ENERGY DETECTION BASED SPECTRUM SENSING PERFORMANCE EVALUATIONS IN COOPERATING COGNITIVE RADIO NETWORKS

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Abstract –The ever growing wireless technologies has put a lot of demand on the usage of available spectrum, thus leading to spectrum underutilization and scarcity. To address this issue and improve spectrum utilization gave rise to the concept of the cognitive radio. The cognitive radio is known to enhance the utilization of spectrum of where a secondary user can utilize the spectrum of the primary user without causing harmful interference to the incumbent primary user. In this paper, we evaluated the performance of the energy detection based spectrum sensing in a fading and non-fading environments. Also we presented results on the single user detection and cooperative detection applying the energy detector. The performance of the energy detection technique was assessed by the use of the receiver operating characteristics (ROC) curves over additive white Gaussian noise (AWGN), Rayleigh and Nakagami channels. The cooperative detection shows better performance to the single user in the fading environments.

Keyword– Cognitive radio, cooperative sensing, spectrum sensing.

I. INTRODUCTION

The ever growing demand for radio spectrum in wireless communication has led to the scarcity of the spectrum. However, analysis has shown that the scarcity is caused by the underutilization of the licensed spectrum. Contemporary researches have shown that a very high percentage of available radio spectrum is highly underutilized [1]. This scarcity however leads to the emergence of the cognitive radio (CR) technology which has the ability to exploit the spectrum opportunistically [2]. The CR technology was proposed by Mitola in 1999 [3]. This technology provides an opportunistic way of reusing spectrum by sensing the radio environment for white spaces without causing harmful interference to the primary networks. Spectrum sensing is a key component of the CR which consists of spectrum sensing, management, sharing and spectrum mobility [4]. In order to achieve the aim of the CR, the cognitive user must perform spectrum sensing to detect the presence of primary user (PU). The PU is the incumbent licensed user to the network and has high priority to a specific portion in the spectrum. While the secondary user (SU) is users with lower priority therefore they are permitted to use the portion allocated to the PU with a condition that they do not cause destructive interference to the primary network. However, the SU possesses CR capabilities in other to sense the radio environment in other to ascertain when the channel is occupied by the PU then changes its radio parameters to exploit the vacant portion in the spectrum. Spectrum sensing is a process of identifying a white space which can be exploited opportunistically by the secondary user (SU) without causing a destructive interference to the primary network [5]. A number of spectrum sensing techniques has been proposed and numerically analyzed in literature. There are three commonly known methods for spectrum these include: energy detection, matched filtering and Cyclostationary detection [6-8]. In the course of this work, we would limit the spectrum sensing evaluation to the energy detection based spectrum sensing. The energy detection is an optimal way to detect signal when prior knowledge of the primary signal is unknown to the SU. The Energy detector (ED) performance has been studied in some research literature [6], [9-10] and it was found to perform poorly under very low SNR and wrong estimation because noise degrades performance significantly when the ED scheme is implemented in the cooperative spectrum sensing. The SU reports the local sensing to the fusion center (FC) either as Data fusion or Decision fusion [11]. The rest of this paper is organized as follows; Section II. We discussed some preliminaries of Energy detection. Section III. Cooperative energy based spectrum sensing over fading channels. Section IV. Simulation Results and discussions and Section V. Conclusion.

II. PRELIMINARIES OF ENERGY DETECTION

The primary signal \( x(t) \) which is transmitted through a wireless channel which has a channel gain of \( h \), the signal at the receiver then becomes \( y(t) \). When it follows a binary hypothesis, \( H_0 \) (represents absence of signal) and \( H_1 \) (signifies the presence of signal) it can then be represented as:

\[
y(t) \begin{cases} 
\omega(t) : H_0 \\
hx(t) + \omega(t) : H_1 
\end{cases}
\]

(1)
where $n(t)$ is the additive white Gaussian noise (AWGN), it is presumed to be circularly symmetric complex Gaussian random variable with a zero mean and a one-sided power spectra density (PSD) $N_0 (\text{i.e.}, \omega(t) \sim \text{CN}(0, N_0))$.

A. Energy Detector Through AWGN Channel

In the energy detector, the received signal is passed through an ideal band pass filter (BPF) with bandwidth $W$. With a center frequency $f_0$ and transfer function;

$$H(f) = \begin{cases} \frac{2}{N_0}, & |f - f_0| \leq W \\ 0, & |f - f_0| > W \end{cases}$$

where $N$ represents the one sided noise PSD to calculate $E_{FA}$ and $P_D$ by implementing the transfer function. The transfer function output then squared and integrated over the time interval $T$ to generate the test statistics. The test statistics $\gamma$ is compared to a predefined threshold value $\delta$ [12]. However, the probability of false alarm (PFA) and probability of detection (PD) can then be estimated; $\Pr (\gamma > \delta | H_0)$ and $\Pr (\gamma > \delta | H_1)$ respectively to produce the following [6];

$$E_{FA} = \frac{\Gamma(u, \delta)}{\Gamma(u)}$$

$$P_D = Q(x, \sqrt{2}\delta)$$

where $u = WT, \lambda$ represents the SNR which is given as $\lambda = E_p |h|^2 |N_0|$ where $E_p$ is the budget at the primary user, $Q(x, \cdot)$ is the generalized Marcum Q function $\Gamma(\cdot)$ and $\Gamma(\cdot, \cdot)$ which are the gamma and incomplete gamma functions respectively [13].

B. Energy Detector over Fading Channel

Rayleigh fading channel is one of the most common distributions in modelling fading channels. However, a universal fading distribution was created to accommodate all forms of empirical measurements [15]. This distribution is known as Nakagami fading and is given as follows;

$$f(\lambda) = \frac{1}{\Gamma(m)\lambda^m} \lambda^{m-1} \exp \left(-\frac{\lambda}{\mu} \right), \lambda \geq 0$$

The average $E_{FA}$ in respect to Nakagami channels is obtained by averaging (5) over (4) to achieve the following

$$P_{bm} = \int_0^\infty P_0 (\lambda) f(\lambda) d\lambda$$

where $f(\lambda)$ denotes the probability density function (PDF) of the instantaneous SNR at the receiver. The variable $x = \sqrt{2}\lambda$ is modified then we obtain

$$P_{bm} = \alpha \int_0^\infty x^{m-1} \exp \left(-\frac{\lambda x^2}{2} \right) Q(\lambda, \sqrt{\delta}) dx$$

where $\alpha = \frac{1}{\Gamma(m)\lambda^m} \left(\frac{m}{\lambda}\right)^m$ (8)

where $m$ is the Nakagami-m fading parameters, this explains the strength of fading $m < 1$ indicates strong fading and $m > 1$ denotes lower fading [15]. A solution to the integral in (7) is an expression a closed form PD in Nakagami channels. It is expressed as;

$$P_{bm} = \alpha \left[ F_1 \left( \frac{\delta}{\lambda}, \frac{\lambda}{2m+\lambda} \right) \right]$$

where $F_1(\cdot, \cdot, \cdot)$ is the confluent hypergeometric function.

III. ENERGY BASED COOPERATIVE SPECTRUM SENSING OVER FADING CHANNELS

In the cooperative spectrum sensing, the collective sensed data collected at different locations of the SUs are jointly used to make a decision on the availability of spectrum. The receivers performs sensing either individually or based on measured energy then transmits its hard decision to a fusion center (FC) to make a combined decision on the presence or absence of the primary user (PU). The process of combining the sensed results is known as data fusion; in this case, the ED node sends its detection to be combined at the FC, when the combination of the sensed data is done. In literature, there are available diversity receiver techniques which includes; the equal gain combining (EGC), the maximal ratio combining (MRC) and the square law combining (SLC). These techniques are used for self-combination of the local sensing by the energy detection. However, most of the listed algorithms can be implemented by the energy detection but in this work we would limit our analysis to the MRC and SLC schemes [16]. The performance of each of the following is considered using the minimum, average and maximum selection methods

Scenario I: Minimum selection.

In this scenario, the energy detector makes its decision only if the detector which has the minimum decision variable is higher than the detection threshold which is $Y = \min (Y_1, Y_2, \ldots, Y_N)$ then $P_D$ is expressed as;

$$P_D^T = P_0 \left[ \min (Y_1, Y_2, \ldots, Y_N) > \delta \right]$$

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\[
H = - N P (13)
\]

where \( Y > \delta \). \( \delta \) is the threshold value used to decide whether the signal is present or not. \( P_k \) is the probability of the decision variable. The detection and false alarm probabilities at fusion center are;

\[
P^T_x = \prod_{i=k-1}^{N} P_i^T \prod_{j=k+1}^{N} (1 - P_{j}^T) \quad (15)
\]

where \( (x = "T") \) denotes the \( P_{FA} \) and \( (x = "d") \) represents the \( P_d \).

For the special instance of \( K=1 \), this represents the “OR” decision rule, specifying that if any local decision which is forwarded to the FC is a logical 1, then its decision is 1, (i.e. when at least 1 out of the k SUs detects a PU, then the presence of PU is considered). Then (15) becomes;

\[
P^T_x (k = N) = \prod_{i=1}^{N} P_i^T \quad (16)
\]

This is numerically equivalent to (13) and (14) \( K=N \) is the “AND” rule which means that when the local decision transmitted to the FC is 1 then the resulting decision becomes 1.

\[
P^T_x (k = N/2) = \prod_{i=1}^{N/2} P_i^T \prod_{j=N/2+1}^{N} (1 - P_j^T) \quad (17)
\]

we set \( k = N/2 \) to correspond to the majority decision rule; which is forwarded to the FC is 1, then resulting in the terminal decision of 1 (i.e. setting \( k=N/2 \) in (16)) becomes;

\[
P^T_x (k = N/2) = \sum_{i=1}^{N/2} \prod_{j=1}^{i-1} (P_j^T) \prod_{j=i+1}^{N/2} (1 - P_j^T) \quad (18)
\]

IV. SIMULATIONS AND RESULTS

In this section, we presented the simulated results representing various scenarios of sensing primary user signals in different forms of noise when implementing the energy detection scheme. The analyses performed are as follows; In figure 1, we shown the SNR affects the detection performance using energy detector over a non-fading (AWGN) channel. We have shown the performance
of a single energy detector which operates over an AWGN channel. We have shown the performance of a single energy detection which operates over an AWGN channel. The system has been setup as follows: the $P_{FA}$ is set to 0.01, time bandwidth factor $d=1$, number of iteration of Monte Carlo’s sample $N=1000$. It can be concluded that the detection performance becomes by increasing SNR values, it is negligible before 15dB and precisely thereafter. This is the overall concept of energy detector since the method offers optimal performance as signals power level increases (high SNR).

Figure 3; have shown that the complementary ROC curves over Rayleigh channel for average SNR values between 0-15dB. It has shown that energy detection performance over Rayleigh channel shows a better performance in comparison to the AWGN. From the plot of $P_{M} - P_{FA}$ it can be seen that the curves are lower for $P_{FA} > 0.1$ and a 5dB increment in SNR affects the missed detection probability of up to 0.6 times when compared to probability of detection over AWGN.

In figure 2, we have shown the complementary ROC curve for energy detection over a non-fading Gaussian channel (AWGN). It explains the link between the probability of missed detection $P_{M}$ and probability of false alarm $P_{FA}$ for 0-15dB average SNR. The system was setup as follows time bandwidth product $d=4$, sample size $N=1000$. From the figure, we can conclude that the probability of missed detection is a compliment of detection probability which is expressed as ($P_{M} = 1 - P_{D}$). The probability of miss detection greatly increases when the SNR increases. This clarifies the point that the increase in SNR produces greater detection in a non-fading channel.

In this figure the performance of Energy detection in a Nakagami channel is explored, it shows that the probability of miss detection enhances detection with increase in average SNR. In this figure we set the Nakagami fading parameter $m$ to 2 as against the Rayleigh which was set to 1. This shows that simple signals face less obstruction as they travel along the transmitter’s line-of-sight route to the receiver.

In this figure we show a case for SNR=20dB, from this figure there is approximately an increase of roughly one order of magnitude from $P_{M}$ perspective for $m=2$. We conclude that the receiver performance improves using the energy detection scheme when the Nakagami fading reduces detection is achieved.
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In figure 6, we have analyzed the networks of cooperative energy detector; the figure represents a complementary ROC performance curve of the energy detector over Rayleigh fading. The numbers of cooperating nodes (M) are set to 10 with average SNR values 0 – 15dB and time bandwidth product d=5. We applied same parameters in the Nakagami fading from the figure we can see a detection using energy detection method in comparison to the single user detection.

Figure 7, shows a complementary ROC performance curves of energy detector in Nakagami fading channel, the parameters are the same with that of the Rayleigh fading. From the figure we can see a gain of one order magnitude improvement in missed detection probabilities using energy detection method in comparison to the Rayleigh fading. The Nakagami fading has the highest performance gain. From both results we can see that the cooperative sensing is a promising scheme of fighting the existing performance degradation of the energy detector at severe fading and shadowing environment.

CONCLUSION

In this work, we have considered the performance analysis of energy detection based spectrum sensing in a cooperative scheme, we evaluated the performance of energy detection in detecting unused spectrum in fading and non-fading channels models. The effects of cooperating nodes using energy detection over various fading channels are assessed by using complementary ROC curves. In conclusion, simulation results show that the cooperating spectrum sensing is a viable technique in combating the inherent performance degradation of the energy detectors in a severe fading and shadowing environments.

REFERENCES

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