Performance Analysis of Spectrum Sensing Techniques for Cognitive Radio

Eleftherios Chatziantoniou, Ben Allen
Centre for Wireless Research
University of Bedfordshire
Luton, LU1 3JU ,UK
e-mail: eleftherios.chatziantoniou@beds.ac.uk, ben.allen@beds.ac.uk

Abstract— **Spectrum sensing is a key element for cognitive radio and is process of obtaining awareness about the radio spectrum in order to detect the presence of other users. In this paper we study the performance of different spectrum sensing techniques in terms of detection performance and required SNR, based on theoretical expressions.**

Keywords- cognitive radio; spectrum sensing; energy detection;matced filter detection; cyclostationary feature detection

I. INTRODUCTION

Recent investigations have shown that a large portion of the licensed spectrum, especially between 0-6GHz, remains unused for as much as 90% of the time, resulting in low spectrum utilization [1]. Taking into account the rapidly growing demand for high data rate wireless services, the problem of radio spectrum utilization has become even more critical.

Cognitive Radio technology has been proposed as a tempting solution to improve spectrum under-utilization. In contrast to conventional wireless networks where all radios operate at a fixed frequency band, in cognitive radios two sets of users coexist: Primary users and Secondary users. Primary users operate in a fixed licensed band, while secondary users are designed to sense their spectral environment in order to detect the presence of primary or other secondary users. When a white space is detected, secondary users autonomously adapt their transmission parameters (such as carrier frequency transmission power, modulation and coding scheme, etc.) in order to opportunistically access the available spectrum by causing no or minimal interference to other users.

Several spectrum sensing techniques have been proposed such as: Energy Detection, Matched Filter detection and Cyclostationary Feature detection [2]. Among the proposed spectrum sensing, Matched Filter detection is known as the optimal one since it maximizes the received SNR. However, its implementation complexity is high since it requires perfect prior knowledge of the primary signal's characteristics such as bandwidth, operating frequency, modulation and pulse shape. Cyclostationary feature detection is robust to noise uncertainty, can perform in low SNR regions and is capable of distinguishing cognitive radio transmissions among different types of primary signals. This technique employs Cyclic Autocorrelation Function and Cyclic Spectral Density function which make it computationally complex. On the other hand, Energy detection is a more generic sensing method because of its low computational and implementation requirements.

This paper, presents an analytical comparison between different spectrum sensing techniques in terms of detection performance and required SNR.

II. ENERGY DETECTION

Conventional Energy Detector (ED) [3] consists of a band-pass filter which rejects out of band noise, an A/D converter, a square law device and an integrator (Fig.1). Let us assume a received signal with the following form:

$$y(n) = hx(n) + w(n) \tag{1}$$

where, $y(n)$ is the signal received by the Secondary User, $x(n)$ is the Primary User's transmitted signal, $w(n)$ is the additive white Gaussian noise (AWGN), h is the amplitude of the channel and $n = 1,...,N$; where N is the observation interval. The test statistic, T , for the energy detector can be obtained by the summation of the observed energy within N number of samples.

$$T = \sum_{n=0}^{N} |\, y(n)\,|^2 \tag{2}$$

Hence, the Energy Detector has to distinguish between the following hypotheses:

$$\begin{aligned} H_0 &: \quad y(n) = w(n) \qquad , \textit{primary user absent} \\ H_1 &: y(n) = hs(n) + w(n) \, , \textit{primary user present} \end{aligned} \tag{3}$$

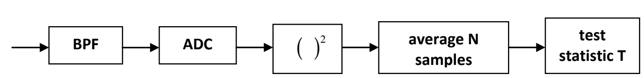

Fig.1. Energy Detector block diagram.

Under hypothesis (3), the probability of false alarm, P_{FA}, and probability of detection , P_D , can be expressed as [4]:

$$P_{FA} = \frac{\Gamma(m, \lambda/2)}{\Gamma(m)} \qquad P_D = Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \tag{4}$$

where $\Gamma(.,.)$ and $\Gamma(.)$ are the incomplete and complete gamma functions respectively, λ is the detection threshold m is the time-bandwidth product, $Q_m(.)$ is the generalized Marcum Q function and γ is the SNR.

III. MATCHED FILTER DETECTION

Pilot signals are frequently used in communication systems for receiver synchronisation. The power of a pilot tone sine-wave is typically 1% to 10% of the total transmitted power. Given the complete knowledge of the pilot tone at the Secondary User, Matched Filter Detection (MFD) can be employed.

Assuming a pilot tone X_p with power θ, the Matched Filter detector has to distinguish between the following hypotheses:

$$\begin{aligned} H_0 &: \quad Y[n] = W[n] \qquad , \textit{primary user absent} \\ H_1 &: \quad Y[n] = X_p[n] + W[n] \ , \textit{primary user present} \end{aligned} \tag{5}$$

where $W[n]$ is AWGN with variance σ_W^2 and $n = 1,...,N$; where N is the observation interval.

By correlating the received primary signal with a unit vector in the pilot's direction $\hat{X}_p$ the test statistic T can be obtained by:

$$T = \sum_N Y[n]\hat{X}_p[n] \tag{6}$$

By (5) and (6) P_{FA} and P_D can be evaluated as [5]:

$$P_{FA} = Q\left(\frac{\gamma}{\sqrt{\varepsilon\sigma_W^2}}\right) \qquad P_D = Q\left(\frac{\gamma - \varepsilon}{\sqrt{\varepsilon\sigma_W^2}}\right) \tag{7}$$

IV. CYCLOSTATIONARY FEATURE DETECTION

Modulated signals are, in general, coupled with sine-wave carriers, pulse trains, repeating spreading functions, hoping sequences, or cyclic prefixes, which all result in built-in periodicity. Such modulated signals are characterized as cyclostationary since their statistics (mean and autocorrelation) exhibit periodicity.

Implementation of a Cyclostationary Feature Detector (CFD) requires computation of the spectral correlation function (SCF). Hence, it requires computation of an N point FFT and a cross-correlation of all bins and averaging over a period of detection time T.

In this paper a detection method, based on the autocorrelation properties of OFDM signals that employ cyclic prefix (CP) is considered. This method uses the maximum likelihood estimate of the autocorrelation coefficient of the received signal. The autocorrelation coefficient can be calculated by correlating the input signal with a delayed version of itself by using the continuous autocorrelation function $R_{ff}(\tau)$:

$$R_{ff}(\tau) = f^*(-\tau) \otimes f(\tau) = \int_{-\infty}^{\infty} f(t+T)f(t)dt \tag{8}$$

where f^* represents the complex conjugate and $\otimes$ the convolution.

For such a detection scheme, P_{FA} and P_D are given by [6]:

$$P_{FA} = \frac{1}{2}erfc(\sqrt{M\eta_l}) \quad P_D = \frac{1}{2}erfc\left(\sqrt{M}\,\frac{\eta_l - \rho_1}{1-\rho_1^2}\right) \tag{9}$$

where M is the number of samples needed for the autocorrelation estimate, η_l is the detection threshold and ρ_1 is the autocorrelation coefficient.

V. PERFORMANCE COMPARISON

An OFDM signal with 32 subcarriers and a detection period of 100 OFDM symbols is assumed. Fig.2. presents the detection performance of ED, MFD and CFD as a function of required SNR. These results were obtained by evaluating (4), (7) and (9) for a $P_{FA} = 0.1$.

It can be observed that for ED and MF detection, much higher SNR is required to obtain a performance comparable to CFD. More specifically, ED and MF detection require an SNR of 11dB and 6dB respectively in order to achieve a $P_D = 0.9$, while CFD requires a SNR of -6dB. Hence, it is clear that CFD outperforms ED and MFD at very low SNR regions.

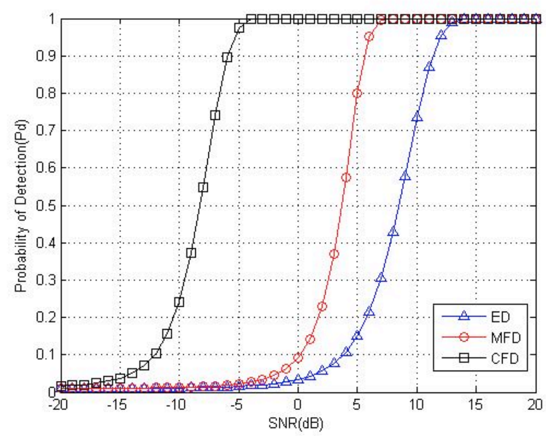

Fig. 2. Probability of detection vs. SNR for different spectrum sensing techniques.

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