International Journal of Recent Trends in Engineering & Research
ISSN (ONLINE) : 2455 – 1457
IMPACT FACTOR : 4.101
ICNSCET19- International Conference on New Scientific Creations in Engineering and Technology

Improved Cyclostationary Detection based Spectrum Sensing Technique in Cognitive Radio Networks

A. Narendra Kumar[1], R.Karthipan[2]
Professor[1], Assistant Professor[2]
ECE Department[1], EEE Department[2]
VV College of Engineering, Tisaiyanvilai.

Abstract—Cognitive Radio (CR) is an intelligent device which is aware of the environment and its changes, can automatically detect available channels in a wireless spectrum. CR has been used to limit natural resourses efficiently without any interference to Primary Users (PUs), and can coexist with licensed user. Reliable detection of Primary Users in the presence of noise is a crucial problem in Cognitive Radio Networks (CRN). To address the above issue, spectrum sensing based on Cyclostationary Feature Detection (CFD) is proposed, which can robustly detect hidden primary signals even in low Signal to Noise Ratio (SNR). Here, CFD method is used to investigate the problem of detecting vacant spectral bands. Probability of detection is more precise in CFD which accurately detects the presence of an active primary user by computing the Spectral Correlation Function (SCF) which applies only to the cyclostationary processes, whereas stationary processes do not exhibit spectral correlation density. In this regards, the parameters, such as the Probability of detection, Probability of false alarm and the Signal to Noise ratio (SNR) are used to find the vacant frequency bands. Thus this method is more reliable than traditional energy detection scheme, as CFD can perfectly distinguish primary user signal from noise, and can perform efficiently even in low SNR region and also in fading environments.

Keywords—Cognitive Radio (CR), Cyclostationary Feature Detection (CFD), Spectrum Sensing, Cyclic Autocorrelation Function (CAF), Spectral Correlation Function (SCF).

I.INTRODUCTION

The range of frequency bands are underutilized more often than not, as per the overview discharged by the Federal Communications Commission (FCC). The underutilization or the groups of frequencies which are not utilized by the essential user at a specific time and at specific land area are called spectrum holes. Spectrum usage can be enhanced by making it feasible for a Secondary user to get to a frequency gap abandoned by the Primary User at the correct area and the time. The ordinary method for spectrum detecting is estimating energy of radio recurrence range over a wide band of intrigue. In intellectual radio working spectrum detecting includes estimating energy in different measurements like time, space, recurrence and code. It additionally attempts to distinguish kinds of signal involving the spectrum, for example, adjustment, data transfer capacity, and transporter recurrence.

Cognitive Radio (CR) was proposed to help reduce tight supplies of spectrum by identifying spectrum holes in the radio condition. In light of the CR framework, the Secondary Users (SU) are permitted to get to spectrum progressively without meddling to the Primary Users (PU). The cognitive radios must most likely effectively identify the essential users even in low Signal to Noise Ratio (SNR). These challenges can be overwhelmed by exploiting the cyclostationary marks shown by correspondences signal. Cyclostationary marks are implanted in the physical properties of correspondences signal and they can be utilized to recognize the essential user and optional user [1].

An extensive depiction of the CR organize engineering that tends to the dynamic range difficulties is fundamental for the improvement of correspondence conventions. The engineering of the CR system can be delegated two gatherings, the essential system and the CR network. The Primary network (or authorized system) is alluded to as a current system where the Primary users have a permit to work in a specific recurrence band. Essential user exercises are controlled through essential base stations if essential systems have a framework. The CR network (additionally called the optional system or unlicensed system) does not have a permit to work in an ideal band. Thus, extra usefulness is required for to share the authorized frequency band for the CR users. CR systems give single-bounce association with CR users when it is furnished with CR base stations. At long last, CR systems may incorporate frequency intermediaries for conveying the range assets among various CR systems.

Spectrum sensing is the major task in cognitive cycle and the major threat to the CRs. In spectrum sensing, scanning the spectrum and finding the unused bands and sharing it while avoiding the spectrum that is occupied by PU. It can be defined as “action of a radio measuring signal feature”. The important requirement of the CRN is to sense spectrum holes. The most efficient way to detect spectrum holes is to detect the Primary Users. Spectrum detecting gives us the prompt inhabitance of the frequency. By knowing which part of the range is unoccupied, we can utilize it to acknowledge deft range, get to while keeping away from the involved range to avoid meddling with the essential users. Since the radio condition can change whenever it is necessitated that the frequency be detected occasionally with the goal that the optional users can back off from utilizing the frequencies involved by the essential users. Spectrum or range detecting increments unearthly proficiency in this manner expanding framework throughput

Spectrum sensing is the main task upon which the entire operation of cognitive radio works. We must be able to detect precisely the spectrum holes at the link level (that is certain frequency bands are not used for transmission at certain times) to allow reliable operation of cognitive radios, which gives spectrum sensing a critical role. In practice, to find the Spectrum Holes (SHs), which is defined as the spectrum bands, the unlicensed users, also called Secondary Users (SUs), need to continuously monitor the activities of the licensed users, also called Primary Users (PUs), without interfering with the PUs.

This paper enlightens the importance of Spectrum sensing in Cognitive Radio Network. Cyclostationary Feature Detection (CFD) method is used to investigate the problem of detecting vacant spectral bands. Probability of detection is more precise in CFD which accurately detects the presence of an active primary user by computing the Spectral Correlation Function (SCF) which applies only to the cyclostationary processes, whereas stationary processes do not exhibit spectral correlation density. In this regards, the parameters, such as the Probability of detection is increased and Probability of false alarm is reduced to find unused spectrum bands. It is shown that the proposed method has reliable performance even in low SNR region and also in fading environments. The contributions of this paper are categorized as follows:

1. CFD method detects the unused spectrum without interference to other users.
2. It achieves increase in Probability of detection and Signal to Noise ratio (SNR).
3. This approach reduces the Probability of false alarm.

The rest of this paper is presented as follows. Section II summarizes the related work. Section III describes the system model. Section IV elaborates the flow chart for the proposed method. Section V analyzes the simulation performance of the proposed method. Finally, this paper is concluded in Section

I. RELATED WORKS

Cyclostationary Feature Detector (CFD) includes finding the quick Fourier change, connecting, averaging and highlight recognition. Last yield of the CFD is the evaluated Cyclic Spectral Correlation Function (SCF), which is utilized to identify the signal, which is then demodulated before it achieves the essential user's beneficiary. The cyclic SCF contains a top peak in the middle of the signal if there is an essential PU in the range. Without any essential PU the cyclic SCF won't have any pinnacle. The signal from an essential PU is tweaked and afterward handed-off by various subjective transfers and the information is sent to the combination focus. The transferring strategy includes intensifying and forward handing-off. At the fusion center AND principle is utilized which recognizes the essential user motion as well as distinguishes the adjustment conspiracy utilized by the essential Primary user (PU)

frequency detecting in psychological radio systems, the first arrange comprises of different energy indicators, where every energy detector has a solitary receiving antenna with fixed edge for settling on a neighborhood twofold choice. The second stage involved ED with versatile twofold limit.. A traditional ED has less exactness. In this technique [4], the territories of the fundamental authorities are not known to the CRs as there is no motioning between the PUs and the CRs. It gathers the test measurement and contrasts it and an edge to choose whether the PU signal is available or missing. It give more exactness than various adjustment conspire [2].

A cooperative spectrum sensing based on asymptotic properties of cyclic autocorrelation estimates helps in identifying the frequency band. The cyclic frequency of the received signal is estimated and a decision of identifying the primary user is found at the fusion centre based on CAF [7]. The soft decision for several secondary user’s are combined at the fusion centre. The accuracy is more as compared to the cyclic correlation significance test method [9], which consist values for each samples signal. The energy value is compared with threshold. The minimum SNR is that the smallest amplitude needed to rewrite the received signals.10 dB SNR value and the false alarm probability of 0.01 is considered for hundred samples from the simulated signalling to calculate their energy.

An algorithm proposed by Paulo Urriza et al., (2013) for multiple antennas which can be classified into two categories [10]. To do this the total of the unearthly connection test measurement evaluated separately from every receiving antenna and to aggregate the crude examples from every reception apparatus and afterward play out a single spectral correlation test. In both the classifications a gauge of the relative stage contrast between every radio antenna is determined by finding both the cyclic connection of one reception apparatus picked as reference and the cross cyclic relationship of each other recieving antenna and the reference radio antenna. Dazzle channel estimation is accomplished by taking the vector comparing to the most astounding solitary estimation of a gauge of the channel. Cyclic connection test is then performed on the joined examples measure. This discovery strategy dependent on the eigen estimations of the cyclic covariance grid of got signs. Specifically, the cyclic relationship significance test is utilized to recognize a specific signal of enthusiasm by exploiting information of its cyclic frequencies.

An execution assessment of straight mix based agreeable cyclostationary specctrum detecting when both detecting and detailing joins are described as autonomous. A delicate choice combination rule for performing Cooperative Cyclostationary Spectrum Sensing (CCSS) in Cognitive Radio Network (CRN) is detailed [8]. CCSS plot significantly improves the auxiliary system execution as far as worldwide recognition likelihood metric, when contrasted with the generally utilized equivalent addition joining technique in which each SU is accepted to transmit its delicate choice measurement to the FC, which settles on a final choice by direct weighted mix. The False Alarm (FA).An execution assessment conspire through the probabilities of discovery and false alert is explored [14]. The likelihood of identification is found by finding the connection work. The example estimate is significantly decreased by the proposed plan contrasted with energy locator under a similar identification execution [4], where the example measure is diminished to about 65%. The entropy of the deliberate signal is assessed in the recurrence area with the likelihood space apportioned into fixed measurements.

III. SYSTEM MODEL

Cyclostationary Feature Detection (CFD) exploits the periodicity in the got essential signal to distinguish the nearness of PU. The periodicity is normally implanted in sinusoidal carriers, beat trains, spreading code, bouncing groupings or cyclic prefixes of the essential signs. Because of the periodicity, these cyclostationary signals display the highlights of periodic statistics and spectral correlation, which isn't found in stationary commotion and impedance.

CFD is hearty to noise vulnerabilities and performs superior to anything energy identification in low SNR districts. Despite the fact that it requires from the earlier learning of the signal attributes, CFD is equipped for recognizing the CR transmissions from different sorts of PU signals. This disposes of the synchronization prerequisite of energy recognition in spectrum detecting by CFD. Also, CR users may not be required to keep quiet amid detecting and in this manner enhancing the general CR throughput.

The examination of the stationary irregular signs depends on autocorrelation work and spectral density. Then again cyclostationary signals show connection work between broadly isolated spectral segments because of the unearthly repetition brought about by the periodicity of the balanced signal and the block diagram of CFD is shown in the figure 1.

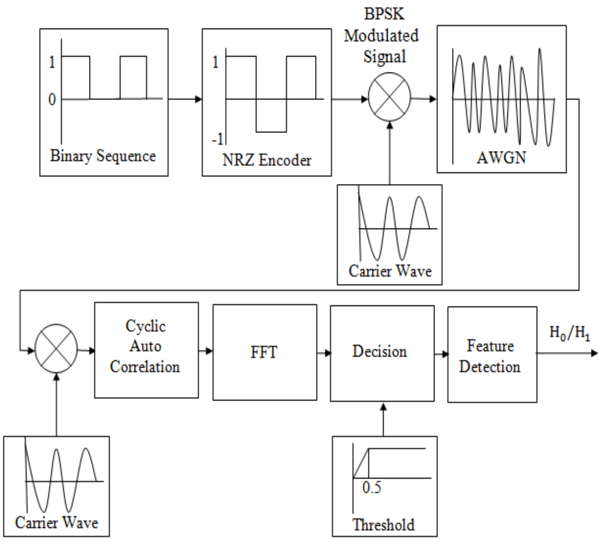

Figure 1: Block diagram for CFD

In cyclostationary signal the mean and autocorrelation function have periodicity. Spectrum sensing is to distinguish the following two hypotheses as shown in equation 1 and 2

$$H_0 : x(t)=n(t) \qquad 0 < t \leq T \qquad (1)$$
$$H_1 : x(t)=hs(t)+n(t) \qquad 0 < t \leq T \qquad (2)$$

where,

T denotes the observation time

x(t) is the received signal by SU

h is the amplitude gain of the channel

s(t) is the transmitted signal of the PU

n(t) is the additive white Gaussian noise (AWGN) with zero mean and variance.

A. GENERATING THE RANDOM SIGNAL

Initially samples of random binary sequence x(n) is generated with 0's and 1's which is then modulated and transmitted afterwards. The sequences are produced in an N×M matrix format. In the generated signal the x-axis represents the discrete time while the y-axis represents the amplitude (0 for bit 0 and 1 for bit 1).

B. BPSK MODULATION

The system is evaluated by BPSK classification because they are applied to Cyclostationary Feature Detector in the presence of AWGN. CFD gives better performance for AWGN channel compared to fading channel. The information stream is encoded utilizing Non Return to Zero (NRZ) encoding. In NRZ encoding the principal thing is to keep the twofold signal's amplitude of 1, where it has an incentive ON and supplant estimation of '0' with '- 1'. At that point, the quantity of components of double signal are up tested by rehashing the quantity of 1's and - 1's to make the extent of grid equivalent to the span of transporter wave over a particular time. A while later, the NRZ encoded information is increased by a carrier wave to get the BPSK tweaked signal as shown in equation 3.

$$s(t) = \sqrt{2} * \cos(2\pi f_c t + \pi(1-n)) \qquad (3)$$

n = 0 for bit '0'
n = 1 for bit '1'

This will act to make a 180 degree phase shift of the carrier wave, where -1 is present and a 0 degree phase shift where 1 is present.In BPSK, a carrier sinusoidal wave with center frequency is generated and multiplied by the NRZ encoded binary signal. This part of model can be implemented physically by using a simple multiplier circuitry.

C. AUTOCORRELATION

Autocorrelation of a signal is the correlation of the signal with itself. It portrays the energy density distribution of the signal. A cyclostationary signal is a signal whose statistics vary periodically with time. A signal x(t) is wide sense cyclostationary if its mean and autocorrelation are periodic. The cyclic autocorrelation function (CAF) is given by the equation 4.

$$R_X^{\alpha}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_T x\left(t + \frac{\tau}{2}\right) x^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi\alpha\tau} dt \qquad (4)$$

when,
$\alpha = 0$ is the conventional autocorrelation

Using the cyclic autocorrelation function (CAC) we can derive the spectral correlation function (SCF) is given by the equation 5.

$$S_X^{\alpha}(f) = \int_{-\infty}^{+\infty} R_X^{\alpha}(\tau)\, e^{j2\pi f\tau}\, d\tau \qquad (5)$$

D. The cross correlation between frequency components of signal separated by f - $\frac{\alpha}{2}$ and f + $\frac{\alpha}{2}$.

E. FAST FOURIER TRANSFORM (FFT)

The Fourier transform of a signal gives us the frequency spectrum of a signal. It is very useful to analyze the signals frequency spectrum in signal processing.The formulae to calculate the Fourier transform of signal x(t) is given in the equation 6.

$$X(\omega) = \int_{-\infty}^{+\infty} x(t)\, e^{-j\omega t} dt \qquad (6)$$

where,
x(t) represents the incoming signal
X(ω) gives the FFT of x(t)

Discrete Fourier Transform (DFT) can be used to compute the Fourier Transform of a discrete signal, although (FFT) is a faster version of (DFT). It takes less computation time and thus is preferred. The peak of the spectrum indicates the carrier frequency at which the signal is modulated. In this model FFT is used to estimate the carrier frequency of the signal. Where On x-axis represents its frequency and on y-axis represents its amplitude.

F. SIGNAL DETECTION

One of the most efficient detection methods in cognitive radio is cyclostationary detection especially when the SNR value is low. As the incoming modulated signal exhibits periodicity in its statistical behavior (i.e. auto correlation function) the signal is considered to be a cyclostationary process. Now for the detection approach certain features like carrier frequency which is distinct and can be exploited to detect the modulated signal immerged in noise is implemented.A sensing mechanism is introduced which includes detection of modulation scheme at the receiver end. The transmitter has the ability to switch between QPSK and BPSK modulation accordingly to the modulation classification.

The cyclostationary detection exploits the distinct behavior shown in the carrier frequency and estimate the carrier frequency. So, the first step in detection is the full awareness of the carrier frequency. Then the cyclostationary detector generates the cosine, sine, (sine + cosine), (sine - cosine) waves of the same frequency and correlates them with the modulated signal

Afterwards, the cyclostationary detector compares the absolute value with the Spectral Correlation Function, and the value of threshold must be greater than 0.5, which ensures that the receiver actually receives some signal and is not receiving only noise. Now if the value with cosine or the value of (sine + cosine) is greater than threshold, it indicates the presence of Primary User else it indicates that noise is present.

If the spectral correlation of signal with carrier frequency cosine wave and the correlation of signal with carrier frequency cosine plus sine wave are greater than threshold value 0.5, it indicates that the Primary User is present.If the spectral correlation of signal with carrier frequency cosine and the correlation of signal with carrier frequency cosine plus sine wave is less than threshold value 0.5, it indicates the presence of Noise or the absence of Primary User.

The probability of detection of PU is found by Generalized Marcum Q function which is given by the equation 7, which indicate the function for a and b.

$$Q(a,b) = \int_b^{\infty} x \exp\left(-\frac{(x^2+a^2)}{2}\right) I_0 ax\, dx \qquad (8)$$

where,

a and b are nonnegative real numbers.

I_0 is the modified Bessel function of the first kind of zero order.

FLOW CHART OF CFD

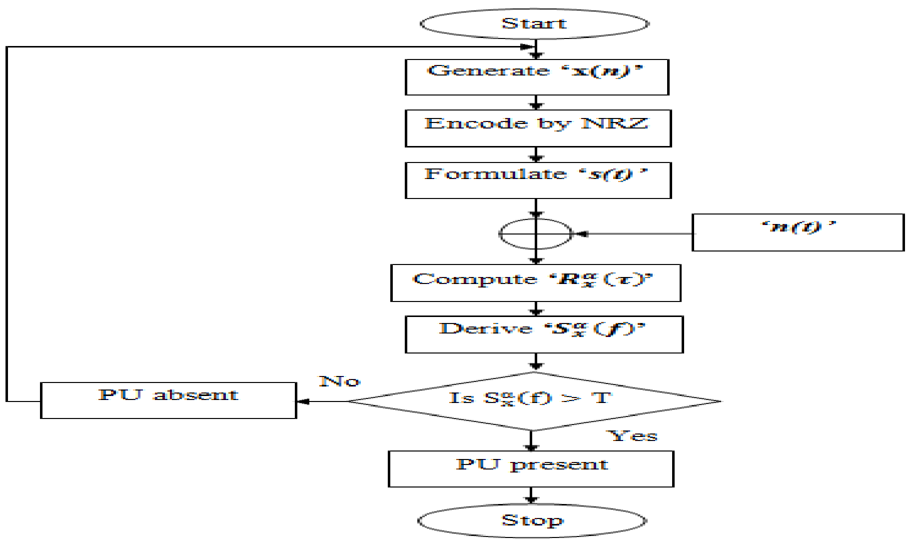

Figure 2 :Flow chart of CFD

Figure 2 shows the flow chart for Enhanced Cyclostationary Feature Detection (CFD) based spectrum sensing in Cognitive Radio Networks for detecting the unused spectrum holes.

IV.ALGORITHM

1. Initially samples of binary sequence x(n) are generated with 0's and 1's.
2. The generated sequence are encoded by Non Return to Zero (NRZ) encoding, where the quantity of components of double arrangement are up inspected by rehashing the quantity of 1's and - 1's.
3. BPSK modulated signals (s(t)) were produced by multiplying the encoded data stream with a carrier wave.
4. Additive White Gaussian Noise (n(t)) is included to the received modulated signal.
5. Cyclic Autocorrelation Function ($R_x^\alpha(\tau)$) is computed to find correlation between noise added modulated signal and carrier signal.
6. Spectral correlation Function ($S_x^\alpha(f)$) is derived by taking Fourier transform of $R_x^\alpha(\tau)$, and the peak spectral magnitude is obtained.
7. Threshold (T) value is set as 0.5 for signal detection, by comparing with $S_x^\alpha(f)$ the PU is identified.
8. CFD perfectly distinguishes primary user signal from noise, and performs efficiently even in low SNR region with reduced probability of false alarm.

V.SIMULATION RESULTS

CFD method is used to investigate the problem of detecting vacant spectral bands. In this regards, the parameters, such as the Probability of detection, Probability of false alarm and the Signal to Noise ratio (SNR) are used to find the vacant frequency bands.

Initially samples of binary sequences are generated and then encoded utilizing Non Return to Zero (NRZ) encoding, which is then duplicated by a transporter wave to get the BPSK modulated signal. AWGN is added to the received signal, and is then multiplied by a carrier wave. Autocorrelation is done for the resulted modulated signal and the carrier signal for computing Cyclic Autocorrelation Function (CAF), and then Fourier Transform is performed for the CAF to produce the Spectral Correlation Function (SCF), which helps in spectrum detection.

A. Signal Generation

Binary sequences are generated with 100×1 matrix of pseudorandom integers from a uniform distribution with 0's and 1's as shown in figure 3.

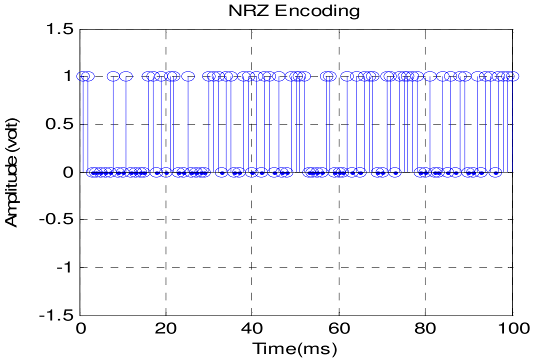

Figure 3: Sequence of NRZ encoded binary data

Double successions are then encoded utilizing Non Return to Zero (NRZ) encoding. The quantity of components of double signal are up inspected by rehashing the quantity of 1's and -1's to make the extent of network equivalent to the span of carrier wave over the particular time.

B. BPSK modulation

The NRZ encoded data are multiplied by a carrier wave to get the BPSK modulated signal as shown in figure 4.

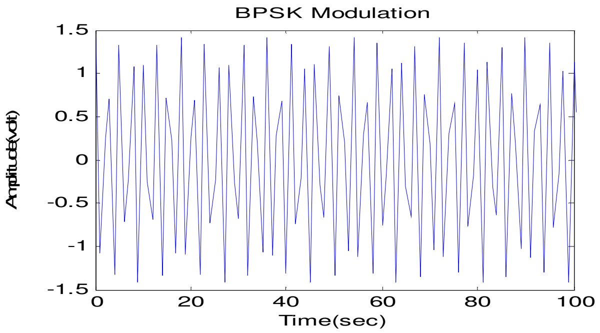

Figure 4 BPSK modulation

The BPSK modulation is a two phase modulation scheme, where the 1’s and -1’s in a binary message are represented by two different phase states in the carrier signal. This will make a 180 degree stage move of the transporter wave, where - 1 is available and a 0 degree stage move where 1 is available.

C. Additive white Gaussian noise (AWGN)

Added substance white Gaussian Noise is a direct model in which the main disability to correspondence is a straight option of repetitive signal a consistent spectral density and amplitude, which can be demonstrated by Gaussian appropriation..

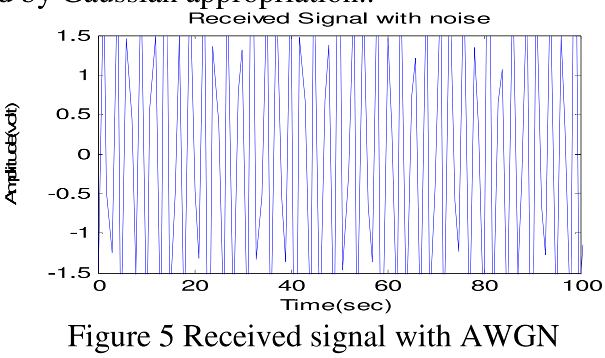

Figure 5 Received signal with AWGN

The noise is additive which implies that the received signal is equal to the transmitted signal plus noise as shown in Figure 5.

D.Correlation

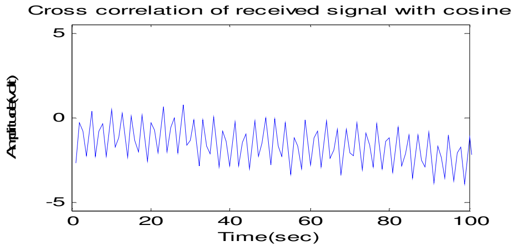

Figure 6: Cross correlation of received signal with cosine

In figure 6 Correlation is done for the modulated signal and the carrier signal with cosine wave. Cross-correlation is a measure of similarity of two series as a function of the displacement of one relative to the other, and then the correlation function is represented by the Fourier series which gives the Cyclic Autocorrelation Function (CAF), which helps in signal detection.

D. Fast Fourier Transform (FFT)

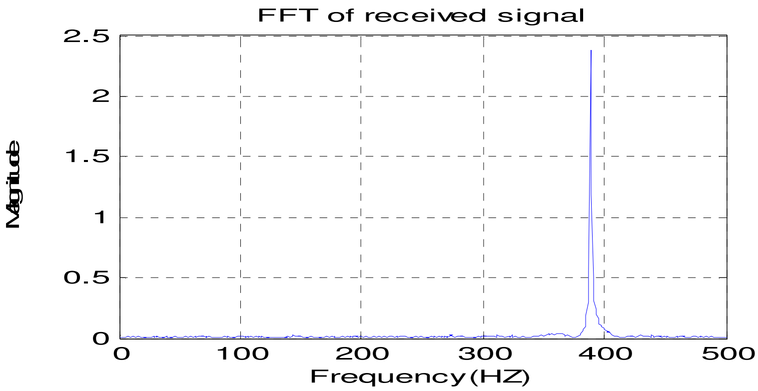

Figure 7: FFT of the received signal

Fast Fourier Transform (FFT) is an algorithm that samples a signal over a period of time and divides it into its frequency components as shown in figure 7. The Spectral Correlation Function (SCF) is found by taking Fourier Transform to the Cyclic Autocorrelation Function (CAF).The SCF applies only to cyclostationary processes because stationary processes do not exhibit spectral correlation. It is used in signal detection and signal classification.The peak value in the graph indicates the presence of primary user, and it occurs near the frequency of about 400 HZ.

E. Signal detection

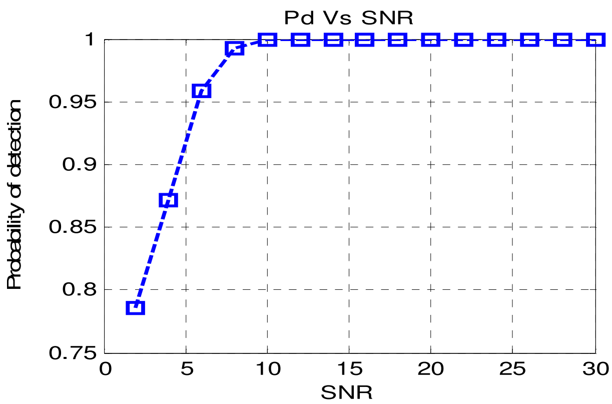

Figure 8 SNR Vs Probability of detection

Detection Probability is that a CR network accurately detects the presence of an active primary user. The probability of detection of PU is found by Generalized Marcum Q function. Figure 8 shows the linear increase of Probability of detection for increasing Signal to Noise Ratio (SNR). The detection probability reaches 1 at SNR=10 db.

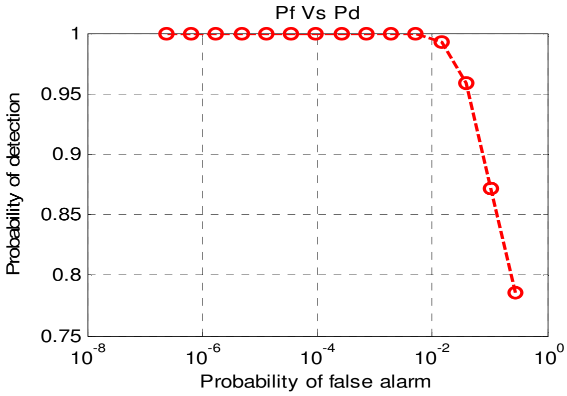

Figure 9 Probability of false alarm Vs Probability of detection

Probability of false alarm denotes the probability of a CR user declaring that a PU is present when the spectrum is actually free. Figure 9 shows the tradeoff between Probability of false alarm and Probability of detection. For the lower value of P_f upto .001, Probability of detection is 1 and detection of Primary User (PU) is more for less value of false alarm.CFD produces reduced probability of false alarm, as it has the capacity to distinguish Primary User signal from noise source. The Spectral frequency is compared with the suitable threshold value and if the average value is greater than the threshold value, it indicates the presence of Primary User, and if the average value is less than the threshold, it indicates the absence of Primary User.

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VI.CONCLUSION

Spectrum is a valuable resource in wireless communication systems, and it has been a focal point for development efforts and research over the last several decades. Cognitive Radio is one of the efforts to utilize the available spectral band more efficiently through opportunistic spectrum usage. In this paper, Cyclostationary detection based spectrum sensing technique is utilized, which is able to detect the Primary users signal accurately. The parameters, such as the Probability of detection, Probability of false alarm and the Signal to Noise ratio (SNR) are used to find the vacant spectral bands by computing the Spectral Correlation Function (SCF). The simulation result shows that the Probability of detection of Primary User (PU) is more accurate compared to other sensing methods. It is shown that the proposed method has reliable performance even in low signal-to-noise ratio (SNR) region. conclusions also give more meaning to the need for future analysis of other spectrum sensing technique like Matched Filter Detection.

REFERENCES

1. Antoni Ivanov, Albena Mihovska and Krasimir Tonchev (2018) 'Real-Time Adaptive Spectrum Sensing for Cyclostationary and Energy Detectors', IEEE Aerospace and Electronics Systems Magazine, Vol. 33, No. 5-6, pp. 20-33.
2. Amir Mirdamadi and Maryam Sabbaghian (2015) 'Spectrum Sensing of Interleaved SC-FDMA Signals in Cognitive Radio Networks', IEEE Transactions on Vehicular Technology, Vol. 64, No. 4, pp. 1633-1637.
3. Aparna P.S and M. Jayasheela (2012) 'Cyclostationary Feature Detection in Cognitive Radio using Different Modulation Schemes', International Journal of Computer Applications, Vol. 47, No. 21, pp. 012-016.
4. Ashish Bagwari, Geetam Singh Tomar, and Shekhar Verma (2013) 'Cooperative Spectrum Sensing Based on Two-Stage Detectors With Multiple Energy Detectors and Adaptive Double Threshold in Cognitive Radio Networks', Canadian Journal of Electrical and Computer Engineering, Vol. 36, No. 4, pp. 172-180.
5. Chad M. Spooner and Apurva N. Mody (2018) 'Wideband Cyclostationary Signal Processing Using Sparse Subsets of Narrowband Subchannels', IEEE Transactions on Cognitive Communications and Networking, Vol. 4, No. 2, pp. 162-176.
6. Danda B.Rawat (2016) 'Evaluating Performance of Cognitive Radio Users in MIMO-OFDM Wireless Networks', IEEE Wireless Communications Letters, Vol. 5, No. 5, pp. 476 – 479.
7. H. Sadeghi, P. Azmi and H.Arezumand (2012) 'Cyclostationarity based soft cooperative spectrum sensing for Cognitive Radio Networks', IET Communications, Vol. 6, No. 1, pp. 29-38.
8. Hamed Sadeghi and Paeiz Azmi (2014) 'Performance Analysis of Linear Cooperative Cyclostationary Spectrum Sensing over Nakagami-m Fading Channels', IEEE Transactions on Vehicular Technology, Vol. 63, No. 9, pp. 4748-4756.
9. Milan Patel, Kirtan Patel and Sagar Patel (2017) 'Spectrum Sensing with Energy Detection in Cognitive Radio Networks', International Research Journal of Engineering and Technology , Vol. 4, No. 3, pp. 1301-1308.
10. Paulo Urriza, Eric Rebeiz, and Danijela Cabric (2013) 'Multiple Antenna Cyclostationary Spectrum Sensing Based on the Cyclic Correlation Significance Test', IEEE Journal on Selected Areas in Communications, Vol. 31, No. 11, pp. 2185-2195.
11. S. Chaudhari, M. Kosunen, S. Makinen and J. Oksanen (2018) 'Spatial Interpolation of Cyclostationary Test Statistics in Cognitive Radio Networks: Methods and Field Measurements', IEEE Transactions on Vehicular Technology, Vol. 67, No. 2, pp. 1113-1129.
12. Tazeen S. Syed and Ghazanfar A. Safdar (2017) 'History assisted Energy Efficient Spectrum Sensing for Infrastructure based Cognitive Radio Networks', IEEE Transactions on Vehicular Technology, Vol. 66, No. 3, pp. 2462-2473.
13. Waleed Ejaz, Ghaith Hattab, Nesrine Cherif, and Mohamed Ibnkahla (2018) 'Cooperative Spectrum Sensing with Heterogeneous Devices: Hard Combining Versus Soft Combining', IEEE Systems Journal, Vol. 12, No. 1, pp. 981-992.
14. Ya Lin Zhang, Qin Yu Zhang and Tommaso (2010) 'A Frequency-Domain Entropy-Based Detector for Robust Spectrum Sensing in Cognitive Radio Networks', IEEE Communications Letters, Vol. 14, No. 6, pp. 533-535.
15. Yang Li and Sudharman K. Jayaweera (2013) 'Dynamic Spectrum Tracking Using Energy and Cyclostationarity-Based Multi-Variate Non-Parametric Quickest Detection for Cognitive Radios', IEEE Transactions on Wireless Communications, Vol. 12, No. 7, pp. 3522-3532.
16. Yang Mingchuan, Li Yuan, Liu Xiaofeng and Tang Wenyan (2015) 'Cyclostationary Feature Detection Based Spectrum Sensing Algorithm under Complicated Electromagnetic Environment in Cognitive Radio Networks', International Journals on Synergetic Radio Cooperative and Collaborative Radio, Vol. 12, No.9, pp.35-44.