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Comparative study of spectrum sensing for cognitive radio system using energy detection and matched filter detection techniques

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Abstract

The key component of Cognitive Radio technology (CR) is spectrum sensing. The characteristic of CR system is sensing the electromagnetic environment to adapt their operation for better radio operating parameters. One of the challenges for CR is to detect the primary users present over the spectrum. This paper presents the performance analysis of energy detection and matched filter detection based spectrum sensing .Also highlights the effect of different parameters like number of samples, signal to noise ratio and noise uncertainty on the probability of detection and probability of false alarm for both cases of energy detection and matched filter detection. Moreover apply comparison between the two methods using the simulation technique. The obtained results are plotted using MATLAB Software.

Keywords: Spectrum Sensing, Cognitive Radio, Energy Detection, Matched Filter Detection, Probability of Detection, Probability of False Alarm.

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1. Introduction

Demand of radio spectrum is increasing day by day due to wireless applications and devices. CR technique has been proposed to solve the conflicts between spectrum limitation and spectrum usage. It allows to Cognitive Radio user to share spectrum with primary users (PU). When it does not cause interference to the PU, the CR can use the spectrum. So spectrum sensing is a critical issue for CR technology because it needs to detect the presence of PU accurately [1]. So it allows secondary user (SU) to access dynamically the under-utilized licensed bands whenever and wherever PU are not present [2]. The main challenge with SU is to sense accurately the PU signal without any interference. To successfully achieve that the CR must constantly sense the spectrum to detect the presence of PU. If it detect primary user, the cognitive radio should vacate from particular spectrum band which it was using. So that leads to decrease the interference. This is very challenging task as a lot of primary users will be employing different modulation, data rate and transmission power plus the presence of interference. The spectrum sensing is the first step that needs to be performed. But it is very difficult task because cognitive radio has to decide the best spectrum band while maintaining the Quality of Service for the entire band of frequencies since interference with other users is illegal. The holes in spectrum are not constant. They changes with time and frequency. The algorithm of spectrum sensing should be fast enough to detect the changes in moving holes rapidly [3]. In this paper we analyze the performance of energy detection and matched filter detection algorithms and effects of number of samples, signal to noise ratio and noise uncertainty on performance parameters like probability of detection and probability of false alarm.

2. Spectrum Sensing Model

The algorithm of spectrum sensing depends on many parameters like number of samples, signal to noise ratio and noise uncertainty. It aims to make decision between two hypotheses (choose H0 or H1) based on the received signal.

$$\text{H0: } X(N) = W(N)$$

$$\text{H1: } X(N) = S(N) + W(N) \qquad (1)$$

Where N is number of samples, X(N) is the received signal , S(N) is the primary users signal, W(N) is the noise , H0 Gaussian noise (AWGN) with zero mean [4]. The key metric in spectrum sensing are the probability of correct detection (p_d), probability of alarm (occurs when the channel is empty (H0) but spectrum sensor decides that the channel is occupied and probability of misdetection occurs when the channel is occupied (H1) but spectrum sensor decides that the channel is unoccupied [5].

A. Energy Detection technique

The energy detector is the most optimal choice if the signal is a not deterministic one and if only the average power is known, Energy detector calculates the energy of the received signal at receiver, and comparison with a set threshold to indicate if primary user is present or not. This detector can be expressed as

$$D(Y) = \frac{1}{N}\sum_{n=0}^{N-1} X(N)X(N) \quad \begin{matrix} > \gamma & H1 \\ < \gamma & H0 \end{matrix} \qquad (2)$$

Where D(Y) is the decision variable, N is the number of samples and γ is the decision threshold. Now if the noise variance is known, then the following approximations can be made [6].

$$D(Y|H0) \sim N\left({\sigma_n}^2, 2\frac{{\sigma_n}^4}{N}\right) \qquad (3)$$

$$D\ (Y|H1) \sim N\ (P + \sigma_n{}^2\ ,\ 2(p + \ \sigma_n{}^2)^2/N) \qquad (4)$$

The expressions for the probabilities are

$$p_{fa} = Q\left(\frac{\gamma - \sigma_n}{\sqrt{\frac{2\sigma_n{}^4}{N}}}\right) \qquad (5)$$

$$p_d = Q\left(\frac{\gamma - (p + \sigma_n{}^2)}{\sqrt{\frac{2(p + \sigma_n{}^2)^2}{N}}}\right) \qquad (6)$$

To calculate the sensitivity of detector, noise power should be known, which is impractical. Thus γ_{min} should be calculated with worst case noise assumption.
Now considering the case with uncertainty in the noise model. The expressions for the probabilities can be represented as [6].

$$p_{fa} = Q\left(\frac{\gamma - \rho\sigma_n}{\sqrt{2/N}\,\rho\sigma_n{}^2}\right) \qquad (7)$$

$$p_d = Q\left(\frac{\gamma - (p + \sigma_n{}^2/\rho)}{\sqrt{2(p + \sigma_n{}^2/\rho)^2/N}}\right) \qquad (8)$$

B. Matched filter detection technique
Matched-filter is the optimal choice if the transmitted signal is known [7] .The main advantage of matched filter is the short time to achieve a certain probability of false alarm or probability of misdetection [8].

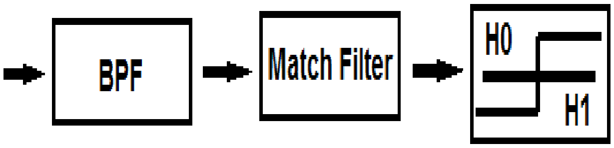

Fig.1: Block diagram of matched filter [9]

First step the input signal passes band pass filter. This will measure the energy around the related band. Then the output involves with match filter whose impulse response as same as reference signal. Finally the output from match filter is compared to threshold to detect the presence or absence of primary user .The operation of matched filter detection is expressed as [10].

$$Y[n] = \sum_{k=-\infty}^{\infty} h[n-k]X[k] \qquad (9)$$

Where x[k] is the unknown signal convolved with the 'h' the impulse response of matched filter that is matched to the reference signal for maximizing the SNR [11].

$$h[n]=S[N-n] \qquad (10)$$

$$Y[n]*h[n] = \sum_{k=0}^{N} h[n-k]Y[k] \qquad (11)$$

$$Y[n]*h[n] = \sum_{k=0}^{N} S[N-(n-k)]\,\left[s[K]W[k]\right] \qquad (12)$$

$$= \sum_{k=0}^{N} S[(N-n)+K]S[k] + \sum_{k=0}^{N} S[(N-n)+K]\ W[k] \qquad (13)$$

When N=n

$$Y[n]*h[n] = \sum_{k=0}^{N} S^2[K] + \sum_{k=0}^{N} S[k]W[k] \qquad (14)$$

In case of detecting H0

$$Y[n]*h[n] = \sum_{k=0}^{N} S[k]W[k] \qquad (15)$$

$$p_{fa} = P_r\ (\sum_{k=0}^{N} S[k]W[k]) \quad \geq \ \gamma \qquad (16)$$

The probability of a Gaussian Random Variable X~N *(μ, σ2)*

$$Q(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_x^{\infty} e^{\frac{(x-\mu)^2}{2\sigma^2}} \qquad (17)$$

Where $\mu = 0\ and\ \sigma = 1$
So,

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{\frac{x^2}{2}} \qquad (18)$$

$$p_{fa} = P_r(D = H1|H0) \qquad (19)$$

The expressions for the probability of false alarm can be represented as

$$P_{fa} = Q\left(\frac{\gamma}{\sqrt{\sigma_n{}^2 p_s}}\right) \qquad (20)$$

Where,
p_s is the energy of the signal.
For m-numbers of bits (odd only) using binomial distribution the expression for probability of false alarm can be represented as

$$p_{fa} = \sum_{k=\frac{m+1}{2}}^{m} \binom{m}{k} \left[Q\left(\frac{\gamma}{\sqrt{\sigma_n{}^2 p_s}}\right)^k\right] \left][1 - Q\left(\frac{\gamma}{\sqrt{\sigma_n{}^2 p_s}}\right)\right]^{m-k} \qquad (21)$$

$$N=m*L \qquad (22)$$

Where L is number of samples per bit and m is number of bits. To get the value of γ_{min} use Genetic Algorithm (GA).

$$p_{fa(desired)} = \gamma_{min}\left|p_{faT} - p_{faD}\right| \ ,\gamma \geq 0 \qquad (23)$$

3. Result and Analysis

The analysis of energy detection and matched filter detection algorithms for different parameters like number of samples, Signal to noise ratio and noise uncertainty is done. The study shows the following finding.
Comparing the work done in [4] and shown in fig. 2a where N was taken to be [100, 2000] and SNR=-10dB to our work shown in fig.2b in which N= [150, 2500] and SNR=-10dB.We found that the obtained results matched with what was obtained in reference [4] such that in both of them by increasing the noise uncertainty the performance degrades, which indicates that Energy detector is very sensitive to noise uncertainty. Also

increasing in number of samples, while keeping the same uncertainty values show improvement in probability of detection.

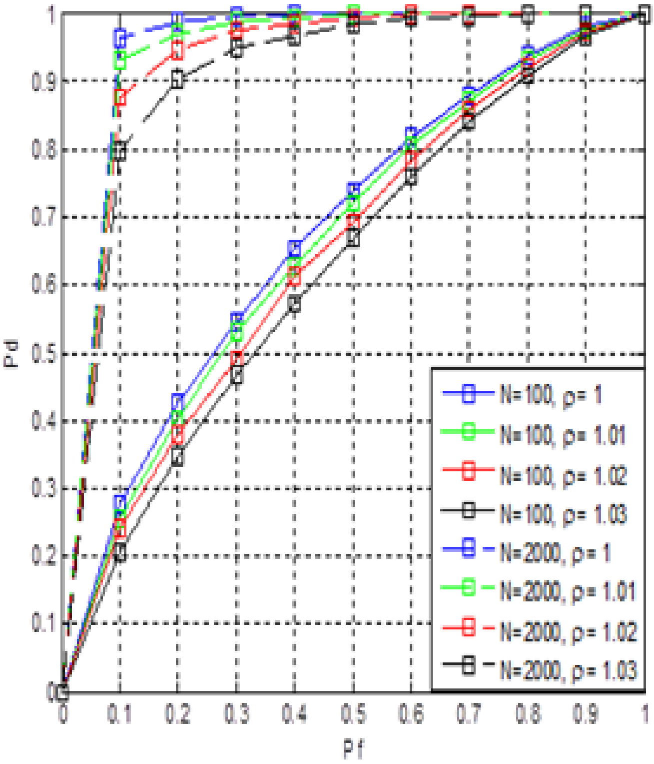

Fig 2a: curves with noise uncertainty values ρ = [1, 1.01, 1.02, 1.03] for different number of samples N= [100, 2000] [4].

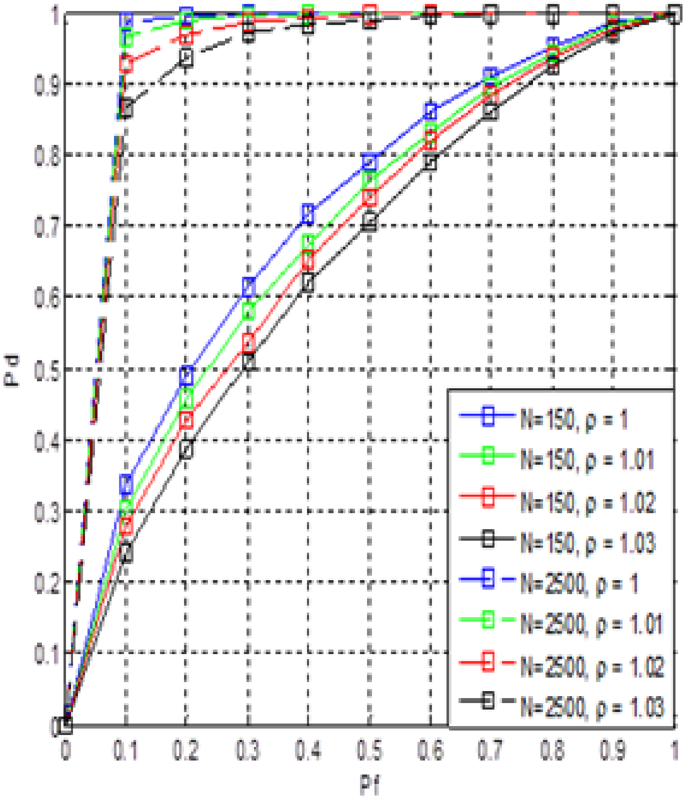

Fig 2b: curves with noise uncertainty values ρ = [1, 1.01, 1.02, 1.03] for different number of samples N= [150, 2500].

Comparison the work done in [4] and shown in Fig.3a where N was taken to be 100 and SNR= [-5dB,-10dB] to our work shown in Fig.3b in which N=150 and SNR=[-6dB,-12dB]. We found that the obtained results matched with what was obtained in reference [4] such that performance drops as Uncertainty increases. It is clear that effect of uncertainty is less if SNR is high. A suitable threshold can be chosen to guarantee a good performance for uncertainty problem.

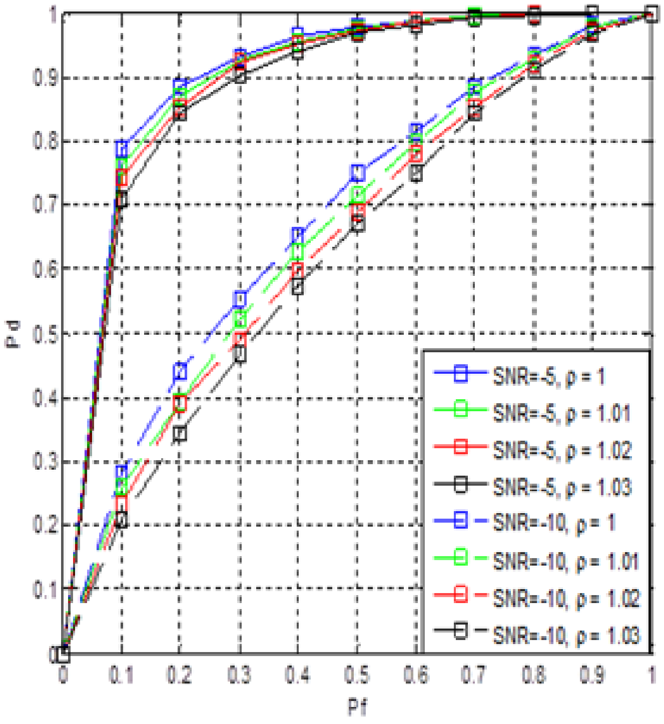

Fig 3a: curves for Energy Detector with noise Uncertainty = [1, 1.01, 1.02, 1.03] for different values for SNR= [-5,-10] [4].

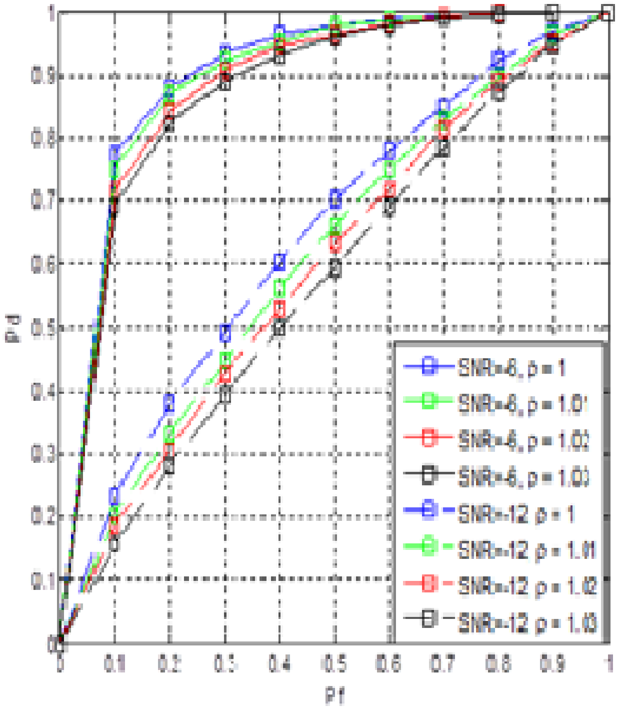

Fig 3b: curves for Energy Detector with noise Uncertainty = [1, 1.01, 1.02, 1.03] for different values for SNR= [-6,-12].

Fig.4, shows the comparison between the energy detector and matched filter on spectrum sensing when m=5, N=1000 and SNR=-20 .keeping the noise uncertainty =1

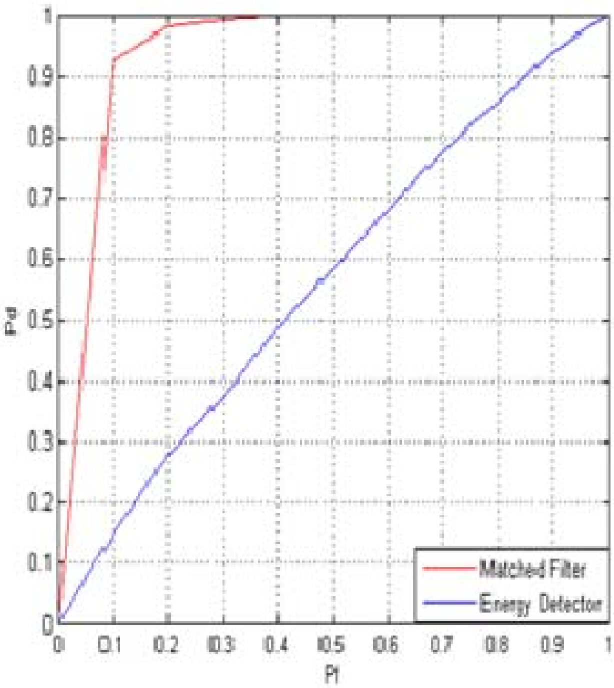

Fig 4: comparison between energy detector and matched filter on m=5, N=1000, SNR=-20dB and ρ=1

Fig.5, shows the comparison between energy detector and matched filter on m=5, N=500, SNR=-20dB and ρ=1

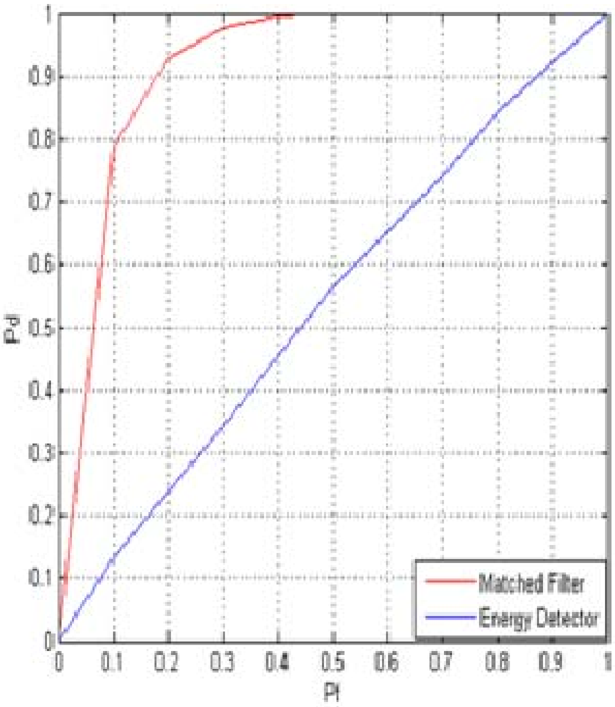

Fig 5: shows the comparison between the energy detector and matched filter on spectrum sensing when N=500 and SNR=-20 .keeping the noise uncertainty =1

Fig.6, shows the performance of matched filter with different values of m (3, 5,7and 9) when N=500 and SNR=-25dB.it is clear that when we increase the number of bits, the performance of matched filter is improving.

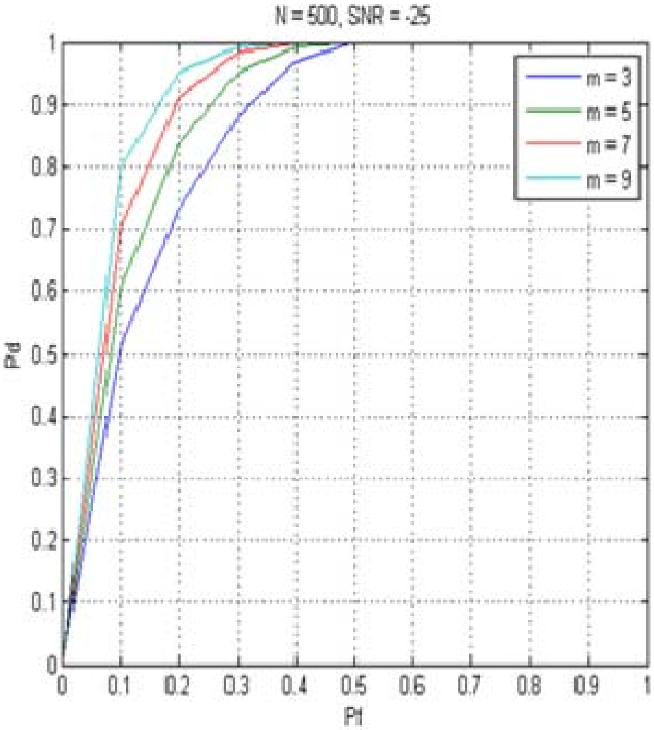

Fig 6: performance of matched filter with different values of m.

4. Conclusion

In this paper the performance investigation for both the relationship of energy detection and matched filter detection with respect to signal to noise ratio, the number of samples and noise uncertainty were applied. The obtained results shows that using matched filter scheme lead to improved performance over energy detection scheme. Adding to that by increasing the number of sample points, the detection performance is much better even at lower SNR values. In our future work we will try to involve the noise uncertainty with different values and show how the performance of energy detector and matched filter will be affected. Also we can use different values of number of samples and signal to noise ratio to get the optimum for them.

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