International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 08 | Aug 2019 www.irjet.net p-ISSN: 2395-0072

Simulating Spectrum Sensing in Cognitive Radio Network using Cyclostationary Technique

Fele Taiwo[1], **Ogunlola Okunola Olasunkanmi**[2], **Fele Yetunde Olamide**[3]

[1]*Computer Science Department, The Federal Polytechnic, Ado-Ekiti, Nigeria*
[2]*Computer Science Department, The Federal Polytechnic, Ado-Ekiti, Nigeria*
[3]*Logistics Management and Coordination Unit, Ministry of Health, Ado-Ekiti, Nigeria*

***

Abstract - *The demand for wireless communication applications are increasing and the available electromagnetic spectrum band is getting crowded geometrically. Spectrum sensing helps to detect the spectrum holes (unutilized bands of the spectrum) in providing high spectral resolution capability. Therefore for efficient utilization of spectrum, we need to sniff the spectrum to determine whether it is being used by licensed owner or not. In an attempt to contribute to the possibility of adopting dynamic spectrum access as an alternative radio spectrum regulation system. The paper review different spectrum sensing techniques used in finding spectrum holes in available radio resource, model and simulate cyclostationary based spectrum sensing technique and classify primary user signals of different modulation scheme. The results of this study show that accurate and prompt modulation classification is possible beyond the lower bound of 5 dB acclaimed in literature. The performance of the detection technique is measured in terms of the ROC curve. The proposed model is simulated on a Laptop PC running on Windows 10 platform and requires MATLAB R2015a/Simulink and LibSVM.*

Key Words: Spectrum sensing, Cognitive radio, Modulation classification, Spectrum holes, Cyclostationary detection.

1. INTRODUCTION

The need for wireless communication applications are increasing and the available Electromagnetic Spectrum band is getting crowded day by day. According to many researches it has been found that the allocated spectrum (licensed spectrum) is not utilized properly because of static allocation of spectrum. It has become most difficult to find vacant bands either to set up a new service or to enhance the existing one. In order to overcome these problems we are going for “Dynamic Spectrum Management” which aims at improving spectrum utilization [1].

Wireless multimedia applications and other real-time applications need high bandwidth, as static frequency allocation techniques cannot resolve the problems of an increasing number of high data rate services. This problem can be resolved by improving spectrum resource utilization. In this paper we investigate the performance of Cyclostationary Spectrum Sensing technique. Specifically we investigate a cyclostationary based sensing detector’s ability to differentiate between a BPSK or a QPSK modulated signal. The objectives of this study are to: study and analyse existing spectrum sensing techniques; Design optimized sensing technique based on cyclostationary and; simulate the design above.

1.1 Cognitive Radio (CR)

Cognitive Radio (CR) is a form of wireless communication in which a transmitter / receiver can intelligently detect communication channels that are in use and those which are not, and can move to unused channels. This optimizes the use of available radio frequency spectrum while minimizing interference with other users. A primary feature of cognitive radios is the ability to adapt the transmission parameters given a dynamic wireless environment. Cognitive Radio works on dynamic Spectrum Management principle which solves the issue of spectrum underutilization in wireless communication in a better way. This radio provides a highly reliable communication. Fig - 1 shows the Dynamic Spectrum Access in Cognitive Radio.

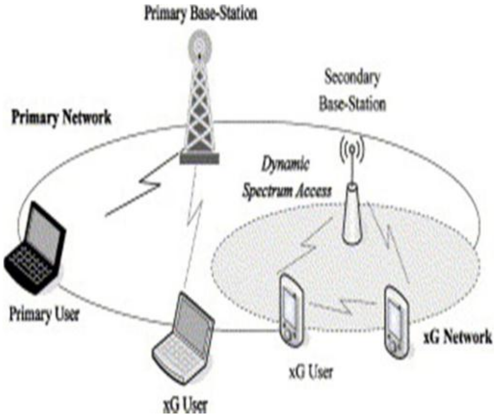


Fig -1: Dynamic Spectrum Access [2]

CR technologies utilize a radio frequency (RF) sensor to detect unused spectrum that is available and capable of communications. CR understands the properties inherent to the user such as battery life, signal interface, and attenuation, which are then used in a set of decision-making algorithms to provide the best capabilities for each user.

Cognitive radios can also change frequencies dynamically to maintain reliable communications [3]. As a result, CR helps improve the efficiency of spectrum usage. CR technologies can also be used to ensure that new unlicensed users do not interfere with TV signals when databases of incumbent licensees are available for a given location, devices can be instructed to avoid those frequency bands [4].

Cognitive radio has four major functions. They are: Spectrum Sensing, Spectrum management, Spectrum Sharing and Spectrum Mobility [5]. Spectrum Sensing is to identify the presence of licensed users and unused frequency bands i.e., white spaces in those licensed bands. Spectrum Management is to identify how long the secondary users can use those white spaces [7]. Spectrum Sharing is to share the white spaces fairly among the secondary users. Spectrum Mobility is to maintain unbroken communication during the transition to better spectrum [8].

In terms of occupancy, sub bands of the radio spectrum may be categorized as follows:

i. White spaces: These are free of RF interferers, except for noise due to natural and/or artificial sources.
ii. Gray spaces: These are partially occupied by interferers as well as noise.
iii. Black spaces: The contents of which are completely full due to the combined presence of communication and (possibly) interfering signals plus noise [10].

Fig - 2 shows the White Spaces and Used Frequencies in Licensed Spectrum.

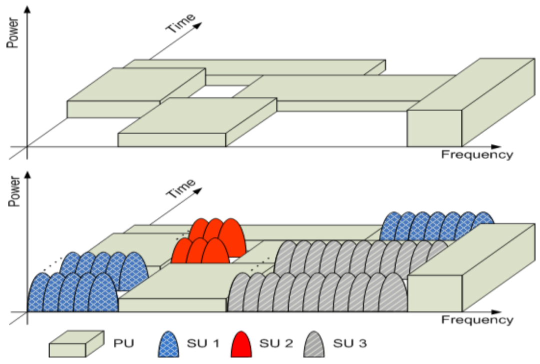


Fig - 2: White Spaces in Licensed Bands. [2]

When compared to all other functions, Spectrum Sensing is the most crucial task for the establishment of cognitive radio based communication networks.

1.2 Frequency Management Policy

Radio frequency spectrum is one of the key natural resources of great economic value as a result of its direct application in telecommunications, broadcasting, military operations, and scientific research in addition to a range of other socioeconomic activities such as social services, law enforcement, education, healthcare, transportation, etc. As a result, many industries depend heavily on the efficient utilization of radio frequency spectrum.

These crucial factors therefore, make it mandatory for the government to develop comprehensive and clear-cut policies that will ensure that spectrum resource is optimally utilised for the overall benefit of the nation [6].

2. SPECTRUM SENSING IN COGNITIVE RADIO

Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks(infrastructures) and nodes, local policies and other operating restrictions [9]. It is done across Frequency, Time, Geographical Space, Code and Phase. A number of different methods are proposed for identifying the presence of signal transmission all of which are in early development stage. They are:

i. Energy-Detection Based
ii. Waveform Based
iii. Cyclostationary Based
iv. Radio Identification Based
v. Matched filtering Based

2.1 Cyclostationary Feature Detection

Cyclostationary feature detection based on introduction of periodic redundancy into a signal by sampling and modulation. The periodicity in the received primary signal to identify the presence of Primary Users (PU) is exploited by Cyclostationary feature detector [10] which measures property of a signal namely Spectral Correlation Function (SCF) given by

$$S_x^{\alpha}(f) = \int_{-\infty}^{\infty} R_x^{\alpha}(\tau)\, e^{-j2\pi f\tau}\, dt$$

Where $R_x^{\alpha}(\tau)$ is cyclic autocorrelation function (CAF).

Cyclostationary feature detector implementation can differentiate the modulated signal from the additive noise, distinguish Primary User signal from noise [11]. It is used at very low SNR detection by using the information embedded in the Primary User signal which does not exist in the noise. This technique is robust to noise discrimination and it performs better than energy detector. It has disadvantage of more computational complexity and longer time observation [12].

3. METHODOLOGY

The paper started with literature review of previous research works relevant to the topic was highlighted. This work assumed a cognitive radio network with N primary users and W secondary users. For any one of the secondary user, the presence of the primary user can be summarized as a hypothesis test model of two elements:

$$H_0 : \quad x(t) = w(t) \qquad (1)$$
$$H_1 : \quad x(t) = s(t) + w(t) \qquad (2)$$

Based on received signal x(t), which is a function of transmitted signal s(t) and white additive Gaussian noise w(t) there are two hypothesis: in which when the primary user is present, H_1 and the other, in which the primary user is absent, H_0.

Considering a known signal s(t) corrupted by additive white Gaussian noise w(t) as the received signal x(t). Then,

$$x(t) = s(t) + w(t) \qquad 0 \le t \le T \qquad (3)$$

A continuous time signal x(t) is said to be cyclostationary (in wide sense), if it exhibits a periodic auto-correlation function which is given by:

$$R_x\,(t,\tau) = E[x(t)x*(t-\tau)] \qquad (4)$$

Where E[·] represents statistical expectation operator. Since R_x (t, τ) is periodic, it has the Fourier series representation.

$$R_x\,(t,\tau) = \sum_\alpha R_x^\alpha\,(\tau)e^{-j2\pi\alpha t}\,dt \qquad (5)$$
$$R_x^\alpha(\tau) = \lim_{t\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x(t)x*(t-\tau)\,e^{-j2\pi\alpha t}dt \qquad (6)$$

Where sum is taken over integer multiple of fundamental cyclic frequency, α and$R_x^\alpha(\tau)$ is Cyclic Autocorrelation Function (CAF). Considering a time series of length T, the expectation in the definition of autocorrelation can be replaced by time average. So that:

$$R_x^\alpha(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} R_x\,(t,\tau)e^{-j2\pi\alpha t}\,dt \qquad (7)$$

'n/T' 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/T = α = 0'. Therefore, a signal exhibit second-order cyclostationarity in the wide sense when its cyclic autocorrelation function, $R_x^\alpha(\tau)$ is different from zero for some non-zero α. For zero frequency shift, the spectral correlation density is equivalent to standard power spectral density. The amount of correlation between frequency shifted versions of x(t) in the frequency domain is determined. The spectral correlation density (SCD) function is defined as Fourier transform of Cyclic Autocorrelation Function of x(t). The SCD of a signal x(t) is given by:

$$S_x^\alpha(f) = \int_{-\infty}^{\infty} R_x^\alpha\,(\tau)e^{-j2\pi f\tau}d\tau \qquad (8)$$

To analyze a signal in the frequency domain, the power spectral density (PSD), S_x(f), is used to characterize the signal, which is obtained by taking the Fourier Transform of the autocorrelation R_x(τ) of the signal x(t). The PSD and the autocorrelation of a function, R_x(τ), are mathematically related by the Einstein-Wiener-Khinchin (EWK) relations, namely:

$$S_x^\alpha(f) = \int_{-\infty}^{\infty} R_x^\alpha\,(\tau)e^{-j2\pi f\tau}dt$$

$$R_x(f) = \int_{-\infty}^{\infty} S_x\,(\tau)e^{+j2\pi f\tau}df \qquad (9)$$

Using the EWK relations, we can derive some general properties of the power spectral density of a stationary process, such as:

$$S_x(0) = \int_{-\infty}^{\infty} R_x\,(\tau)d\tau$$
$$E\{X^2(t)\} = \int_{-\infty}^{\infty} S_x(f)df$$
$$S_x(f) \ge 0\ for\ all\ f$$
$$S_x(-f) = S_x(f)$$

Power Spectral Density is a special case of SCF when α = 0. The power spectral density, appropriately normalized, has the properties usually associated with a probability density function:

$$P_x(f) = \frac{S_x(f)}{\int_{-\infty}^{\infty} S_x(f)df} \qquad (10)$$

(5)

Using H(*f*) to denote the frequency response of the system, we can relate the power spectral density of input and output random processes by the following equation:

$$Y(f) = |H(f)|^2 X(f) \qquad (11)$$

Where X(*f*) is the PSD of input random process and Y(*f*) is the PSD of output random process.

We calculate SCF for each one of BPSK, QPSK, MPSK and QAM and found that a sinusoidal signal with carrier frequency f_c have four peaks in CSD at ($\alpha = 0, f = \pm f_c$) and ($\alpha = \pm 2f_c, f = 0$). We compute the SCF of the received signal y(t) taking into account that the primary user transmits a cyclostationary signal, so, its SCF has nonzero component at some nonzero cyclic frequency. Hence we can rewrite the hypothesis in (7) and (8) as:

$$S_y^{\alpha}(f) = \begin{cases} S_w^{\alpha}(f) < \lambda, & H_0 \\ S_x^{\alpha}(f) + S_w^{\alpha}(f) \geq \lambda, & H_1 \end{cases} \qquad (12)$$

Where $S_w^{\alpha}(f)$ and $S_x^{\alpha}(f)$ is SCF of AWGN and primary signal respectively and λ is threshold. This states that $S_y^{\alpha}(f) \geq \lambda$ that is, x(t) is cyclostationary signal, then we can robustly detect the presence of the primary signal. We focus only on frequencies ($\alpha = 0$, $f = \pm f_c$) and ($\alpha = \pm 2f_c$, $f = 0$) and look for peaks. These peaks are compared to a pre-determined threshold, so that if they are greater than the threshold and the other values on the same frequencies ($\alpha = 0$ and $f = 0$), then the signal exists in the band under sensing or the band is free otherwise[10].

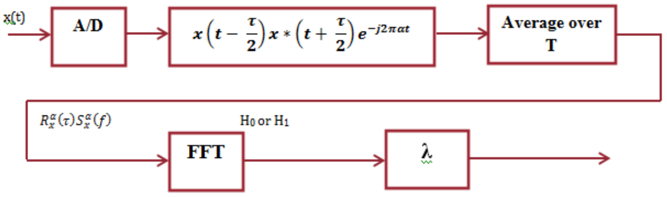


Fig - 3: Block diagram of the proposed Cyclostationary Feature Detection.

3.1 Signal Generation

The first step of this experiment was to generate signals belonging to different families of modulation schemes. This was done in order to highlight how certain modulation schemes can vary spectrally while others possess similar characteristics. This model features four very basic modulation schemes that are pulse shaped for over the air transmission BPSK, QPSK, M-PSK and QAM. Vectors of each transmission were saved to the MATLAB workspace.

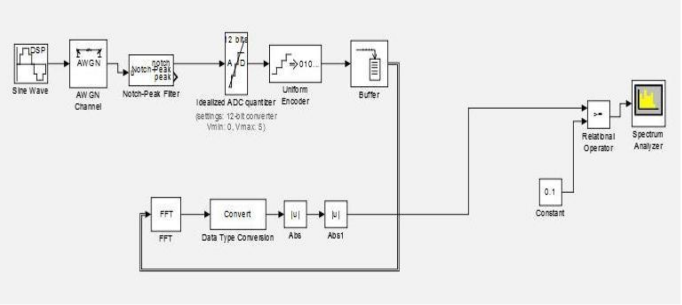
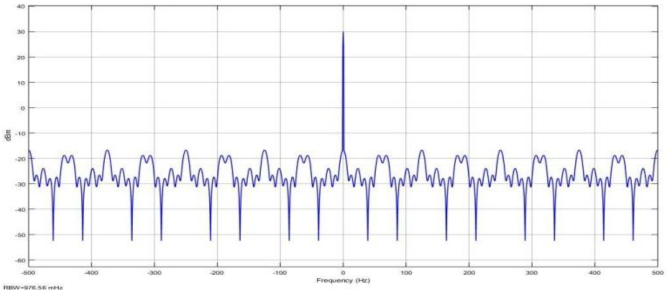


Fig -4a: Simulink model of cyclostationary without using modulation



ig -4b: Simulink model of cyclostationary without using modulation (output)

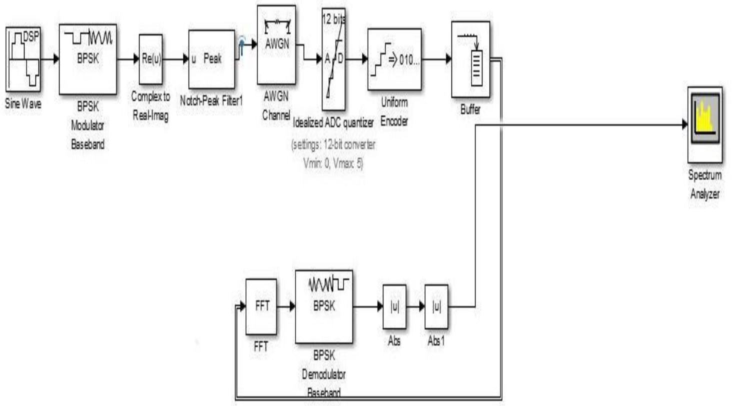


Fig - 5a: Simulink model of cyclostationary using BPSK modulation

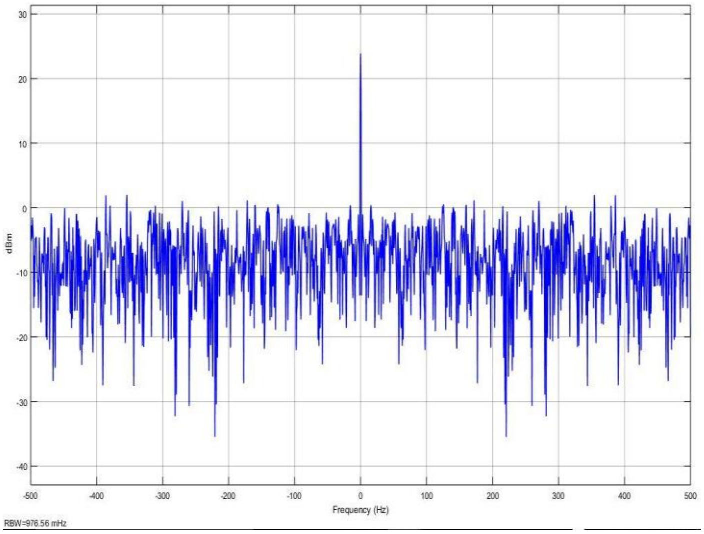


Fig – 5b: Simulink model of cyclostationary using BPSK modulation (output)

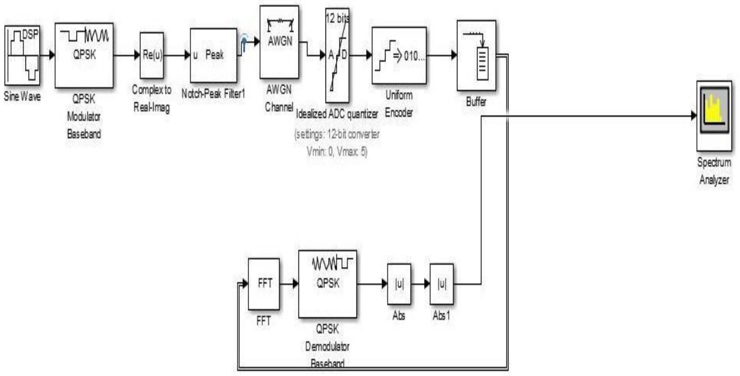


Fig – 6a: Simulink model of cyclostationary spectrum sensing using QPSK

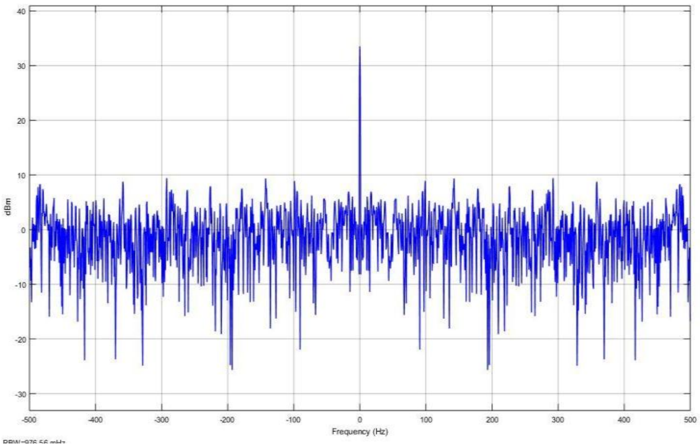


Fig – 6b: Simulink model of cyclostationary spectrum sensing using QPSK (output)

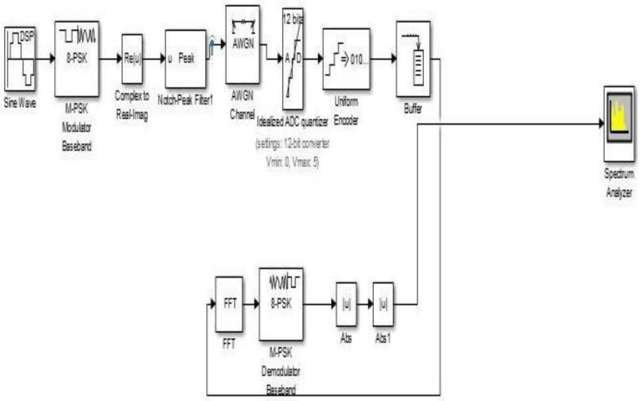


Fig – 7a: Simulink Model of Cyclostationary spectrum sensing using MPSK

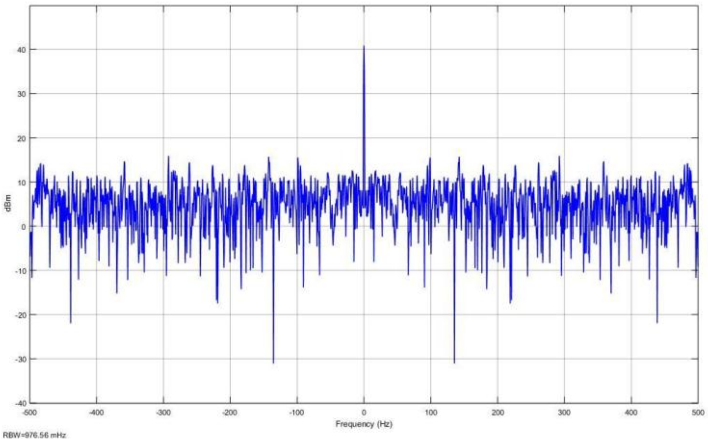


Fig – 7b: Simulink Model of Cyclostationary spectrum sensing using MPSK (output)

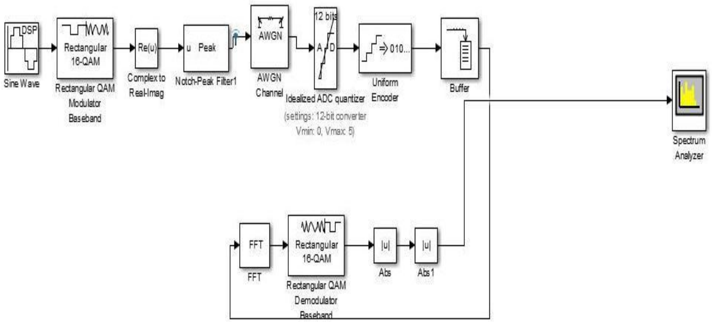


Fig – 8a: Simulink model of cyclostationary spectrum sensing using QAM

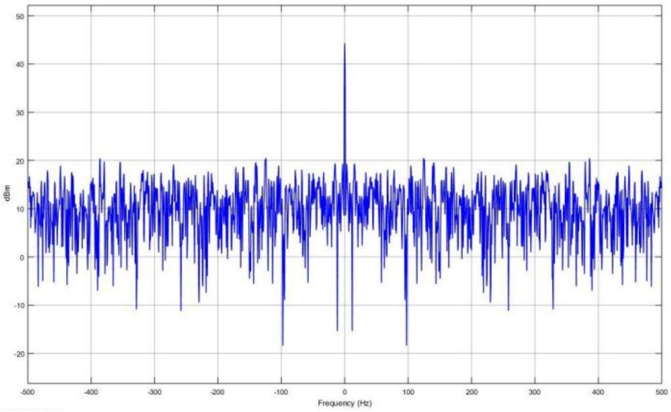


Fig – 8b: Simulink Model of Cyclostationary spectrum sensing using QAM (output)

When the transmitted signal used is QPSK modulated and the carrier frequency is 200 Hz and cyclostationary spectrum sensing is performed, we get two peaks at 400Hz frequency. The two peaks signify that the modulation scheme used by the primary user is QPSK and the reason for getting peaks at double the carrier frequency is autocorrelation of the received signal. When the transmitted signal used is BPSK modulated and the carrier frequency is 200 Hz and cyclostationary spectrum sensing is performed, we get a single peak at 400Hz frequency which signifies that the modulation scheme used by the primary user is BPSK and the reason for getting a peak at double the carrier frequency is autocorrelation of the received signal.

4. SIMULATION RESULTS

The cyclic spectral density using cyclostationary detector has been plotted for white Gaussian noise, QPSK modulated signal for different SNR values. By observing the cyclic spectral density of signal, the decision about the signal presence and its modulation scheme can be made. When the transmitted signal used is QPSK modulated and the carrier frequency is 200 Hz and cyclostationary spectrum sensing is performed, we get two peaks at 400Hz frequency. The two peaks signify that the modulation scheme used by the primary user is QPSK and the reason for getting peaks at double the carrier frequency is autocorrelation of the received signal.

The performance of a detector is characterized by two parameters, the probability of missed detection (P_{MD}) and the probability of false alarm (P_{FA}), which are defined as:

$\varepsilon = P_{FA} = \text{Prob}\ \{\text{Decide } H_1|H_0\}$ and
$\delta = P_{MD} = \text{Prob}\ \{\text{Decide } H_0|H_1\}$.
A typical receiver operating characteristic (ROC), which is a plot of $1-\delta$, the probability of detection (P_D), versus the probability of false alarm (P_{FA}), is shown in Fig -9, 10 and 11.

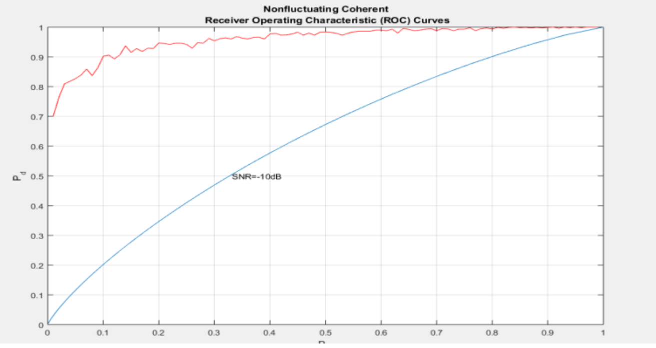


Fig – 9: Performance at SNR of -10dB

Fig – 10: Performance at SNR of -15dB

Fig – 11: Performance at SNR of -20dB

The graph represents probability of false alarm x axis and in y axis the probability of detection is represented. In Fig - 9 at low SNR -10dB, it begins with high probability of detection (0.7210). In Fig - 10 When decrease low SNR to -15dB, cyclostationary detection begin with probability of detection(0.1840)and in Fig - 11 at low SNR to -20dB, cyclostationary detection is begin with probability of detection(0.073). It is observed that cyclostationary detection probability is decrease when decreased SNR.

3. CONCLUSION

In this paper we have implemented Simulink based spectrum sensing using Cyclostationary Detection technique. Cyclostationary feature detector implementation can differentiate the modulated signal from the additive noise, distinguish Primary User signal from noise. It is used at very low SNR detection by using the information embedded in the Primary User signal which does not exist in the noise. The merits of the Cyclostationary Detection technique is that it is robust in low SNR and robust to interference, whereas the demerits of this technique is that it requires partial information of the primary user and that it has a high computational cost. With Cyclostationary spectrum sensing, the primary user's modulation scheme can also be easily found out.

REFERENCES

[1] M. Ghozzi, M. Dohler Marx and J. Palicot. Cognitive radio: methods for the detection of free bands, ComptesRendus Physique, vol. 7, no. 7, pp. 794-804, 2006.

[2] M. Bodepudi, R. C. Kolli, and R. K. Rayala, Spectrum sensing technique and issues in cognitive radio. International Journal of Engineering Trends and Technology(IJETT) Volume 4, 2013.

[3] D. Cabric, and R. W. Brodersen, Physical layer design issues unique to cognitive radio systems," in Proc. IEEE PIMRC, 2005.

[4] M. António and B. C. Nuno, White Spaces Communications in Europe ,Working Paper, Universidade de Aveiro, Aveiro, Portugal, 2011.

[5] Hong L., Junfei, Fangmin, X. Shurong, L. and Zheng, Z. (2008). Optimization of Collaborative Spectrum Sensing for Cognitive Radio, in Proc. IEEE International Conference on Networking, Sensing and Control, ICNSC' 08, Sanya, , pp. 1730–1733.

[6] G. Amir, and S. Elvino, Spectrum Sensing in Cognitive Radio Networks: Requirements, Challenges and Design Trade-offs, IEEE Communication Magazine. Page (s): 32-39, 2008.

[7] S. Haykin, Cognitive Dynamic Systems, Proceedings of the IEEE, vol. 94, no. 11, pp. 1910-1911, 2006.

[8] W. Ejaz, N. Hasan, M. Asam and S. Kim, Improved local spectrum sensing for cognitive radio networks. EURASIP J. Adv. Signal Process, 2012.

[9] I. F. Akyildz, B. F. Lo, and R. Balakrishnan, Cooperative spectrum sensing in cognitive radio networks: A survey. *Physical Communication*, vol. 4, no. 1, pp. 40-62, 2011.

[10] M. M. Buddhikot and K. Ryan, Spectrum management in coordinated dynamic spectrum access based cellular networks, in: Proc. IEEE DySPAN 2005, pp. 299-307, 2005.

[11] Y. Helin, X. Xianzhong, and W. Ruyan, SOM- GA-SVM Detection Based Spectrum Sensing in Cognitive Radio. National Nature Science Foundation of China, 2012.

[12] K. Hamdi and K. B. Letaief, Cooperative communications for cognitive radio networks, in 8th Postgrad. Symp. Converg. Telecom., Net. Broadcasting, Liverpool John Moores University, 2007.