcum Q function defined by

$$Q_M(a,b) = \int_b^\infty x\left(\frac{x}{a}\right)^{M-1}\exp\left(-\frac{x^2+a^2}{2}\right)I_{M-1}(ax)\,dx$$

(16)

with modified Bessel function I_{M-1} of order M-1.

Outage probability of our system model is given by

$$P_{OUT} = \left(\frac{2^{(M+1)R} - 1}{\gamma_R} \right)^{(MP_D+1)}$$

(17)

The capacity of the system is also found to be enhanced by the combination of MRC scheme and relays. The normalized channel capacity of this composite system is given by

$$C = \int_0^{\infty} \frac{1}{\Gamma(Km)(1+z)} \Gamma\left(Km, \frac{mz}{\Omega}\right) dz$$

(18)

The variable z in above expression denotes the instantaneous SNR of the received signal.

V. SIMULATION RESULTS

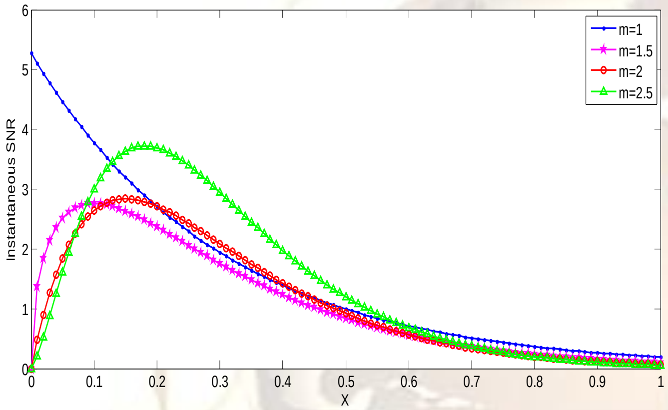

Fig.2. PDF of Instantaneous SNR under MRC Scheme for K=3

Figure 2 shows the probability density function of instantaneous SNR under MRC scheme with three receiving antennas for various cases of Nakagami (m,Ω) fading channel. It is seen that as the value of m increases, the signal to noise ratio is improved.

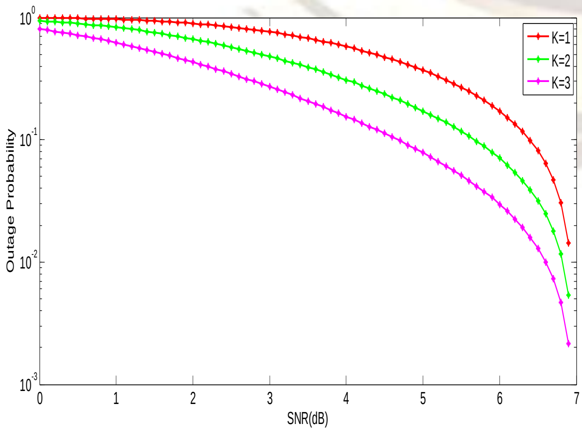

Fig.3. Variation of Outage Probability against SNR for different Receiving cases with m=1.

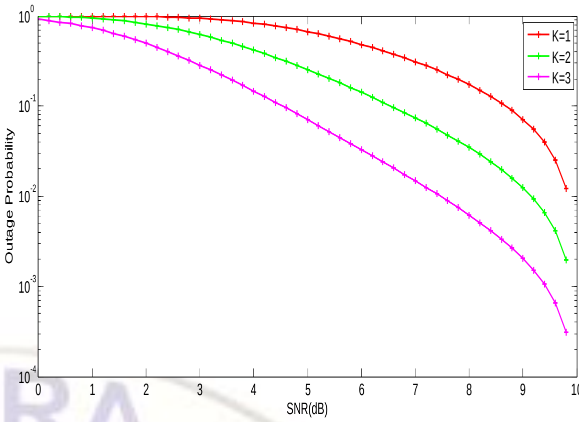

Fig.4. Variation of Outage Probability against SNR for different Receiving cases with m=2.

Figures 3 and 4 show the variation of outage probability against SNR for different numbers of receiving antennas in MRC diversity scheme. It is seen that outage probability decreases with increase in SNR and also with the increase in number of receiving antennas. At high SNR region the improvement in outage performance is higher compared to that of low SNR. On comparing the profiles in figures 1 and 2, it is seen that for the same level of improvement in outage performance, the SNR requirement is quite high for Rician fading than Rayleigh fading.

The receiver performance with five relays in terms of probability of false alarm is shown as a function of decision threshold in figure 5. The channels from primary user to relay andfrom relays to cognitive center are independent of each other and are identicallyNakagami faded. It is shown that probability of false alarm decreases with increase in threshold and also with the severity of fading that is the probability of false alarm is decreased for larger values of fading parameter. Finally the profile of outage performance is presented in figure 7 considering different number of relays in the fading environment. Here the case of M=4, M=2 and M=0 (direct link) are considered. It is observed that the outage performance is improved by about 5 fold with 2 relays and by about 10 fold by having 4 relays in the path between primary and cognitive users. The performance is compared at high SNR region as there will not be any other outage constraint other than the number of relays.

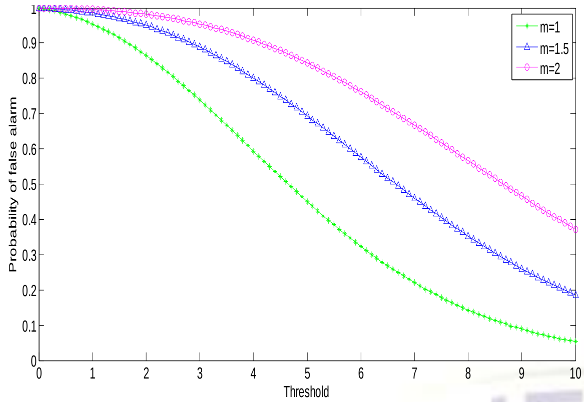

Fig.5. Probability of false alarm in Nakagami Fading Channel for M=5

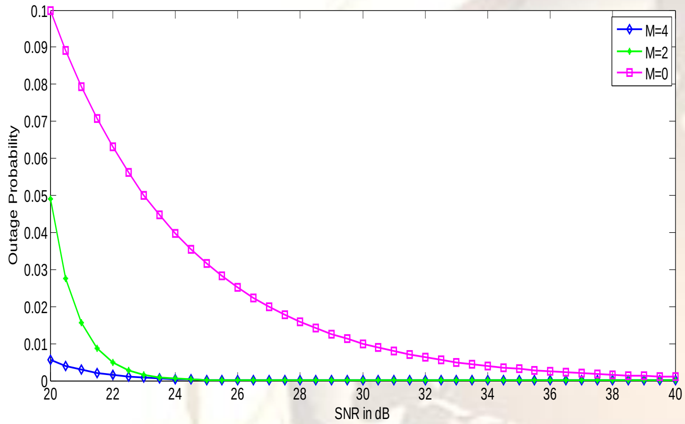

Fig.6. Outage Probability at high SNR region for different number of relays.

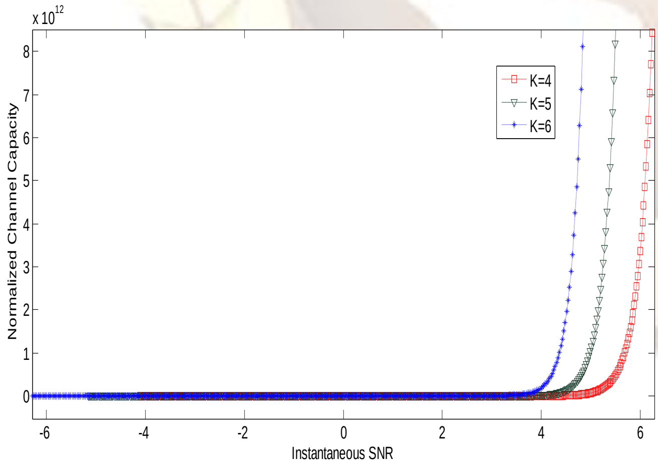

Fig.7. Variation of Normalized Channel Capacity against SNR for three different receiving Antenna Cases for M=5.

From figure 7 it is clearly seen that throughput of the system is considerably increased with the aid of MRC scheme. As the number of antennas increases, the SNR requirement of the system 5 relays to achieve the higher channel capacity reduces.

VI. CONCLUSION

This paper analyzes the outage performance of the cognitive radios with maximal ratio combining diversity scheme and relays under Nakagami fading conditions. The performance is analyzed in terms of probability of false alarm, detection probability and outage probability for different relay, receiving and fading conditions. It is observed that the outage probability is significantly reduced with increased number of antenna and relays. The results show that the path between the primary and the cognitive center provides a major impact on the outage probability. The results also quantify the improvement in throughput of the system in terms of channel capacity at low SNR.

References

[1] Marco Cardenas-Juarez and MounirGhogho, “Spectrum Sensing andThroughput Trade-off in Cognitive Radio under Outage Constraints overNakagami Fading”, IEEE communications letters, vol. 15, no. 10, October2011.

[2] B.LakshmiPriya and G.Thavaseelan, “Throughput Analysis and Spectrum SensingOverNakagami Fading in Cognitive Radio” International Journal of Computer Science and Management Research (IJCSMR), vol 1, issue 4 November 2012.

[3] M. Cardenas-Juarez and M. Ghogho, “Spectrum sensing and datatransmission trade-off in cognitive radio under outage constraints,” *IETElectron.Lett.*, vol. 47, no. 7, Mar. 2011.

[4] Stefanovic, Z., Hana; and Savic, M., Ana, Integral Characteristics of theNakagami-*m* Distribution of Signal Envelope, Transactions on InternetResearch, Volume 8, Number 1, ISSN 1820 – 4503, January 2012.

[5] Kyounghwan Lee, AylinYener,” Outage Performance of Cognitive Wireless RelayNetworks” Proc. IEEE GLOBECOM 2006