Comparison of Radiometry and Modified Periodogram Spectrum Detection in Wireless Radio Networks

P. Derakhshan-Barjoei  
Dept. of Electrical Engineering  
Islamic Azad University, Science and Research Branch  
Tehran, Iran  
pooyaderakhshan@yahoo.com

G. Dadashzadeh  
Dept. of Electrical Engineering  
Shahed University  
Tehran, Iran  
gdadashzadeh@shahed.ac.ir

F. Razzazi  
Dept. of Electrical Engineering  
Islamic Azad University, Science and Research Branch  
Tehran, Iran  
razazzi@srbiau.ac.ir

S. Mohammad Razavizadeh  
Education and Research Institute for ICT  
Tehran, Iran  
srazaviz@erict.ac.ir

Abstract—The spectrum sensing is a quite important part in cognitive radio. This paper discusses energy sensing, the common spectrum sensing algorithm in cognitive radio, as well as some cooperative algorithms such as AND, OR rule. Also some modified periodogram methods have been investigated and simulated, moreover these various methods of detection of signal simulated by specifying their advantages and their drawbacks. Our simulations shows that the energy detector is so easy to implement and is good when there is no knowledge of secondary users. Besides simulation about modified periodogram shows that there are differences in detection of signals by using different types of filtering and windowing. Finally, sensing features of these current methods are described.

Keywords- Modified periodogram, Spectrum sensing, Radiometry, Power spectral density.

I. INTRODUCTION

The radio frequency spectrum is a natural resource and its efficient use is of the utmost importance. The spectrum bands are usually licensed to certain services, such as mobile, fixed broadcast and satellite. To avoid harmful interference between different networks to affect users, most spectrum bands are allocated to certain services but worldwide spectrum occupancy measurements show that only portions of the spectrum band are fully used. Moreover, there are large temporal and spatial variations in the spectrum occupancy. In the development of future wireless systems the spectrum utilization functionalities will play a key role due to the scarcity of unallocated spectrum. Moreover, the trend in wireless communication systems is going from fully centralized systems into the direction of self-organizing systems where individual nodes can instantaneously establish ad hoc networks whose structure is changing over time. Cognitive radios with the capabilities to sense the operating environment learn and adapt in real time. According to environment creating a form of mesh network are seen as a promising technology spectrum sensing determines the presence or absence of the primary user based on a specific detection model [1,2 and 3].

II. SPECTRUM SENSING AND AWARENESS

Active awareness is a complementary method to passive awareness for achieving information on the current spectrum use in the surrounding environment. The idea of active awareness is to monitor spectrum by signal detection methods so that we can identify these frequency bands which other systems use. The method requires constant monitoring of the channel so that new primary users and possible vacant channels will be detected. When using spectrum sensing, the hidden terminal problem might cause problems when there is an obstacle between the secondary system and the primary transmitter [4, 5 and 6]. In this condition the secondary user might have good connection to primary receiver but it cannot necessarily detect the primary transmitter and its transmission. To overcome this problem, we can use longer sensing period to increase the measurement accuracy but this reduce the available time for transmission, also another method to overcome the problem is to use cooperation. Spectrum sensing determines the presence or absence of the primary user, based on a specific detection model. Here, we assume a received signal with the simple form $y(n)=S(n)+N(n)$, where $S(n)$ is the signal to be detected $N(n)$ is an Additive white Gaussian Noise(AWGN)sample, and $n$ is the sample index[7,8]. Note that when no primary user is transmitting, $S(n)=0$.

III. METHOD AND PROBLEM FORMULATION

A. Radiometry-Based Sensing

Energy detector based approach, also known as radiometry or periodogram is the most common way of spectrum sensing because of its low computational and implementation complexities. Also, receivers do not need any knowledge on the primary user’s signal. The method has also been analyzed in the presence of signals with random amplitude and channel fading. For a low pass signal having bandwidth $W$, the energy in a sample record of duration $T$ is approximated by $2TW$ where the received waveform is sampled at the rate $2W$. The energy is expressed as follow:
\[ E = \int_0^T n^2(t) dt \approx \frac{1}{(2W)} \sum_{i=1}^{2W} a_i^2 \]  

(1)

The block diagram of the energy detector is shown in figure bellow:

![Block diagram of an Energy detector](image1)

Where \( n(t) \) is Gaussian noise process and \( \alpha_i \) is the \( i \)th noise sample the results are the same for a band pass processes provided that \( W \) is interpreted as the positive frequency bandwidth. For zero mean Gaussian distributed noise only (\( H_0 \)), the energy \( E \) follows central chi-square (\( \chi^2 \)) distribution with \( 2TW \) degrees of freedom. In the case that the primary user/signal is present (\( H_1 \)), \( E \) follows a non-central chi-square (\( \chi^2 \)) distribution with \( 2TW \) degrees freedom and a non-centrality parameter \( 2\gamma \), where \( \gamma \) is the signal-to-noise ratio (SNR).

\[ E = \begin{cases} 
\chi^2_{2TW} & H_0 \\
\chi^2_{2TW}(2\gamma) & H_1 
\end{cases} \]  

(2)

The probability of false alarm \( P_f \) and the probability of correct detection \( P_d \) are described as:

\[ P_f = P_t (E > \zeta | H_0) = \frac{\Gamma(\tau_{\zeta}, \frac{\zeta}{2})}{\Gamma(\tau_{\zeta})} \]  

(3)

\[ P_d = P_t (E > \zeta | H_1) = Q_{\zeta} \left( \sqrt{2\gamma}, \sqrt{\zeta} \right) \]  

(4)

The joint probability for detection \( Q_d \) and false alarm \( Q_f \) can therefore be given as:

\[ Q_d = 1 - (1 - P_d)^n \]  

(5)

\[ Q_f = 1 - (1 - P_f)^n \]  

(6)

Where \( n \) denotes number of cognitive users and \( P_d \) and \( P_f \) denote probability of detection and false alarm. Where \( \zeta \) is the decision threshold, \( \Gamma \) is the gamma function, both complete and incomplete types are used, and \( \tau_{\zeta} = TW \) is the time bandwidth and \( Q_{\zeta} \) is the Marcum Q-function [9].

### B. Periodogram-Based Sensing

The periodogram method is a discrete Fourier transform (DFT) based method to estimate power spectral density. The name of the periodogram comes from the fact that it was first used in determining possible hidden periodicities in time services. The periodogram spectral estimator can be given as

\[ \varphi_p(f) = \frac{1}{N} \left| \sum_{i=1}^{N} y(t) e^{-j2\pi ft} \right|^2 \]  

(7)

Where \( \varphi(p) \) is power spectral density function and \( y(t) \) is the received waveform and \( N \) is number of samples [10, 11 and 12]. We show the performance of the periodogram method using four types of windows figure (2) shows the detection of spectrum by four types of windows and we can evaluate the performance of these methods in using different types of windows. A sample received signal is shown in figure(3). In figure(4), probability of detection versus SNR is shown with different number of users the probabilities of detection are shown.

![Spectrum detection by modified periodogram](image2)

![Received Signal](image3)
It shows that with increasing the number of users the probability of detection arises.

![Figure 4. Probability of detection versus SNR](image)

Figure 4. Probability of detection versus SNR

![Figure 5. Probability of detection and decision thresholding](image)

Figure 5. Probability of detection and decision thresholding

The effect of different amount of thresholding on probability of detection versus signal to noise ratio is shown in figure (5). It can be seen from the figure (6) that by increasing the number of cooperative users, the probability of false alarm is reduced.

![Figure 6. Probability of false detection versus number of users](image)

Figure 6. Probability of false detection versus number of users

IV. SIMULATION

We provide some simulation results of the proposed method. In these simulations, the implementation simplicity of energy detector makes it favorable candidate for spectrum sensing task, however, the performance of energy detector is highly susceptible to noise level uncertainty, and noise level uncertainty refers to a situation where the noise variance is only appropriately known. The noise uncertainty causes problem especially in the case of a simple energy detector because it is difficult to set the threshold properly without the knowledge of the accurate noise level. In addition, an energy detector cannot differentiate between modulated signals, noise and interference. The performance of energy detector in shadowing and fading environments degrades clearly and secondary users may need to cooperate in order to detect the presence of primary users. We use AND rule and OR rule algorithm of energy detector. In periodogram method, the main limitations of the periodogram method yield from the variance. The periodogram is an inconsistent spectral estimator which means that it continues to fluctuate around the true power spectral density with a nonzero variance. This effect cannot be eliminates even if the length of the processes sample N increases without a bound. Furthermore, the fact that the periodogram values are uncorrelated for large N value makes the periodogram exhibit an erratic behavior. Some modified periodogram-based methods which attempt to improve the statistical properties of periodogram method have been proposed have we use. Four types of windowing such as Blackman, Kaiser, hamming and Boxcar method and compare them. As a single of interest, we take a 4QAM modulated signal, SNR=10 dB, sensing time of 2 micro second. The length of FFT is 512 and the number of users is 4, 8 and 15 and making four decision thresholds in simulations. We use T=40.
V. CONCLUSION

Spectrum sensing is a crucial task in the cognitive radio system to identify vacant frequency bands to enable opportunistic spectrum access. In particular, reliable detection of the presence of primary users is of uttermost importance since the cognitive radio operating as a secondary system is not allowed to cause harmful interference to the primary user. Thus, the performance evaluation of spectrum sensing schemes is important. We have evaluated the performance of modified periodogram methods and energy detector in terms of the probabilities of detection and false alarm using analysis and simulations, since different spectrum sensing schemes are associated with different advantages and limitations. Due to the limited awareness of a single cognitive radio node, cooperative sensing will be important in practical cognitive systems. This would lead to a tradeoff between reliable sensing information and the costs caused by more extensive cooperation, such as complexity and increased signaling.

REFERENCES