Analysis of Cyclostationary CR Detector for OFDM signals

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Abstract:-

The cyclostationary based spectrum sensing algorithm is especially suitable for detection of orthogonal frequency division multiplexing (OFDM) signals that exhibit strong periodic correlation due to insertion of cyclic prefix between OFDM blocks. Normally, the cyclic prefix is used to remove the Intersymbol interference (ISI) and intercarrier interference (ICI) of the OFDM signal and so it eliminates a need for complex equalizer.

In this paper, simulation results demonstrate the normalized spectrum correlation function of the primary OFDM signal used in cognitive radio systems with different values of cyclic frequency. Two techniques are assumed to be used as PAPR reduction of OFDM transmitted signal. The results show that only one of them has no apparent effect on the correlation performance of the cyclostationary detector. Finally, it is found that a reduction of 30% in the implementation complexity can be taken by suitable choice of detector cyclic frequency.

Keywords:- OFDM, Cognitive Radio, Cyclostationary Detection, Dynamic Spectrum Sensing.

الخلاصــة:-

تعتبر خوارزميــة تحسس نطاق الترددات بالاعتماد على تقنية (cyclostationary) الأكثر ملائمة لكشف إشارات (OFDM) والتي تؤمن خاصية ارتباط متكرر عالية بسبب إدخال بادئة دورية بين رموزها. عادة، البادئة الدوريـة تستعمل للتخلص من التداخل البيني للرموز و الترددات الحاملة والذي يعني عدم الحاجة لاستخدام المصحح المعقد. في هذا البحث، نتائج محاكاة بالحاسبة لدالة ارتباط النطاق الترددي لإشارة (OFDM) للمنظومة الراديوية الإدراكية. تم افتراض تقنيتين لتقليل (PAPR) لتلك الإشارة. أثبتت النتائج أن أحد تلك التقنيات داعمة لخواص الارتباط لهذا الكاشف. أخيرا، تم الحصول من خلال البحث على تقليل مانسبته (30%) من تعقيد بناء الكاشف عمليا عن طريق الاختيار المناسب للتردد الدوري للكاشف المعتمد في هذا البحث.

I. Introduction:

The policy of spectrum licensing and its utilization lead to static and inefficient usage of this spectrum and so it has become essential to introduce new licensing policies to enable dynamic and open way of utilizing the available spectrum efficiently. Recent studies on radio spectrum usage have given birth two concepts: Dynamic Spectrum Access (DSA) and Cognitive Radio (CR) [1]. One of the most suitable techniques to guarantee a dynamic spectral occupancy of the transmitted signal (licensed signal) is the Orthogonal Frequency Division Multiplexing (OFDM) technique . On the other hand, Cognitive radio allows unlicensed users (secondary users) to access licensed frequency bands to reduce spectrum scarcity. Even after the beginning of the transmission, the bands must be continuously checked for any primary user entering to transmit in these bands. If so the secondary users should vacate the bands as quickly as possible and go on to some other empty frequency spectrum [1,2].

A number of schemes have been developed for detecting the presence of primary user in a certain frequency band. Energy detector and matched filter type are examples of such schemes. The first functions properly for high signal to noise ratio while the second complexity is very high. These constrains led to implement a detector which performed well under low signal to noise ratio and with complexity not as high as the matched filter detector. Such type is called cyclosationary detector. This detector is merely a Fourier transform of the correlated received signal and results in peaks at frequencies which are specific to the signal. The searching for these peaks helps in determining the presence of primary user [3, 4].

The rest of the paper is organized as follows; section II describes briefly the mathematical analysis of the cyclostationary detection for OFDM signal and discusses the challenges oppose the implementation of such detector. Section III presents computer simulation tests to show the correlation performance in the presence of techniques used to reduce the peak to average power ratio (PAPR) of the OFDM signal. This section includes also the hardware complexity to implement this detector. Finally, the paper is concluded in section IV.

II. Cyclostationary Detection of OFDM Signal

A. Mathematical Analysis

The mathematical development for cyclostationary analysis is based on Gardner's work [5] and it may be derived as:-

A complex random process $x(t)$ is said to be cyclostationary in wide-sense, if its mean ($E\{x\}$) and autocorrelation (R_x) in time domain are periodic:-

$$E\{X(t+T)\} = E\{X(t)\}$$

$$R_X(t+T,\tau) = R_X(t,\tau) \quad (1)$$

where $R_X(t,\tau) = E\{x(t+T)x(t)\}$

Due to periodicity of autocorrelation, it can be expanded using Fourier series as:-

$$R_x(t+T,\tau) = \sum_{\frac{n}{T}} R_x^{\frac{n}{T}}(\tau) e^{j2\pi\frac{n}{T}t} \quad (2)$$

where $\frac{n}{T}$ represents the cyclic frequency and can be written as α. The coefficients ($R_x^{\alpha}(\tau)$) represent a function, which may be called the Cyclic Autocorrelation Function (CAF), which may be represented by;

$$R_x^{\alpha}(\tau) = \lim_{T\to\infty} \int_{-T/2}^{T/2} R_x(t+T,\tau) e^{-j2\pi\alpha t}\, dt \quad (3)$$

The cyclic Wiener relation states that the Spectrum Correlation Function (SCF) is then calculated using the Fourier transform of the cyclic autocorrelation function and its maximum value is directly proportional to the probability of detection and inversely proportional to the probability of false alarm [6]:-

$$S(f,\alpha) = \int_{\tau=-\infty}^{\infty} R_x^{\alpha}(\tau) e^{-2\pi f\tau} d\tau \quad (4)$$

In this work, the primary signal ($x(t)$) is an OFDM signal, which may be represented as a composite N statistically independent QAM signal [7];

$$x(t) = \sum_k \sum_{n=0}^{N-1} \gamma_n e^{j\left(\left(\frac{2\pi}{T_S}\right)nt\right)} q(t-kT) \quad (5)$$

Where γ_{nk} is a complex sequence corresponds to a rectangular QAM signal point space, $q(t)$ represents a rectangular shaping pulse of duration T and T_s is a source symbol length.

The detection process based on the spectrum correlation function (Eq.4) may be implemented in three steps using the block diagram shown in (Fig.1) [6]:-

- The signal of interest is shifted by $\frac{\alpha}{2}$ and $\frac{-\alpha}{2}$.
- The shifted signals are multiplied after passing through sliding windows, where the symbol (*) represents the complex conjugate.
- Spectrum Correlation Function (SCF) is found by taking the Fourier transform of the multiplied signals .

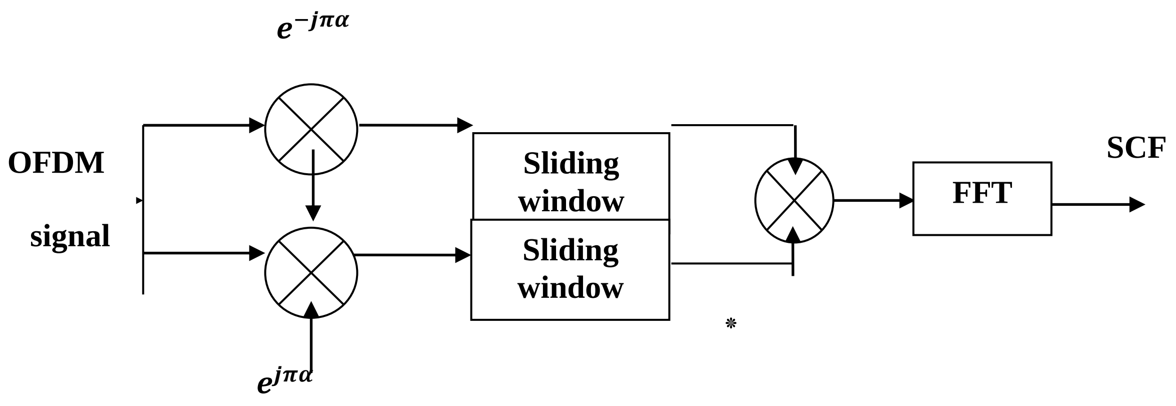


Fig.1 Block diagram of cyclostationary detector

B. Detection Challenges

However, there are two main challenges for using the cyclostationary detector in the OFDM systems. These challenges are [8-10]:-

- The first challenge is appeared due to the property of the IFFT used at the transmitter of the OFDM system, which is a high peak to average power ratio (PAPR) of the transmitted signal. This causing subcarrier intermodulation and undesired out- off band radiation. Such two drawbacks lead to inefficient amplification and a need to an expensive power amplifier. So it is important to use techniques to reduce the PAPR. These techniques may in turn reduce the correlation characteristics of the detector. [11] suggests a simple technique to reduce this ratio by mapping the QPSK symbols at the input of the IFFT of the transmitter with a certain formula. The results included in [11] show that the bit error rate performance is better than that of the conventional clipping PAPR technique. [12] proposed a tone reservation technique (operates with large number of subcarriers) reduces the ratio by a factor of nearly 5 dB. However the complexity is the main drawback of the technique proposed in [12], especially if large number of iterations are needed.
- The second challenge is merely the implementation complexity (number of arithmetic operations) of the cyclostationary detector. Many literatures analyze such issue, for example, problems of cycle leakage, aliasing and cycle phasing had been disused in [5]. In literature [13], the implementation is done mostly in angular domain to avoid complex operation (multiplication and addition/ subtraction). Finally, the signal is mapped back to Cartesian coordinates.

III. Computer Simulation tests

A. Detector performance

To examine the performance of the cyclostaionary detector (Fig,1), computer simulation tests have been carried out using Matlab software. In these tests, the signal to noise ratio is equal to -20 dB and $N = 32$. A sliding window of 32-width Hamming window is used, Firstly, the maximum normalized SCF of the envelop OFDM signal is plotted with different values of cyclic frequency (α). Such plot is shown in Fig.2.

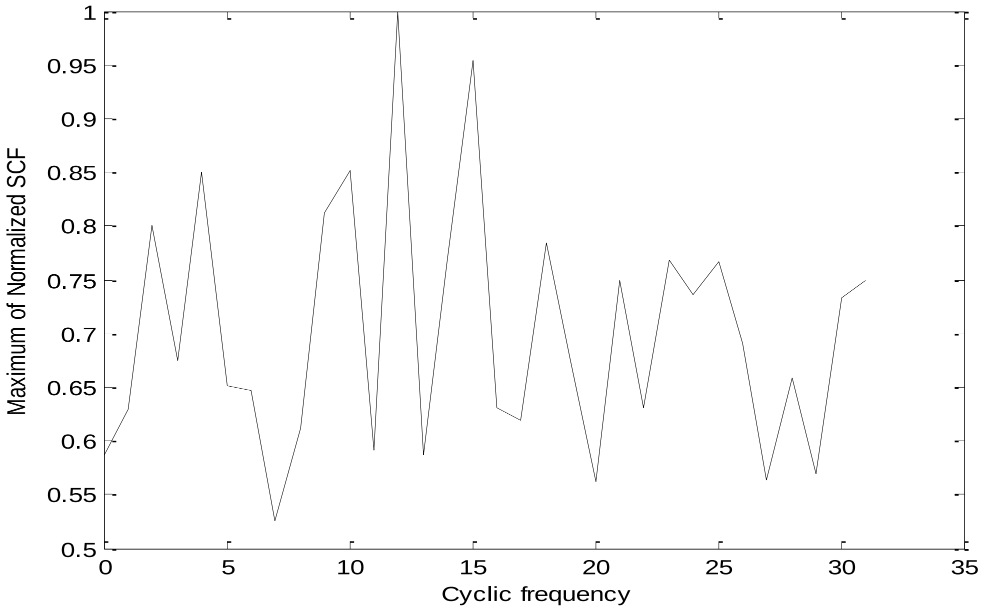


Fig.2 The maximum of SCF for different values of cyclic frequency

For $N = 32$, Fig.2 shows that the normalized spectrum correlation function has its maximum value at cyclic frequency of 12 ($\alpha = (\frac{12}{32}T)$). According to this value, Fig.3 shows the ability for such detector to know the existence of primary OFDM signal with high probability of detection and low probability of false alarm (due to clear maximum value of SCF in this figure).

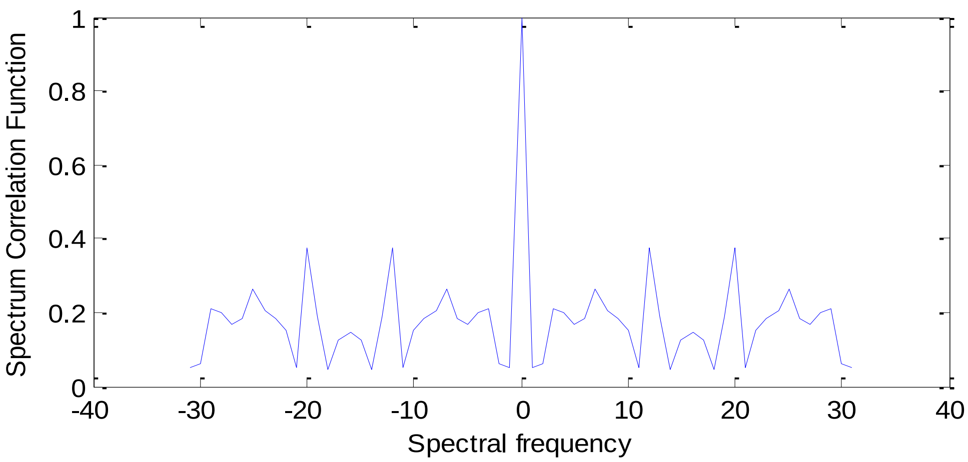
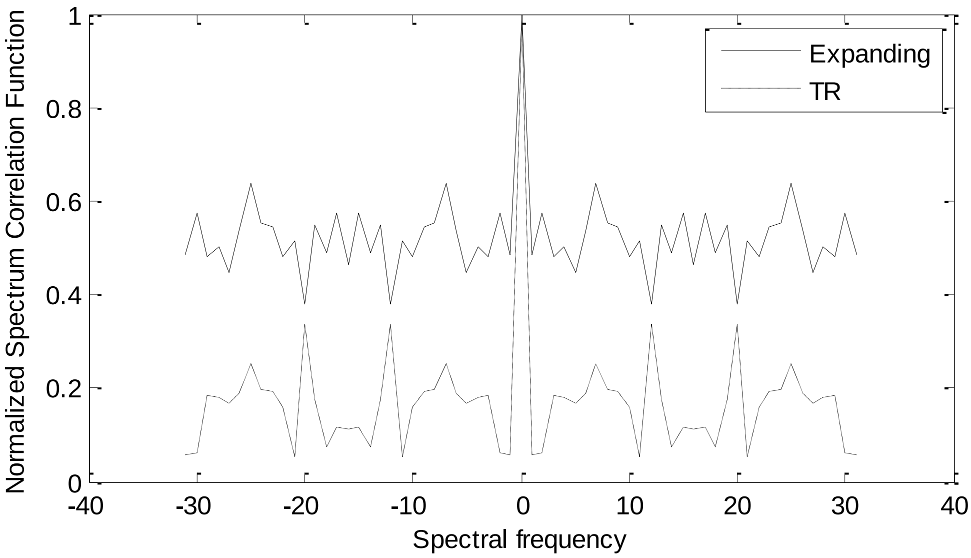


Fig.3 The normalized SCF of cyclostationary detector for OFDM signal

Extra tests shows that the correlation characteristics of the cyclostationary detector may affected when PAPR reduction techniques are used at the transmitter side of the OFDM system (first challenge in section II-B) . In these tests, symbol expanding technique [11] and tone reservation algorithm [12] are used. For an OFDM system with first technique, a reduction in the spectral correlation magnitude for the envelop of the OFDM signal is shown in Fig.4. This reduction makes the detection more difficult. In the other hand, the use of parallel search tone reservation method with memorized values enhances the cyclostationary features. It is clearly appears in Fig.4 that the difference between the maximum and the other values of the spectrum correlation function (SCF) in the tone reservation technique is higher than that of the symbol expanding technique. This means that an OFDM signal with tone reservation technique has better probability of detection and probability of false alarm than that of a same signal with symbol expanding technique.



Further tests are used to estimate the complexity of the cyclostationary detector (Fig.1). The complexity is calculated in terms of the number of addition/subtraction and multiplication operations of the detector algorithm. Table.1 shows the result of these tests with different values of OFDM symbols.

Table.1 The complexity of the cyclostationary detector for different values of OFDM symbols

	OFDM blocks	addition/subtraction	multiplication
1	16	96	204
2	32	192	396
3	64	384	780
4	128	768	1548
5	265	1536	3084
6	512	3072	6156

C. Proposed detector

As expected, Table.1 shows that the complexity of traditional cyclostationary detector is proportional with the number of OFDM symbols. To reduce the detector complexity, this paper suggests an algorithm to implement the cyclostationay detector. This algorithm is mainly based on the reduction of the number of the multiplication and addition / subtraction operations by choosing two suitable values of cyclic frequencies ($\alpha 1$ and $\alpha 2$). These values are used with the exponent function in the upper and the lower arms of the detector shown in Fig.1. As a result, the real or the imaginary parts of the exponent function is equal to zero or constant, so there is no need to more mathematical operations to implement such function. This idea behind this algorithm may be explained by the following two steps:-

- Step 1: for a certain value of N, the cyclic frequency (α) is chosen such that the SCF is maximum.
- Step 2: the values of $\alpha 1$ and $\alpha 2$ are calculated such that the sum of these values is equal to α and the real and imaginary parts of ($e^{j2\pi\alpha 1}$) and ($e^{j2\pi\alpha 2}$) are equal to zero or constant value.

Therefore, the complexity of the proposed detector is then calculated in terms of the number of mathematical operations for different values of OFDM symbols as tabulated in Table.2:-

Table.2 The complexity of the proposed detector for different values of OFDM symbols			
	OFDM blocks	**addition/subtraction**	**multiplication**
1	**16**	**80**	**134**
2	**32**	**160**	**262**
3	**64**	**320**	**518**
4	**128**	**640**	**1030**
5	**265**	**1280**	**2054**
6	**512**	**2560**	**4102**

Finally, the estimated behavior of the traditional and the proposed detectors under multipath propagation is shown in Fig.5. Such behavior is represented by the probability of missed detection for different values of received signal to noise ratio. In this test, the received multipath signal is assumed to be a sum of the received signal with its delayed and attenuated version. The values of attenuation factor and normalized delay are assumed to have 0.75 and 15 respectively. The figure shows that the behavior of the traditional detector is better than that of the proposed detector (nearly 0.5 dB difference at probability of 10^{-4}) as a result of unbalanced values of cyclic frequencies used in the proposed detector.

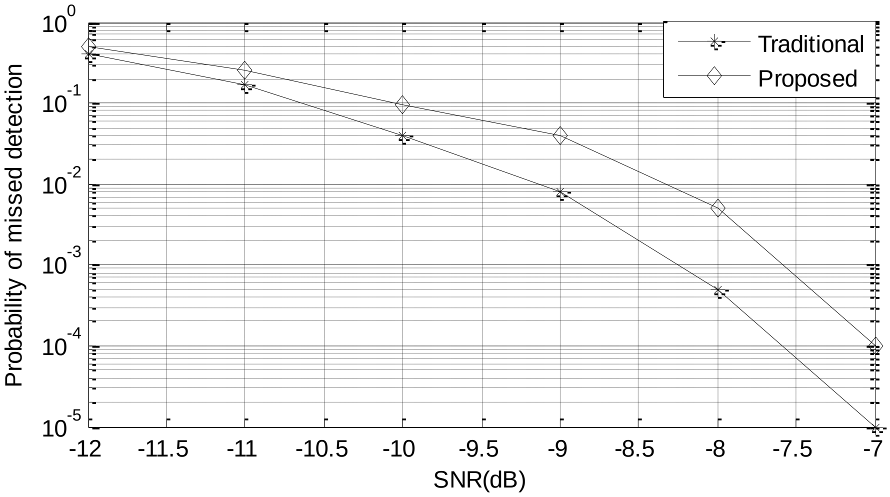


Fig.5 The behavior of the two detectors under multipath propagation conditions.

IV. Conclusion

Based on the correlation characteristics of the cyclostationary detection, this paper proves its ability to detect the OFDM primary signal. The results show the simplicity in the detection when a proposed tone reservation technique is used for reduction the PAPR of the OFDM signal. This work proposes also a method to reduce the complexity of cyclostationary detector in terms of number of arithmetic operations needed for hardware implementation. Further tests show that such hardware complexity reduction has an effect on the behavior of the proposed detector.

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