International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 23 (2015) pp 43603-43610

Performance Analysis of Cyclostationary Spectrum Sensing in Cognitive Radio

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ABSTRACT- For wireless communication systems, Cognitive Radio (CR) is one of the modern technique to utilize the unused spread spectrum effectively with less interference. Sensing of spectrum holes in a particular spectrum is one of the important concepts in implementing a CR system. In this paper we have implemented spectrum sensing technique by Cyclostationary detector. A random signal is generated and it is modulated either by Binary shift phase keying (BPSK) or Quadrature phase shift keying (QPSK). With this modulated signal an Additive White Gaussian Noise (AWGN) is added. The presence of primary user can be found out by passing the output signal of AWGN through Cyclostationary spectrum detector to check whether it crosses the threshold level. The various modules are pre-implemented inside Cyclostationary detector and this includes Fast Fourier transform (FFT), Auto correlation, Sliding window to detect the presence of signal. An Artificial Neural Network has been trained to estimate the threshold value. Finally the simulation indicate that the performance of Cyclostationary detector having better Signal to Noise Ratio (SNR) than other detectors. Cyclostationary detector out performs with other detector under low SNR conditions.

Keywords: Cognitive Radio, Cyclostationary, Energy Detector, Non Cooperative sensing, Probability of detection, Spectrum Sensing.

1. INTRODUCTION

There is heavy demand for the increased number of applications in wireless communication systems. The usage of frequency bands, or spectrum, is strongly regulated and allocated to specific communication technologies [3]. There are several organizations working on standards for frequency allocation, such as the European Telecommunications Standards Institute (ETSI), the International Telecommunication Union (ITU), the European Conference of Postal and Telecommunications Administrations (CEPT). Spectrum is a scarce resource, and licensed spectrum is supposed to be used by the spectrum owners only.

Spectrum is a scarce resource, and licensed spectrum is proposed to be used only by the spectrum owners. Various studies of spectrum utilization have shown unused resources in frequency, space and time [1]. CR is a new method of reusing licensed spectrum in an unlicensed manner [2]. The vacant resources are often referred to as spectrum holes or white spaces. These spectrum holes could be reused by CRs, sometimes called SUs (SUs). There might be geographical positions where some frequency bands are allocated to a primary user system, but not currently used. Nowadays, CR proves to be a valuable solution for opportunistic usage of the frequency bands that are not heavily occupied by licensed users [6]. As a matter of fact, recent measurements by Federal Communications Commission (FCC) have shown that 70% of the allocated spectrum in US is not utilized. Furthermore, the allocated spectrum experiences low utilization [4]. Since CRs are considered lower priority or SUs of spectrum allocated to a Primary User (PU), their fundamental requirement is to avoid interference to potential Primary Users (PUs). IEEE 802. 22 standard is known as CR standard because of the cognitive features it contains.

One of the most distinctive features of the IEEE 802. 22 standard is its spectrum sensing requirement [5]. Spectrum Sensing forms a very essential and foremost step in the setup of CR network. It helps one to determine the empty frequency bands in the spectrum and also finds out the state of the channel over which transmission is to occur [7]. Spectrum sensing is detecting the presence of signal in frequency spectrum and allocating the free spectrum to new SU. The SU detects the spectrum and inform to PU and it has move to the other vacant spectrum if the PU is trying to use this spectrum. This action process requires to find the free spectrum and allocation of this. There are centralized methodologies that rely on a central unit that updates and holds information about the spectrum utilization either using its own spectrum sensing capabilities or even collecting and gathering spectrum information from portable or mobile units. Regardless where the spectrum sensing device is located, it has to be capable detect signal presence over noise levels and even identify and recognize in some applications specific signals or services using the spectrum.

The challenge of the sensing spectrum is to detect reliable spectrum hole within a specific time. IEEE 802.22 standard on cognitive radio has formulized on the sensing time, that it should be not more than two seconds. To scan the spectrum with some flexibility and digital processing takes place regardless of the used detection techniques. The detection processing is done without interrupting the transmission and reception of signals.

There are many methods to determine the presence of signal [8]; we are discussing only three methods such as Matched Filter, Energy Detection and Cyclostationary detection. Due to the CR application requirements these methods are evaluated for spectrum sensing. There are applications where there is not prior knowledge of the signals on air. Some others consider some specifications about the signal as partial range of the spectrum, bandwidth, modulation, etc. Some applications look for identification of specific signals.

This paper is organized as follows, Section II deals with the need for spectrum sensing. Section III gives challenges related to spectrum sensing. Section IV briefs the various sensing methods used. Section V gives the different measurement involved in spectrum. Section VI gives the Non Cooperative sensing. Section VII gives Cyclostationary algorithm and VIII gives the Cooperative sensing algorithm and implementation. Section IX gives the results and discussions. And section X gives the concluding remarks for this Paper.

2. NEED FOR SPECTRUM SENSING

The Cognitive Radio (CR) technology is used to use the underutilized spectrum in wireless communication. In order to efficiently use the underutilized spectrum bands, the unlicensed users, also called SUs (SUs), need to continuously monitor the activities of the licensed users, also called Primary Users (PUs), to find the spectrum holes (SHs) that can be used by the SUs without interfering with the PUs.

3. CHALLENGES RELATED TO SPECTRUM SENSING

Hidden PUs problem can be caused by multipath fading and shadowing, causing SUs to fail to detect the existence of PUs. This will cause unwanted interference to the PU if CR devices try to access this occupied spectrum. Sensing time is the time required for CR users (unlicensed) must be able to recognize the presence of PUs as quickly as possible and should leave the band immediately in order to avoid interference to and from PUs (licensed). This creates performance limits on the spectrum sensing methods for CR design.
Other challenges that need to be considered when designing spectrum sensing methods include power consumption, competition, robustness, cooperation, computational complexity, coherence times and the presence of multiple SUs.

4. SENSING METHODS

Sensing of spectrum holes can be performed by various detection techniques namely non-operative [10] and co-operative sensing [9]. Non-cooperative sensing uses a matched-filter [20] a Cyclostationary feature extraction [22], [23] and simple energy measurement [7], [34]. Although the first two are coherent detection techniques outperform the Energy Detection technique, since they require prior information about the primary signals, and have a primary system-dependent performance. Matched filter provides optimal detection by maximizing Signal to Noise Ratio (SNR) but requires demodulation parameters. Cyclostationary feature detection can detect random signals depending on their cyclic features even if the signal is in the background of noise but it requires information about the cyclic characteristics. Energy detection technique is applied by setting a threshold for detecting the existence of the signal in the spectrum as shown in Fig. 1.

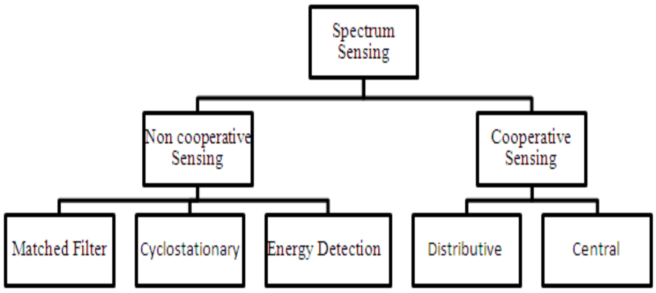

Fig. 1. Different types sensing methods

5. MEASUREMENT DETECTION

5. 1 Probability Of Detection (P_d)

The probability of detection is the time during which the PU (licensed) is detected. The throughput of system depends upon Pd. If the sensing time is increased then PU can make better use of its spectrum and the limit is decided that SU can't interfere during that much of time. More the spectrum sensing more PUs will be detected and lesser will be the interference because PU can make best use of their priority right. SUs might experience losses due to multipath fading, shadowing, and building penetration which can result in an incorrect judgment of the wireless environment, which can in turn cause interference at the licensed primary user by the secondary transmission. This raises the necessity for the CR to be highly robust to channel impairments and also to be able to detect extremely low power signals [11]. These stringent requirements pose a lot of challenges for the deployment of CR networks [13, 14].

5. 2 Probability of False Alarm (Pfa)

Probability of the sensing algorithm mistakenly detects the presence of PUs while they are inactive. Low Pfa should be targeted to offer more chances for SUs to utilize the sensed spectrum hole. From the SU's perspective, however, the lower the Pfa, there are more chances for which the SUs can use the frequency bands when they are available and improve the throughput. Obviously, for a good detection algorithm, the Pd should be as high as possible while the Pfa should be as low as possible [15].

5. 3 Missed Detection (Md)

In the case of Missed detection, the SUs fail to detect PU activity when in fact these users are active i. e., a spectrum hole is detected incorrectly. During missed detection, the channel becomes the interference channel since both PU and SUs are transmitting simultaneously. However, in the interweave scenario, the encoding and decoding for both the PU and SUs do not take this interference into account since it occurs due to an unexpected detection error. Hence, interference from the SU to the PU will degrade its capacity.

6. NON COOPERATIVE SENSING

Spectrum sensing is done by the well known technique called signal detection [12], [17]. Signal detection is the method to identifying the presence of a signal in a noisy environment [18], [16].

H1: X(n) = s(n)h + w(n) (1)

H0: X(n) = w(n) (2)

Where X(n) is the received signal by CR users, s(n) is the transmitted signal of the PU, h is the channel coefficient; and w(n) is Additive White Gaussian Noise with variance σ_ω^2.

The sensing states H0 and H1 means that absence and presence of signal respectively. Another way to say H0 is the null hypothesis which indicates that PU does not communicate and H1 is the alternative hypothesis that indicates the existence of the PU. There are four possible cases for the detected signal:

a. Declaring H1 under H1 hypothesis which leads to Probability of Detection (Pd).
b. Declaring H0 under H1 hypothesis which leads to Probability of Missing (Pm).
c. Declaring H1 under H0 hypothesis which leads to Probability of False Alarm (Pfa).
d. Declaring H0 under H0 hypothesis.

Thus false alarm error leads to inefficient usage of the spectrum [15]. The aim of the spectrum detector is to achieve correct detection all of the time, due to the statistical nature of the problem this cannot be perfectly achieved. Therefore the spectrum detectors are designed to operate within prescribed minimum error levels. Missed detections will leads to SU interfering with the primary system. So, it is desirable to keep false alarm probability as low as possible, so that the system can exploit all possible transmission opportunities [19]. There are number of ways to detect the presence of PU signal transmissions and we are discussing only three methods namely Matched Filter, Cyclostationary and Energy Detector.

6. 1 Matched Filter Design

When a SU has a prior knowledge of the PU signal transmitted, the optimal signal detection for detecting the presence of PU is a matched filter followed by threshold detector[20], [21]. In order to improve the SNR, a optimal linear matched filter is used to remove the additive white stochastic noise. This filter technique is possible if the number of PUs is very small. The functional block diagram is shown in fig. 2.

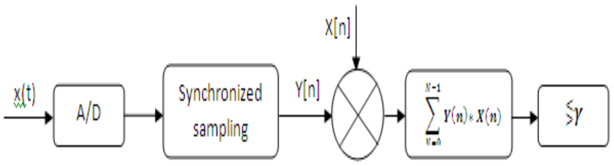

Fig. 2. Block diagram of a Matched Filter Detector

The input signal is passed to A/D converter. After converting to digital signal then it is passed to synchronizing unit. In the detector the secondary sensing node must be synchronized to the primary system and must even be able to demodulate the primary signal. Accordingly, the secondary sensing node has to have prior information about the primary system such as the preamble signaling for synchronization. The unknown signals are convolved with the matched filter by the correlation unit. The impulse response of the filter is the mirror and time shifted version of the reference signal. After that the signals are summed for n samples. Then the signal strength is compared with threshold value to detect whether primary user is present or not.

A matched filter effectively requires demodulation of the signal of the PU and it needs the priori knowledge of the user signal at both physical (PHY) and MAC layers, e. g. modulation type and order, pulse shaping, packet format. In order to perform demodulation, the matched filter technique has to perform timing, carrier synchronization and channel equalization. This is possible since most PUs have pilots, preambles, synchronization words or spreading codes that can be used for synchronization. If the received signal is completely known to the receiver and the optimal detector for the received signal X[n] is

$$T(Y) = \sum_{n=0}^{N-1} Y[n]X[n] \underset{H0}{\overset{H1}{\lessgtr}} \gamma. \quad (3)$$

The number of samples required for optimal detection if γ is the detection threshold:

$$N = [Q\text{-}1(Pd\text{-}Q\text{-}1(Pfd)]^{2} (SNR)^{-1} \quad (4)$$

$$N = O\,(SNR)^{-1} \quad (5)$$

Where Pd and Pfd are the probabilities of detection and false detection respectively. Due to coherency of the matched filter it requires less time to achieve high processing gain. In order to meet probability of detection constraint it requires $O(SNR)^{-1}$ sample. The matched filter spectrum detector requires dedicated receiver for every primary user type.

6. 2 Cyclostationary Detection

If the received signal of the PU exhibits strong Cyclostationary properties, the signal can be detected at very low SNR values by exploiting the information (Cyclostationary feature) embedded in the signal [22-24]. The signal is said to be Cyclostationary (in the wide sense) if its autocorrelation is aperiodic function of time t with some period. The functional block diagram is shown in Fig. 3.

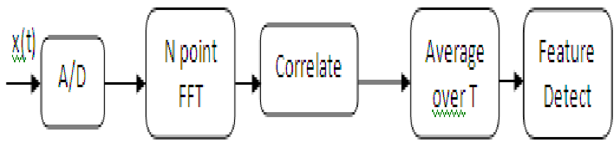

Fig. 3. Cyclostationary feature detector

The detection of signal can be performed as follows. The A/D block converts analog signal to digital signal and it is passed through filter. Here band pass filter is used to pass particular band of frequency and reject the frequencies outside that range. The main function of a filter in a transmitter is to limit the bandwidth of the output signal to the band allocated for the transmission. Then it is converted into the digital signal. Quantizer is the process of mapping a large set of input values to smaller set such as rounding values to some unit of precision. After that signal is passed through the FFT block which convert time domain signal into frequency domain signal. Windowing technique is used for reduce undesirable oscillation in the band. After windowing function signal is processed for autocorrelation function. In this autocorrelation function signal correlates with itself. For that product block is used in which signal can multiple with its conjugate function and taken average over period. Now absolute value of signal is compared with constant value for detecting the PU.

a. First, the cyclic autocorrelation function (CAF) of the observed signal x(t) is calculated as E{x(t+τ) x*(t-τ) e-i2παt }, where E{. } denotes statistical expectation operation and α is called the cyclic frequency.

b. The spectral correlation function (SCF) S(f, α) is then obtained from the discrete Fourier transformation of the CAF. The SCF is also called cyclicspectrum, which is a two-dimension function in terms of frequency f and cyclic frequency α.

c. The detection is done by searching for the unique cyclic frequency corresponding to the peak in the SCF plane.

This Cyclostationary detection algorithm is robust to random noise and interference from other modulated signals because the noise has only a peak of SCF at the zero cyclic frequency and the different modulated signals have different unique cyclic frequencies. This approach can detect the PU signal from other signals over the same frequency band provided that the cyclic features of the PU is differ from others. However, the implementation of Cyclostationary detection is more complex than the other detection and it requires a prior modulation format knowledge of PU signal.

Cyclostationary feature detection has several advantages such as

a. Cyclostationary feature detection is more robust to changing noise level than other detection.

b. Cyclostationary detectors can work in lower SNR because feature detectors exploit information embedded in the received signal.

c. It has the capability to distinguish between primary user and noise and it can differentiate between different types of signals

The drawbacks of the Cyclostationary feature are

a. It requires prior knowledge on the primary user's signal.

b. If the SU does not have the knowledge of the cyclic frequencies giving the peak values of CSF, it needs to compute CSF for all possible cyclic frequencies and find the peak value. Therefore the implementation cost extremely increases. Cyclostationary feature detection is very complex to implement rather than other detectors

6. 3 Energy Detector

In this method, the channel freeness is detected by measuring the received signal energy [25-27]. The received signal is squared by a function and it is compared with predetermined threshold value. If this value exceeds the threshold value, the signal is present otherwise it is absent. Due to signal power measurement this detection will give false detections [15]. When the signal is changing heavily, it is very difficult to find the presence or absence of the signal, if the prior knowledge of signal is unknown. This detection method is optimal for detecting any zero mean constellation signals [28, 29]. The functional block diagram is shown in Fig. 4,

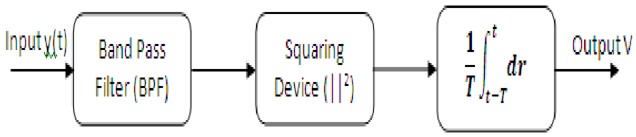

Fig. 4. Block diagram of Energy Detector

The input signal y(t) is filtered with a Band Pass Filter (BPF) in order to limit the noise and to select the bandwidth of interest. The noise in the output of the filter has a band-limited, flat spectral density. The next blocks are a squaring device and a finite time integrator. The output of squaring device is further processed by integrator to obtain output V. Finally, this output signal V is compared to the threshold in order to decide whether a signal is present or not. The threshold is set according to statistical properties of the output V when only noise is present.

Finally, this output signal V is compared to the threshold in order to decide whether a signal is present or not. The threshold is set according to statistical properties of the output V when only noise is present.

The drawbacks of the energy detection can be concluded as

a. The energy detection performance is very susceptible to changing noise level.

b. It requires longer time for detection.

c. This technique cannot distinguish modulated signals, noise and interference.

d. The detection of spread spectrum signals is not possible.

e. The threshold used to detect the PU depends on the noise variance

f. Errors due to small noise power estimation result in performance loss.

g. Energy detection approach has several advantages:

h. It is more generic (as compared to methods given in this section) as receivers do not need any knowledge on the PU's signal.
i. It's low computational and implementation complexities
j. The signals can be detected at low SNRs, provided the detection interval is adequately long and noise power spectral density is known.

Pd (Probability of Detection) and Pfa (Probability of False Alarm) are the important factors for energy based detection which gives the information of the availability of the spectrum. Another challenging issue is the inability to differentiate interference between the PU and the SU sharing the same channel. The threshold level used in energy detection techniques depends on the noise variance. The performance loss purely depends on noise power estimation errors.

7. CYCLOSTATIONARY ALGORITHM

In telecommunication, RADAR and SONAR fields it arises due to modulation, coding etc. It might be that all the processes are not periodic function of time but their statistical features indicate periodicities and such processes are called Cyclostationary process. For a process that is wide sense stationary and exhibits Cyclostationarity has an auto-correlation function which is periodic in time domain. Now when the auto-correlation function is expanded in term of the Fourier series co-efficient it comes out that the function is only dependent on the lag parameter which is nothing but frequency. The spectral components of a wide sense Cyclostationary process are completely uncorrelated from each other. The Fourier series expansion is known as cyclic auto-correlation function (CAF) and the lag parameter i. e. the frequencies is given the name of cyclic frequencies. The cyclic frequencies are multiples of the reciprocal of period of Cyclostationarity. The cyclic spectrum density (CSD) which is obtained by taking the Fourier transform of the cyclic auto-correlation function (CAF) represents the density of the correlation between two spectral components that are separated by a quantity equal to the cyclic frequency.
The following conditions are essential to be filled by a process for it to be wide sense Cyclostationary:-

$$E\{x(t+T0)\} = E\{x(t)\} \quad (6)$$

$$Rx(t+T0, \tau) = Rx(t, \tau) \quad (7)$$

where $Rx = E\{x(t+\tau)x(t)\}$. Thus both the mean and auto-correlation function for such a process needs to be periodic with some period say T0. The cyclic auto-correlation function (CAF) is represented in terms of Fourier co-efficient as:-

$$R_x^{\frac{n}{T_0}}\tau = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} R_x(t,\tau)e^{-j2\pi\left(n/T_0\right)t}dt \quad (8)$$

'n/T0' represent the cyclic frequencies and can be written as 'α'. A wide sense stationary process is a special case of a wide sense Cyclostationary process for 'n/T0= α=0'. The cyclic spectral density (CSD) representing the time averaged correlation between two spectral components of a process which are separated in frequencies by 'α' is given as

$$S(f,\alpha) = \int_{\tau=-\infty}^{\infty} R_x^{\alpha} e^{-j2\pi f\tau} d\tau \quad (9)$$

The power spectral density (PSD) is a special case of cyclic spectral density (CSD) for 'α=0'. It is equivalent to taking the Fourier transform of special case of wide sense Cyclostationary for 'n/T0= α=0'. The signals which are used in several applications are generally coupled with sinusoid carriers, cyclic prefix, spreading codes, pulse trains etc. which result in periodicity of their statistics like mean and auto-correlation. Such periodicities can be easily highlighted when cyclic spectral density (CSD) for such signals is found out.
Primary user signals which have these periodicities can be easily detected by taking their correlation which tends to enhance their similarity. Fourier transform of the correlated signal results in peaks at frequencies which are specific to a signal and searching for these peaks helps in determining the presence of the primary user. Noise is random in nature and as such there are no such periodicities in it and thus it doesn't get highlighted on taking the correlation.

8. IMPLEMENTATION OF CYCLOSTATIONARY FEATURE DETECTION

The analysis of the stationary random signals is based on autocorrelation function and spectral density. On the other hand Cyclostationary signals exhibit correlation function between widely separated spectral components due to the spectral redundancy caused by the periodicity of the modulated signal. In this section, Cyclostationary feature detection is described step by step:
a. Determine the points of cyclic frequency, carrier frequency, window size and FFT size.
b. Sliding windows are very useful in the analysis of dominant cyclic features. In our simulations we decided to use Rectangular window.
c. A Fourier Transform of these windowed signals is conducted to continue the computation in the frequency domain.
d. The Spectral Correlation Function is computed for each frame, and then normalize by taking its mean.
e. By the use of the spectral correlation function we can detect the primary user.
f. Afterwards BPSK/QPSK modulation classification is undertaken based on the cyclic spectrum.

We generate a binary sequence which is then modulated and transmitted. The generated signal is shown in fig 5, where the x-axis represents the discrete time whilst the y-axis represents the amplitude (0 for bit 0 and 1 for bit 1). We evaluated our system by BPSK and QPSK modulation. Considering the results, Cyclostationary feature detection gives better performance for AWGN channel compared to fading channel. The data stream is encoded using non return to zero NRZ encoding. In NRZ encoding the first thing is to keep the binary signal's amplitude of 1, where it has value on and replace value of '0' with '-1'. Secondly, the number of elements of binary signal are up sampled by repeating the number of 1's and number of-1's to make the size of matrix equal to the size of carrier wave over the specific time. Afterwards, the NRZ encoded data is multiplied by a carrier wave, according to equation (10). 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.

$$S_b(t) = \sqrt{2E_s/T} * Cos\,(2\pi f_c t + \pi(1-n)) \quad (10)$$

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

In BPSK, a carrier sinusoidal wave with centre frequency fc is generated and multiplied by the NRZ encoded binary signal. This part of model can be implemented physically by using a simple multiplier circuitry. In QPSK modulation, the binary data stream is divided into an even number of bits and odd number of bits. Then both parts of the signal are separately encoded through NRZ encoding. After that, the even part of the signal is multiplied by the sinusoidal wave with 0 degree phase shift. The odd part of the signal is multiplied by sinusoidal wave with a 90 degree phase shift. This can easily be done by multiplying the even part by cos(2πft) and the odd part by sin(2πft). After that both parts are added up to generate a QPSK modulated signal.

$$S_b(t) = \sqrt{2E_S/T} * Cos\,(2\pi f_C t + (2n-1)\tfrac{\pi}{4}) \quad (11)$$

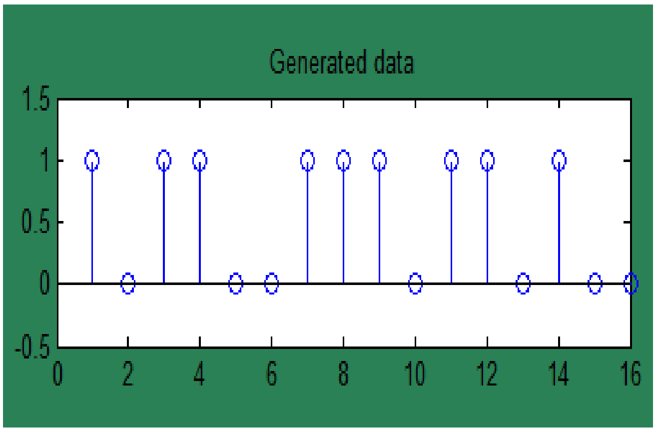

Fig. 5. Generated signal

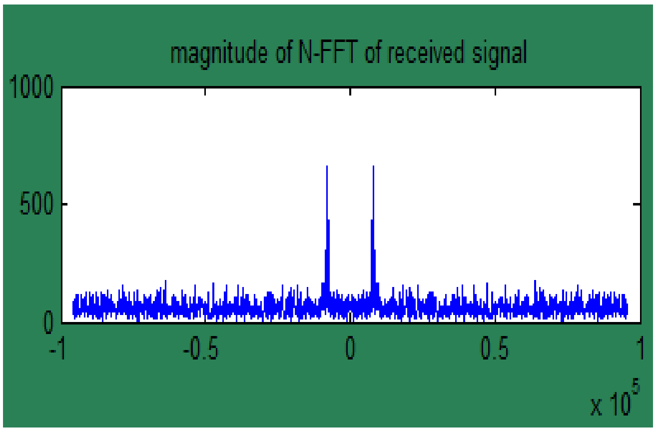

Fig. 6. Fast Fourier Transform

n=1, 2, 3, 4 representing four phases π/4, 3 π/4, 5 π/4 and 7π/4 respectively. Signal-to-noise ratio (SNR) is defined as the ratio of signal power to the noise power. Linear addition of white noise or wideband with constant spectral density and amplitude is called additive white Gaussian noise (AWGN) and the modelled distribution is shown in the following equation.

$$X(T) = Y(T) + N\,(T) \quad (12)$$

$$SNRdb = Psignal / Pnoise \quad (13)$$

$$SNRdb = 10 \log10\,(Asignal / Anoise)^2 \quad (14)$$

$$= 20 \log10\,(Asignal / Anoise) \quad (15)$$

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 Fourier transform of a signal gives us the frequency spectrum of a signal. It is very useful to analyze the signal's frequency spectrum in signal processing. The formulae to calculate the Fourier transform of signal x(t) is given below in equation.

$$X(\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt \quad (16)$$

Where x(t) represents the incoming signal, while X(ω) gives the FFT of x(t). After sampling and quantizing, we get the discrete version of x(t) in both the time and amplitude domain, which is referred to as x(n). FFT model is a discrete implementation of the Fourier transform, so the formulae used to calculate the transform of the signal x(n) is given below in equation.

$$X(k) = \sum_{n=0}^{N-1} x(n)\, e^{-j2\pi k} \quad (17)$$

where X(k) = Fourier Transform of signal, x(n) = Sampled Signal of x(t), N = Time period of signal and n = Discrete sample time. The peak of the spectrum indicates the carrier frequency at which the signal is modulated.

9. RESULTS AND DISCUSSIONS

We generated n random signals (also mentioned as number of trials) repeatedly, and modulated them by BPSK and QPSK methods, added AWGN and then detected the signal with the help of Cyclostationary detector. In the Table 1, the probability of primary detection for various sensing methods are shown with different SNR value. From this we found that Cyclostationary detection had outperformed with respect to other detection techniques and it is shown graphically in the Fig. 7. In the Table 2, the probability of false alarm for various sensing methods are shown with different SNR values. From this we found that Cyclostationary detection is better option with respect to other sensing methods and the same is illustrated in Fig. 8.

TABLE I PROBABILITY OF PRIMARY DETECTION.

Sl.No	SNR (db)	Energy detection	Matched filter	Cyclo stationary Detection
1	-30	0	0.05	0.3
2	-20	0	0.05	0.6
3	-10	0.05	0.1	0.98
4	0	0.85	0.32	1
5	10	1	0.95	1
6	20	1	1	1
7	30	1	1	1

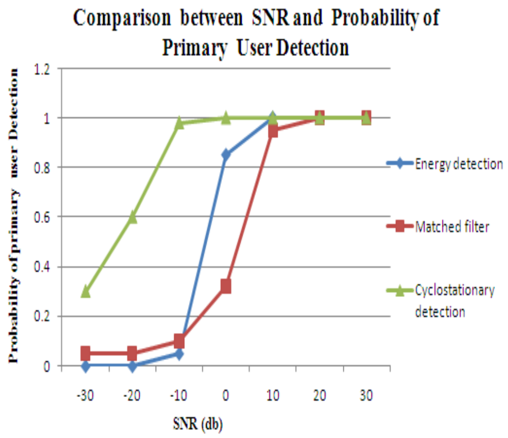

Fig. 7. Comparison of various primary user detectors

TABLE II PROBABILITY OF FALSE DETECTION.

Sl.No	SNR (db)	Energy detection	Matched filter	Cyclo stationary Detection
1	-30	1	1	1
2	-20	1	0.8	1
3	-10	0.98	0.65	1
4	0	0.9	0.15	1
5	10	0.05	0	1
6	20	0	0	1
7	30	0	0	1

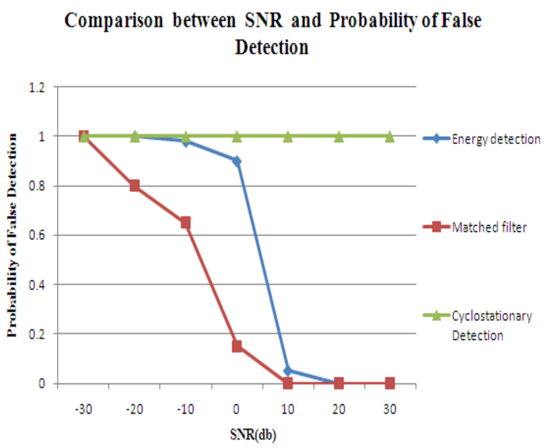

Fig. 8. Comparison of False Alarm detection of different sensing techniques.

10. CONCLUSION

In this paper we have evaluated different types of spectrum sensing scheme. The data is transmitted by two different modulation techniques namely BPSK and QPSK using three different detection techniques with varying signal to noise ratio. We found that Cyclostationary detection method out forms the other two methods in terms of detection of primary user and false detection. The probability of detection and Probability of false detection is better in this Cyclostationary detection. The proposed Cyclostationary method can also be implemented in hardware in the future.

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