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Collaborative Spectrum Sensing over Nakagami Fading Channel in Cognitive Radio

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***Abstract*— Spectrum sensing is a challenging task for cognitive radio. In this paper we analyze collaborative spectrum sensing over Nakagami fading channel in cognitive radio. Through computer simulation, we evaluate the performance of collaborative spectrum sensing and signal detection by employing OR, AND and MAJORITY rules as decision combining. Energy detection is one of the popular spectrums sensing technique for cognitive radio. Energy detector is used to observe the presence of primary user (PU) signal. Simulation results show that expected higher *m* gives better performance in Nakagami fading channel in Cognitive Radio. It also shows that collaboration improves the probability of detection to detect PUs signal in cognitive radio (CR) system and OR rule is the best among the hard fusion rules.**

***Index Terms*— Cognitive Radio, Hard Decision Fusion Rules, Collaborative Spectrum Sensing, Nakagami, Fading Channels and Energy Detection**

I. INTRODUCTION

RADIO signals generally propagate according to the mechanisms of reflection, diffraction, and scattering, which roughly characterize the radio propagation by three nearly independent phenomena: Path loss variance with distance, shadowing (or long-term fading), and multipath (or short-term) fading. Except path loss, which is only distance dependent, the other two phenomena can be statistically described by fading models where their parameters can be determined by using outputs of experimental radio propagation measurements. These channel models find use in the design and pretest evaluation of wireless communications systems in general and of fading mitigation techniques in particular. As expectations for the performance and reliability of wireless systems become more demanding, the significance of accurate channel modeling in system design, evaluation, and deployment will continue [1]. Due to the existence of a great variety of fading environments, several statistical distributions have been proposed for channel modeling of fading envelopes under short- and long-term fading conditions. Short-term fading models include the well-known Rayleigh, Weibull, Rice, and Nakagami-m [2]-[4] distributions. For long-term fading conditions, it is widely accepted that the probability density function (PDF) of the fading envelopes can be modeled by the well-known Log-normal distribution [5], [6]. In recent years, cognitive radio (CR) has emerged as a promising paradigm for exploiting the spectrum opportunity, which is restricted by the current rigid spectrum allocation scheme, to solve the spectrum scarcity problem [7], [8]. One of the fundamental challenges in spectrum sensing is to reliably detect the primary users (PUs) signals. A number of different techniques have been proposed for identifying the presence of the PU. The existing spectrum sensing techniques can be broadly divided into three categories [9]: cyclostationary detection, matched filter detection and energy detection. Among them, energy detection has been widely applied since it does not require any a priori knowledge of the primary signals and has much lower complexity than the other two schemes. But spectrum sensing [10] is a tough task because of shadowing, fading, and time-varying natures of wireless channels. To combat these impacts, cooperative spectrum sensing schemes have been proposed to obtain the spatial diversity in multiuser CR networks [11]–[14]. In collaborative spectrum sensing, information from different CR users is combined to make a decision on the presence or absence of the primary user. Cooperation among CR user is usually coordinated by a fusion center through hard fusion strategies. In hard decision technique the individual CR user makes the one-bit decision regarding the existence of the PU. The bit-1 indicates the presence of PUs. After observing the PU signal, the local detection forwards them to data fusion centre for further process. The final decision then is taken by combining all local detection based on predefined rules. Cooperative spectrum sensing has been addressed in [15]-[19]. However, the existed works only examined the additive white Gaussian noise (AWGN) channel and Rayleigh fading channel. In this paper, we study collaborative spectrum sensing over Nakagami fading channels.

The rest of this paper is organized as follows. In Section II, the system model is introduced. Nakagami fading channel is illustrated in section III. In Section IV, data fusion is described and hard combination method is derived in Section V. The

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simulation result and discussion are presented in section VI. Finally, we draw our conclusions in Section VII.

II. SYSTEM MODEL

The energy detector [20] consists of a square law device followed by a finite time integrator. The output of the integrator at any time is the energy of the input to the squaring device over the interval T in the past (fig.1). The noise pre-filter serves to limit the noise bandwidth; the noise at the input to the squaring device has a band-limited, flat spectral density.

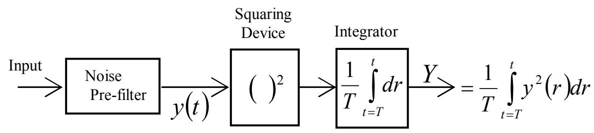

Fig.1. Energy Detection

The received signal $r(t)$ takes the form

$$r(t) = h\ s(t) + n(t), \tag{1}$$

where h=0 or 1 under hypotheses H_0 or H_1, respectively. The received signal in [21] is first pre-filtered by an ideal bandpass filter with transfer function

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

to limit the average noise power and normalize the noise variance. The output of this filter is then squared and integrated over a time interval T to finally produce a measure of the energy of the received waveform. The output of the integrator denoted by Y will act as the test statistic to test the two hypotheses H_0 and H_1.

The detection is a test of the following two hypotheses.

1) H_0 : The input $y(t)$ is noise alone:
   a) $y(t) = n(t)$
   b) $E[n(t)] = 0$
   c) noise spectral density = N_{02}, (two-sided)
   d) noise bandwidth = W cycles per second.
2) H_1 : The input $y(t)$ is signal plus noise :
   a) $y(t) = n(t) + s(t)$
   b) $E[n(t) + s(t)] = s(t)$

According to the sampling theorem, the noise process can be expressed as [22]:

$$n(t) = \sum_{i=-\infty}^{\infty} n_i \sin c(2Wt - i) \tag{3}$$

Where $\sin c(x) = \frac{\sin(\pi x)}{\pi x}$ and

$$n_i = n\left(\frac{i}{2W}\right).$$

One can easily check that

$n_i \approx N(0, N_{01}W)$, for all i.

Over the time interval $(0,T)$, the noise energy can be approximated as

$$\int_0^T n^2(t)dt = \frac{1}{2W}\sum_{i=1}^{2u} n_i^2 \tag{4}$$

where $u = TW$. We assume that T and W are chosen to restrict u to integer values. If we define

$$n_i' = \frac{n_i}{\sqrt{N_{01}W}}, \tag{5}$$

then, the test or decision statistic Y can be written as

$$Y = \sum_{i=1}^{2u} n_i'^2 \tag{6}$$

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

$$Y \approx \begin{cases} \chi_{2u}^2 & H_0 \\ \chi_{2u}^2(2\gamma), & H_1 \end{cases} \tag{7}$$

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

$$f_Y(y) = \begin{cases} \frac{1}{2^u \Gamma(u)} y^{u-1} e^{-\frac{y}{2}} & H_0 \\ \frac{1}{2}\left(\frac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{-\frac{2\gamma + y}{2}} I_{u-1}\left(\sqrt{2\gamma y}\right), & H_1 \end{cases} \tag{8}$$

where $\Gamma(.)$ is the gamma function and $I_v(.)$ is the vth-order modified Bessel function of the first kind.

The probability of detection and false alarm can be generally computed by

$$P_d = \Pr(Y > \lambda \mid H_1) \tag{9}$$

$$P_f = \Pr(Y > \lambda \mid H_0) \tag{10}$$

where λ is the final threshold of the local detector to decide whether there is a primary user present. Using (9) to evaluate (11) yields:

$$P_f = \frac{\Gamma\left(u, \frac{\lambda}{2}\right)}{\Gamma(u)} \quad (11)$$

Hence,

$$P_d = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \quad (12)$$

where $\gamma = \frac{\sigma_x^2}{2\sigma_n^2} = \frac{\sigma_x^2}{2}$ denotes the signal to signal to noise ratio (SNR), $Q_u(a,b) = \int^{\infty} x(x/a)^{m-1} e^{-(x^2+a^2)/2} . I_{m-1}(ax)dx$ is the generalized Marcum's Q function and I_{m-1} denotes the modified Bessel function of the first kind.

If the signal power is unknown, we can first set the false alarm probability P_f to a specific constant. By equation (11), the detection threshold λ can be determined. Then, for the fixed number of samples $2TW$ the detection probability P_d can be evaluated by substituting the λ in (12). As expected, P_f is independent of γ since under H_0 there is no primary signal present. When *h* is varying due to fading, equation (12) gives the probability of detection as a function of the instantaneous SNR, γ. In this case, the average probability of detection P_d may be derived by averaging (12) over fading statistics [12],

$$P_d = \int_x Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) f_\gamma(x) dx \quad (13)$$

where *fγ(x)* is the probability distribution function (PDF) of SNR under fading.

III. NAKAGAMI FADING CHANNEL

Although Rayleigh and Ricean distributions are the most popular distributions to model fading channels, some experimental data does not fit well into neither of these distributions. Thus, a more general fading distribution was developed whose parameters can be adjusted to fit a variety of empirical measurements [23]. This distribution is called the Nakagami fading distribution. The Nakagami distribution was introduced by Nakagami in the early 1940's to characterize rapid fading in long distance HF channels [24]. It is possible to describe both Rayleigh and Rician fading with the help of a single model using the Nakagami distribution. The Nakagami m-distribution is used in communication systems characterize the statistics of signal transmitted through multipath fading channels.

The Nakagami distribution is often used for the following reasons. First, the Nakagami distribution can model fading conditions that are either more or less severe than Rayleigh fading. When m=1, the Nakagami distribution becomes the Rayleigh distribution, when m=1/2, it becomes a one-sided Gaussian distribution, and when m=∞ the distribution becomes an impulse (no fading). Second, the Rice distribution can be closely approximated by using the following relation between the Rice factor *K* and the Nakagami shape factor *m* [24];

$$K = \frac{\sqrt{m^2 - m}}{m - \sqrt{m^2 - m}} \qquad m > 1$$

$$m = \frac{(K+1)^2}{(2K+1)}$$

Since the Rice distribution contains a Bessel function while the Nakagami distribution does not, the Nakagami distribution often leads to convenient closed form analytical expressions that are otherwise unattainable. Using the alternative representation of Marcum-Q function given in [25, eq. (4.74), pp. 104], (1) can be written as,

$$Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) = \sum_{n=0}^{\infty} \frac{\gamma^n e^{-\gamma}}{n!} \sum_{k=0}^{n+u-1} \frac{e^{-\frac{\lambda}{2}}}{k!} \left(\frac{\lambda}{2}\right)^k \quad (14)$$

If the signal amplitude follows a Nakagami distribution, then the PDF of γ follows a gamma PDF given by

$$f(\gamma) = \frac{1}{\Gamma(m)} \left(\frac{m}{\bar{\gamma}}\right)^m \gamma^{m-1} \exp\left(-\frac{m\gamma}{\bar{\gamma}}\right), \ \gamma \ge 0 \quad (15)$$

where *m* is the Nakagami parameter. The average P_d in the case of Nakagami channels $\bar{P}_{dNak}$ can now be obtained by averaging (12) over (15) and then using again the change of variable $x = \sqrt{2\gamma}$ yielding

$$\bar{P}_{dNak} = \alpha \int_0^{\infty} x^{2m-1} \exp\left(-\frac{mx^2}{2\bar{\gamma}}\right) Q_u\left(x, \sqrt{\lambda}\right) dx \quad (16)$$

where

$$\alpha = \frac{1}{\Gamma(m) 2^{m-1}} \left(\frac{m}{\bar{\gamma}}\right)^m \quad (17)$$

In this case, a closed-form formula of Nakagami channels can be given by

$$\bar{P}_{dNak} = \alpha \left[G_1 + \beta \sum_{n=1}^{u-1} \frac{(\lambda/2)}{2(n!)} {}_1F\left(m; n+1; \frac{\lambda}{2} \frac{\bar{\gamma}}{m+\bar{\gamma}}\right)_1 \right] \quad (18)$$

where ${}_1F_1(.;.;.)$ is the confluent hypergeometric function [23].

$$\beta = \Gamma(m) \left(\frac{2\bar{\gamma}}{m+\bar{\gamma}}\right)^m e^{-\lambda/2} \quad (19)$$

and

$$G_1 = \int_0^{\infty} x^{2m-1} \exp\left(-\frac{mx^2}{2\bar{\gamma}}\right) Q_u\left(x, \sqrt{\lambda}\right) dx \quad (20)$$

Where Q(.,.)=Q(.,.) is the first-order Marcum Q-function. G1 can be evaluated for inter m with the aid of [23, Eq. (25)]

$$G_1 = \frac{2^{m-1}(m-1)!}{\left(\frac{m}{\bar{\gamma}}\right)^m} \frac{\bar{\gamma}}{m+\bar{\gamma}} e^{-\frac{\lambda}{2}\frac{m}{m+\bar{\gamma}}} \left| \left(1+\frac{m}{\bar{\gamma}}\right)\left(\frac{m}{m+\bar{\gamma}}\right)^{m-1} \right.$$

$$\left. \times L_{m-1}\left(-\frac{\lambda}{2}\frac{\bar{\gamma}}{m+\bar{\gamma}}\right) + \sum_{n=0}^{m-2}\left(\frac{m}{m+\bar{\gamma}}\right)^n L_n\left(-\frac{\lambda}{2}\frac{\bar{\gamma}}{m+\bar{\gamma}}\right) \right| \quad (21)$$

where is the Laguerre polynomial of degree n [23, 8.970].

IV. DATA FUSION

In cooperative sensing, data fusion is a process of combining local sensing data for hypothesis testing, which is also an element of cooperative sensing. Depending on the control channel bandwidth requirement, reported sensing results may be of different forms, types, and sizes [26]. In general, the sensing results reported to the shared with neighboring users can be combined in three different ways in descending order of demanding control channel bandwidth [26]: Soft Combining: CR users can transmit the entire local sensing samples or the complete local test statistics for soft decision. Quantized Soft Combining: CR users can quantize the local sensing results and send only the quantized data for soft combining to alleviate control channel communication overhead. Hard Combining: CR users make a local decision and transmit the one bit decision for hard combining. Obviously, using soft combining at the Fusion Center can achieve the best detection performance among all three at the cost of control channel overhead while the quantized soft combining and hard combining require much less control channel bandwidth with possibly degraded performance due to the loss of information from quantization. In order to realize the cooperative detection among CR users, the spectrum sensing and signal detection information over individual users should be sent to a fusion center for further process and the fusion center makes the final decision whether primary user signal is present or absent. Since cooperative spectrum sensing under communication bandwidth constraints, it is proper that all cognitive radio users send their one-bit decision on spectrum sensing to fusion center based on their local observations.

As described in Figure 2, information of local signal observation from all cognitive users transmits to data fusion center. They forward 1-bit local detection to avoid communication overhead when CR users increased. Then, the final decision is performed whether signal is present (H_1) or absent (H_0) by regarding to decision rule.

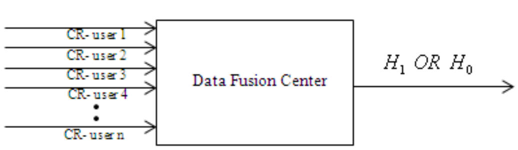

Fig. 2. Data fusion center

V. HARD COMBINATION METHOD

We investigate cooperative spectrum sensing in a centralized CR network consisting of an access point or base station and a number of CR users. In this network, each CR user sends its sensing data to the base station periodically via the common control channels while the base station combines the sensing data from different CR users and makes a decision on the presence or absence of the primary user. In the hard combination scheme, local decisions of the nodes are sent to the decision maker. Every node first performs local spectrum sensing and makes a binary decision on whether a signal of interest is present or not by comparing the sensed energy with a threshold. All nodes send their one-bit decision result to the decision maker. Then, a final decision on the presence of the signal of interest is made by the decision maker.

With a hard decision counting rule, the fusion center implements an *n*–out-of-*M* rule that decides on the signal present hypothesis whenever at least *n* out of the *M* local decisions indicate H_1. Assuming uncorrelated decisions, the probability of detection at the fusion center is given by [27]:

$$P_d = \sum_{n}^{M} \binom{M}{k} P_{d,i}^{\ k} \left(1-P_{d,i}\right)^{M-k} \quad (22)$$

Where $P_{d,i}$ is the probability of detection for each individual node.

Three of the rules used by the decision maker for a final decision are now discussed.

OR-rule: In this rule, if any one of the local decisions sent to the decision maker is a logical one the final decision made by the decision maker is one. Cooperative detection performance with this fusion rule can be evaluated by setting *n*=1 in equation (22).

$$P_{d,OR} = 1-\left(1-P_{d,i}\right)^M \quad (23)$$

AND-rule*:* In this rule, if all of the local decisions sent to the decision maker are one the final decision made by the decision maker is one. The fusion center's decision is calculated by logic AND of the received hard decision statistics. Cooperative detection performance with this fusion rule can be evaluated by setting *n*=*M* in equation (22).

$$P_{d,AND} = P_{d,i}^{\ M} \quad (24)$$

MAJORITY-rule: In this rule, if half or more of the local decisions sent to the decision maker are the final decision made by the decision maker is one. Cooperative detection performance with this fusion rule can be evaluated by setting *n*=⌊M/2⌋ in equation (22).

$$P_{d,MAJ} = \sum_{\lfloor M/2 \rfloor}^{M} \binom{M}{k} P_{d,i}^{\ k} \left(1-P_{d,i}\right)^{M-k} \quad (25)$$

where $\lfloor . \rfloor$ represents the floor operator.

VI. SIMULATION RESULT AND DISCUSSION

All simulation was done on MATLAB version R2011a over Nakagami fading channel. We use complementary receiver operating characteristics (ROC) analysis for the signal detection theory to study the performance of the energy detector. Complementary ROC has been widely used in the signal detection theory due to the fact that it is an ideal technique to quantify the tradeoff between the probability of missed detection and the probability of false alarm.

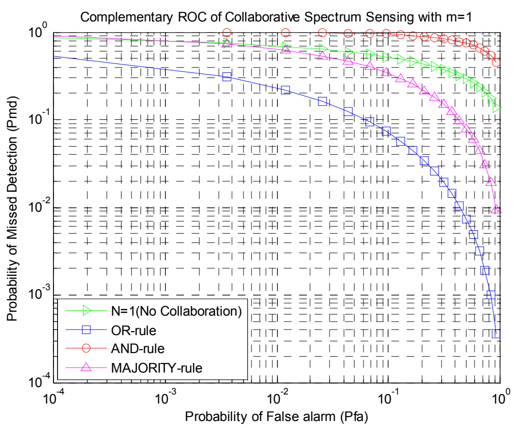

Fig. 3. Complementary ROC over Nakagami fading channel (N=4, $\bar{\gamma}$=10dB, u=5, m=1)

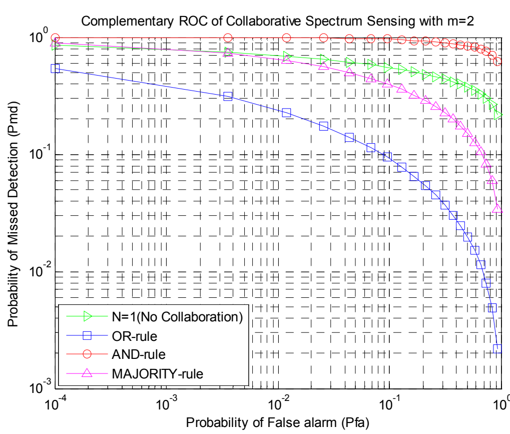

Fig.4 Complementary ROC over Nakagami fading channel (N=4, $\bar{\gamma}$=10dB, u=5, m=2)

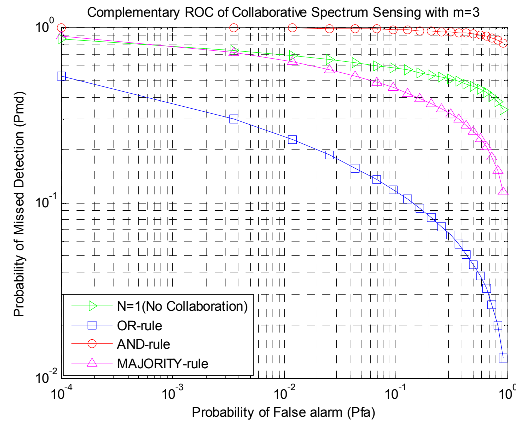

Fig. 5. Complementary ROC over Nakagami fading channel (N=4, $\bar{\gamma}$=10dB, u=5, m=3)

Fig. 3, Fig. 4 and Fig. 5 show complementary ROC of hard decision fusion rule (AND-rule, OR-rule and MAJORITY-rule) of 4 user's spectrum sensing in Nakagami fading channel where Nakagami parameters are m=1, m=2 and m=3 respectively. The simulation was carried out under average SNR and u are assumed to be 10 dB and 5 respectively. The simulation result shows that expected higher m gives better performance. When m=3, the probability of false alarm is less than m=1 and m=2.

We also observe that the OR rule has the better performance than AND and MAJORITY rule in Nakagami fading channels. Comparing with the non-collaboration curve with those collaborating curve, we observe that spectrum sensing is harder in non-collaboration. So the combining decisions from individual CR users improve the overall detection probability. We conclude that the improvement using OR rule with cooperative scheme is better than the case using AND and MAJORITY rule. Because the OR rule is very conservative for the CRs to access the licensed band.

VII. CONCLUSION

Cognitive radio is a novel technology that can potentially improve the utilization efficiency of the radio spectrum. Cooperative communications can play a key role in the development of CR networks. In this paper, we have studied collaborative spectrum sensing over Nakagami fading channel in Cognitive Radio with three parameter m=1, m=2 and m=3. From the simulation result, we get higher m gives the better performance in spectrum sensing. It also shows that OR rule is the best among the fusion rules and gives better performance than AND and MAJORITY rule.

REFERENCES

[1] L. J. Greenstein, J. B. Andersen, H. L. Bertoni, S. Kozono, D. G. Michelson, and W. H. Tranter, "Channel and propagation models for wireless systems design," IEEE J. Select. Areas Commun, vol. 20, no. 3, pp. 493-495, Apr. 2002.

[2] M. K. Simon and M.-S. Alouini, Digital Communication over Fading Channels, 2nd Ed. New York: Wiley, 2004.

[3] N. C. Sagias, G. K. Karagiannidis, D. A. Zogas, P. T. Mathiopoulos, and G. S. Tombras, "Performance analysis of dual selection diversity in correlated Weibull fading channels," IEEE Trans. Commun., vol. 52, no. 7, pp. 1063-1067, July 2004.

[4] M. Nakagami, "The m-distribution - A general formula of intensity distribution of rapid fading," in Statistical Methods in Radio Wave Propagation, W. G. Hoffman, Ed. Oxford, UK: Permagon Press, 1960, pp. 3-36.

[5] G. L. Turin, F. D. Clapp, T. L. Johnston, S. B. Fine, and D. Lavry, "A statistical model of urban multipath propagation," IEEE Trans. Veh. Technol., vol. VT-21, p. 19, Feb. 1972.

[6] F. Hansen and F. I. Meno, "Mobile fading-Rayleigh and Lognormal superimposed," IEEE Trans. Veh. Technol., vol. VT-26, pp. 332-335, Nov. 1977.

[7] S. Haykin, “Cognitive radio: brain-empowered wireless communications,” IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, pp. 201-220, Feb. 2005.

[8] Q. Zhao and B. M. Sadler, “A survey of dynamic spectrum access: signal processing, networking, and regulatory policy,” IEEE Signal Processing Magazine, pp. 79-89, May 2007.

[9] D. Cabric, S. M. Mishra, and R. W. Brodersen, “Implementation issues in spectrum sensing for cognitive radios,” in Proc. Asilomar Conf. on Signals, Systems, and Computers, Nov. 2004, vol. 1, pp. 772–776.

[10] Shamim Hossain, Ibrahim Abdullah and Alamgir Hossain, “Energy Detection Performance of Spectrum Sensing in Cognitive Radio” PP.11-17, Pub. Date: 2012-10-9, DOI: 10.5815/ijitcs.2012.11.02

[11] G. Ganesan and Y. (G.) Li, “Cooperative spectrum sensing in cognitive radio–part I: two user networks,” IEEE Trans. Wireless Commun., vol. 6, no. 6, pp. 2204–2213, June 2007.

[12] G. Ganesan and Y. (G.) Li, “Cooperative spectrum sensing in cognitive radio part II: multiuser networks,” IEEE Trans. Wireless Commun., vol. 6, no. 6, Jun 2007.

[13] A. Ghasemi and E. S. Sousa, “Collaborative spectrum sensing for opportunistic access in fading environments,” in Proc. IEEE Int. Symp. on New Frontiers in Dynamic Spectrum Access Networks, Nov. 2005, pp. 131–136.

[14] S. M. Mishra, A. Sahai, and R. W. Brodersen, “Cooperative sensing among cognitive radios,” in Proc. IEEE Int. Conf. on Commun. June 2006, vol. 4, pp. 1658–1663.

[15] S. H Lee, Y. H. Lee, S, “Hard Decision Combining-based Cooperative Spectrum Sensing in Cognitive Radio Systems”.

[16] S. Kyperountas, N. Correal and Q. Shi, “A comparison of Fusion Rules for Cooperative Spectrum Sensing in Fading Channels”, EMS Research, Motorola.

[17] L. Jiajun, T. Zhenhui, Ai Bo and Y. Shan, “Weighted Hard combination for cooperative Spectrum Sensing in Cognitive Radio Networks”, Research paper, pp.111-116, March, 2011.

[18] N. Armi, N.M. Saad and M. Arshad, “Hard Decision Fusion based Cooperative Spectrum Sensing in Cognitive Radio System”, ITB, vol.3, No.2, 2009, pp. 109-122.

[19] Shahoreare, Shamim Hossain, Ibrahim Abdullah and Alamgir Hossain, “Cooperative Spectrum Sensing over Rayleigh Fading Channel in Cognitive Radio”, pp. 2583- 2592, IJECSE,Vol.1,No.4, ISSN 2277-1956/V1N4-2583-2592.

[20] H. Urkowitz, “Energy detection of unknown deterministic signals,” Proc. IEEE, vol. 55, pp. 523–531, Apr. 1967.

[21] F. F. Digham, M. -S. Alouini, and M. K. Simon, “On the energy detection of unknown signals over fading channels,” in Proc. IEEE Int. Conf. on Commun., May 2003, vol. 5, pp. 3575–3579.

[22] C.E. Shannon, “Communication in the presence of noise,” Proc. *IRE,* vol. 37, pp. 1&21, January 1949.

[23] I. S. Gradshteyn and I. M. Ryzhik, Table of Integrals, Series, and Products, 7th ed. Academic Press, 2007.

[24] M. Nakagami, “The m distribution; a general formula of intensity distribution of rapid fading,” Statistical Methods in Radio Wave Propagation, W.G. Hoffman, ed., pp. 3–36, 1960.

[25] A. H. Nuttall, “Some integrals involving the QM-function,” Naval Underwater Systems Center (NUSC) technical report, May 1974.

[26] I. F. Akyildiz, B. F. Lo, and R. Balakrishnan, "Cooperative Spectrum Sensing in Cognitive Radio Networks: A Survey," Physical Communication (Elsevier) Journal*,* vol. 4, no. 1, pp. 40-62, March 2011.

[27] Spyros Kyperountas, Neiyer Correal, Qicai Shi “A Comparison of Fusion Rules for Cooperative Spectrum Sensing in Fading Channels”. EMS Research, Motorola.

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