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Cyclostationary Feature Detection Based Spectrum Sensing for Cognitive Radio Users in MIMO-OFDM-A Review

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ABSTRACT: *Spectrum sensing is an important part of cognitive radio systems to find spectrum hole for transmission which enables cognitive radio systems coexist with the authorized radio systems without harmful interference. The resource of radio frequency spectrum is not efficiently managed, and the increased dependence on wireless devices in the modern era just adds to the problem. The concept of cognitive radio aims to overcome the problem of limited radio frequency spectrum by helping to achieve improved spectral management, utilization, and efficiency. One of the ways to improve the efficiency and utilization of an available frequency spectrum is to share it between the users. One of the most important step for spectrum sharing is spectrum sensing. There are many spectrum sensing algorithms available for cognitive radio. This paper describes the Cyclostationary Detection based method of cognitive spectrum sensing along with other available sensing technique.*

KEYWORDS: Cognitive Radio, Cyclostationary Signal, Spectrum Sensing.

INTRODUCTION

Modern wireless systems are capable of offering a wide variety of high data-rate applications to various users at the same time. In order to realize this objective, they have to overcome the practical constraints imposed by the resources they need such as power and spectrum. But, these resources are limited in nature. The rapid increase in the number of wireless systems and the scarcity of these resources, especially of the frequency spectrum, continues to be a problem. Cognitive radio is a concept that aims to overcome these very problems by proposing an opportunistic spectrum usage approach, in which the frequency bands that are not being used by their licensed users can be utilized by cognitive radios. The basic function of a cognitive radio is to accurately sense the spectrum by evading any chances of obstruction or interference to the primary or licensed users. By using spectrum sensing, cognitive radios can adapt themselves to the external wireless network. The cognitive radio users can be divided into primary users (PU) and secondary users (SU). The users who has the license to use a specific band of the spectrum are known as the primary users and the secondary users (SU) do not have license to use the spectrum but can use the spectrum when the PU is absent .Three basic sensing technique are explained below.

SPECTRUM SENSING TECHNIQUES

Spectrum Sensing is a key aspect of cognitive radio (CR). The objective of cognitive radio is to utilize the empty channels in the spectrum to reduce the traffic in congested areas. Proper sensing of the spectrum is the integral part of this software defined radio. Also, communication should not be obstructed or hindered by fading. Spectrum sensing in cognitive radio is applicable to radio frequencies only. Observing the unused spectrum of a licensed user is crucial for the concept of cognitive radio to be a success. So, the primary user is sensed perpetually to allow channel mobility of SU to another part of the spectrum; in case the primary user initiates to transmit. This requires an efficient hardware with minimum possible error. The threshold for detection forms the crux. This should be in consideration of the interference in the worst-case scenario. Future spectrum analysis and decision-making processes are dependent on sensing the primary user correctly. This is defined as managing the spectrum dynamically.

There are various spectrum sensing techniques which are employed for spectrum sensing; such as:

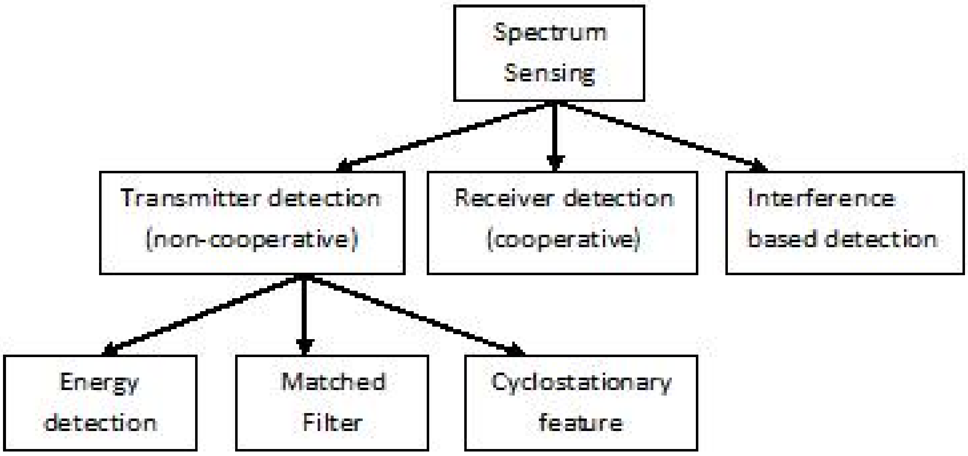

Figure 1: Various spectrum sensing techniques

MATCHED-FILTER DETECTION

The matched-filter (also known as coherent detector), can be considered as a best sensing technique if CR has prior knowledge of the PU. It is very accurate because it maximizes the received signal-to-noise ratio (SNR). Matched-filter correlates the received signal with its time shifted version. Comparison between the final output of the matched-filter and a pre-determined threshold will determine the presence of primary user. Hence, if this information is not accurate, then the matched-filter will operate weakly.

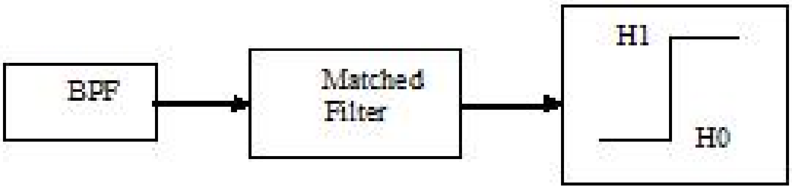

Figure 2: The Matched filter detector block diagram

H0 = Absence of user

H1 = Presence of user

CYCLOSTATIONARY FEATURE DETECTION

Implementation of a Cyclostationary feature detector is a spectrum sensing technique which can differentiate the modulated signal from the additive noise. A signal is said to be Cyclostationary if its mean and autocorrelation are a periodic function. Cyclostationary feature detection can distinguish PU signal from noise, and used at very low Signal to Noise Ratio (SNR) by using the information present in the PU signal that are not present in the noise.

ENERGY DETECTION

Energy detection is the most popular way of spectrum sensing because of its low computational and implementation complexities. The receivers do not need any previous knowledge about the primary users. An energy detector (ED) simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal.

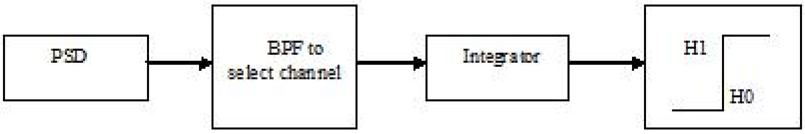

Figure 3: The Periodogram Energy detector block diagram.

H0 = Absence of user

H1 = Presence of user

CYCLOSTATIONARY DETECTION

Man-made signals are normally not stationary, but some of them are cyclostationary, i.e., they show periodicity in their statistics. This periodicity can be utilized for the detection of a random signal which has a particular modulation type in a background of noise. Such detection is called cyclostationary detection. The signal of the PU can be detected at very low SNR values if it exhibits strong cyclostationary properties. If the autocorrelation of a signal is a periodic function of time 't' with some period then such a signal is called cyclostationary and this cyclostationary detection is performed as follows:

$$Rx(\tau) = E[x(t+\tau) * x(t-\tau)e^{-j;\,\pi d}\,]$$

In eq. above, 'α' is cyclic frequency and E [.] is the statistical expectation operation. The spectral correlation function (SCF) denoted by S(f, α), also called the cyclic spectrum is obtained by computing the discrete Fourier transformation of the cyclic autocorrelation function (CAF).

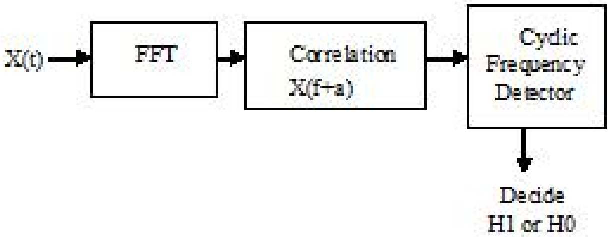

Figure 4: Cyclostationary detection

Detection is completed finally by searching for the unique cyclic frequency corresponding to the peak in the SCF plane. This approach is vigorous to interference and random noise from other modulated signals because different modulated signals have different unique cyclic frequencies, while noise has only a peak of SCF at zero cyclic frequency. The theoretical implementation of this method for spectrum sensing is shown in above figure.

The performance depends on the probabilities of detection. The probability of false alarm (P_{fa}) is defined as the probability that the detector declares the presence of PU, when the PU is actually absent. The probability of miss detection (P_m) is defined as the probability that the detector declares the absence of PU, when the PU is actually present. The probability of correct detection (P_d) and probability of false alarm (P_{fa}) for the frequency domain can be computed below:

$$P_d = \frac{1}{2} erfc\left[\frac{\lambda + P_n}{2\sqrt{2}\sqrt{\lambda + P_n}}\right]$$

$$P_{fa} = \frac{1}{2} erfc\left[\frac{\lambda - P_n}{2\sqrt{2}\sqrt{\lambda + P_n}}\right]$$

'λ' represents the threshold of the system and 'Pn' represents the power of the noise generated by the AWGN channel and erfc(x) returns the Complementary Error Function evaluated for each element of x. The probability of miss detection (Pm) can be calculated by subtracting the probability of correct detection from a probability 100% as shown in equation.

$$P_m=1-P_d$$

LITERATURE REVIEW

In the cognitive radio for the effective spectrum utilization the most critical task is that the spectrum sensing. Many articles are studied revealed on spectrum sensing up to now. In [1], gives the survey about local spectrum sensing methods. Problem associated with energy detection, matched filter. Also the hard and soft combination rules for the cooperative spectrum sensing are given. A hidden node problem and spectrum allocation and its sharing after its detection stated.

A Simulation and analysis of cognitive radio in MATLAB projected in [2]. During this the Energy detection method of spectrum sensing is used. The periodogram MATLAB functions used to compute the Energy of the received signal for its detection. In the low SNR the performance of the system degrades as the amplitude is does below threshold.

In [3] use the Matched filter method for the spectrum detection. In which known primary signal is correlated with the data received at the secondary user. This method has drawback that it require primary user information for its detection. The primary User can’t detected if its information not known.

In [4] projected the Cyclostationary methodology in the Simulink. The use the FFT and auto Correlation for the User detection and the computed sum of the Autocorrelation is compare with the constant for user detection. It does not have cyclic autocorrelation computation so the performance degrades in low SNR.

In [5] proposed comparison of the spectrum sensing methods with the performance matrix. The Probability of Detection is should be high for the good system performance and the probability of false alarm should be low. The Energy detection has low Probability of detection due to noise power consideration as compare to other methods.

In [6] proposed Cyclostationary Spectrum Sensing method. This method use the cyclic property of the received signal as all the First User signals are modulated by Carrier. The Mean and autocorrelation property are used for the User detection. Also the synchronization does not require which overcome match filter spectrum sensing drawback. Also this method correctly identify primary user signal due to the noise rejection ability.

In [7], we evaluate the performance of the MIMO-OFDM cognitive radio (CR) system where CR devices continuously sense the channel to check whether it is idle or not using compressed sensing with cyclostationary detection, and reconstruct the signal if communication is for the given CR receiver from its transmitter. We use the probability of misdetection and probability of false alarm as metrics to evaluate the spectrum sensing, and mean square error and successful reconstruction rate as metrics to evaluate the reconstruction of the signal for CR communications. Simulation results show that the proposed method outperforms the existing method.

In [8] author focuses on improving the detection performance of spectrum sensing in cognitive radio (CR) networks under complicated electromagnetic environment. In this paper, an algorithm based on the cyclostationary feature detection and theory of Hilbert transformation is proposed. Comparing with the conventional cyclostationary feature detection algorithm, this approach is more flexible i.e. it can flexibly change the computational complexity according to current electromagnetic environment by changing its sampling times and the step size of cyclic frequency. Results of simulation indicate that this approach can flexibly detect the feature of received signal and provide satisfactory detection performance compared to existing approaches in low Signal-to-noise Ratio (SNR) situations.

In [9], three types of self-coherent restoral (SCORE) algorithms are LS-SCORE, auto-SCORE and cross-SCORE, which are based on adapting the array. For maximize the degree of cyclostationary at a particular frequency and time lag of the output signal. The main advantage of SCORE algorithms over the conventional methods is that the only necessary parameters for these algorithms are the cycle frequencies of the desired signals. A cycle frequency is calculated from a carrier frequency or a baud rate. The cross-SCORE can achieve better results over the LS-SCORE, both in terms of the maximum signal to-interference-and-noise ratio (SINR) and the convergence rate, at the cost of the computational complexity. The SCORE algorithms have been use for generalized received data [10].

If the cycle frequency is not available in some applications then it can be estimated directly from the received data. A method for estimating the cycle frequency by using array direction finding and spatial filtering has been presented in [11].

Group of simulation examples in [12] have shown that their cyclic adaptive beamforming (CAB) algorithm is comparable in performance to the cross SCORE algorithm. But for fast implementation of CAB algorithm requires a computational complexity of O(n) complex multiplications, where n is the number of array elements. Two more complicated CAB-based algorithms are constrained CAB (C-CAB) and the robust CAB (RCAB), have been proposed [13].The CAB algorithm been used to track a moving speech source in [13]. By using matrix factorization in conjunction with power normalization scheme in the LS-SCORE and cross-SCORE algorithms have been reformulated. And a new algorithm has based on the Gram–Schmidt orthogonalization (GSO) technique [12]. The GSO algorithm achieve a computational complexity of O(n2) complex multiplications, further it can be reduced by a pipeline implementation of the GSO process. A simple and fast cyclostationary beamforming algorithm has been proposed in [13].

The gradient-descent based adaptive beamforming algorithm proposed in [14] is based on the property of cyclostationary signals, which is generated spectral line by using a particular class of nonlinear transformations. The beamforming weight is calculated by mean square error between the array output after the nonlinearity and a complex exponential at a specified frequency. As a gradient based algorithm, the determination of the step size is also a difficult. By maximizing the cyclic autocorrelation of the output signal under the constraints of maximum gain in the direction of the desired signal and nulls in the directions of the interfering signals, a cyclostationary beamforming algorithm has been proposed in [15].

However, a direction finding procedure is needed for the algorithm. In [16], a gradient-based algorithm with a computational complexity of O(n) complex multiplications has been proposed by maximizing the self-coherent coef¿cient of the output under the constraint of a normalized beamforming weight. Develop a strategy for selection of step size, which has also been given.

In [17], a SCORE-like beamformer has been developed for AMPS communication systems. In the presence of a mismatch in the cycle frequency of the desired signal due to Doppler shift or carrier frequency offset. Existing cyclostationary beamforming algorithms suffer from severe performance degradation .Robust algorithms estimating the true cycle frequency of the desired signal in conjunction with the SCORE algorithms.

To increase the robustness of the LS-SCORE for small cycle frequency error use windowing version of the LS-SCORE it given in [18]. Buy using time-domain windowing it help for mitigate the error of the estimate. Robust schemes based on the CAB algorithm are given in [18].

In [19] the popular cyclostationary beam formers which has two algorithms namely the adaptive cross self-coherent- restoral (ACS) and cyclic adaptive beam forming (CAB), algorithms that provide good performance in the case of medium or weak interference. The CAB algorithm is a special case of the least-square self-coherent restoral (LS-SCORE) algorithm. The proposed adaptive algorithm is to implement which is very promising for applications in wireless and mobile communications.

In[20] the authors reviews all the existing techniques and according to his cyclostationary feature based detection is best suitable technique for spectrum sensing because it optimizes all the parameters.

RESULT AND DISCUSSIONS:

The previous mentioned techniques of spectrum sensing have been implemented to a given primary user signal with operating frequency of 200 Hz and sampling frequency 4KHz using two different types of modulation BPSK and QPSK. The channel model was assumed to be single path Rayleigh fading only change

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in amplitude and also AWGN Noise with zero mean and varied variance according to a range of SNR values under test from -20dB to 20dB. The constellation diagram of the primary signal under 20dB for both BPSK and QPSK are shown in below.

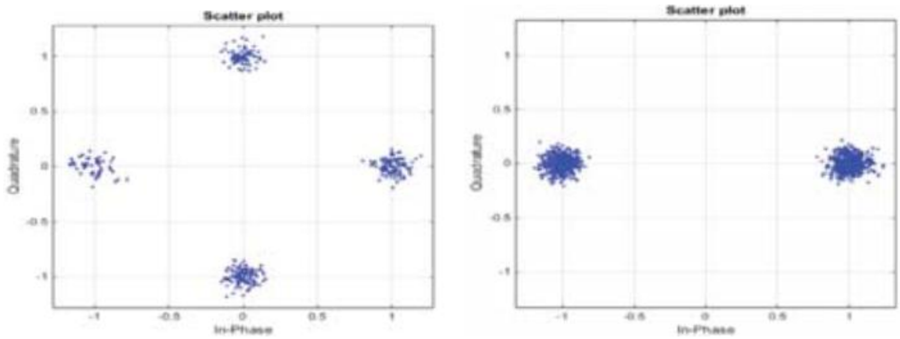

Figure 5: BPSK and QPSK Constellation for primary user signal.

The Periodogram Energy detector detect a primary signal at 20KHz under good SNR values in BPSK while it cannot be identify the primary signal under low SNR values. The same results are found in QPSK also.

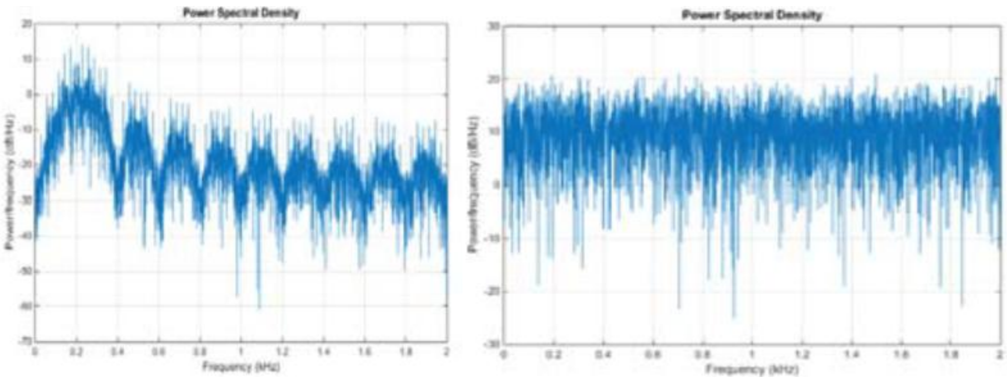

Figure 6: Matched filter detector output.

Now the second technique that is matched filter method with works for good SNR values. The third technique that is cyclostationary detection gives best results but it is complex technique. It gives peak output at the center and double the frequency of primary user signal at 400KHz under the SNR (20dB) for BPSK while two peaks occurs in the QPSK modulation .This has been shown in below.

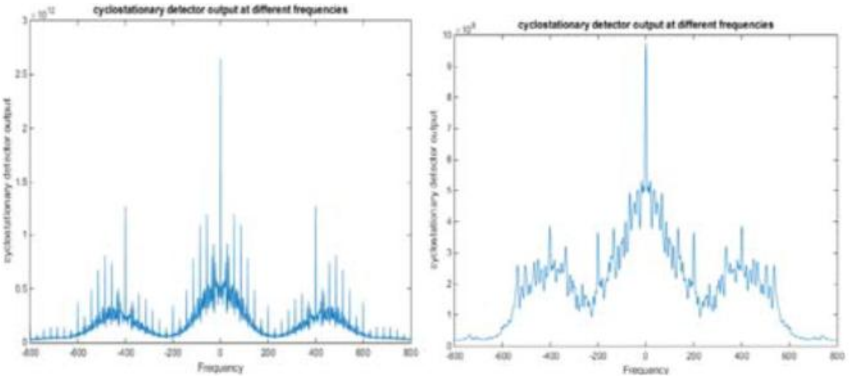

Figure 7: Cyclostationary detector output for good SNR values.

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But drawback of this technique is that it cannot differentiate the primary user signal for low SNR (-20dB) for both BPSK and QPSK. This is shown in below figure.

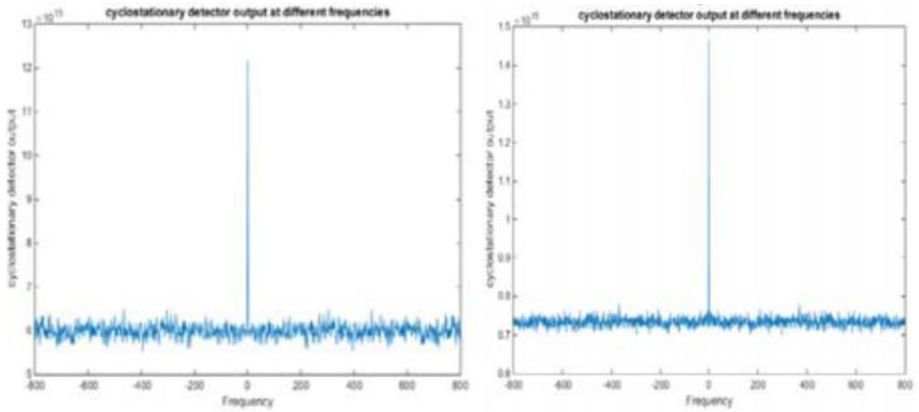

Figure 8: Cyclostationary detector output for low SNR values.

The sensing time is the time taken by CR user to detect the presence of primary user signal. This time is proportional to the number of samples used by detector. Less sensing time is preferable because it provides more time for transmission to CR user. The quantitative analysis for sensing time is given as follows when different detection methods are used.

Table:1 Sensing time for different sensing techniques

Modulation Technique	Energy Detection	Matched Filter	Cyclostationary Detection
BPSK(N=1260)	0.375	0.078	1.25
QPSK(N=540)	0.188	0.062	0.73

N denotes number of samples

CONCLUSION:

In this paper different sensing techniques have been implemented and their detection performance was tested under different SNR values by researchers working in this field. The well-known sensing techniques energy detection has low computational and implementation complexities and does not required any knowledge about the primary user signal but its accuracy depends on the SNR and number of samples which effect the sensing time. To improve the performance of energy detector improved energy detector is used which requires less number of samples for giving same performance. The performance of matched filter is optimum if primary user signal is known to the receiver side. It has high detection accuracy with less sensing time but drawback of this technique is that it has complexity in implementation of local carrier at receiver side. cyclostationary feature detection is computationally complex with more sensing time but it performs well under lower SNR values with probability of feeling under a strong channel fading conditions.

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