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Performance evaluation of Matched Filter Detection Based on Non-Cooperative Spectrum Sensing in Cognitive Radio Network

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ABSTRACT

The recent and rapid evolution of wireless technologies has led to a high demand in terms of resources. To solve this prob-lem the idea of cognitive radio has been introduced to facilitate a good spectrum management and efficient use of the spectrum. In this article, a method for the detection of the spectrum with the purpose of detecting the presence of bands of unoccupied frequencies is proposed. The method used is the matched filter. The performance was assessed by using the MATLAB based on the AWGN channel.

Keywords: *Performance, Cognitive Radio, Matched Filter Detection, Spectrum sensing, AWGN channel.*

1 INTRODUCTION

Since the first experience of Marconni on the radio, radio-communication systems do not cease to multiply to become indispensable to our days. This evolution has been accompa-nied by an increased demand in radio resources. However, the resources accessible by the existing technologies do not allow them to meet the demand. In order to overcome the scarcity of frequencies, new concepts of sharing of resources, as the dynamic allocation of a radio channel has a new communication has been developed. Nevertheless, the last two decades have seen a veritable explosion of telecommunications services. From mobile telephony to wireless transmissions of data, the quantity of general public services increases and the scarcity of frequencies is more than ever aggravated.

In 2002, the Federal Communications Commiss-ion (FCC), body of regulation and spectrum management in the United States, published a report [1] on the use of frequencies in which it is noted that, in more than 70% of cases, the spec-trum is under-used next time or space. The problem of the shortage of frequencies is artificial and the current policy of static management of the spectrum is responsible. Therefore, 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.

In effect, this approach proposes to a new category of users so-called secondary users (SUs) to access the frequential resources allocated to primary users (PUs) when the latter do not use them. Thus, the spectral efficiency is increased by allowing the transmission by the SUs on frequency bands detected free. These systems SUs are qualified cognitive radio (CR) or radio opportunistic (RO) because, in addition to de-tect-ion of autonomous bands free, they must also be able to change their settings of transmissions in order to answer, on the one hand, the expectations of the user and, on the other hand, the constraints of availability of frequencies.

The detection of the spectrum is the crucial task for the suc-cess of the opportunistic access. It is a cardinal feature of cognitive radio to avoid harmful interference with authorized users and recognize the spectrum available to improve the use of the spectrum.

The main functions of the Cognitive Radio are the following [2]: Spectrum management, Detec-tion of the spectrum, Deci-sion of the spectrum, sharing of the bands free, and mobility of the spectrum.

There are several spectrum detection techniques namely: Matched Filter, Cyclostationary and Energy Detections [3]. These methods have the same time good points and bad points depend of the framework. The main objective of this paper is to study Matched Filter (MF) detection techniques and evaluate its performance.

This paper is organized as follows: Section II presents the different detection technique. The system description used is presented in the section III. We are going to present the results of the simulation in section IV and the last section V we have the conclusion.

2 TECHNIQUES FOR DETECTION OF THE SPEC-TRUM

One of the key objectives of the cognitive radio is the detec-tion of the spectrum. It is to find the spectrum holes in the radio environment for users of CR. The detection techniques that are mostly used in the case of detection non-cooperative are the following:

- The method based on the detection of energy
- Cyclostationary Detection
- The detection method with the Matched Filter

Each of these methods actually presents its own advantages and disadvantages.

Energy detection Spectrum Sensing: If the prior information about the primary transmitted signal is unknown, then the energy detection (ED) technique is the optimal one [4], [5]. The detection of energy is widely used due to its low com-plexity of implementation and calculation. However, this method has several disadvantages, which may limit its im-plementation in the framework of the opportunistic radio. In fact, the calculation of the threshold used for the detection of the signal is very sensitive to the level of the noise which is unknown and in some cases variables; therefore a small esti-mation error on the level of noise caused a significant loss of performance. In addition the radiometer does not work in an efficient manner to detect the signals spread out.

Cyclostationary feature Spectrum Detection: When the primary transmitted signal is cyclostationarity, it can be de-tected by exploring the periodic manner of the cyclostationary parameter. This method is more resistant to noise uncertainty than energy detection [6], [7], [8]. A cyclostationary signal can be detected during the decreasing of the signal-to-noise ratio (SNR) compared to other detection techniques; cyclostationary detection is more difficult than energy detection. Moreover, this method requires a priori information about the signal to transmit as in the case of matched filter.

Matched Filter Spectrum Detection: If SUs know the in-formation about a PU signal a priori, in this case, the optimal detection method is the matched filter since it maximizes the SNR of the received signal. Detection MF needs just a little time in order to obtain a good performance unlike other methods, such as the low probability of false alarm and missed detection, since the MF has less need for the samples received. As disadvantages, MF has an implementation complexity and high power consumption, because of the need of the detector receivers for all types of signals and the algorithms of corresponding receiver to be executed. The process screening requires a perfect knowledge of the PU signal and its frequency of operation, for example, the modulation type and order, the bandwidth, the pulse shape, packet format etc [9]. Whenever the information used by the matched filter is false the efficiency of the detection will be degraded, which leads to distortion of the CR concept and from the PU's perspective, may cause low QoS for the licensed users.

3 SYSTEM DESCRIPTION

The matched filter is a system of linear filter used in the framework of the digital signal processing. It is used to optimize the SNR in presence of the additive noise stochastic. It provides the coherent detection. Figure 1 shows the block diagram for this [10] in which a signal received from primary user is transmitted through AWGN (Additive White Gaussian Noise) channel and the transmitted signal is applied to matched filter. Matched filter correlates the signal with time modified version and comparison between the predetermined threshold and the final output of matched filter will determine the presence of the primary user.

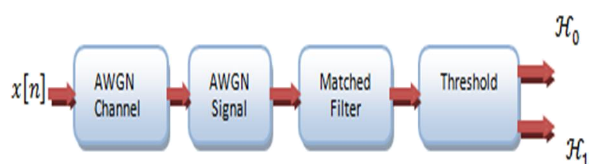

Fig. 1. Synoptic Representation of Matched Filter Detection

3.1 The Hypothesis Test for Matched Filter

The situation is to know whether or not there is the presence of the primary signal:

$$\mathcal{H}_0: x[n] = w[n], \qquad n = 0,1,\dots,N-1$$
$$\mathcal{H}_1: x[n] = s[n] + w[n], n = 0,1,\dots,N-1. \qquad (1)$$

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 $\mathcal{H}_0$ is called the null hypothesis, which proves that it is not recognized as authorized user signal active in a specific spectrum band, and $\mathcal{H}_1$ is the alternative hypothesis, which shows that there is an active primary user signal [6].

3.2 The Statistical Decision in the Framework of the Matched Filter

The Neyman – Peason (NP) detector decides $\mathcal{H}_1$ if the likelihood ratio exceeds a threshold γ or

$$L(X) = \frac{p(X;\, \mathcal{H}_1)}{p(X;\, \mathcal{H}_0)} > \gamma \qquad (2)$$

where $X = [x[0]\; x[1] \dots [N-1]]^T$.

The probability density function (PDF) of the received signal $\boldsymbol{x}$ under hypotheses $\mathcal{H}$ is $p(X;\mathcal{H})$ where $\mathcal{H} \in \{\mathcal{H}_0, \mathcal{H}_1\}$

$$p(X;\, \mathcal{H}_1) = \frac{1}{(2\pi\sigma^2)^{\frac{N}{2}}} exp\left[-\frac{1}{2\sigma^2}\sum_{n=0}^{N-1}(x[n] - s[n])^2\right]$$

$$p(X;\, \mathcal{H}_0) = \frac{1}{(2\pi\sigma^2)^{\frac{N}{2}}} exp\left[-\frac{1}{2\sigma^2}\sum_{n=0}^{N-1}x^2[n]\right]$$

we have

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

After a series of mathematical calculations we have evaluated the decision statistics T(X) of the MF detector. Thus, the detector MF decides $\mathcal{H}_1$ if:

$$T(X) = \sum_{n=0}^{N-1} x[n]s[n] > \gamma' \qquad (3)$$

where γ' is the new threshold of decision

3.3 The Statistical Test of Distribution for Matched Filter

Under both hypotheses, $T(X)$ is Gaussian and $x[n]$ is also Gaussian as it is a linear combination of Gaussian random variables. By $\mathrm{E}(T;\, \mathcal{H}_i)$ we denote the expected value and by $var(\mathrm{T}; \mathcal{H}_i)$ we denote the variance under hypothesis $\mathcal{H}_i$. Then we have subsequently:

$$\mathrm{E}(T;\, \mathcal{H}_0) = E\left(\sum_{n=0}^{N-1} w[n]s[n]\right) = 0$$

$$var(\mathrm{T}; \mathcal{H}_0) = var\left(\sum_{n=0}^{N-1} w[n]s[n]\right) = \sum_{n=0}^{N-1}(w[n])s^2[n]$$

$$var(\mathrm{T}; \mathcal{H}_0) = \sigma^2 \sum_{n=0}^{N-1} s^2[n] = \sigma^2\varepsilon$$

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

$$\mathrm{E}(T;\, \mathcal{H}_1) = E\left(\sum_{n=0}^{N-1}(s[n] + w[n]s[n]\right) = \varepsilon$$

and in conclusion the variance under hypothesis $\mathcal{H}_1$ is:

$$var(\mathrm{T}; \mathcal{H}_1) = var\left(\sum_{n=0}^{N-1} s[n] + w[n]s[n]\right) = \sigma^2\varepsilon$$

Thus, the distribution of the test statistic under either hypotheses, $\mathcal{H}_0$ and $\mathcal{H}_1$ are, respectively:

$$T \sim \begin{cases} \mathrm{N}(0, \sigma^2\varepsilon) & u\ nder \mathcal{H}_0 \\ \mathrm{N}(\varepsilon, \sigma^2\varepsilon) & u\ nder \mathcal{H}_1 \end{cases}$$

3.4 The Key Parameters of Performance for Matched Filter

The performance of the MF detector is based on the following two parameters: the probability of detection (P_D) and the probability of false alarm (P_{FA}).

We talk about the probability of false alarm P_{FA} when there is no signal, i.e. just the noise, and we detect signal, from the distribution $\mathcal{H}_i$ of the test statistic T under hypothesis $\mathcal{H}_0$ we have:

$$P_{FA} = P(T > \gamma'/\mathcal{H}_0) = P\left(T' > \frac{\gamma'}{\sqrt{\sigma^2\varepsilon}}/\mathcal{H}_0\right), T'(X) = \frac{T(X)}{\sqrt{\sigma^2\varepsilon}}$$

$$P_{FA} = Q\left(\frac{\gamma'}{\sqrt{\sigma^2 \varepsilon}}\right) \tag{4}$$

with $\gamma' = Q^{-1}(P_{FA})\sqrt{\sigma^2 \varepsilon}$
where Q(.) is the standard Gaussian complementary Cumulative Distribution Function (CDF) and Q^{-1} (.) is considered as the inverse standard Gaussian complementary CDF.

$$P_D = P(T > \gamma'/\mathcal{H}_1)$$
$$= Q\left(\frac{\gamma' - \varepsilon}{\sqrt{\sigma^2 \varepsilon}}\right)$$
$$= Q\left(\frac{Q^{-1}(P_{FA})\sqrt{\sigma^2 \varepsilon} - \varepsilon}{\sqrt{\sigma^2 \varepsilon}}\right)$$
$$P_D = Q\left(Q^{-1}(P_{FA}) - \sqrt{\frac{\varepsilon}{\sigma^2}}\right) \tag{5}$$

4 SIMULATION RESULT FOR MATCHED FILTER DETECTOR

As mentioned above, the matched filter detector performance is based on two parameters P_D and P_{FA}. Performance is shown by the curve P_D vs SNR and the curve of the Receiver Operating Characteristic (ROC). The simulation was focused on AWGN Channel.

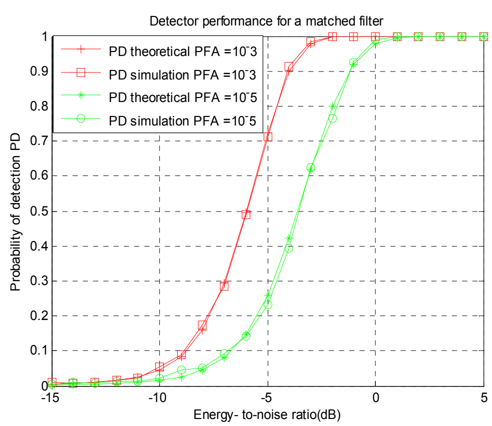

Fig. 2. Detection performance of matched filter

Figure2 presents the performance of the MF detector for the different values target $P_{FA.}$ As we can see from this figure, if we want to increase the detection performance we can increase the P_{FA} and /or increase the energy-to-noise (ENR). We define ENR as $10\log_{10}(\varepsilon/\sigma^2)$ and $\varepsilon = \sum_{n=0}^{N-1} s^2[n]$.

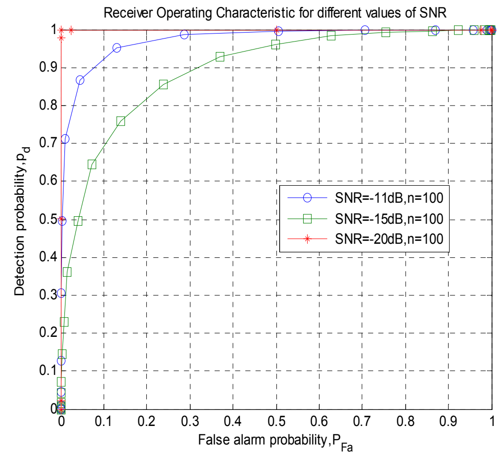

Fig. 3. ROC curves for matched filter detector

Another way to in prove the performance of a detector MF is the ROC in which the P_D is plotted versus P_{FA}. Each point of the curve corresponds to a value of the set (P_D, P_{FA}) for a given threshold γ. When γ increases, P_D and P_{FA} decrease and, when γ decreases, P_D and P_{FA} increase. Figure3 shows the ROC for the MF detector for the different values of the SNR, where $SNR_{(dB)}$ =$10\log_{10}(\sigma_s^2/\sigma^2)$.

5 CONCLUSION

In this paper, the technique for detection of the spectrum in networks of cognitive radio based on the method of detection of matched filter is presented. The result obtained through the curves, shows that the method of detection of matched filter maximizes the SNR of the received signal and also has a short duration of detection compared to the other methods. The method of detection of MF provides good performance when the signal information is known a priori. The detection of the spectrum in cognitive radio is a very important step to prevent interference between the primary and secondary user and facilitates the proper operation of the spectrum. In future work, large power consumption due to the execution of different receiver algorithms for the detection will be studied.

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