International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

Performance Evaluation of Spectrum Sensing Methods for Cognitive Radio

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Accepted 08 Oct 2016, Available online 12 Oct 2016, **Vol.6, No.5 (Oct 2016)**

Abstract

Spectrum is an important asset in communication. Efficient spectrum utilization is of major concern for the wireless communication networks in the future. The allocated spectrum is scarce and has been challenging the unlicensed wireless users. An ingenious technology, cognitive radio, has been proposed which is proving to be an answer to this situation. Spectrum Sensing is the building block in cognitive radio. It helps the unlicensed users to access the licensed spectrum, thus increasing the spectrum utilization and efficiency. In this paper, two of the most practiced spectrum sensing methods, namely Matched filter detection and Energy detection, have been compared on the basis of their performances. The performance evaluation of these two methods is done by using different parameters.

Keywords: *Cognitive Radio, Spectrum Sensing, Primary user, Secondary user, Threshold, Energy detection, Matched Filter Detection, Probability of detection, Probability of false alarm, Probability of missed detection*

1. Introduction

The available electromagnetic radio spectrum is a limited natural resource and is getting crowded day by day due to increase in wireless devices and applications. It has also been found that the allocated spectrum is utilized inefficiently because of the static allocation of the spectrum. Traditionally, a wireless operator is assigned an exclusive license to operate in a specified band(J. Mitola III *et al*,2000). It is not easy to find a spectrum hole since most of the spectrum has been allocated already. Thus for unlicensed users, spectrum allocation becomes complex. To overcome this situation, we need to find an alternative for efficient utilization of the spectrum creating opportunities for dynamic spectrum access (FCC,2005).

A solution to this problem has been proposed as Cognitive radio, which facilitates the opportunistic sharing of spectrum. Cognitive Radio is designed to enable more efficient use of frequency spectrum (Tevfik Y ¨ucek, H¨useyin Arslan *et al*,2005). Cognitive functionality in the form of awareness, reasoning, learning and frequency agility abilities are necessary to detect and exploit spectrum opportunities.

This paper presents a definition, functions and spectrum sensing techniques (FCC, 2011). in cognitive radios. More specifically, we focus our discussion on the selection of the best suitable method for development of cognitive radio. Here, we have discussed the methods in brief and then a performance evaluation has been done.

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2. Spectrum Sensing

The radio frequency spectrum is divided to frequency bands that are then allocated to different systems Federal Communications Commission decides the allocation of the spectrum.

The primary blocks of cognitive radio are Spectrum sensing, its management, mobility and spectrum sharing (FCC, 2010). Each of them has a specific role in cognitive radio technology. Spectrum Sensing is the method by which the cognitive radio system can scan over the entire range of frequencies and detect the Spectrum holes or absence of licensed users(Carl R. Stevenson *et al*, 2009). It also requires special attention due to many uncertain parameters in wireless communications. The decisions made in this block can affect the performance of CR system. The uncertain parameters could be summarized in two broad definitions, Noise Uncertainty and Channel Uncertainty (FCC, 2011).

Most wireless communication channels are subjected to fading shadowing and dispersion (time). Moreover, time-dispersion of wireless channel affects the detection signal. These together will contribute to the uncertainty of wireless channels for reliable communication. This is known as channel uncertainty. Noise is uncertain parameter existing in radio communication. The uncertainties could be categorized as, environment noise uncertainty and receiver noise uncertainties. Receiver contains non-linear elements that produce noise. The noises from environment include interferences both intentional and non-intentional. This is known as noise uncertainty (IEEE 802.22, 2011).

3. Spectrum sensing methods

3.1 Matched Filter Detection

In signal processing, matched filter correlates a known signal (template), with an unknown signal, to detect the presence of the template in the unknown signal. This concept has been used to determine the presence of primary user. This is equivalent to convolution of an unknown signal with a conjugated time-reversed version of the known signal.

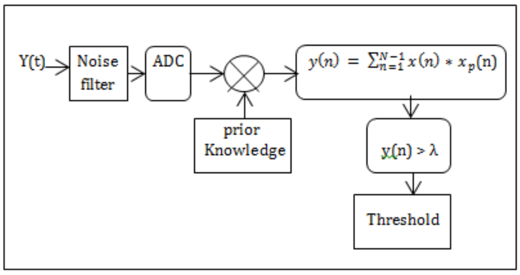

Fig.1. Block diagram of matched filter detection

A detector using matched filter is able to maximize signal-to-noise ratio (SNR). This helps in coherent detection of primary user by a secondary node. But, to do this, synchronization of secondary node to primary system is required. Further, there is a requirement that the secondary node must be able to sense and even demodulate the primary signal.

This prior information includes preamble, signaling for synchronization, pilot patterns for channel estimation and even modulation patterns of the transmitted signal. Detection by using matched filter is useful only when primary user information is known to the cognitive radio.

Here, transmitted signal is received by analog to digital (A/D) converter. The prior information signal 'xp(n)' is multiplied with output of A/D converter 'x (n)'. Now the multiplied signal is fed to summation block to produce summation components.

Finally, the matched filter output y(n) is compared to threshold to determine the presence or absence of PU signal.

The mathematical expression of matched filter detection is expressed as:

$$y(n) = \sum_{n=1}^{N-1} x(n) * x_p(n) \quad (1)$$

Where,

x(n) = Input transmitted signal.
xp(n) = Conjugate of the known pilot data.
y(n) = Received Signal
w(n) = Noise
n = 1, 2, 3 ….. , N-1.

Probability of False alarm:

$$Pf = Pr\ (H1|H0) \quad (2)$$

$$Pf = Pr\ (y(n) > \lambda \mid H0) \quad (3)$$

During False alarm, the input signal will be

$$x(n) = w(n)$$

$$y(n) = \sum_{n=1}^{N-1} w(n) * x_p(n) \quad (4)$$

Thus, from eq. (3) and (4), final expression for probability of false alarm is given by,

$$P_f = \exp\left(\frac{-\lambda^2}{E\sigma_\omega^2}\right)$$

Probability of Detection:

$$Pd = Pr\ (H1|H1) \quad (5)$$

$$Pd = Pr\ (y(n) > \lambda \mid H1) \quad (6)$$

During the detection phase, the input signal will be

$$x(n) = s(n) + w(n)$$

$$y(n) = \sum_{n=1}^{N-1} (s(n) + w(n)) * x_p(n) \quad (7)$$

Thus, from eq. (6) and (7), the final expression for probability of detection is,

$$P_d = Q\left(\sqrt{\frac{2E}{\sigma_\omega^2}}, \sqrt{\frac{2\lambda^2}{E\sigma_\omega^2}}\right)$$

Where,
λ = Threshold used for detection.
Q(,) = Generalized Marcum Q-function
Im-1(,) = Modified Bessel function of first kind of order (m-1).

Generalized Marcum Q-function:

$$Q(a,b) = \frac{1}{a^{(m-1)}} \int_b^\infty x^m e^{\left(-\frac{x^2+a^2}{2}\right)} I_{(m-1)}(ax)dx$$

Where,
a, b = non-negative real numbers
m = positive integer.

Probability of Miss Detection:

$$Pmd = Pr\ (H0|H1) \quad (8)$$

$$Pmd = 1 - Pr\ (y(n) > \lambda \mid H1) \quad (9)$$

$$Pmd = 1 - Q\left(\sqrt{\frac{2E}{\sigma_\omega^2}}, \sqrt{\frac{2\lambda^2}{E\sigma_\omega^2}}\right)$$

Matched filter is very advantageous as it is Optimum method for detection of primary users when the transmitted signal is known. It takes short time for achieving a certain probability of false alarm or probability of miss detection and also it requires less time to achieve high processing gain due to coherency.

3.2 Energy Detection

Energy detection technique measures the received signal power in order to detect the presence or absence of primary users. It is a very simple method to implement, amongst all the sensing techniques. However, to implement energy detector, perfect noise variance is required. There is no need for cognitive radio to have the prior information of primary user.

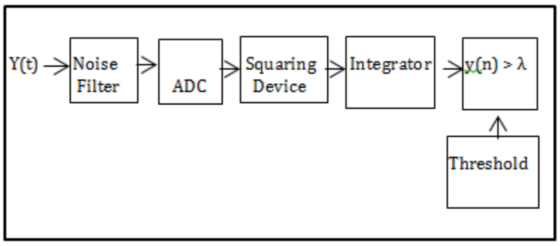

Fig.2. Block diagram of Energy detection

Threshold value is used to decide whether primary user is present or not. This threshold value depends on the noise floor. The detected energy is compared with the threshold to determine the same.

Energy detection technique is useful to detect unknown deterministic signal that is corrupted by noise while transmitting through the channel.

The received signal y(n) is of the given form:

$y(n) = h(n) * s(n) + w(n)$

Where,
h(n) = impulse function of the channel.

Thus, the two hypotheses are,

H0: y (n) = w (n)
H1: y (n) = h (n) * s (n) + w (n)

$$M = \sum_{n=1}^{\infty} |y(n)|^2 \qquad (10)$$

Where,
y (n) = Received signal.
M = Decision Metric.

The Probability Density function (PDF) of the decision metric is:

$$F(y) = \begin{cases} \frac{1}{2^u \Gamma(u)} y^{u-1} e^{\frac{-y}{2}} & : H0 \\ \frac{1}{2}\left(\frac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{\frac{2\gamma - y}{2}} I_{u-1}\left(\sqrt{2y\gamma}\right) & : H1 \end{cases} \qquad (11)$$

Where,
Γ(.) = Gamma function
Iu(.) = uth order modified Bessel function of the first kind.

The decision metric M is compared with the fixed threshold (λ), to decide the occupancy of the band.

Pd = Pr (M > λ |H1) (12)
Pfa = Pr (M < λ |H0) (13)

Where,
Pd = Detection Probability.
Pfa = Probability of False Alarm.

These probabilities are given by,

$P_d = Q_m\left(\sqrt{2\gamma}, \sqrt{\lambda}\right)$ from eq. 10 and 11

$P_f = \frac{\Gamma\left(m, \frac{\lambda}{2}\right)}{\Gamma(u)}$ from eq. 10 and 13

Where,
Γ(,), Γ(.,.) = Complete and incomplete gamma functions.
Qm (.) = Generalized Marcum Q-function

Thus, Probability of miss detection is,

Pm = 1-Pd

Energy detection is optimal detector when the receiver cannot gather sufficient information about the primary user signal and also it has low computational and implementation complexities.

Results

Simulation results are shown using following parameters in which signal to be transmitted and probability of false alarm are input parameters. For various values of probability of false alarm, threshold is calculated. Based on above threshold values, probability of detection and hence probability of missed detection are found.

The Receiver Operating Characteristics (ROC), which is determined by Pd versus Pfa graph or similarly by complementary ROC which is Pm versus Pf.

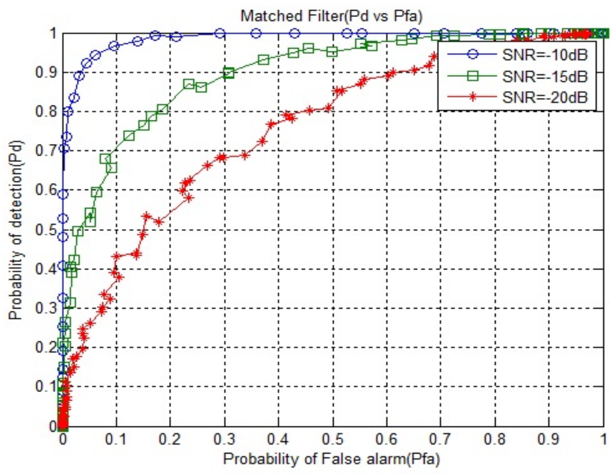

Fig.3. ROC of Matched filter detection

Figure 3 demonstrates the complementary ROC for matched filter detection for both theoretical and simulation under noisy channel for different SNR values. Improvement in the performance is observed as the curve goes upwards with increasing SNR values. Similar conclusion can be deduced for Figure 4 of energy detection.

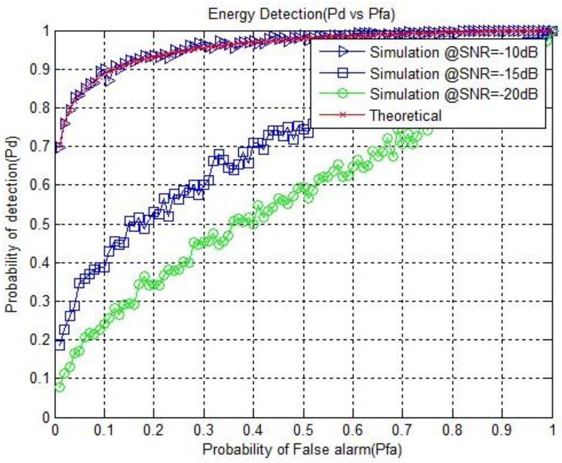

Fig.4 ROC of energy detection

Probability of Detection

Pd is the probability of detecting a signal when it actually is present.

Figure 5 shows the comparison of the two techniques in terms of Probability of detection (Pd) with respect to SNR is plotted. For better results, probability of detection as much as possible with respect to SNR.

As we can observe from the graph, matched filter is showing better results for the low SNR also.

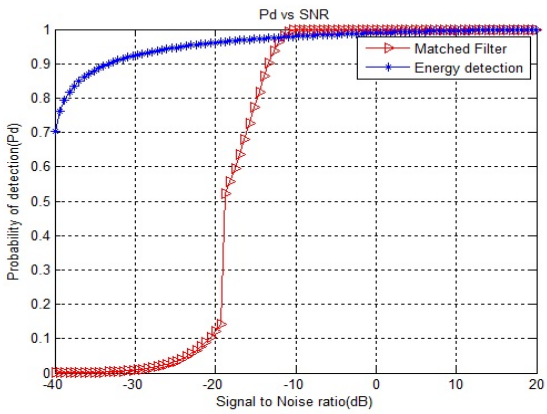

Fig.5 Probability of detection Vs SNR

Probability of Missed detection

Pmd is the probability of missing a signal on the considered frequency when it truly is present.

Figure 6 demonstrates probability of miss detection (Pm) with respect to SNR. For better results probability of missed detection should be as small as possible. Figure 6 shows that matched filter has better response for lower SNR.

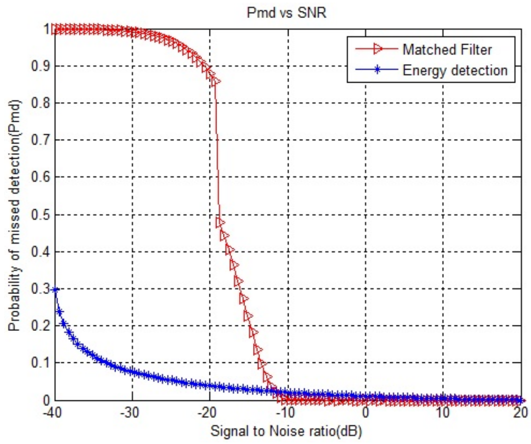

Fig.6 Probability of miss detection Vs SNR

Conclusion

In this paper, performance analysis of two spectrum sensing techniques is made based upon detection probabilities in terms of Pfa, Pd, Pmd for various SNR values. Every method has advantages and disadvantages. No prior information is required in energy detection. But this technique does not perform good at low SNR values. Whereas the prior information is must for matched filter detection, but it performs very good even at low SNR values.

Acknowledgment

We would like to express our gratitude to our project guide Mrs. S. D. Borde (*Asst. Prof.* P.E.S.Modern College of Engg, Pune) whose special guidance made this project achieve the results successfully.

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