Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 5, Issue 10, October -2018

Performance Analysis of Energy Detection Using Cognitive Radio

Fatamatuz Ayasa Khan

Computer Science & Engineering, Islamic University, Kushtia, Bangladesh

Abstract —*Cognitive radio is an economical communication framework, which can pick the accessible frequencies and waveforms naturally at the start of abstaining from meddling the authorized users. The range detecting is the key empowering innovation in intellectual radio systems. It can fill voids in the remote range and can significantly increment unearthly potency. Range detecting is the key segment of intellectual radio innovation. Be that as it may, identification is endangered when a cognitive radio (CR) user encounters profound shadowing or fading impacts. Keeping in mind the end goal to recognize the primary user (PU) all the more precisely, we enable the CR users to participate by sharing their data. In this venture, we research execution of helpful range detecting plan utilizing vitality identification to enhance the detecting execution in channels, for example, AWGN and Rayleigh fading channels. Hard choice joining guideline (OR-rule & AND-rule) is performed at fusion centre (FC) to settle on an ultimate choice about primary user present or not. Correlation among data fusion rules has been examined for an extensive variety of normal SNR values. The execution has been evaluated in terms of probability of miss detection (P_{md}) and probability of false alarm (p_{fa}). The decision likewise thinks about the hypothetical esteem and the simulated result and afterward depicts the connection between the signal to noise ratio (SNR) and the detections. Finally, energy detection and simulation and result are discussed.*

Keywords- *Cognitive Radio; Energy Detection; Spectrum Sensing; Communication framework; Intellectual radio systems;*

I. INTRODUCTION

The spectrum was nearly occupied with the development of science and technology. Still there are a large number of multiple allocations needed to provide enough capacity for the many wireless services for commercial and noncommercial application such security purpose, air traffic, and scientific research. Figure 1 shows the spectrum allocations in the United States. Each color stands for a service type that is allocated to the special frequency band in the United States. Many of the primary allocations such as television (TV), frequency modulation (FM) radio, Global positioning systems (GPS), Wi-Fi, Bluetooth etc are identical. 2.4 GHz and 5 GHz bands are commonly used for wireless computer networking. These bands and some others are known as the industrial, scientific, medical (ISM) bands. In the communication system, there were fixed radios. The radios transmitter parameters were fixed and set up by their operators.

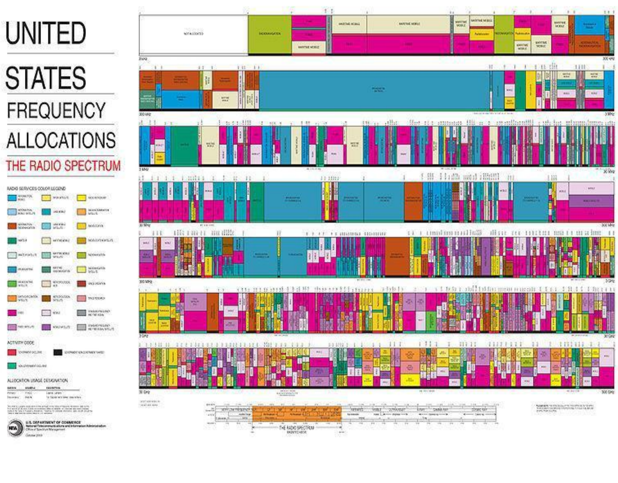

Figure 1: Spectrum allocations in the United States

These limitations can be solved by the Software Defined Radio (SDR). SDR is the new era of wireless communication. A SDR is a radio that includes a transmitter in which the operating parameters including the frequency range, modulation

type or maximum radiated or conducted output power. It can be altered by making a change in software without making any hardware changes. SDR is used to decrease hardware requirement. It gives user a cheaper and reliable solution, But it will not take into account spectrum possibility. Cognitive Radio (CR) is an advanced version of SDR in which all the transmitter parameters change like SDR but it will also change the parameters according to the spectrum availability.
Due to the rapid growth of wireless communications, more and more spectrum resources are required. The current spectrum framework, most of the spectrum bands are completely allocated to specific licensed services. However, the licensed bands, such as those for TV transmitting are underutilized, resulting in spectrum wastage. The key reflection behind the concept "Cognitive Radio" is to allow unlicensed Secondary (US) to use licensed bands through efficient Spectrum Sensing (SS). The Federal Communications Commission (FCC) made available these unused portions of the RF spectrum for civil use. Government spectrum regulatory agencies serve licenses to all wireless service providers to use a fixed frequency band in a fixed area. As the new multimedia service is growing day by day, the higher bandwidth requirement is also increased. But the problem is the radio spectrum is limited. As a result a number of investigations are carried out to manage available radio resources.

Energy detectors measure the energy of the signal by considers the targeted frequency band for a fixed amount of sensing time. The received energy is in comparison with a fixed threshold (λ). If the received energy is larger than the threshold value, it indicates that PU is present, otherwise PU is considered to be absent. Due to noise uncertainties and other environmental effects, the observed energy values in the vicinity of the threshold (λ) are not quite reliable. Decisions from such CRs become unreliable and they are referred as Fuzzy CRs. The reliable CRs report their local binary decisions, while the Fuzzy CRs directly report their energy measurement to the fusion center.

Below the following Figure 2 showed the measurement of the power spectral density (PSD) of the received 6 GHz wide signal. It shows very low utilization of spectrum from 3-6 GHz. In order to increase spectrum efficiency, dynamic spectrum access technique is imperative. Dynamic spectrum access techniques confess the cognitive radio to operate in the best available channel. More specifically the cognitive radio technology will permit the user determine which

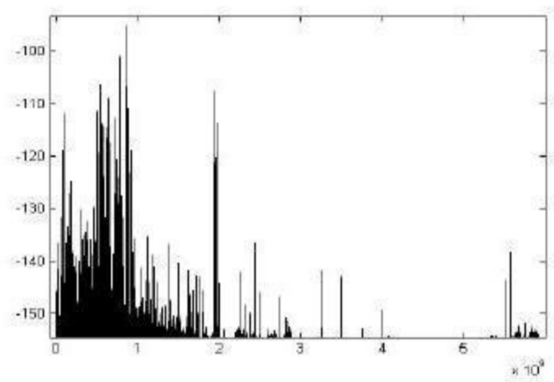

Figure 2: Measurement of 0-6 GHz spectrum utilization at BWRC

portion of the spectrum is available, detect the existence of primary user (spectrum sensing), select the best channel (spectrum management), coordinates the access to the channel with other users (spectrum sharing) and migrate to some other channel whenever the primary user is detected (spectrum mobility).

II. SYSTEM MODEL

We consider that energy detection Figure 3 is applied at each CR user throughout this project. The energy detector contains of a square law device followed by a finite time integrator. The integrator output at any time is the energy of the input to the squaring device over the interval T. The noise pre-filter serves to limit the noise bandwidth and the noise at the input to the squaring device has a band-limited, flat spectral density.

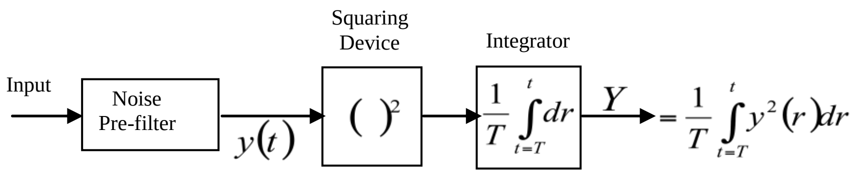

Figure 3: Energy Detection

The detection is a test of two hypotheses:

H_0: *y(t)*is input 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.

H_1: *y(t)*is input signal plus noise:

a) *y(t) = n(t)+s(t)*
b) *E[n(t)+s(t)] = s(t).*

The local spectrum sensing determine between the following two hypotheses

$$y(t)=\begin{cases} n(t) & H_0 \\ hs(t)+n(t) & H_1 \end{cases} \tag{1}$$

Here, *x(t)* is signal received by secondary user and *s(t)* stands for primary user's transmitted signal and *n(t)* is the Additive white Gaussian noise (AWGN), *H* is the amplitude gain of the channel and γ is the signal-to-noise ratio (SNR). The received signal is first pre-filtered ideal band-pass filter along with transfer function [15][16],

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

The limit of average noise power as well as normalize the noise variance. The filter output is then squared and integrated over a time period T to produce a measure of the energy of the received waveform. The output of the integrator represented by Y, it acts as the test statistic to test the two hypotheses H_0 and H_1. According to the theorem, noise process [17] can be expressed

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

Where $\sin c(x)=\frac{\sin(\pi x)}{\pi x}$ and $n_i = n\left(\frac{i}{2W}\right)$

We can easily test that $n_i \approx N(0, N_{01}W)$, for all i. Using the case that [17],

$$\int_{-\infty}^{\infty} \sin c(2Wt-i)\sin c(2Wt-k)\,dt = 1/2W, \quad i=k$$
$$= 0, \qquad i \ne k \tag{4}$$

Therefore,

$$\int_{-\infty}^{\infty} n^2(t)\,dt = \frac{1}{2W}\sum_{i=-\infty}^{\infty} n_i^{\,2} \tag{5}$$

Over the time period $(0,T)$ and $n(t)$ the noise energy can be approximated by a finite sum of $2TW$ terms

$$n(t)=\sum_{i=1}^{2TW} n_i \sin c(2Wt-i), \quad 0<t<T \tag{6}$$

Hence, the energy in a sample of duration T is approximated by $2TW$ terms of the right-hand side

$$\int_0^T n^2(t)\,dt = \frac{1}{2W}\sum_{i=1}^{2u} n_i^{\,2} \tag{7}$$

Where, $u = TW$. We consider that T and W are picking to restrict u to integer values. We can define

$$n_i^{'} = \frac{n_i}{\sqrt{N_{01}W}} \tag{8}$$

Where, N_{01} = One-sided noise power spectral density. Then, the decision statistic Y can be expressed as

$$Y = \sum_{i=1}^{2u} n_i^{'2} \tag{9}$$

Y can be considering as the sum of the squares of 2u standard Gaussian variation with zero mean and unit variance. Moreover, Y follows [15] a basic chi-square (χ^2) distribution with 2u degrees of freedom. The exact way 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 opinion statistic Y will have a non-central χ^2 distribution with 2u degrees of freedom and a non-centrality parameter 2λ. Consequently the short-hand notations mentioned in the beginning of this section, we can describe the decision statistic as following:

$$Y \approx \begin{cases} \chi_{2u}^{\;2} & H_0 \\ \chi_{2u}^{\;2}(2\gamma), & H_1 \end{cases} \tag{10}$$

The probability density function (PDF) [15] of Y can be represented as

$$f_Y(y) = \begin{cases} \dfrac{1}{2^u\Gamma(u)} y^{u-1} e^{-\frac{y}{2}} & H_0 \\ \dfrac{1}{2}\left(\dfrac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{-\frac{2\gamma+y}{2}} I_{u-1}\left(\sqrt{2\gamma y}\right), & H_1 \end{cases} \tag{11}$$

Here, $\Gamma(.)$ is the gamma function.

Testing H_0 versus H_1 are two types of errors that can be built; H_0 can be falsely rejected or H_1 can be falsely rejected. The first of these two errors is termed as False Alarm, and the second error is termed as misdetection [15]. The performance of energy detector can be consistent by the probability of occurrence of both types of errors, i.e., the probability of false alarm (p_{fa}) which describes the probability of erroneously decide that the band is occupied, when is actually not, and the probability of misdetection (p_{md}), which is the probability of erroneously decide that the primary user is absent, when is actually present. Another process used to explain performance is by the complement of the probability of misdetection, i.e., the probability of detection (p_d).

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

$$P_d = \Pr(Y > \lambda \mid H_1) \tag{12}$$

$$P_f = \Pr(Y > \lambda \mid H_0) \tag{13}$$

Here, λ is the final threshold of the local detector to decide if there is a primary user present. Using (11) to

Evaluate (13) yields,

$$P_f = \frac{\Gamma\left(u, \frac{\lambda}{2}\right)}{\Gamma(u)} \tag{14}$$

So,

$$P_d = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{15}$$

Here, $\gamma = \frac{\sigma_x^{\ 2}}{2\sigma_n^{\ 2}} = \frac{\sigma_x^{\ 2}}{2}$ denotes the signal to noise ratio [21] (SNR), Q_u is the generalized Marcum's Q function.

III. PERFORMANCE OF ENERGY DETECTION TECHNIQUE FOR SPECTRUM SENSING

We evaluated performance of energy detection method where the number of used samples is set to $N = 2 * u$, time bandwidth product u = 5 with SNR= 6dB in this simulation result. Following Figures clearly describes the performance of the energy detection such as detection probability increases as (p_{fa}) values increases from 0.01 to 1 with increasing 0.1 under AWGN and Rayleigh Fading channel.

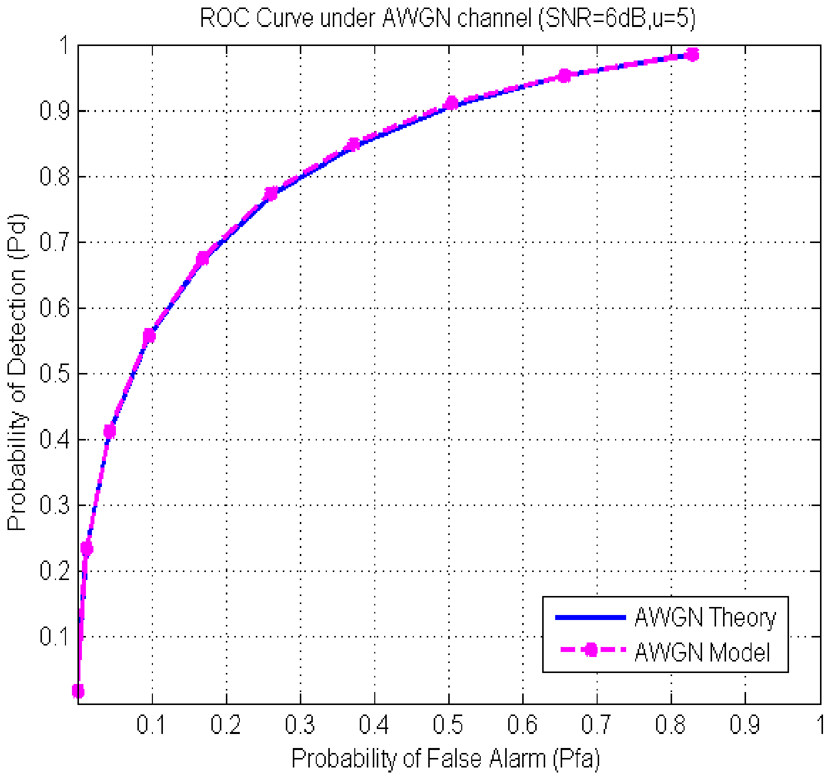

Figure 4: ROC Curve under AWGN channel (SNR=6dB, u=5)

From Figure 4, ROC of spectrum sensing for different probability of false alarm under AWGN channel. The simulation result was carried out for the analysis of detection probability beneath different number of (p_{fa}). This Figure describe that performance of detection varies based on (p_{fa}). It also describe that with the increasing of the (p_{fa}) (from 0.0001to 0.8281) the detection also increased. It also shows that theory result and simulated result are almost same. Table 1 shows the measurement of probability of detection based on different (p_{fa}).

Table 1: Probability of False Alarm vs. Probability of Detection for SNR = 6dB

Probability of False Alarm (p_{fa})	Probability of Detection (p_d)
0.0001	0.0192
0.0121	0.2347
0.0441	0.4115
0.0961	0.5552
0.1681	0.6726
0.2601	0.7682
0.3721	0.8451
0.5041	0.9058
0.6561	0.9517
0.8281	0.9839

In the following Figure 4 we can make sure that the value of *(p_{fa})* will influence the detections we get. So in this Figure, we compare the theoretical value and the simulated result to get a suitable value for *(p_{fa})*.

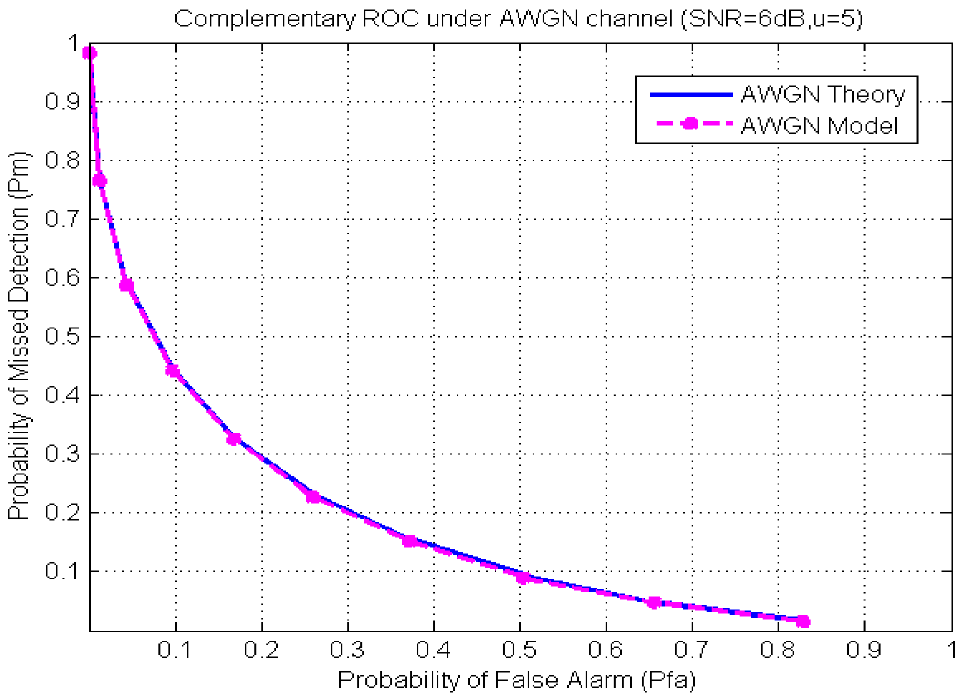

Figure 5: Complementary ROC under AWGN channel (SNR=6dB, u=5)

Figure 5 show Complementary ROC under AWGN channel where signal to noise ratio is 6dB and u = 5. This Figure shows complementary of Figure 4 where probability of missed detection is analyzed and measured that is shown in table 2.

Table 2: Probability of False Alarm vs. Probability of Detection for SNR = 6dB

Probability of False Alarm (p_{fa})	Probability of Missed Detection (p_{md})
0.0001	0.9808
0.0121	0.7653
0.0441	0.5885
0.0961	0.4448
0.1681	0.3274
0.2601	0.2318
0.3721	0.1549
0.5041	0.0942
0.6561	0.0483
0.8281	0.0161

Table 2 shows that as values of (p_{fa}) increases; there is drastic decrease in (p_{md}).

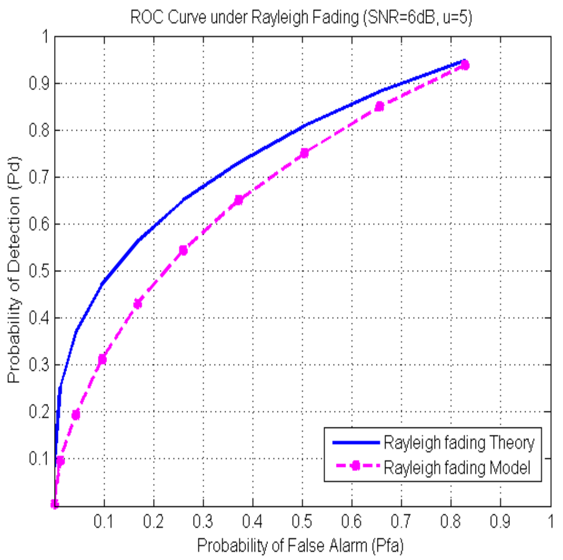

Figure 6: ROC Curve under Rayleigh Fading (SNR=6dB, u=5)

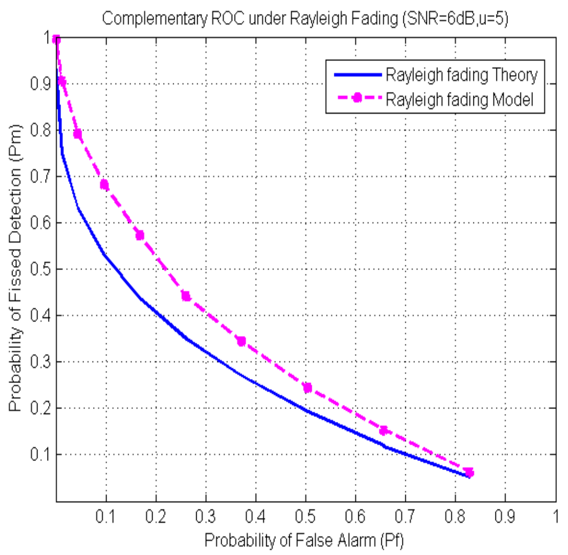

Figure 7: Complementary ROC under Rayleigh Fading (SNR=6dB, u=5)

Figure 6 shows ROC Curve under Rayleigh Fading (SNR=6dB, u=5) like as Figure 4 but difference is that theatrical and simulated result are not same for the Rayleigh fading channel. Figure 7 Complementary ROC under Rayleigh Fading (SNR=6dB, u=5) where only difference from the Figure 6 is that here probability of missed detection is measured and plotted.

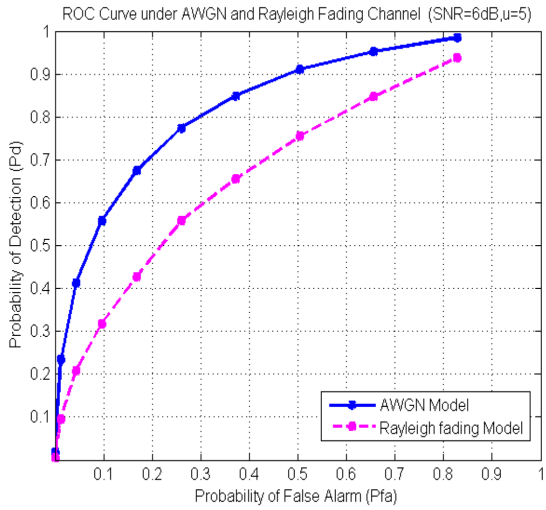

Figure 8: ROC Curve under AWGN and Rayleigh Fading Channel (SNR=6dB, u=5)

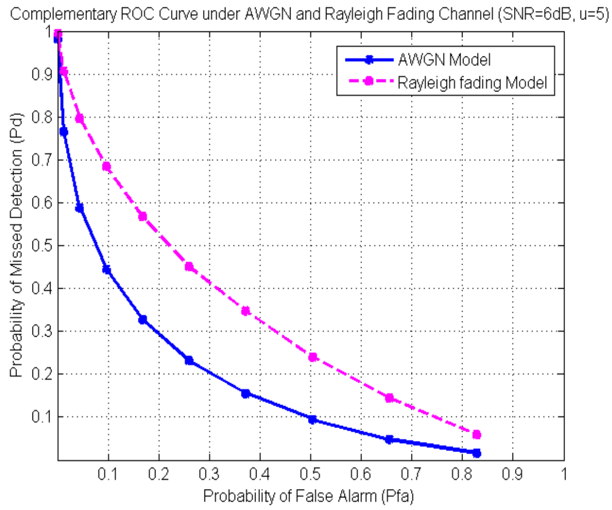

Figure 9: Complementary ROC curve under AWGN and Rayleigh Fading Channel (SNR=6Db, u=5)

Figure 8 shows ROC Curve under AWGN and Rayleigh Fading Channel (SNR=6dB, u=5) where probability of detection is analyzed based on probability of false alarm. Here Energy detection is calculated both AWGN channel and Rayleigh fading channel based on the theatrical equation. From Figure it shows that probability of detection in AWGN channel is better than Rayleigh fading channel where Rayleigh fading channel is more degraded. Figure 9 shows Complementary ROC Curve under AWGN and Rayleigh Fading Channel (SNR=6dB, u=5) and this is as like as Figure 8 only with difference is that probability of missed probability of missed detection is measured.

IV. FOOTNOTES

In the following Figures shows the comparison of probability of missed detection verses probability of false alarm where signal to noise ratio is varying over AWGN channel and Rayleigh Fading channel with simulated result are plotted. The following Figures 10, 11, and 12 shows the complementary ROC curve for energy detection over a non- fading AWGN channel (a case where the form of interference is only noise) and Rayleigh Fading channel.

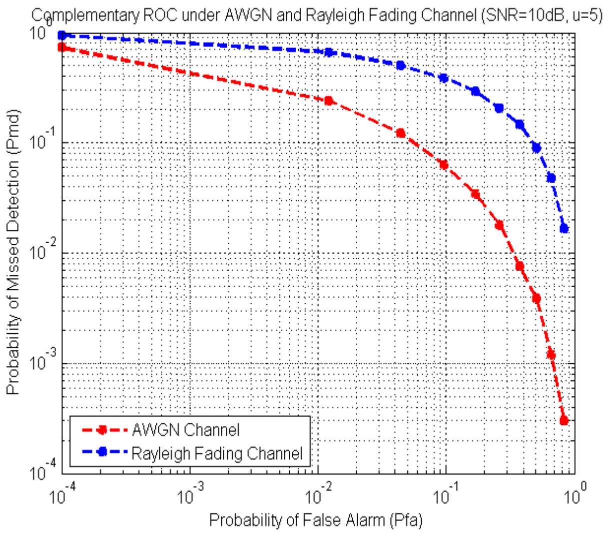

Figure 10: Complementary ROC under AWGN and Rayleigh Fading Channel (SNR=10dB, u=5)

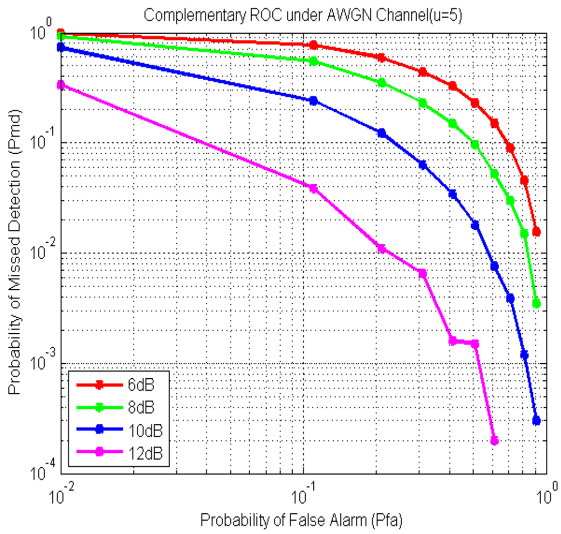

Figure 11: Complementary ROC under AWGN Channel (u=5)

It can be seen in Figure 10 that values of (p_{fa}) increases; there is drastic decrease in (p_{md}). So, as values of SNR are varying there is still decrease in values of (p_{md}). It is apparent that energy detection executed over a Rayleigh channel exhibits a tough detection performance, as to that of AWGN. This is not far- fetched, for the fading severity is more in a Rayleigh channel compared to that of AWGN. Figure 11 shows the probability of missed detection for energy detection under AWGN for various SNR (SNR=6dB, 8dB, 10dB, 12dB).

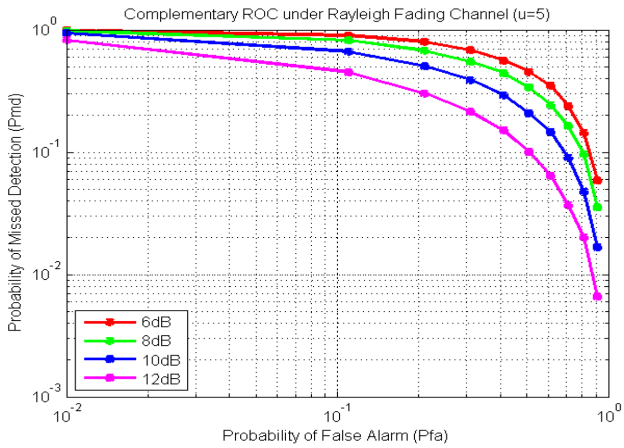

Figure 12: Complementary ROC under Rayleigh Fading Channel (u=5)

In the Figure12 shows the probability of missed detection for energy detection under Rayleigh fading channel for various SNR (SNR=6dB, 8dB, 10dB, 12dB). In the simulation, we have studied spectrum sensing error is low when SNR value is 10dB or 12dB. Figure 11 and 12 show the comparison of the miss detection schemes for different mean SNR values .It shows the relationship between the probability of missed detection (p_{md}), and false alarm probability (p_{fa}), for 6dB to 12dB average SNR, time bandwidth product u = 5, sample size N = 2* u respectively .The probability of missed detection is a complement of detection probability. We noticed in the both channel, the probability of miss improves rapidly with increasing $\bar{\gamma}$. This shows that an increase in SNR produces greater detection performance for both channels. In this(p_{fa} *vs* p_{md}) plot, it is observed that the slopes are low for(p_{fa})< 0.1, and a 6 dB increase in SNR (from 6dB to 12dB), has an increase in missed detection probability reduced p_d).

V. CONCLUSION

In this research we have explain about a radio or system that senses and is conscious of its operational environment and can be trained to dynamically and autonomously adapt its radio operating parameters accordingly. The radio is known as cognitive radio. However, a common assumption regarding cognitive radios is that they are unlicensed spectrum users that should be avoiding interference with the licensed primary users. Effective detection of primary users is the major point of cognitive radio was to use the existing traditionally allocated spectrum in an opportunistic way. One of the important elements of the cognitive radio is detecting the available spectrum opportunities. Generally, we have discussed about cognitive radio and the point in spectrum detection performance of detector algorithms under both AWGN and Rayleigh fading channel in order to decrease interference between primary users and cognitive users.

Spectrum is a very valuable resource in wireless systems and applications. It has been a central point for inquire about over the final a few decades. Cognitive Radio is a novel technology that can potentially refine the utilization efficiency of the radio spectrum. Within a few range detecting methods have been surveyed and a comparison is made. But special attention has been given to Energy Detection because of its low computational complexity, it does not require any earlier knowledge of PU signal and Cooperative Spectrum Sensing (CSS) improves the detection performance under severe fading and hidden terminal problem. Cooperative spectrum sensing is better than classical spectrum sensing techniques as it overcomes the hidden node problem, reduces false alarm and gives more accurate signal detection. To analyze the execution of vitality location calculation for range detecting in cognitive radio by drawing the ROC (Collector Working Characteristics) and complementary ROC bends between likelihood of untrue alert vs. likelihood of location, SNR vs. likelihood of location, Likelihood of mistake vs. Limit in cognitive radio frameworks. We have analyzed the execution of vitality discovery over AWGN channel and over blurring environment (Rayleigh). We considered the challenges of multipath blurring and covered up terminal issue. To overcome it we examined and displayed agreeable range detecting with difficult combination over AWGN channel and Rayleigh blurring channel. At last agreeable Vitality range detecting (CESS) location based on difficult choice with AND run the show assessed which appears superior comes about totally different circumstances

A simulation comparison of AND & OR cooperative result fusion rules was undertaken and decision show that OR rule (corresponding to considering the decision of at least one detector out of k available detectors) out- performs the AND & OR rule combining rules.

REFERENCES

1. S. Haykin, “Cognitive radio: brain-empowered wireless communications,” IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, pp. 201-220, Feb. 2005.
2. 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. 7-10, 2004, vol. 1, pp. 772–776.

3. B. Sklar, "Rayleigh fading channels in mobile digital communication systems, Part I: Characterization", IEEE Communications Magazine, 1997, vol. 35, no. 7, p. 90 - 100.
4. H. Suzuk, "A statistical model for urban radio propagation", IEEE Transactions on Communications, 1977, vol. COM-25, no. 7, p. 673 to 680.
5. M. K. Simon and M.-S. Alouini, Digital Communication over Fading Channels, 2nd edition. New York: Wiley, 2004.
6. 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.
7. 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.
8. F. Hansen and F. I. Meno, "Mobile fading-Rayleigh and Lognormal superimposed," IEEE Trans. Veh. Technol., vol. VT-26, pp. 332-335, Nov. 1977.
9. 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.
10. G. Ganesan and Y. (G.) Li, "Cooperative spectrum sensing in cognitive radio part II: multiuser networks," IEEE Trans. Wireless Commun., vol. 6, no. 6, pp. 2214–2222, June 2007.
11. 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.
12. S. Nallagonda, S. Suraparaju, S. D. Roy and S. Kundu, "Performance of energy detection based spectrum sensing in fading channels", in Proc. of IEEE International Conference on Computer and Communication Technology (ICCCT'11),September, pp. 575-580.
13. S. Nallagonda, S. D. Roy and S. Kundu, "Performance of cooperative spectrum sensing with censoring of cognitive Radios in Rayleigh Fading Channel", in Proc. of IEEE INDICON 2011, December.
14. S. Nallagonda, S. D. Roy and S. Kundu, "Cooperative spectrum sensing with censoring of cognitive Radios in Rayleigh Fading Channel", accepted in Proc. of IEEE Eighteenth National conference on Communications (NCC 2012), February.
15. S. Nallagonda, S.D Roy and S. Kundu, "Performance of Cooperative Spectrum Sensing in Log-normal Shadowing and Fading under Fusion Rules", Int. Jour. Of Enery. Infor. And Comm. pp. 15-28, Vol. 3, Aug. 2012.
16. A. Ghasemi and E. S. Sousa, "Opportunistic spectrum access in fading channels through collaborative sensing," IEEE Journal on selected Areas in Communications, vol. 2, no. 2, pp. 71-82, March, 2007.
17. A. Ghasemi and E. S. Sousa, "Impact of user collaboration on the performance of opportunistic spectrum access," in Proc. IEEE Vehicular Technology Conference (VTC Fall'06), Montreal, September 2006.
18. A. Ghasemi and E. S. Sousa, "Collaborative spectrum sensing for opportunistic access in fading environments," in Proc. of 1st IEEE Symp. New Frontiers in Dynamic Spectrum Access Networks, Baltimore, USA, Nov. 8-11, 2005, pp. 131-136.
19. S. H Lee, Y. H. Lee, S, "Hard Decision Combining-based Cooperative Spectrum Sensing in Cognitive Radio Systems".
20. S. Kyperountas, N. Correal and Q. Shi, "A comparison of Fusion Rules for Cooperative Spectrum Sensing in Fading Channels", EMS Research, Motorola.
21. 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.
22. 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.
23. H. Urkowitz, "Energy detection of unknown deterministic signals," Proc. IEEE, vol. 55, pp. 523–531, Apr. 1967.
24. F. F. Digham, M.-S. Alouini and M. K. Simon, "On the energy detection of unknown signals over fading channels," in Proc. of IEEE International Conference on Communications (ICC'03), pp. 3575–3579, May 2003.
25. I. S. Gradshteyn and I. M. Ryzhik, Table of Integrals, Series, and Products, 7th ed. Academic Press, 2007.
26. G. L. Stuber, Principles of Mobile Communications, second ed. Norwell, MA: Kluwer Academic Publishers, 2002.
27. 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.
28. A. H. Nuttall, "Some integrals involving the QM-function," Naval Underwater Systems Center (NUSC) technical report, May 1974.
29. G. Ganesan and Y. Li, "Cooperative spectrum sensing in cognitive radio networks," in Proc. DySPAN, Nov. 2005, pp. 137-143.
30. Spyros Kyperountas, Neiyer Correal, Qicai Shi and Zhuan Ye, "Performance analysis of cooperative spectrum sensing in Suzuki fading channels," in Proc. of IEEE International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom'07), pp. 428-432, June 2008