Performance Analysis of Energy Detection Based Spectrum Sensing Over Wireless Non-Fading AWGN Channels in Cognitive Radio Network

Md. Nahid Sultan, Emran Ali, Md. AhsanHabib, Md. Ibrahim Abdullah

Abstract—Energy detection has been adopted as an alternative spectrum sensing method for cognitive radios (CR) due to its low computational complexity and not requiring a priori information of the signal to be detected. The biggest challenge related to spectrum sensing is in developing sensing techniques which are able to detect very weak primary user signals while being sufficiently fast and low cost to implement. This paper analyses the strategy of spectrum sensing by detecting energy over non-fading channels. Two types of filtering scheme are used for signal filtering lowpass and bandpass. The energy of the received signal is used to compute the possibility of primary user.

Index Terms—Additive White Gaussian Noise (AWGN), Cognitive Radio Network (CRN), Energy Detection, Filtering, Non-fading Channel, Software Defined Radio (SDR), Spectrum Sensing.

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1 INTRODUCTION

NOwadays,with the technology and the science development, the spectrum is nearly fully occupied. However, there are still large number of multiple allocations needed to provide enough capacity for the many wireless services for commercial and noncommercial application, such as defense, air traffic, and scientific exploration.

The usable electromagnetic radio spectrum is a precious natural resource and of limited physical extent. However, wireless devices and applications are increasing daily. It is therefore not surprising that we are facing a difficult situation in wireless communications. Moreover, given the reality that, currently, the licensed part of the radio spectrum is poorly utilized [1], this situation will only get worse unless we find new practical means for improved utilization of the spectrum. Cognitive radio, a new and novel way of thinking about wireless communications, has the potential to become the solution to the spectrum underutilization problem **[2]**, **[3]**.

To address these critical problems, the Federal Communications Commission (FCC) recently decided to make a paradigm shift by allowing more and more number of unlicensed users to transmit their signals in licensed bands so as to efficiently utilize the available spectrum. Consequently, dynamic spectrum access techniques are proposed to solve these current spectrum inefficiency problems **[5]**. The term Cognitive Radio was first introduced by **Joseph Mitola** in his paper in 1999, and its core idea is that the CR has the ability to learn and communicate with the surrounding environment so as to perceive the available spectrum in the space, limit and reduce the occurrence of conflicts **[6]**. Cognitive Radio Network (CRN) allows intelligent spectrum-aware devices to opportunistically use the licensed spectrum bands for transmission **[7]**. Cognitive radio is being widely adapted, as many researchers look to it as the ultimate solution for efficient spectrum sharing **[8]**-**[12]**.

IEEE defines CR as, "A cognitive radio is a radio frequency transmitter/receiver that is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use, and to jump into (and out of, as necessary) the temporarily-unused spectrum very rapidly, without interfering with the transmissions of other authorized users."
Definition of CR adopted by Federal Communications Commission (**FCC**):"Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets"**[2]**.

Cognitive radio is developed on software defined radio (SDR) **[13]**. A SDR refers to the technology wherein software modules running on a generic hardware platform consisting of digital signal processing (DSP) capabilities. General purpose microprocessors are used to implement radio functions such as generation of transmitted signal (modulation) at transmitter and tuning/detection of received radio signal (demodulation) at receiver **[13]**. SDR technology can be used to implement military, commercial and civilian radio applications. CR is an SDR that additionally senses its environment, tracks changes, and reacts upon its findings. A CR is an autonomous unit in a communications environment that frequently exchanges information with the networks it is able to access as well as with other CR users' **[14]**.

More specifically, the cognitive radio technology will enable the users to

1) determine which portions of the spectrum is available and detect the presence of licensed users when a user operates in a licensed band (spectrum sensing),
2) select the best available channel (spectrum management),
3) coordinate access to this channel with other users (spectrum sharing), and
4) Vacate the channel when a licensed user is detected (spectrum mobility).

2 SYSTEM MODEL

Energy detector is composed of four main blocks:

1) Pre-filter
2) A/D Converter (Analog to Digital Converter)
3) Squaring Device
4) Integrator.

The Energy Detection diagram is given below, where an input signal Y(n) first passing through filter. The filtered single convert into an A/D converter. Then the result signal will have squared and integrated by integrator.

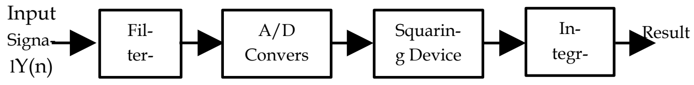

Fig 1: Energy Detection Procedure

The Energy detection is the test of the following two hypotheses:

$$Y(n)=\begin{cases} W(n)H_0 \\ h(n)s(n)+W(n)H_1 \end{cases}$$

where n denotes the sample index, h(n) denotes the impulse response of the channel between the primary and secondary users, s(n) is the signal from the primary user with zero mean and unit variance (i.e., $E\{|s(n)|^2\}=1$), w(n) denotes zero-mean circular-symmetric complex Gaussian (CSCG) noise with variance σ^2_w.

For,
H_0: The input Y(n) is noise.
H_1: The input Y(n) with noise.
We find the result for input signal Y(n) by using lowpass and Bandpass Filter. Which given below.

3 LOWPASS FILTERING (DETECTION IN WHITE NOISE)

It is known that a sample function, of duration *T*, of a process which has a bandwidth *W* (negligible energy outside this band) is described approximately by a set of sample values 2TW in number. In the case of a low-pass process, the values are obtained by sampling the process at times 1/2*W* apart.
Let us start with a low-pass process. With an appropriate choice of time origin.
Mathematically we can express each sample of noise as [1]

$$n(t)= \sum_{n=-\infty}^{\infty} a_i \frac{\sin\pi\,(2Wt-n)}{\pi(2Wt-n)} \quad (1)$$

We can rewrite the equation as

$$n(t)= \sum_{i=-\infty}^{\infty} a_i sinc(2Wt-i) \quad (2)$$

Where sinc x =sinπx/πx and a_i= n (i/2W)
Clearly, each $\boldsymbol{a_i}$is a Gaussian random variable with zero mean and with the same variance σ_i^2, which is the variance of n(t); i.e.,

σ_i^2= 2No₂W, all **i.**
Using the fact that

$$\int_{-\infty}^{\infty} sinc(2Wt-i)sinc\,(2Wt-k)dt = \begin{cases} 1/2W, & i = k \\ 0, & i \neq k \end{cases} \quad (3)$$

We may write

$$\int_{-\infty}^{\infty} n^2(t)dt = (1/2W)\sum_{i=-\infty}^{\infty} a_i^2 \quad (4)$$

Over the interval (0, *T),* n (t) may be approximated by a finite sum of 2TW terms, as follows:

$$n(t)=\sum_{i=1}^{2Wt} a_i sinc(2Wt-i),\ 0<t<T \quad (5)$$

Similarly, the energy detection in a sample of duration T is approximated by 2TW terms of the right-hand side of (4)

$$\int_0^T n^2\,(t)dt = (1/2W)\sum_{i=0}^{2TW} a_i^2 \quad (6)$$

We can see that (6) is $\boldsymbol{No_2}V'$, with ***V'*** here being the test statistic under hypothesis ***Ho.***
Let us write

$$a_i/\sqrt{2WN_{02} = \ b_i} \quad (7)$$

$$V' = \sum_{i=1}^{2TW} b_i^2 \quad (8)$$

Thus, *V′* is the sum of the squares of the 2WT Gaussian random variables, each with zero mean and unity variance. *V′* is said to have a chi-square distribution with 2WT degrees of freedom, for which extensive table exists [3]-[5].
Under the hypothesis $\mathbf{H_1}$**,** the test statistic ***V'*** is

$$V' = (\frac{1}{N_2})\int_0^T y^2(t)dt = \sum_{i=1}^{2TW}(b_i+\beta_i)^2. \quad (9)$$

The sum in (9) is said to have a non-central chi-square distribution [6], [7] with 2TW degrees of freedom and a non-centrality parameterλ given by

$$\lambda = \sum_{i=1}^{2TW}\beta_i^2 = (1/N_2)\int_0^T s^2(t)dt \equiv E_s/N_2 \quad (10)$$

λ, the ratio of signal energy to noise spectral density, provides a convenient definition of signal-to-noise ratio.

4 BANDPASS FILTERING (DETECTION IN WHITE NOISE)

Let us now determine some of the statistical properties of the envelope and phase when the narrow-band random process in question is a stationary Gaussian random process. To this end, it is convenient to represent the given process over the interval 0 <t ≤T by the Fourier series [8]

$$x(t)=\sum_{n=1}^{\infty} x_{cn} \cos n\omega_0 t + x_{sn} \sin n\omega_0 t \quad (11)$$

Where $\omega_0 = \frac{2\pi}{T}$

$$Xcn= \frac{2}{T}\int_0^T x(t)\cos n\omega_0 t\ dt \quad (12)$$

$$Xsn = \frac{2}{T}\int_0^T x(t)\sin n\omega_0 t\ dt \quad (13)$$

The mean frequency of the narrow spectral band may be introduced by
Writing $n\omega_0$ in Eq. (11) as $(n\omega_0 - \omega_c)$ where $\omega_c == 2\pi f_c$, and expanding the sine and cosine factors. In this way, If the noise is a bandpass random process, we can obtain the expression

n(t) = $n_c(t) \cos\omega_c t$- $n_s(t) \sin \omega_c t$ (14)

Where $\omega_c$is the reference angular frequency, and $n_c(t)$and $n_s(t)$ are respectively, the in-phase and quadrature modulation components. Where $n_c(t)$ and $n_s(t)$ are defined as

$n_c(t)=\sum_{n=1}^{\infty}[x_{cn} \cos(n\omega_0 - \omega_c)\, t + x_{sn} \sin(n\omega_0 - \omega_c)t]$ (15)

$n_s(t)=\sum_{n=1}^{\infty}[x_{cn} \sin(n\omega_0 - \omega_c)\, t + x_{sn} \cos(n\omega_0 - \omega_c)t]$(16)

By following the reasoning in the previous section, we get similar series expansion for the energy in $n_c(t)$and $n_s(t)$ as follows:

$\int_0^T n_c^2(t)dt = (1/W) \sum_{i=0}^{TW} a_{ci}^2$ (17)

$\int_0^T n_s^2(t)dt = (1/W) \sum_{i=0}^{TW} a_{si}^2$ (18)

Now we can write from the above equation two hypotheses are for bandpass filter is given below [2]

$H_0: V' = (\frac{1}{N_2}) \int_0^T n^2(t)dt = \sum_{i=1}^{2TW} (b_{ci}^2 + b_{si}^2)$ (19)

and

$H_1: V' = \sum_{i=1}^{TW} \{(b_{ci} + \beta_{ci})^2 + (b_{si} + \beta_{ci})^2\}$ (20)

Where $a_{ci} = n_c(i/W)$, $a_{si} = n_s(i/W)$
and$b_{ci} = a_{ci/\sqrt{2WN_2}}$, $b_{si} = a_{si/\sqrt{2WN_2}}$

We can define the coefficients β_{ci} and β_{si} as follows:

$\beta_{ci} = s_c(1/W)/\sqrt{2WN_2}$
$\beta_{si} = s_s(1/W)/\sqrt{2WN_2}$

5 PRIMARY USER DETECTION AND FALSE ALARM PROBABILITIES

The output of the integrator is denoted by V and we concentrate on a particular interval, say, (0,T),and take the statistics as Vor any quantity monotonic with V. We shall find it convenient to compute the false alarm and detection probabilities using the related quantity [2]

V = $(1/H_2)\int_0^T y^2(t)dt$ (21)

The choice of T as the sampling instant is a matter of convenience; any interval of duration T will serve. Another quantity of interest is the false alarm rate Qo/T, where Qo is the false alarm probability based upon the energy in a sample of duration T.

The probability of false alarm Q, for a given threshold V'_T is given by

Qo= Prob{V ’>V'_T | (H_0)} =Prob{$x^2{}_{2TW}(\lambda)$>V'_T } . (22)

The far right-side of () indicates a chi-squared variable with 2TW degrees of freedom. For the same threshold level v'_T the probability of detection $Q_d$is given by

Qd= Prob{V′ >V'_T | (H_1)} = Prob($x^2{}_{2TW}$ (λ)>V'_T} (23)

The symbol $X'^2{}_{2TW}(\lambda)$ indicates a non-central chi-square variable with 2TW degrees of freedom and noncentrality parameter λ; in our case λ =E_s/N_{o2}, and is defined as the signal-to-noise ratio.

If the energy detection can be applied in a non-fading environment where h is the amplitude gain of the channel as shown in (1), the probability of detection P_d and false alarm P_f are given as follows [9]:

$P_d = P\{Y> \lambda | H_1\} = Q_m(\sqrt{2\gamma}\sqrt{\lambda})$ (24)

And

$P_f = P\{Y> \lambda | H_0\} = \frac{\Gamma(m,\lambda/2)}{\Gamma(m)}$ (25)

Where, λ is the SNR, u = TW is the time bandwidth product, $\Gamma(.)$ and $\Gamma(.,.)$ are complete and incomplete gamma functions and $Q_m(\ )$ is the generalized Marcum Q-function. From the above functions, while a low P_d would result in missing the presence of the primary user with high probability which in turn increases the interference to the primary user, a high P_f would result in low spectrum utilization since false alarms increase the number of missed opportunities. Since it is easy to implement, the recent work on detection of the primary user has generally adopted the energy detector [10, 11].

6 SIMULATED RESULT AND DISCUSSION

All simulation was done on MATLAB version R2014a over non-fading AWGN channel. Figure 2, 3 and 4 show complementary ROC curves of energy detection based spectrum sensing in non-fading AWGN channel respectively. Average SNR and P_f are assumed to be 10 dB and 0.2 respectively. Figure 2 shows ROC curve for Probability of detection versus probability of false alarm. Figure 3 shows ROC curve for Probability of miss detection versus probability of false alarm. Figure 4 shows ROC curve for Probability of detection versus Signal to noise ratio.

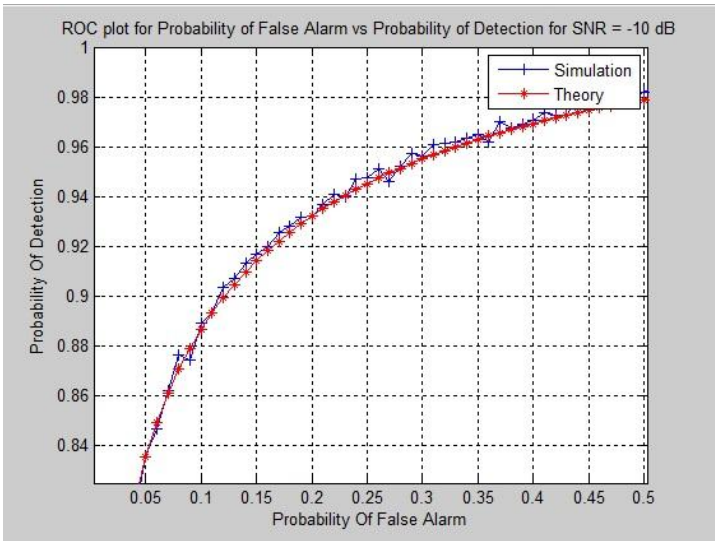

Fig. 2 ROC curve for Probability of detection versus probability of false alarm, SNR = -10dB

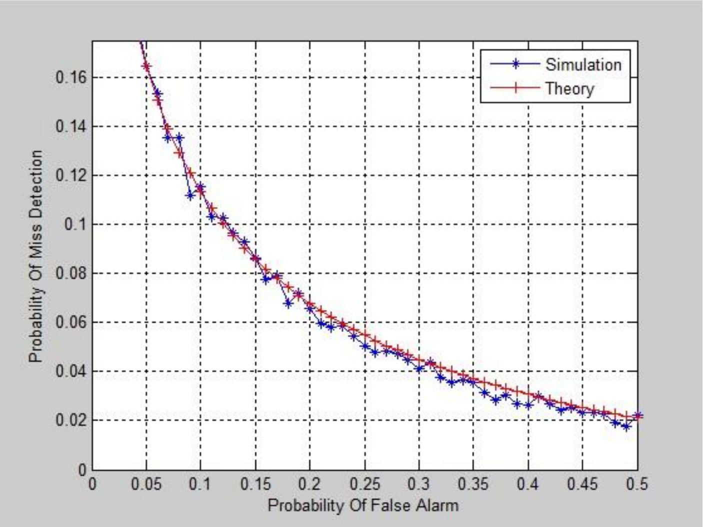

Fig. 3ROC curve for Probability of miss detection versus probability of false alarm, SNR = -10dB

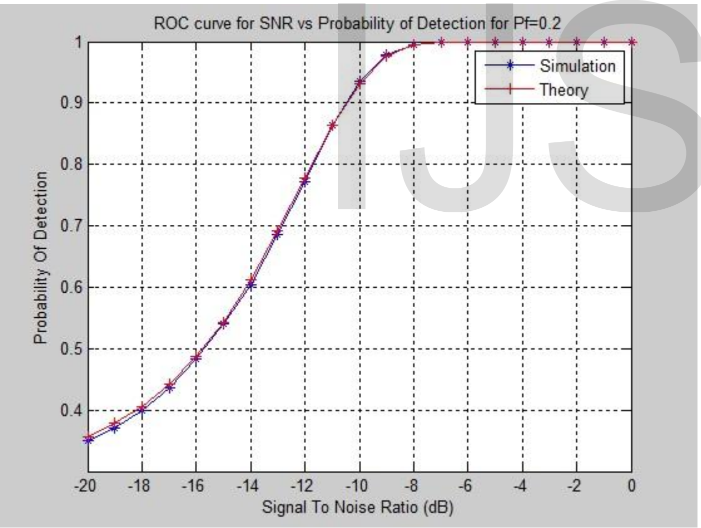

Fig. 4 ROC curve for Probability of detection versus Signal to noise ratio, Probability of False alarm = 0.2

7 CONCLUSION

In this paper we have studied energy detection based spectrum sensing in CRs technology in non-fading AWGN channel. Energy Signal Detection is performed and filtered by low-pass and bandpass filter. The problem of the spectrum detection schemes was formulated which include Energy detection in time and frequency domain Closed form expressions for probability of detection and false alarm over wireless Nom-fading channels are evaluated.

Three performance metrics such as probability of detection, probability of false alarm and signal to noise ratio are considered for analysis for energy detection based spectrum sensing technique.

Various ROC (Receiver Operating Characteristics) curves i.e Plot of $P_d$versus P_f, P_fVs SNR etc. has been plotted over non fading channels. Average SNR and P_f are assumed to be 10dB and 0.2 respectively.

Thus in Cognitive Radio Network, it is observed that with low computational complexities, detection of presence of primary user signal is easiest job by using Energy detection based Spectrum sensing technique. From comparative plot, it is clearly observed that, it gives more improvement in spectrum sensing and Probability detection in Cognitive Radio.

In future, performance analysis can be done over other wireless fading channels. Also, cooperative spectrum sensing method can be used to achieve still better sensing performance in detection of Cognitive Radio Network.

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Authors

- ***Md. Nahid Sultan***, *faculty member, Department of Computer Science and Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.*
  E-mail: nahidsultan111@gmail.com
- ***Emran Ali***, *faculty member, Department of Computer Science and Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.*
  E-mail: emran.cse@hstu.ac.bd
- ***Md. AhsanHabib***, *faculty member, Department of Computer Science and Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.*
  E-mail: ahsan.habib@hstu.ac.bd
- ***Md. Ibrahim Abdullah***, *faculty member, Department of Computer Science and Engineering, Islamic University, Kushtia, Bangladesh.*
  E-mail: ibrahim25si@yahoo.com