Cyclostationary Features Based Spectrum Sensing For Cognitive Radio

Swash Sami Muhammed, Sarmad Nozad Mahmood, Aydin Akan

Abstract— A cognitive radio is a communication wireless system that can control on its transmitter parameters according to sensing the environment in which it operates to maximize the efficiency of spectrum utilization. The aim is to make wireless communication possible with less interference. In our work we have investigated one of the functions of cognitive radio called spectrum sensing. We have specifically used the method of Cyclostationary feature for detection. Randomly generated information is modulated by BPSK, QPSK, BFSK, QFSK, BASK, or QASK, then passed through additive white Gaussian noise (AWGN) channel. The received signal is then processed by cyclostationary detector which uses an adaptive thresholding on the cyclic spectral density. Simulation results on spectrum detection rate for different signal to noise ratios are demonstrated.

Keywords — spectrum sensing, cognitive radio, cyclostationarity, Wigner-Ville transform.

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1 Introduction

Many communication systems such as mobile telecommunications, WLAN, Bluetooth utilize the radio spectrum. Wireless services and communications are very important for social and economic development in today's world. The requirement of radio spectrum is increasing rapidly because of this advancement in wireless systems.

As the demand for wireless communication capacities is continuously growing, Federal Communications Commission's (FCC) frequency allocation chart implies that we are running out of spectrum. However the actual measurements have shown that most of the allocated spectrum is underutilized. To enable future wireless communication services, the radio spectrum management is considered to be very important. The utilization of the radio spectrum must be responsive, active, and flexible to the present needs. Today, every wireless system has its own license to avoid interference. In case of new technologies, it is difficult to operate in their radio spectra because they are already engaged by government and commercial operators. A new scheme of spectrum licensing was adopted by the Federal Communication Commission (FCC) [1] and the Swedish Post and Telecom Agency (PTS) [2].

- *Name : Sarmad Nozad Mahmood , Position : Master student in Electronic & Communication Eng. Department , University : Cankaya University , Address : Çukurambar Mah,06520, Ankara, Turkey , PH : 00905344156524 , Email : sarmad.mahmood@yahoo.com*
- *Name : Swash Sami Muhammed , Position : Master degree program in Electrical & Electronics Eng. Department , University : Istanbul University , Address : Avcilar, Istanbul 34320, Turkey , PH : 009647722164818 , Email : savaskrkk@gmail.com*
- *Name : Prof . Dr. Aydin Akan , Position : Prof in Electrical & Electronics Eng. Department , University : Istanbul University , Address : Avcilar, Istanbul 34320, Turkey , Email : akan@istanbul.edu.tr*

Both parties have chosen to divide users into two categories; such as a licensed user (primary user) and an unlicensed user (secondary user). Cognitive radio provides an opportunity to secondary users to use spectrum that are free for the moment (white space). Cognitive radio also provides the ability for the radio to take decisions about its operations and behavior according to its surrounding environment in order to improve the service. Cognitive Radio will act as an unlicensed (secondary) user who should be able to reliably sense the spectral environment over a wide bandwidth, detect the presence/absence of licensed (primary) users and use the spectrum only if communication does not interfere with any primary user or other cognitive devices. Therefore, spectrum sensing is one of the key issues for the implementation of cognitive radio [3]. The challenge of spectrum sensing is the detection of weak signals in noise with a small probability of miss detection. Modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hoping sequences, or cyclic prefixes, result in built-in periodicity. The periodicity or cyclostationary can be exploited for detection of modulated signals. In this work, we evaluate the performance of cyclostationary features-based spectrum sensing algorithm for signal detection.

2 Spectrum Sensing Concept

Spectrum sensing is based on a well known technique called signal detection. Signal detection can be described as a method for identifying the presence of a signal in a noisy environment. Signal detection has been thoroughly studied for radar purposes since the fifties. Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis test [5]:

$$\begin{aligned} H_1 &: y(n) = x(n)h + w(n) \\ H_0 &: y(n) = w(n) \end{aligned} \tag{1}$$

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Where y(n) is the received signal by secondary users, x(n) is the transmitted signal of the primary user, h is the channel coefficient; and w(n) is additive white Gaussian noise with variance σ_ω^2. H0 and H1 are the sensing states for absence and presence of signal respectively. Another saying; H0 is the null hypothesis which indicates that primary user does not communicate and H1 is the alternative hypothesis that indicates the existence of the primary user. We can define four possible cases for the detected signal:

1. Declaring H1 under H1 hypothesis which leads to Probability of Detection (Pd).
2. Declaring H0 under H1 hypothesis which leads to Probability of Missing (Pm).
3. Declaring H1 under H0 hypothesis which leads to Probability of False Alarm (Pf).
4. Declaring H0 under H0 hypothesis.

If H0 is decided under H1 hypothesis, then it leads to probability of missing, Pm, that is probability of deciding that there's no primary signal while primary signal actually exists. Another saying it's the probability of signal missing. If H1 is decided while H0 is observed then it refers to find the probability of false alarm which indicates to decide primary signal exists while there's actually no primary user communicating. Thus false alarm error leads to inefficient usage of the spectrum.

The aim of the signal detector is to achieve correct detection all of the time, but this can never be perfectly achieved in practice because of the statistical nature of the problem. Therefore signal detectors are designed to operate within prescribed minimum error levels. The tradeoff between P_{md} and P_{fa} has a vital role in a sensing algorithm. High P_{md} increases interference to the primary users. On the other hand, high P_{fa} would result in low spectrum utilization since false alarms increase the number of missed opportunities. For WRAN IEEE 802.22 standard, the requirements are $P_d \geq 90\%$ and $P_{fa} \leq 10\%$ [4].

3 Cyclostationary Features

Data symbol is modeled as stationary random process, however communication signals are in general coupled with carriers, pulse trains, repeating sequences or cyclic prefixes which results in hidden periodicity. These communication signals have distinctive features and are classified as cyclostationary random processes [7]. A signal x(t) is defined as second order wide sense cyclostationary if its statistics, mean and autocorrelation, are periodic with some period τ_0 :

$$\mu_x(t) = \mu_x(t + \tau_0) \qquad (2)$$

$$R_x(t, \tau) = R_x(t + \tau, \tau_0) \qquad (3)$$

Since the autocorrelation function is periodic, it can be represented by Fourier series [6]:

$$R_x^\alpha(\tau) = \lim_{T\to\infty} \frac{1}{T}\int_T x(t - \frac{\tau}{2}) x\,(t + \frac{\tau}{2})^*\, e^{-i2\pi\alpha t}\, dt \qquad (4)$$

$R_x^\alpha(\tau)$ is called Cyclic Autocorrelation Function (CAF) which is used to examine the second order periodicity of the cyclostationary signals. If the signal is cyclostationary with period T then cyclic auto-correlation has component at α where $\alpha = \frac{1}{T}$ (see Fig.1) and α is assumed to be known at the receiver. Notice that CAF is in fact the Wigner-Ville transform of x(t) given in the joint time-frequency domain; its bi-frequency domain counterpart can be obtained by

$$S_x^\alpha(f) = F\{R_x^\alpha(\tau)\} = \int_{-\infty}^{+\infty} R_x^\alpha(\tau)\, e^{-i2\pi f\tau}\, d\tau \qquad (5)$$

$S_x^\alpha(f)$ is referred to as the spectral correlation function (SCF) or cyclic spectral density (CSD). Obviously, SCF is a 2-D symmetric transform with two variables; the cyclic frequency α and the spectral frequency f. Power spectral density (PSD) is a special case of SCF when α= 0:

$$PSD = S_x^0(f) \qquad (6)$$

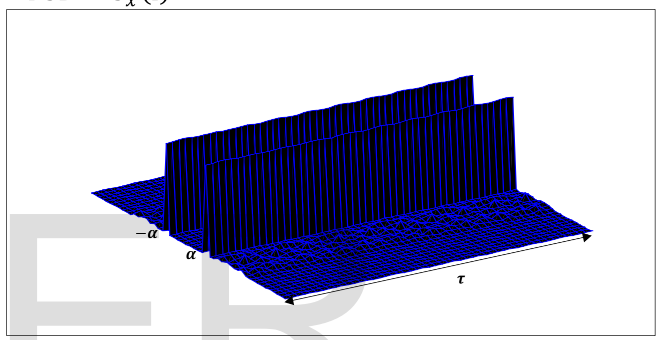

Fig. 1.Cyclic autocorrelation function (CAF).

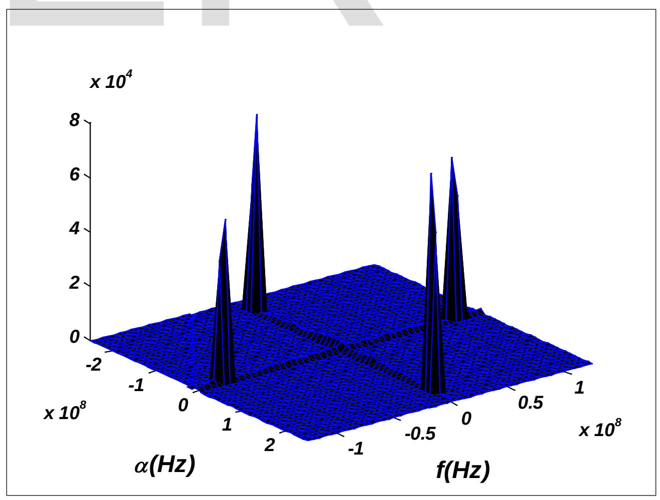

Fig. 2.Cyclic spectrum density for BPSK signal with 0dB SNR.

4 Proposed Spectrum Sensing Algorithm

The main advantage of using spectral correlation function is that the white Gaussian noise (WGN) is a stationary process, so for α ≠ 0 SCF is ideally zero which makes the cyclostationary-features based detector robust against noise uncertainty [7]. We calculated SCF for each one of BPSK, BASK, BFSK, QASK, QFSK and QPSK and found that a sinusoidal signal with carrier frequency f_c have four peaks in CSD at $(\alpha = 0, f = \pm f_c)$ and $(\alpha = \pm 2f_c, f = 0)$ (see Fig.2).

In this work we compute the SCF of the received signal y(t) taking into account that the primary user transmits a cyclostationary signal, so it's SCF has nonzero component at some nonzero cyclic frequency. Hence we can rewrite the hypotheses in (1) as:

$$S_y^\alpha(f) = \begin{cases} S_w^\alpha(f) < \lambda, & H_0 \\ S_x^\alpha(f) + S_w^\alpha(f) \geq \lambda, & H_1 \end{cases} \qquad (7)$$

Where $S_w^\alpha(f)$ and $S_x^\alpha(f)$ is SCF of AWGN and primary signal, respectively and λ is threshold.

This states that if $S_y^\alpha(f) \geq \lambda$ (i.e. x(t)is cyclostationary signal), then we can robustly detect the presence of the primary signal. We focus only on frequencies $(\alpha = 0, f = \pm f_c)$ and $(\alpha = \pm 2f_c, f = 0)$ and look for peaks. These peaks are compared to a pre-determined threshold, so that if they are greater than the threshold and the other values on the same frequencies $(\alpha = 0$ and $f = 0)$, then the signal exists in the band under sensing; or the band is free otherwise.

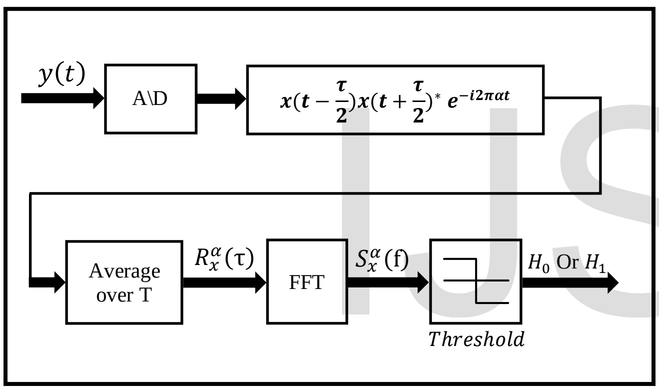

Fig. 3.Block Diagram of a Cyclostationary Feature Detector

5 Spectrum Sensing Tests & Computer Simulations

In our simulations, we consider Binary Phase Shift Keying (BPSK), Binary Amplitude Shift Keying (BASK), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Shift Keying (QASK) modulated signals. We assume that signals are transmitted over AWGN channel and spectrum sensing is performed by the secondary user. We tested our sensing algorithm by using the communication parameters given in Table 1. We show the detection performance in terms of probability of detection for different levels of channel noise in Figs. 4 and 5. We compared the performance of our algorithm with Energy detector [5] and the results are given in Figs. 6 and 7.

Table 1. SIMULATION PARAMETERS

PARAMETER	***VALUE***	***UNIT***
CARRIER FREQUENCY (f_c)	100	MHz
NYQUIST RATIO	5	
SAMPLING FREQUENCY (f_S)	500	MHz
SYMBOL RATE	1,000,000	SYMBL/SEC
SAMPLES PER SYMBOL	500	SAMPLE/SYMBL

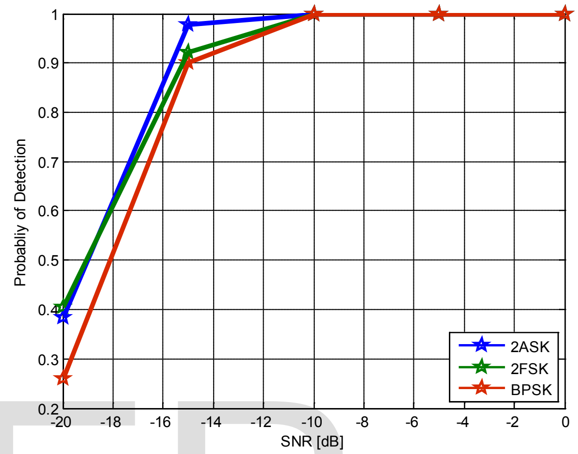

Fig. 4.Spectrum Detection Probabilities for 2ASK, 2FSK, BPSK for different SNR values.

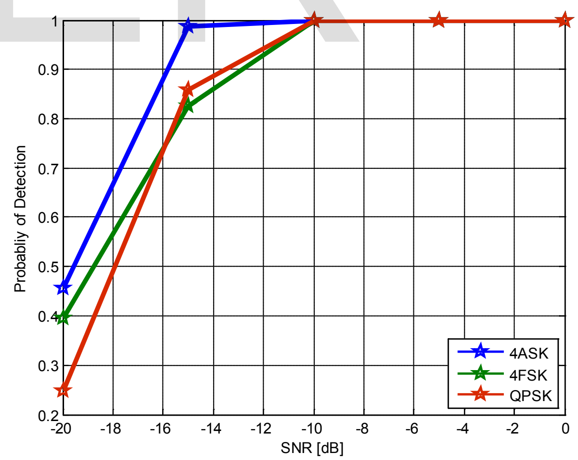

Fig. 5.Spectrum Detection Probabilities for 4ASK, 4FSK, QPSK for different SNR values.

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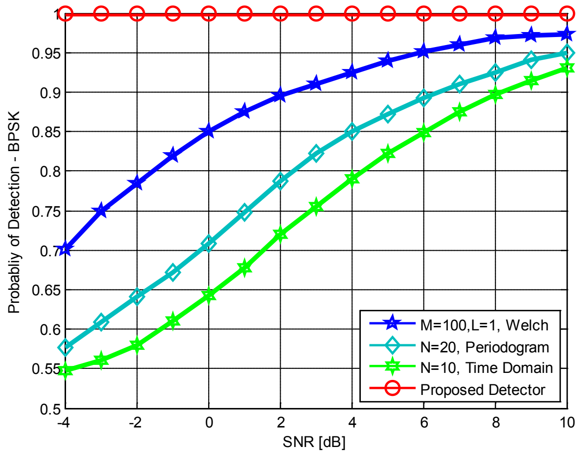

Fig. 6.Proposed Detector vs different types of Energy Detector (BPSK)[5].

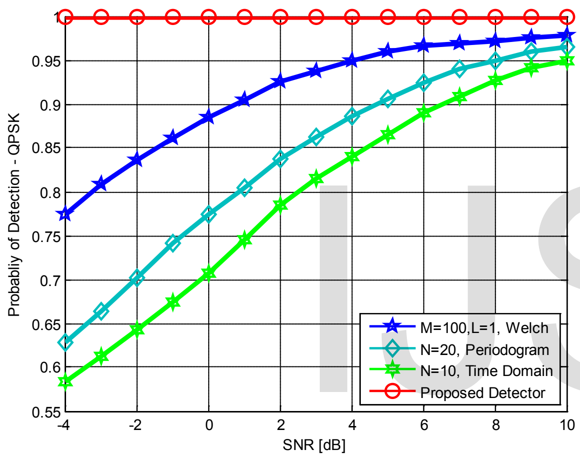

Fig.7.Proposed Detector vs. different types of Energy Detector (QPSK)[5].

6 Conclusion

Conventionally, due to the ease of implementation, Energy Detector is been used for detection the signal of interest. However, it is prone to the noise uncertainty. Hence, efforts had spent in exploiting cyclostationarity features of signal as cyclostationarity features based spectrum detector is well known for its noise robustness. Although its performance is superior to Energy Detector, it is also more complex in terms of calculation.

In this study, a cyclostationary features based spectrum detector is proposed with the aim of maintaining a comparable detection rate and zero false alarm probability. To verify the performance, we tested the proposed detector for BASK, BFSK, BPSK, QASK, QFSK and QPSK modulated signals corrupted by AWG channel noise. Based on the simulation results, cyclostationary features based spectrum detector's performance is as anticipated better than Energy Detector under noise uncertainty and its false alarm is zero for SNR values greater than -5dB, and less than 5% between -5 and -20 dB. Therefore, cyclostationary features based spectrum detector may be used in Cognitive Radio applications.

7 References

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