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Blind Spectrum Sensing Techniques for Cognitive Radio System

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Abstract

As the mobile communication environments grow rapidly, much attention has been paid on the use of spectrum resources. Recently, a new technology called Cognitive Radio (CR) was developed for using the unused spectrum bands efficiently. In the CR system, one possible way to locate these unused spectrum bands is to use so-called spectrum sensing. This technique, however, should be computationally simple and fast in order to catch up with the changing signal parameters. In this paper, we propose a cyclostationary feature based detection technique for spectrum sensing. To improve spectrum sensing performance, the proposed spectrum sensing technique computes the circular correlation of received signal before the cyclostationary feature based detection. Simulation results show that the proposed spectrum sensing technique provides better spectrum sensing performance than cyclostationary feature based detection technique even in the low SNR environment.

1. Introduction

As wireless communications become more complicated and widely used, the demand of more spectrum resources will increase significantly and it is especially important to manage spectrum resources efficiently. However, according to the recent studies and numerous reports done by Federal Communications Commission (FCC), there are a lot of available spectrum bands temporarily and geographically even though they are allocated to the primary user [1]. It is indicated that scarcity of spectrum resources is not due to fundamental lack of spectrum resources, but to inefficient spectrum allocation. In this situation, the cognitive radio (CR) technology has been proposed as a candidate for improving the efficiency of spectrum allocations by adopting dynamic spectrum resource management. On the CR regulation, the secondary user has to guarantee that it does not interfere with the primary user. To achieve that, the CR system essentially requires dynamic spectrum sensing technique that detects the primary user signal and switch the spectrum band in use into another empty one as quickly and accurately as possible.

Various spectrum sensing techniques have been presented, including energy detection and cyclostationary feature based detection [2]. An energy detection based non-coherent method is measuring the energy around the peak area of the received signal. It is easy to implement and does not require knowledge of the modulated signal and noise. However, it is extremely vulnerable to noise and interference level. Moreover, the energy detection does not differentiate between modulated signals, noise and interference. As an alternative, cyclostationary feature based detection is to exploit the built-in periodicity of modulated signal for primary user detecting, and is based on the theory of cyclostationary. The spectrum sensing performance of cyclostationary feature based detection has been found to be superior to the energy detection and various signal types can be differentiated by the cyclic spectrum density. However, in the low SNR environment, the spectrum sensing performance of cyclostationary feature based detection will become worse, because the cyclic spectrums related to some signal information parameters are overwhelmed by those related to noise [3].

In this paper, we propose a cyclostationary feature based detection technique that enhances the spectrum sensing measurements. The proposed spectrum sensing technique can more accurately detect the unused spectrum in the low SNR environment, while its overall complexity is almost same as the cyclostionary feature based detection technique. Also, proposed spectrum sensing technique does not require knowledge of the channel or noise information. This paper is organized as follows: Section 2 describes the conventional spectrum sensing techniques. Section 3 introduces the proposed spectrum sensing technique. The simulation results are shown in Section 4. Finally, the conclusions are presented in Section 5.

2. Spectrum sensing techniques

2.1. Energy detection

The classical method for detecting unknown signals is referred to as energy detection which was first proposed by *Urkowitz* in *1967*. This technique has been extensively used in radiometry. The block diagram for energy detection is shown in figure 1. First, the input signal is filtered to select the bandwidth of interest. The filtered signal is squared and integrated over the observation time *T*. Finally, the output of the integrator is compared to a threshold to decide whether the primary user is using or not. When the spectral environment is analyzed in the digital domain, energy detection can be implemented similar to a spectrum analyzer by fast Fourier transform (FFT) based method. Also, longer observation time reduces the noise power, and thus improves SNR.

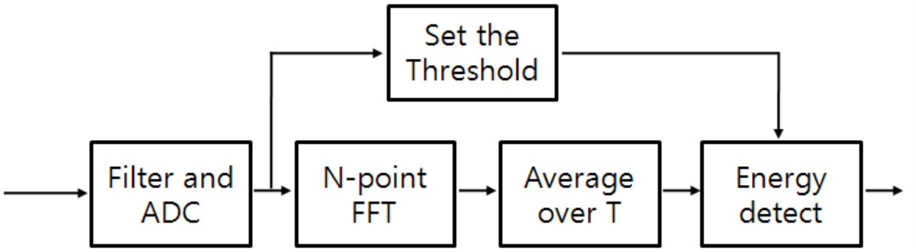

Figure 1. Implementation of an energy detection using the Welch's periodogram

The implementation simplicity of the energy detection is perhaps its advantage. However, its performance is highly susceptible to noise level uncertainty. This uncertainty causes problems especially in the case of simple energy detection because it is difficult to set the threshold used for primary user detection without the knowledge of accurate noise level. Furthermore, energy detection does not differentiate between modulated signals, noise and interference. Thus, it cannot benefit from adaptive signal processing for cancelling the interferer and it is also prone to false detection triggered by unintended signals. Therefore, we should consider designing the better spectrum sensing technique.

2.2. Cyclostationary feature based detection

Generally, the information signal is modeled as a stationary random process. However, modulated signals are in general coupled with sine wave carriers, pulse trains, repeating spreading, hoping sequences, or cyclic prefixes which result in built-in periodicity. These modulated signals can be modeled as a cyclostationary random process because their statistics, mean and autocorrelation, exhibit periodicity. This periodicity is typically introduced in the signal format so that a receiver can exploit it for: parameter estimation such as carrier phase or pulse timing. Under this assumption, this can then be used for detection of a random signal with a particular modulation in a background of noise and other modulated signals.

Consider a process *x(t)* which is cyclostationary with time period *T*. We can define the mean and autocorrelation of *x(t)* as follows.

$$m_x(t+T) = m_x(t) \tag{1}$$

$$R_x\left(t+T+\frac{\tau}{2}, t+T-\frac{\tau}{2}\right) = R_x\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right) \tag{2}$$

$R_x(t+\tau/2,\ t-\tau/2)$, which is a function of two independent variables, t and τ, is periodic in t with period T for each value of τ. It is assumed that the Fourier series representation for this periodic function converges, so that R_x can be expressed as

$$R_x\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right) = \sum_{\alpha} R_x^{\alpha}(\tau)\cdot e^{j2\pi\alpha t} \tag{3}$$

$$R_x^{\alpha}(\tau) = \frac{1}{T}\int_{-T/2}^{T/2} R_x\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right)\cdot e^{-j2\pi\alpha t}\,dt \tag{4}$$

where R_x^{α} is called cyclic autocorrelation function and α denotes the cyclic frequency. The conventional power spectral density function is defined by the Fourier transform of the autocorrelation function. By similarity with the definition of conventional power spectral density function, we can define the spectral correlation function (SCF).

$$S_x^{\alpha}(f) = \lim_{T\to\infty}\lim_{\Delta t\to\infty}\frac{1}{\Delta t}\int_{-\Delta t/2}^{\Delta t/2}\frac{1}{\sqrt{T}}X_T\left(t, f+\frac{\alpha}{2}\right)\cdot\frac{1}{\sqrt{T}}X_T^{*}\left(t, f-\frac{\alpha}{2}\right)dt \tag{5}$$

In the equation (5), the spectral of *x(t)* over time interval [*t-T/2,t+T/2*] is given by

$$X_T(t, v) = \int_{-T/2}^{T/2} x(u)\cdot e^{-j2\pi vu}\,du \tag{6}$$

Implementation of cyclostationary feature based detection technique is depicted in figure 2. The cyclostationary feature of the modulated signals provides us a richer domain signal detection method. Unlike power spectral density which is one dimensional transform, the spectral correlation function is two dimensional transform, in general complex valued and the parameter α. Power spectral density is a special case of a spectral correlation function for α=0.

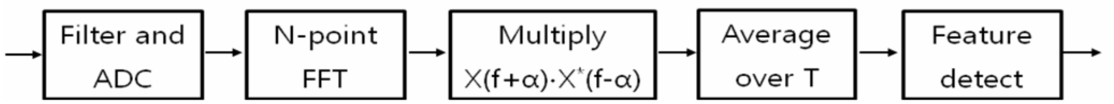

Figure 2. Implementation of a cyclostationary feature based detection

The main advantage of the cyclostationary feature based detection is that discriminates the noise signal from the modulated signal. This is because stationary noise and interference exhibit no spectral correlation while modulated signals are cyclostationary with spectral correlation due to embedded redundancy of signal periodicities. Thus, cyclostationary feature based detection is more robust to noise uncertainty than energy detection. Another motivation of implementing the cyclostationary feature based detection is that different types of modulated signals can have highly distinct spectral correlation functions. Therefore, we can accomplish the detection by searching the unique cyclic frequency of modulated signals. On the other hand, cyclostationary feature based detections are more complexity to implement than their counterpart energy detections. Moreover, in the low SNR environment, the spectrum sensing performance of cyclostationary feature based detection will become worse. Because the cyclic spectrum associated to some signal information parameter such as carrier frequency are whelmed by those associated to noise power.

3. Proposed spectrum sensing technique

This section proposed a cyclostationary feature based detection technique that enhances the spectrum sensing measurements. The block diagram of proposed spectrum sensing technique is shown in figure 3.

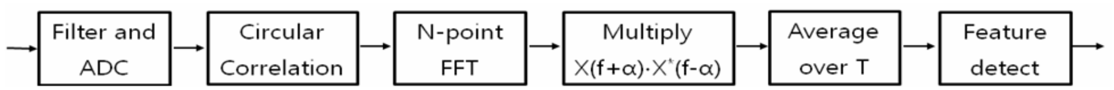

Figure 3. Implementation of a proposed spectrum sensing technique

In noise environment, the received signal is given by

$$x(t) = s(t) + n(t) \tag{7}$$

where *s(t)* denotes the modulated signal, and *n(t)* denotes the noise signal. After filtering and sampling the received signal, discrete-time received signal is entered to the circular correlation module. The circular correlation is expressed as

$$R_{xx}(k) = \sum_{n=0}^{N-1} x(n) \cdot x^*(n-k)_N \tag{8}$$

where $x^*(n-k)$ is shifted circularly by k samples.

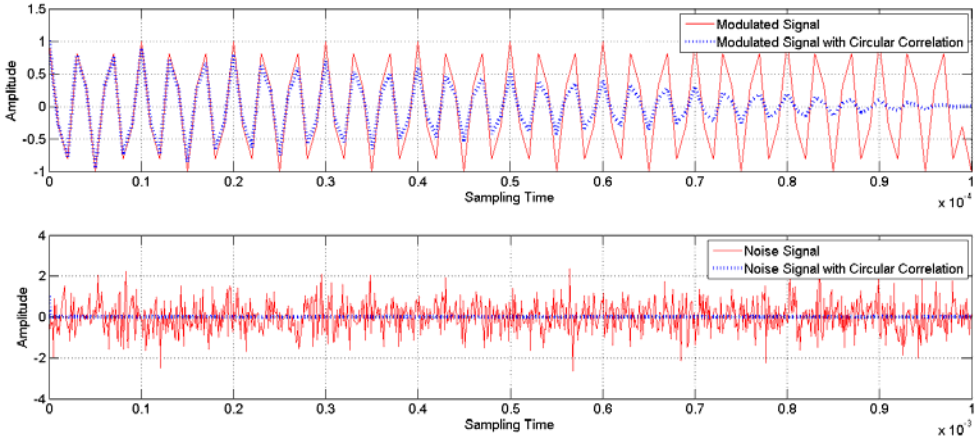

Figure 4. Example of circular correlation

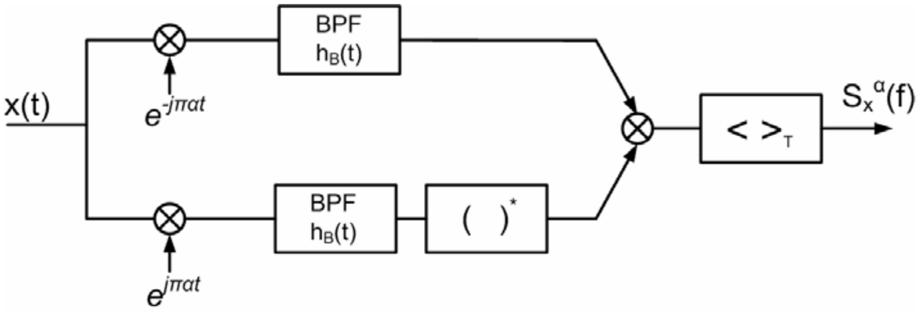

Figure 5. Spectral correlation function generator

As shown in figure 4, since the modulated signal has periodicity, circular correlation of the modulated signal has also periodicity. However, since the noise signal has randomicity, circular correlation of the noise signal has almost zero value at all time shifted. Using this characteristic, the circular correlation of the noise signal is easily distinguished from that of the modulated signal. After that, calculate the spectral correlation function based on equation (5). As shown in figure 5, both frequency bands pass through the same band pass filter centered at frequency f. When spectrum sensing begins, the detector will begin to search for the all the possible peak values in the frequency-cyclic frequency plane. As described in the section 2, the random noise does not exhibit cyclostationary features. Therefore, if unique cyclic frequency does not exist, there is no signal in the detected spectrum band. After checking all possible unique cyclic frequencies, detection decision of specific signal type is made by comparing the predetermined threshold.

4. Simulation results

Simulation results are presented to evaluate the performance of the proposed spectrum sensing technique. The simulations have been carried out under different SNR environments. Basic parameters used for the simulation are summarized in table 1.

Table 1. Simulation parameters

Parameter	Value
Modulation type	BPSK,QPSK
Carrier frequency	125 MHz
Bandwidth	20 MHz
Sampling Frequency	800 MHz
Channel environment	AWGN

When SNR equals to 0 dB, as shown in figure 6 and figure 7, the peak values of the received signal in unique cyclic frequencies can clearly be seen in cyclostationary feature based detection technique and proposed spectrum sensing technique. Also, there are four peak values at $(\alpha,f) = (0,f_c)$, $(0,-f_c)$, $(2f_c,0)$, $(-2f_c,0)$ for BPSK and only two peak values at $(\alpha,f) = (0,f_c)$, $(0,-f_c)$ for QPSK. In the case of lower SNR environments, take -5 dB and -10 dB for example, four spectrum lines which are associated with the cross spectral correlation between the modulated signal and noise signal. Thus, the cross points of these spectrum lines denote the unique cyclic frequency and carrier frequency. As the SNR level decreasing, the peak values of the received signal are overwhelmed by the noise signal. When SNR equals to -15 dB, as shown in figure 12 and figure 13, it is hard to detect the unique cyclic frequency by cyclostationary feature based detection due to the overwhelming noise power. However, in the contour figure, the proposed spectrum sensing technique shows better performance of detecting the unique cyclic frequency and carrier frequency than cyclostationary feature based detection due to the circular correlation processing. As we predicted, since the circular correlation of the noise signal is easily distinguished from that of the modulated signal due to its randomness in time, the spectral correlation function of the given circular correlated received signal can be observed the superior spectrum sensing performance in the low SNR environment. Moreover, unlike spectral correlation function which is two dimensional transform, the circular correlation is one dimensional transform and may be expressed as a circular convolution. Thus, the computational complexity of proposed spectrum sensing technique consists of SCF complexity ($O(N^2+0.5\cdot N\cdot log2N)$) and circular correlation complexity ($O(N\cdot log2N)$). In figure 14, since the complexity of SCF is much higher than that of circular correlation, overall complexity of proposed spectrum sensing technique is almost same as that of cyclostationary feature based detection.

5. Conclusions

According as the concern of cognitive radio technology increases, the spectrum sensing technique which could be used to increase the spectral efficiency in wireless communication system is recognized as a key issue. In this paper, we propose a cyclostationary feature based detection technique which is combined with spectral correlation function and circular correlation module. The advantage of the proposed spectrum sensing technique is that it improves spectrum sensing performance without significant increasing in overall complexity. Simulation results show that the proposed spectrum sensing technique works efficiently in the low SNR environment, even if the cyclostationary feature based detection technique does not work well. Therefore, the proposed cyclostationary feature based detection technique is more suitable for spectrum sensing in cognitive radio system.

6. References

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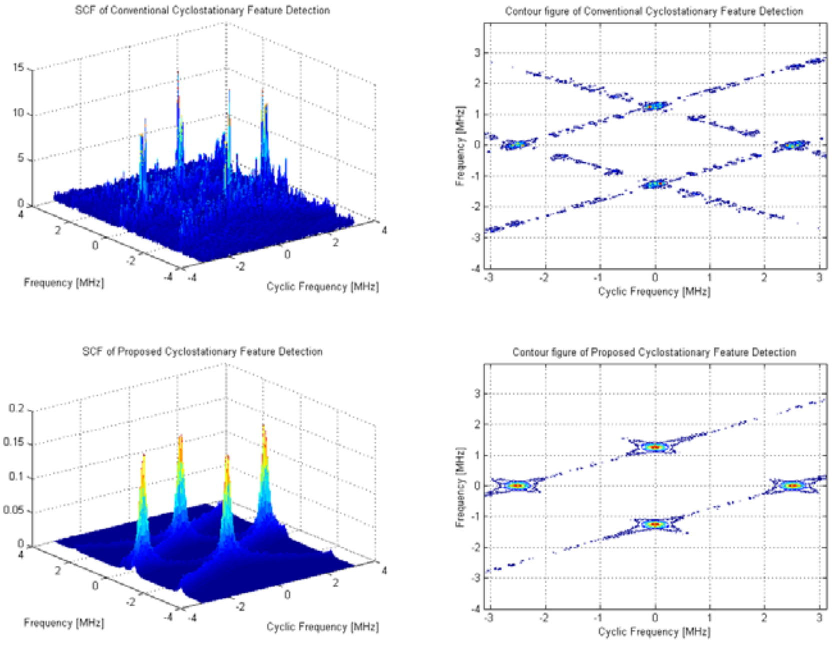

Figure 6. Detection of BPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=0dB

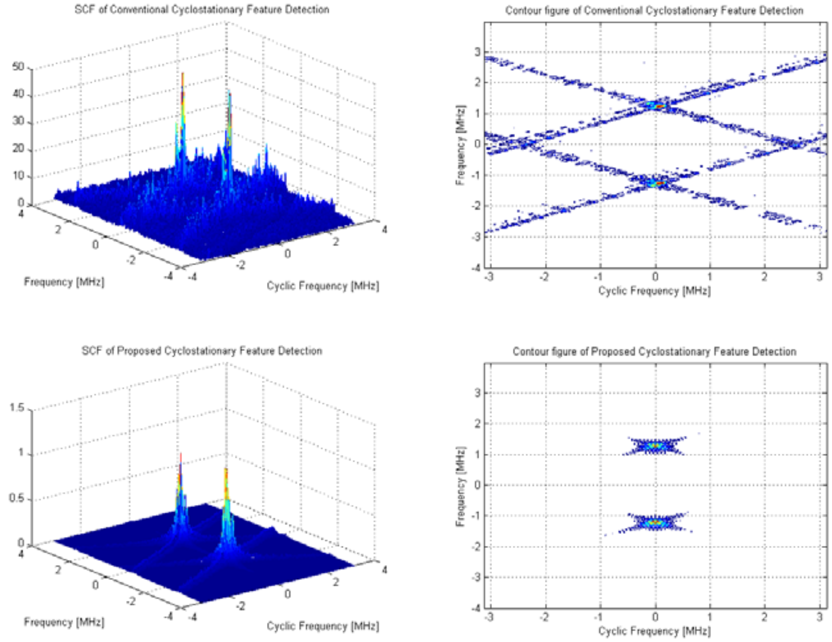

Figure 7. Detection of QPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=0dB

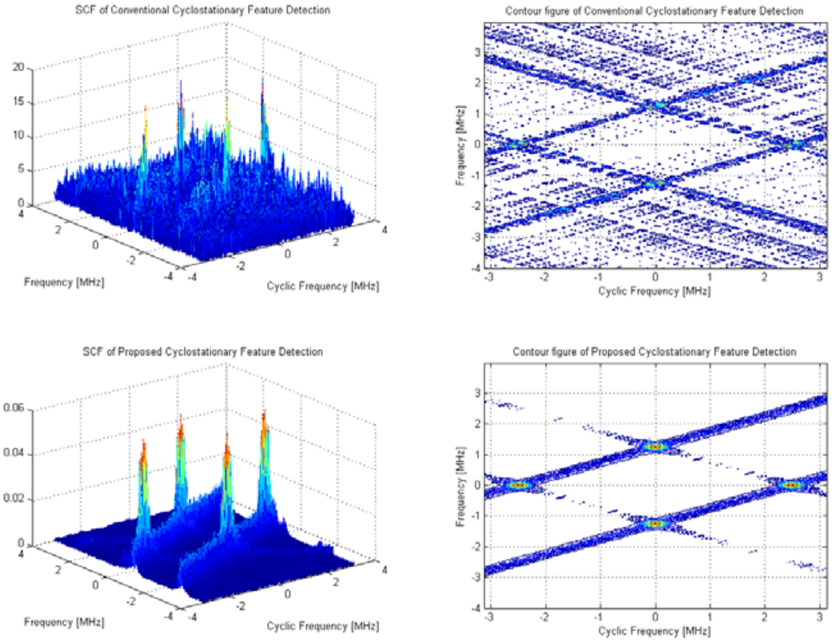

Figure 8. Detection of BPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=-5dB

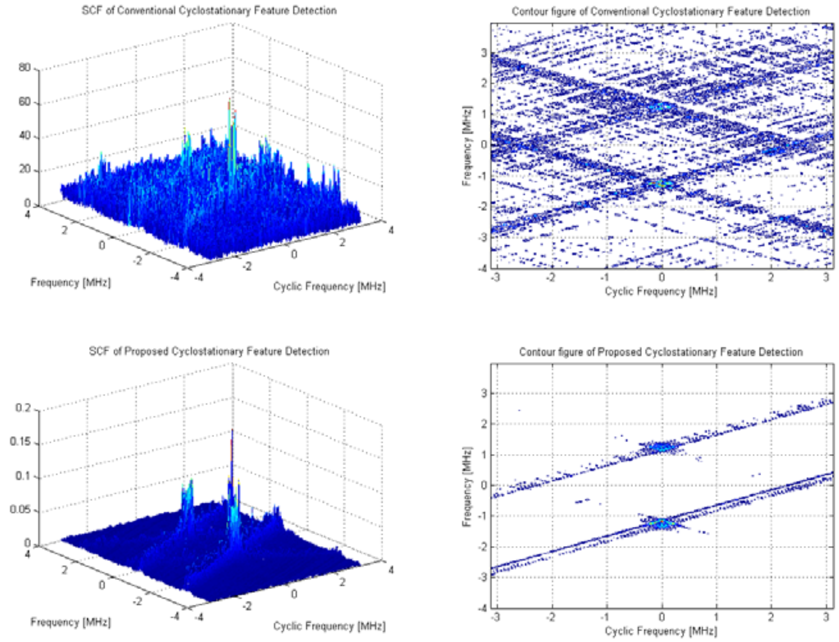

Figure 9. Detection of QPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=-5dB

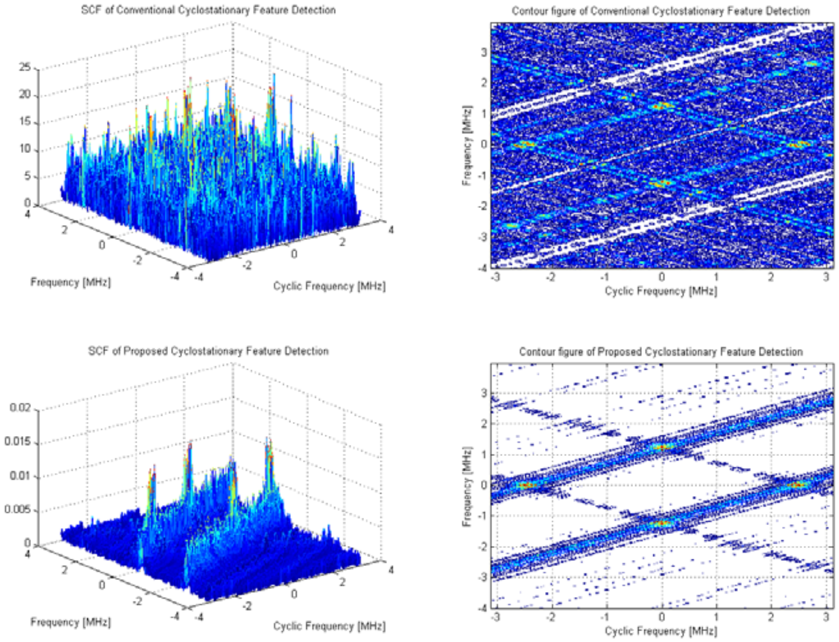

Figure 10. Detection of BPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=-10dB

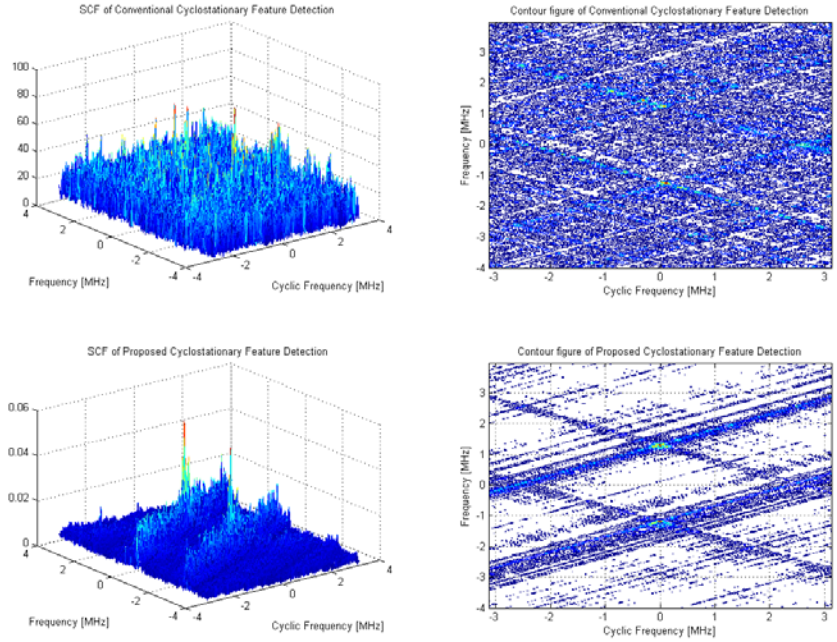

Figure 11. Detection of QPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=-10dB

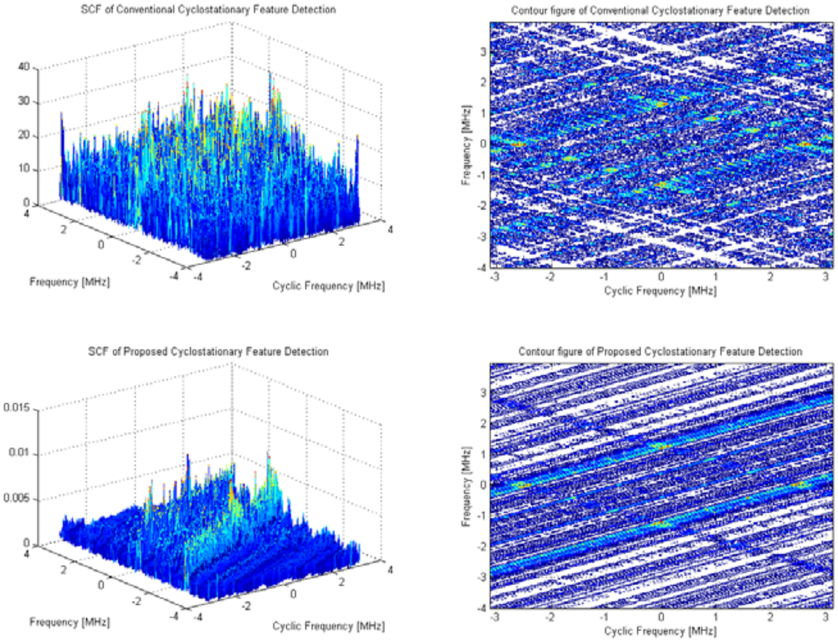

Figure 12. Detection of BPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=-15dB

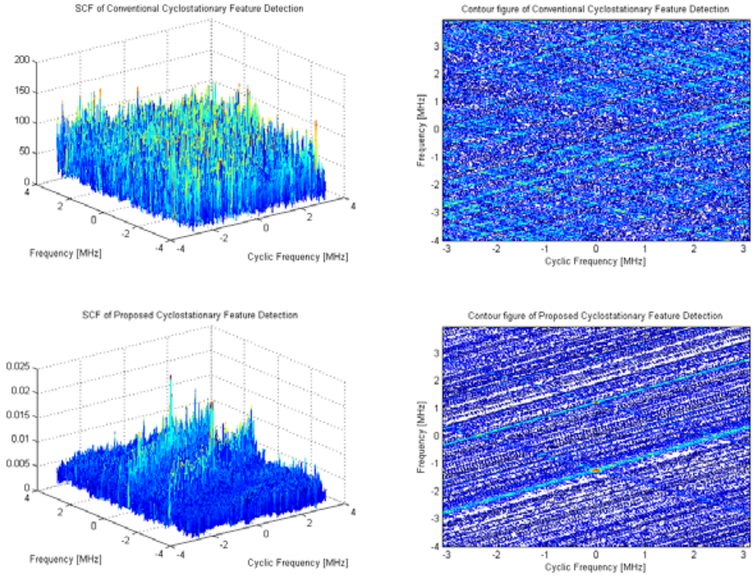

Figure 13. Detection of QPSK signal using proposed spectrum sensing and cyclostationary feature based detection with SNR=-15dB

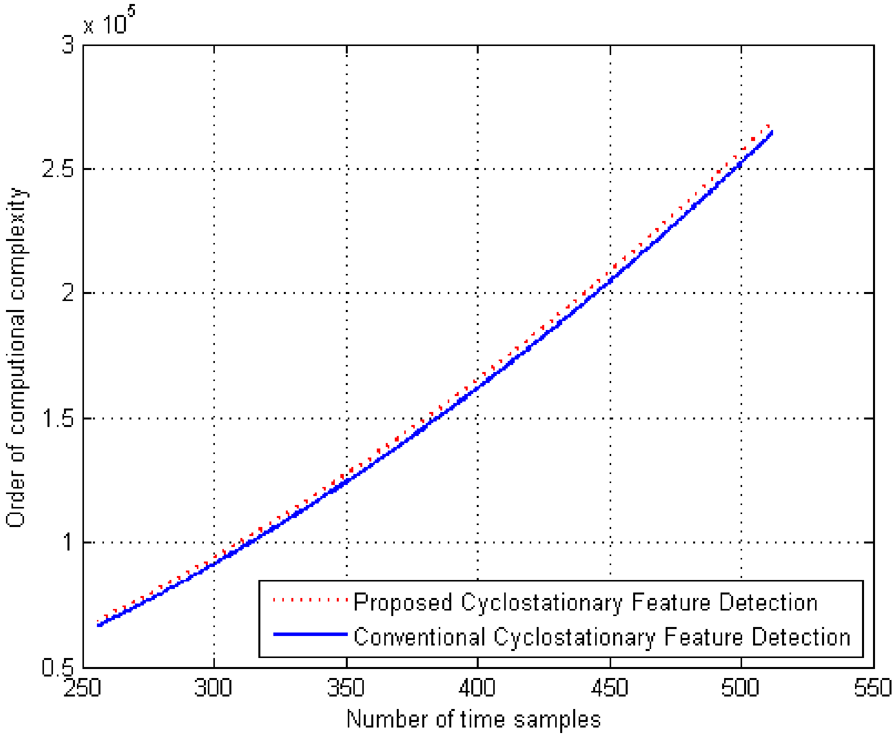

Figure 14. Complexity comparison of proposed spectrum sensing and cyclostationary feature based detection