Analysis of Matched filter based spectrum sensing in cognitive radio

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Abstract - *Cognitive radio is a essential tool for a spectrum utilization. It provides opportunity to use spectrum in strategic manner to both Primary users and secondary users. Primary users have a license to use spectrum. Secondary users doesn't have license to use spectrum resourses. Secondary users are called cognitive users. Purpose of spectrum sensing is to detect presence of unused channels in spectrum. In spectrum sensing, there are three popular methods. Energy detection method, matched filter method and cyclostationary based detection method. In this paper matched filter method implemented according to various parameters. The performance was assessed by using the MATLAB based on the AWGN channel.*

Key Words: Cognitive radio, spectrum sensing, Matched Filter detection, AWGN channel.

1. INTRODUCTION

Marconni (an inventor of radio)'s first experiment on the radio, radio-communication systems do not cease to multiply to become indispensable to our days. This evolution has been accompanied by an increased demand in radio resources. The resources accessible by the existing technologies do not allow them to meet the demand. In order to overcome the scarcity of frequencies, we have new concepts of sharing and sensing of resources, as the dynamic allocation of a radio channel has a new communication has been developed. In the last twenty years have seen a veritable explosion of telecommunication services. From mobile technology to wireless transmission of data, the quantity of general public services increases and the scarcity of frequencies are more than ever aggravated.

According to the Federal Communications Commission (FCC), body of regulation and spectrum management in the US, In more than 70% of cases, the spectrum is under-used next time or space [1]. The problem of the shortage of frequencies is artificial and the current policy of static management of the spectrum is responsible. So, new approaches to dynamic access to the radio spectrum have developed, or access opportunistic is the most widespread because it tackles the cause of the shortage of frequencies. There are four primary objectives of cognitive radio: spectrum sensing, spectrum sharing, spectrum management and spectrum mobility.

2. GENERAL MODEL FOR SPECTRUM SENSING

Spectrum sensing allows the cognitive radio users to learn about the radio environment by detecting the presence of an event using one or multiple sensors. It consists in detecting the PU signal transmission in a given time to make decision to transmit in a frequency band.

The spectrum sensing model can be formulated as follows:

$y(n) = w(n)$ $\quad H_0$: PU absent

$y(n) = h * s(n) + w(n)$ $\quad H_1$: PU present

where, $n=1....N$, N is the sample number, $y(n)$ is the SU received signal, $s(n)$ is the PU signal, $w(n)$ is the additive white Gaussian noise (AWGN) with zero mean and variance σ^2, h is the complex channel gain of the sensing channel, H0 denotes the PU signal is absent, and H1 denotes the PU signal is present.

The output τ of the detector is compared to a threshold to make the right decision:

If $\tau \geq$ threshold then PU signal is present.

If $\tau <$ threshold then PU signal is absent.

3. MATCHED FILTER BASED DETECTION

The matched filter is a system of linear filter used in the digital signal processing. It is used to optimize the SNR in existence of the additive noise stochastic. It provides the coherent detection. Figure 1 shows the block diagram for this in which a signal received from primary use is transmitted through AWGN (Additive White Gaussian Noise) channel and the transmitted signal is given to matched filter. Matched filter correlates the signal with time modified version. Then comparison between the predetermined threshold and the final output of matched filter will determine the presence of the primary user.

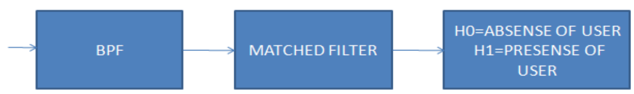

Figure 1: Basic block diagram of matched filter based spectrum sensing

In phased-array applications, you need to decide between two competing hypotheses to determine the reality underlying the data the array receives. For example, suppose one hypothesis, called the *null hypothesis*, states that the observed data consists of noise only. Suppose another hypothesis, called the *alternative hypothesis*, states that the observed data consists of a deterministic signal plus noise. To decide, you must formulate a decision rule that uses specified criteria to choose between the two hypotheses.

H_0: x [n] = w[n], n = 0,1, … , N – 1.

H_1: x [n] = s[n] + w[n], n = 0,1, . . . , N – 1.

Where, w[n] is Additive White Gaussian Noise (AWGN) with variance σ^2 and the source signal s[n] is supposed to be a known deterministic one and Gaussian distributed. x[n] is the received signal by the system. AWGN is defined as a zero-mean Gaussian process with constant spectral density. where H_0 is called the null hypothesis, which proves that it is not recognized as authorized user signal active in a specific spectrum band, and H_1 is the alternative hypothesis, which shows that there is an active primary user signal.

The Neyman–Pearson (NP) detector decides H_1 if the likelihood ratio grater than a threshold ϒ or

$$L(X) = \frac{p(X;H_1)}{p(X;H_0)} > \Upsilon.$$

Where, X= $[x[0]\ x[1]\ \ldots\ [N-1]]^T$.

The probability density function (PDF) of the received signal x under hypotheses H is p(x;H).

$$p(X;H_1) = \frac{1}{(2\pi\sigma^2)^{\frac{N}{2}}} \exp\left[-\frac{1}{(2\sigma^2)} \sum_{n=0}^{N-1} (x[n]-s[n])^2\right].$$

$$p(X;H_0) = \frac{1}{(2\pi\sigma^2)^{\frac{N}{2}}} \exp\left[-\frac{1}{(2\sigma^2)} \sum_{n=0}^{N-1} (x[n])^2\right].$$

$$L(X) = \exp\left[-\frac{1}{(2\sigma^2)} \left(\sum_{n=0}^{N-1} (x[n]-s[n])^2 - \sum_{n=0}^{N-1} (x[n])^2\right] > \Upsilon.$$

Under both hypotheses, T(X) is Gaussian and x[n] is also Gaussian as it is a linear combination of Gaussian random variables. By E (T;H_i) we denote the expected value and by var (T;H_i). We denote the variance under hypothesis H_0. Then we have subsequently:

$$E(T;H_0) = E\left(\sum_{n=0}^{N-1} w[n]s[n]\right) = 0.$$

$$\mathrm{var}(T;H_0) = \mathrm{var}\left(\sum_{n=0}^{N-1} w[n]s[n]\right) = \left(\sum_{n=0}^{N-1} w[n]\right)s^2[n].$$

$$\mathrm{var}(T;H_0) = \sigma^2 \sum_{n=0}^{N-1} s^2[n] = \sigma^2\varepsilon.$$

where , ε is considered as the energy of the signal source s[n].

$E(T;H_1) = E\left(\sum_{n=0}^{N-1} w[n]s[n] + s[n]\right) = \varepsilon$. and variance under hypothesis H_1 is:

$$\mathrm{var}(T;H_1) = \mathrm{var}\left(\sum_{n=0}^{N-1} s[n] + w[n]s[n]\right) = \sigma^2\varepsilon.$$

4. DETECTION THEORY OF MATCHED FILTER

A. Probability of detection (PD): Probability of a present signal occupying the channel and of it being detected correctly.

B. B. Probability of false alarm (PFA): Probability that there is no signal on the channel and that the detector can sense signal levels not correctly.

C. Probability of missed detection (PMD): 1-Probability of detection (PD).

The performance of the MF detector is based on the following two parameters: the probability of detection (PD) and the probability of false alarm (PFA).

We talk about the probability of false alarm PFA when there is no signal, i.e. just the noise, and we detect signal, from the distribution H_i of the test statistic T under hypothesis H_0 we have:

$$PFA = P(T > \Upsilon/H_0)$$

$$= P\left(T' > \frac{\Upsilon}{\sqrt{\sigma^2\varepsilon}}/H_0\right). \text{ Where, } T'(X) = \frac{T(X)}{\sqrt{\sigma^2\varepsilon}}$$

$$= Q\left(\frac{\Upsilon}{\sqrt{\sigma^2\varepsilon}}\right) \text{ with } \Upsilon = Q^{-1}(PFA)\sqrt{\sigma^2}\varepsilon.$$

Where Q (.) is the standard Gaussian complementary Cumulative Distribution Function (CDF) and Q^{-1} (.) is taken as the inverse standard Gaussian complementary CDF.

$$PD = P(T > \Upsilon/H_1) = Q\left(\frac{\Upsilon-\varepsilon}{\sqrt{\sigma^2\varepsilon}}\right).$$

$$= Q\left(Q^{-1}(PFA) - \sqrt{\frac{\varepsilon}{\sigma^2}}\right).$$

5. SIMULATION RESULTS AND DISCUSSION

If we have non fluctuating & coherent system then ROC of different PFA value 0.1, 0.01, 0.001, and SNR requirement of different probability of detection graph shown below:

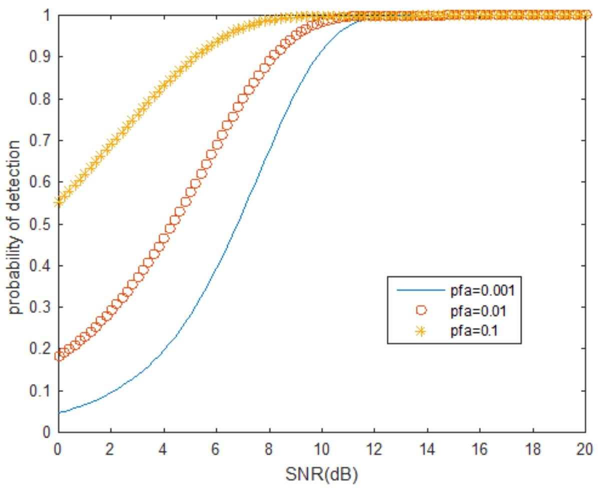

Figure 2: PD vs. SNR for different values of PFA.

Now, we take graph as mentioned in figure.3. for PD vs PFA for single pulse signal for different sample size.

Table -1: Parameter in MATLAB for different sample size

Number of Monte-Carlo simulations	1000
SNR(signal to noise ratio)	3 dB
Noise channel	AWGN
PFA	0.001

After using these parameters we get following graph and results in MATLAB.

Table -2: Results after performing Table-1 parameters

Samples	PD	PFA	New improved SNR
1	0.1310	0	3 dB
3	0.6470	0.001	7.7712 dB
5	0.9230	0.001	9.9897 dB

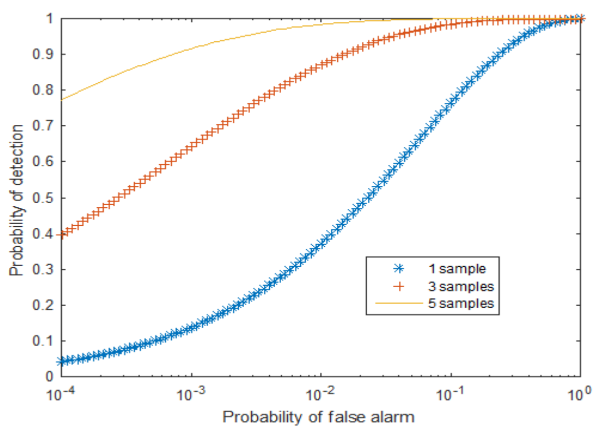

Figure 3: Improve SNR for different number of samples.

A result suggests why we use matched filter to improve SNR ratio. As number of sample pulses increases SNR also improves.

Now we are comparing both energy detection and matched filter method. By comparing both methods at 1 dB, we get following ROC (Receiver Operating Characteristics). By concluding graph we can say that matched filter method is more effective than energy detection method at low value of SNR like 1 dB.

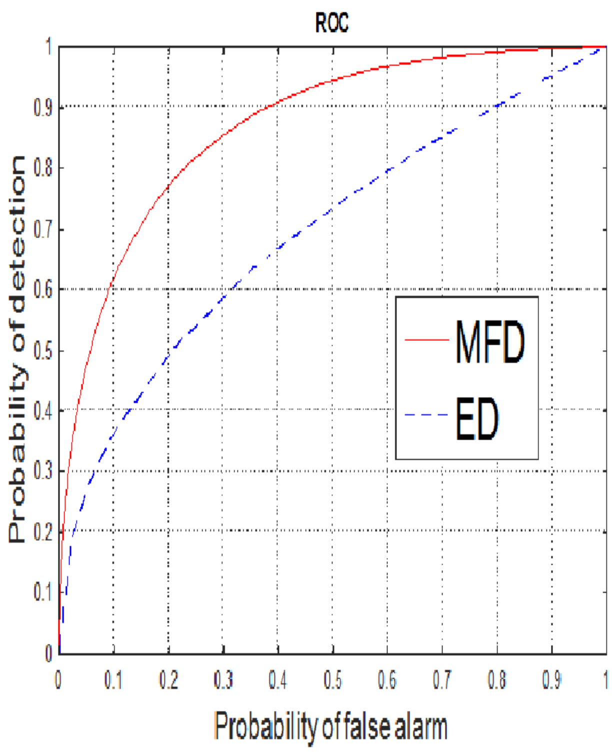

Figure 4: ROC of matched filter vs. energy detection method at 1 dB.

6. CONCLUSION

In this paper by implementing matched filter method, we can say that as SNR value increases probability of detection increases. By studying matched filter parameters, we can say that as number of samples increases probability of detection increases and SNR get improved. So matched filter is also used to improve SNR in wireless communication. At low SNR like 1dB matched filter method has more efficiency than energy detection method. So matched filter method gives more probability of detection at low SNR values.

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