

An Improved Blind Source Separation Using Bispectrum Slide Detection in Blind Spectrum Sensing

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Abstract: Cognitive radio is a pivotal solution to combat the existing problem of inefficient usage of spectrum bands. Spectrum sensing is one of the most important issues in cognitive radio system. The unlicensed secondary user should detect the available idle spectrum resource accurately and thus reuse it opportunistically. Blind spectrum sensing refers to a condition where the signal can be detected under low SNR environment without any prior knowledge about the gain, noise variance and threshold of the channel. Based on the concept of Random Matrix Theory and Blind Source Separation method, a novel spectrum sensing approach is proposed using Bispectrum slide detection analysis. The novel approach of combining Random Matrix Theory with Bispectrum Slide detection based blind source separation in blind spectrum sensing has been proposed in this paper. Simulation results of proposed algorithm are obtained in the form of receiver operating characteristic curves. The results indicate that the proposed approach gives better results with less complexity than commonly used blind spectrum detection techniques.

Index Terms—Bispectrum Slide; Blind Source Separation (BSS); Cognitive radio(CR); Kurtosis; Random Matrix Theory (RMT);

I. INTRODUCTION

The electromagnetic spectrum is becoming a scarce natural resource because of the ever rising demand of bandwidth. Cognitive radio (CR) communication [1] is a promising solution to this problem of spectrum scarcity. CR users have to sense the spectrum constantly in order to detect the presence of a primary signal and allow the secondary users to utilize the allocated but unused spectrum segments [2]. Therefore, making a correct decision about the presence of a primary signal is one of the most important issues in the implementation of each CR system. Moreover, signal processing has always played a critical role in science, technology and development of new systems like computer tomography, wireless communications, digital cameras, HDTV, etc. Blind signal processing (BSP) is now one of the emerging areas in signal processing with solid theoretical foundations and many potential applications [3].

The conventional cooperative spectrum sensing algorithms such as energy detection (ED) [3], cyclo-stationary detection [5], likelihood ratio test [6] and matched filtering [7] cannot cope well with low SNR, noise uncertainty and have considerable computational complexity.

Additionally, conventional sensing algorithms must know the information of Primary User signals and background noise. In real life scenarios, the noise variance depends on the radio characteristics and is hard to be estimated properly. To overcome these shortcomings, we use the concept of Random matrix theory (RMT) [8], which is a cooperative blind spectrum sensing technique based on the eigenvalues of a random covariance matrix of the received signal.

One of the main limitations in spectrum sensing techniques such as RMT or ED is that the cognitive transmitter should not be in operation during spectrum sensing. In other words, conventional algorithms do not have the ability to differentiate between the primary and the secondary (cognitive) transmitted signal. Obviously, this leads to the two main limitations. First, the overall achieved throughputs are reduced and second, the accuracy of spectrum sensing is affected. Blind source separation (BSS) is recently recommended for spectrum sensing in CR systems [9,10]. BSS [11] is proposed to separate the mixed signal of CR and primary user with little collision, in a multi-antenna application. In this paper, a novel algorithm has been proposed to overcome the aforementioned limitations, wherein

Bispectrum slide detection [12] has been applied on the separated BSS signal as an alternative for existing techniques. By doing so, the cognitive transmitter can continue on working during the sensing period. Also, we propose to combine a new method based on RMT with the modified Bispectrum-BSS algorithm in order to enhance the spectrum sensing performance.

The remainder of this paper is organized as follows. In section II, the paper describes the system model of proposed algorithm, elaborates its detection principle and states the assumptions taken. Section III explains the blind RMT-based spectrum sensing method when cognitive radio is off. Section IV applies the Bispectrum slide detection method on the BSS spectrum sensing algorithm when the cognitive radio is on and formulates our proposed improved spectrum sensing technique. Section V provides simulation results and discussions about the performance obtained by the proposed technique. Finally, Section VI draws our conclusions.

II. SPECTRUM SENSING SYSTEM MODEL

Sensing the presence of a primary transmitter inside a given frequency band is usually viewed as a binary hypothesis testing problem with hypothesis H_0 and H_1 defined as:

- H_0 : Absence of signal
- H_1 : Presence of signal

Where H_0 is a null hypothesis that means there is no licensed user signal active in a specific spectrum band, and H_1 is the alternative hypothesis which means that there is an active primary user signal.

In the blind spectrum sensing, since the parameters of the spectrum are unknown to us, we assume the source signal S , channel gain H and noise signal N , as random signals in the form of matrices. The channel gain is assumed to follow a Rayleigh distribution, while the noise is assumed to be the Additive White Gaussian Noise.

$$Y = H * X + N \dots \dots \dots (1)$$

Where X and N are random matrices of the form (i,k) and H is a random matrix of the form (i,i) . Here, i denotes the number of users and k denotes the number of samples. We define H_{PUi} to denote the absence (for $i = 0$) and the presence (for $i = 1$) of the primary signal. Similarly, we define H_{CRi} to indicate the decision based on the received signals during spectrum sensing at cognitive terminals about the absence (for $i = 0$) and the presence (for $i = 1$) of the primary signal. The above hypotheses are

usually used to define the following conditional probabilities:

$$P_d = P(H_{1CR} | H_{1PU}) = P(T > \delta | H_1) \dots \dots \dots (2)$$

$$P_f = P(H_{1CR} | H_{0PU}) = P(T > \delta | H_0) \dots \dots \dots (3)$$

Where δ is the decision threshold and T is the test statistic. (2) (referred to as detection probability) is a performance metric for cases where the cognitive radio successfully detects the presence of the primary signal at H_1 whereas (3) (referred to as false-alarm probability) is another performance metric for cases where the cognitive radio fails to detect the absence of the primary signal at H_0 . Since false alarm errors can lead to inefficient usage of the radio spectrum, P_d must be maximal for the value of P_f as low as possible.

In this model, when the primary user is detected to be absent, we assume that one of the cognitive users has the permission to send its data through the free sensed frequency band to the destination cognitive user. The received signal at the j th cognitive user can be written as follows:

(a) If spectrum sensing is performed while the cognitive system is in operation (H_{0CR}), we obtain the following hypothesis

$$Y = X * H + N_{H_{0PU}} \dots \dots \dots (4)$$

$$Y = X * H_1 + C * H_2 + N_{H_{1PU}} \dots \dots \dots (5)$$

(b) If spectrum sensing is performed while the cognitive system is not in operation (H_{1CR}), the initial model leads to

$$Y = N_{H_{0PU}} \dots \dots \dots (6)$$

$$Y = H_1 * X + C * H_2 + N_{H_{1PU}} \dots \dots \dots (7)$$

III. RANDOM MATRIX THEORY BASED ON MAX-MIN EIGENVALUES

The Concepts of random matrix theory (RMT) [8] have been applied in the proposed algorithm when the cognitive transmitter is considered to be off. As RMT is a blind spectrum sensing technique we do not need to have prior knowledge of the channel gain and noise variance of the sensing spectrum. The most accurate techniques that can simultaneously achieve both high probability of detection and low probability of false-alarms without requiring information of primary user signals are the eigenvalue based detection techniques. When the concept of eigenvalue is applied to the primary signal it is observed that the signal received at the CR user is correlated. Such correlations are present due to the dispersive channels and

can be utilized by the CR user to differentiate between the primary signal and white noise.

RMT is based on maximum and minimum eigenvalues of the covariance matrix. In the proposed algorithm, ratio of maximum to minimum eigenvalue is stated as decision threshold and compared to energy, ξ of the received signal. The decision hypothesis [13] is given by equation (8).

$$\xi = \frac{1}{L} \sum_{i=1}^L |H * X + N| \dots \dots \dots (7)$$

$$\theta_{RMT} = \begin{cases} H_1 & \text{if } \frac{\lambda_{max}}{\lambda_{min}} \geq \xi \\ H_0 & \text{if } \frac{\lambda_{max}}{\lambda_{min}} < \xi \dots \dots \dots (8) \end{cases}$$

IV. SPECTRUM SENSING BASED ON BLIND SOURCE SEPARATION AND BISPECTRUM SLIDE DETECTION

In this section, we introduce the spectrum sensing based on the YGBSS approach. To separate sources from random input matrix signal we will apply the YGBSS method [17]. The goal is to recover the original source signal vectors S, by applying the blind spectrum sensing algorithm with unknown noise variance described as follows.

- Step 1** Perform STFT on the input row random matrix and calculate its energy.
- Step 2** Calculate the peak of the detected signal
- Step 3** Compare the energy with predefined threshold and mask these signals with zeros
- Step 4** Perform Inverse STFT and multiply it with the masked signal

By executing the above mentioned algorithm, signals are separated from the input random matrix. Further the Kurtosis function can be applied to increase the detection probability.

The novelty of this paper is that it combines this existing YGBSS algorithm with Bispectrum Slide Detection technique. The unique feature of the Bispectrum Slide Detection is that it introduces the High Order Analysis into spectrum sensing with better sensing performance in the area of weak signal detection and its unique feature of suppressing Gaussian noise. For a Gaussian random variable, since the high order cumulant

of a Gaussian distributed process is equal to zero, its Bispectrum also becomes zero.

Due to its overlap feature; the Bispectrum of a combined signal is equal to the summation of each original signal's Bispectrum, thereby suitable for restraining Gaussian noise in signal processing even in the low SNR case. High order spectrum is finding its applications in many different fields such as signal processing, array processing and image processing, etc. The algorithm of the same has been described below.

- Step 1** Denote the signal samples by Y(n).
- Step 2** The power spectrum is computed by taking the modulus squared of the Fourier transform, the Fourier transform is defined by $Y(\omega) = \sum y(k)e^{-j\omega k}$ (9)
- Step 3** The power spectrum is then given by $P(\omega) = Y(\omega) \cdot Y^*(\omega)$ (10)
- Step 4** Bispectrum is calculated in its frequency domain.

A third order, complex-valued function known as Bispectrum is defined for discrete energy-bounded signal as $BY(\omega_1, \omega_2) = Y(\omega_1)Y(\omega_2)Y^*(\omega_1 + \omega_2)$ (11)

It depicts the correlation between corresponding frequency components (ω_1, ω_2) . Further, we can simplify the Bispectrum analysis to reduce the dimension from three to two, given by Simplified Bispectrum diagonal slide.

$$BY(\omega) = BY(\omega, \omega) = Y^2(\omega) Y^*(2\omega) \quad (12)$$

It can be observed from the simulation result that a higher detection probability, approaching to one, can be achieved using the Simplified Bispectrum analysis as compared to Bispectrum slide detection, for varying range of Pf. For lower values of Pf, that is 0.2, we obtain the Pd for simplified Bispectrum as 0.9 while it is 0.7 for BSD.

V. RESULTS

As given in the existing algorithm [13], we can see that on combining the random matrix theory with blind source separation in spectrum sensing, the overall throughput is increased. On implementing the following algorithm, we are able to achieve comparable results in the form of desirable Probability of detection (Pd) with respect to Probability of false-alarm (Pf) curves. Simulation results provided in terms of Pd for initial values of Pf show that the improved BSS spectrum sensing outperforms the detection performance achieved with the conventional RMT method.

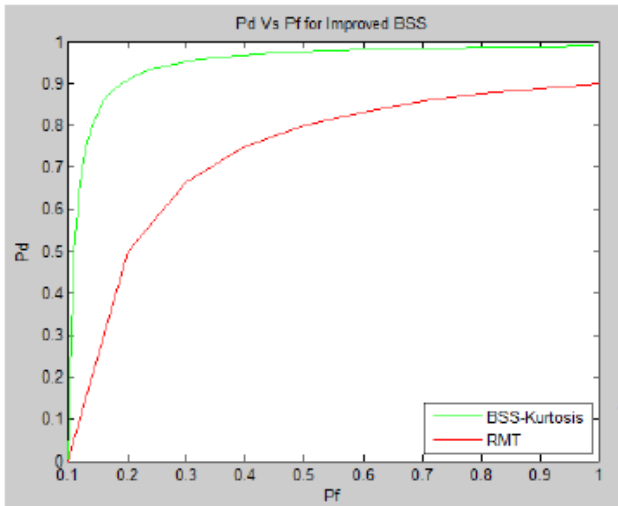


Fig 1. Obtained Pd Vs Pf curve for conventional method

The proposed algorithm includes improvements in the existing algorithm implemented and results show the comparisons of the output obtained. Below mentioned are the few limitations of the proposed algorithm. The minimum number of nodes or users for cooperative sensing in the proposed algorithm must be at least 2 while the minimum number of samples it can take is 20. The number of samples must be greater than the number of nodes. The number of users and samples when comparable provides higher efficiency in the proposed algorithm.

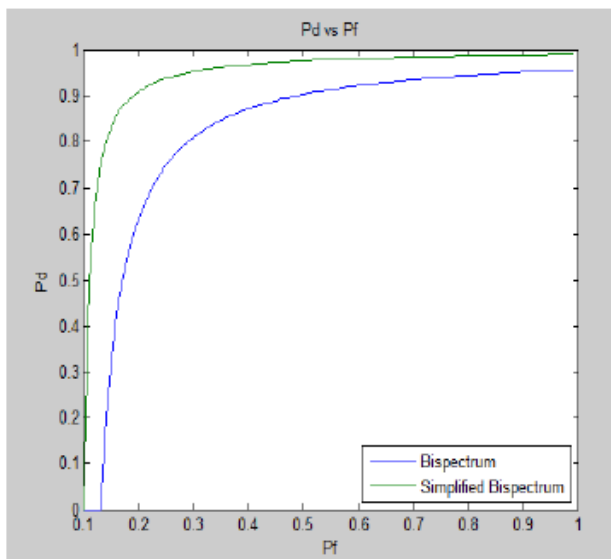


Fig 2. Comparison Curve of Pd Vs Pf for the BSS techniques

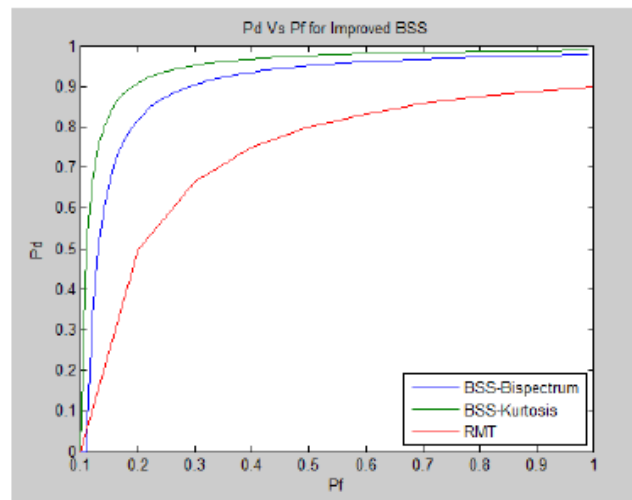


Fig 3. Comparison Pd Vs Pf curve for all the methods

The implemented algorithm [13] suggests applying Kurtosis on separated signals to improve the BSS spectrum sensing.

In probability theory and statistics, kurtosis is the fourth order standardized moment that describes the shape of the probability distribution of a random variable, defined as

$$\text{Kurtosis}(y_i) = \frac{E\{(y_i - \mu)^4\}}{\sigma^4} \quad (13)$$

where μ is the mean and σ is the standard deviation.

In the proposed algorithm, BSS has been improvised using the Bispectrum slide detection method [12], which is a third order complex-valued function, as stated above. Simulated results depict that Kurtosis metric based BSS has higher detection probability achieved than the proposed algorithm, for a particular value of Pf, but the two curves obtained in both the cases are comparable, thereby declaring the proposed algorithm to have reduced complexity as compared to higher order kurtosis.

Considering the input for random matrix as (50,100) at a constant value of Pf=0.3, Pd =0.95 when applying Kurtosis and Pd=0.9 when applied Bispectrum on BSS. For the proposed RMT, at Pf=0.3, Pd=0.65.

One of the limitations is that the Simplified Bispectrum analysis, which being of order two produces better detection probability than BSD, cannot be applied on the proposed algorithm due to assumptions considered for the input random matrix.

VI. CONCLUSION

In this paper, a new blind spectrum sensing method based on the Blind Source Separation technique is proposed. More precisely, we proposed a new spectrum sensing framework that uses the Bispectrum Slide detection method to calculate the detection probability of signals separated using blind source separation algorithms. This framework improves the spectrum sensing detection performance and reduces the computation complexity of high order statistical analysis, which is helpful for the practical implementation of algorithms. We have also proposed to perform spectrum sensing by combining our improvised Bispectrum-blind source separation technique when the cognitive transmitter is on with a new method to implement random matrix theory based on the High Order Statistical analysis when the cognitive transmitter is off in order to increase the net sensing efficiency. Simulation results provided in terms of receiver operating characteristic curves show that the Bispectrum-BSS spectrum sensing gives better detection performance when compared to conventional blind spectrum sensing methods.

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