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Performance Analysis of Energy and Cyclostationary based detection in Cognitive Radio Networks

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Abstract— Due to increase in innovations in communication and mobile technology new wireless devices, applications and services have evolved. The mobile data traffic is doubling every year which leads to demand for huge spectrum. The scarcity, expensiveness and fixed spectrum allocation policy will lead to the deficit in years ahead. The license holders of the spectrum are not utilizing it fully and efficiently, so there are times when spectrum is not being used and this is an opportunity wherein other users can use it to meet growing demands. This is called Cognitive Radio (CR). The information about availability of radio spectrum is the key parameter of functioning of cognitive radio. This paper describes the spaces in radio spectrum, fundamentals of cognitive radio technology and cognitive radio cycle. We compare the performance of energy and cyclostationary based detection method under AWGN and Rayleigh fading channel condition.

Key words: Cognitive radio (CR), Primary User (PU), Dynamic Spectrum Access (DSA), Federal Communications Commission (FCC)

I. Introduction

Due to technological advancement in the field of wireless communication and deployment of 3G, 3.5G and 4G, there is huge demand for Multimedia Broadcast and Multicast Services (*MBMS*). In order to realize this objective, the wireless system providers have to overcome the scarcity of frequency spectrum. The Federal Communications Commission (*FCC*) assigns spectrum to licensed holders, also known as primary users (*PU*). However, it is observed that a large portion of assigned spectrum remains underutilized due to fixed spectrum allocation policy as observed in “Fig. 1.” Thus, there is a need of a more intelligent and flexible way of utilization of wireless spectrum [3].

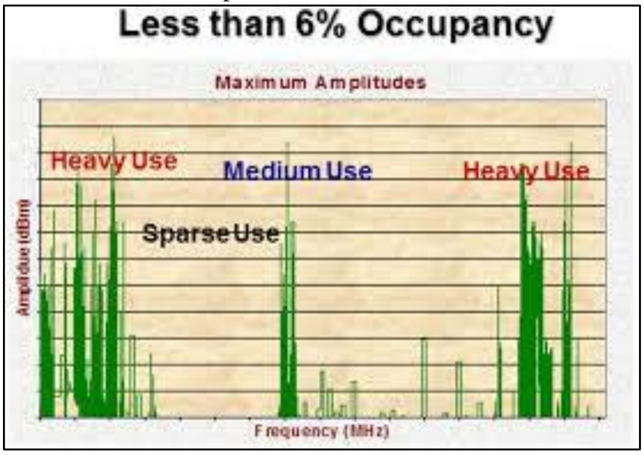

Fig. 1: Spectrum Usage [3]

To overcome the issue of utilization of limited spectrum efficiently, the concept of cognitive radio was proposed by Joseph Mitola in the year 1988.

It is a technology that enables next generation networks, also known as dynamic spectrum access (DSA) networks. In DSA, the users that do not have licensed spectrum also known as secondary users (SU) or Cognitive radio users are allowed to temporarily use the unutilized spectrum of primary users (PU). When PU reappears again the SU leaves that spectrum and is allocated another unused spectrum also called white space which is detected by some sensing technique. A typical CR network is defined as a radio that has ability to sense and gather the information such as frequency, power, bandwidth modulation etc. from the surrounding environment [1]. After receiving the needed information, it changes the transmitted parameters [5] and achieves optimum performance anywhere and anytime without interfering with licensed or unlicensed users.

Section II focuses on the spaces available in the radio spectrum, cognitive radio cycle. Section III describes the energy and cyclostationary based sensing methods. The further section IV and V focuses on results and conclusions.

II. COGNITIVE RADIO

This section describes the spaces in radio spectrum and cognitive radio cycle.

A. Spaces in Radio Spectrum

The FCC assigns spectrum to licensed holders, also known as primary users, on a long-term basis for large geographical regions. The inefficient usage of the limited spectrum necessitates the development of dynamic spectrum access techniques, where users who have no spectrum licenses, also known as secondary users, are allowed to use the temporarily unused licensed spectrum. Licensed portions of the spectrum consist of frequency bands that belong to one of the following categories as seen in “Fig.2.”

- White spaces: Primary users are absent. These bands can be utilized without any restriction.
- Grey spaces: Primary users are present. Interference power at primary receivers should not exceed a certain threshold called interference temperature limit.
- Black spaces: Primary user’s power is very high. Secondary users should use an interference cancellation technique in order to communicate.

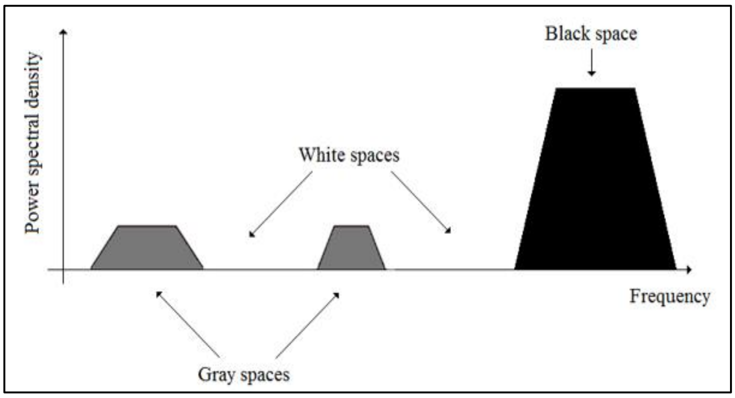

Fig. 2: Spaces in radio spectrum [6]

B. Cognitive Radio Cycle

A typical duty cycle of Cognitive Radio includes detecting spectrum white space, selecting the best frequency bands, coordinating spectrum access with other users and vacating the frequency when a primary user appears as shown in “Fig. 3 and 4.” Such a cognitive cycle is supported by the following functions:

- Spectrum sensing and analysis
- Spectrum management and handoff
- Spectrum allocation and sharing

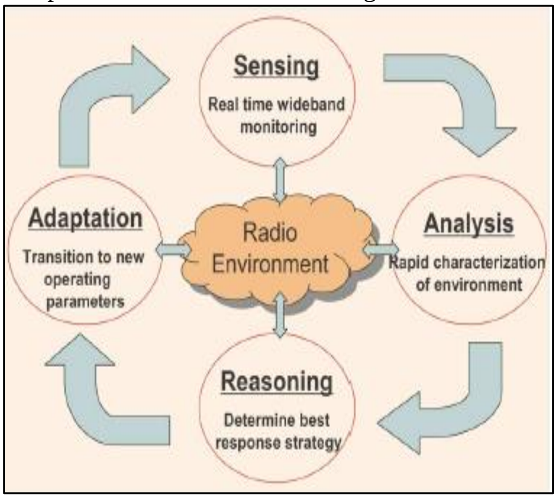

Fig. 3: Cognitive Cycle [1]

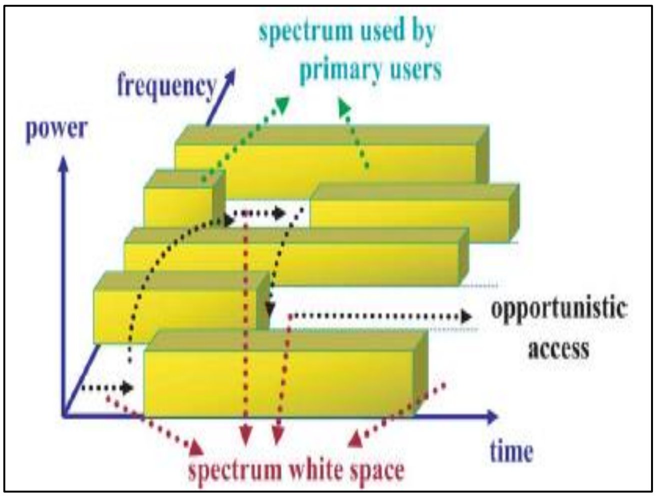

Fig. 4: Illustration of spectrum white space [3]

In spectrum sensing and analysis, CR detects the presence of white spaces in spectrum. If the primary users start using the licensed spectrum again its activity is detected through sensing by the CR so that harmful interference due to secondary user transmission is avoided. For instance, when a primary user reclaims the frequency band, the secondary user that is using the licensed band can direct the transmission to other available frequencies, according to the channel capacity determined by the noise and interference levels, path loss, channel error rate, holding time, and etc. [1]. After the white spaces have been recognized, spectrum management and handoff function of CR enables secondary users to choose the best frequency band available amongst the available white spaces and hop among multiple bands according to the time varying channel characteristics to meet various Quality of Service (QoS) requirements [1]. After the allocation of new spectrum, the CR adjusts its parameters according to the newly available spectrum to achieve optimal performance, which is one of the characteristic of CR known as reconfigurability. Before CR adjust their operating mode to environment variations, they must first gain necessary information from the radio environment. This kind of characteristics is referred to as cognitive capability, which enables CR devices to be aware of the transmitted waveform, radio frequency (RF) spectrum, communication network type/protocol, geographical information, locally available resources and services, user needs, security policy and so on [1].

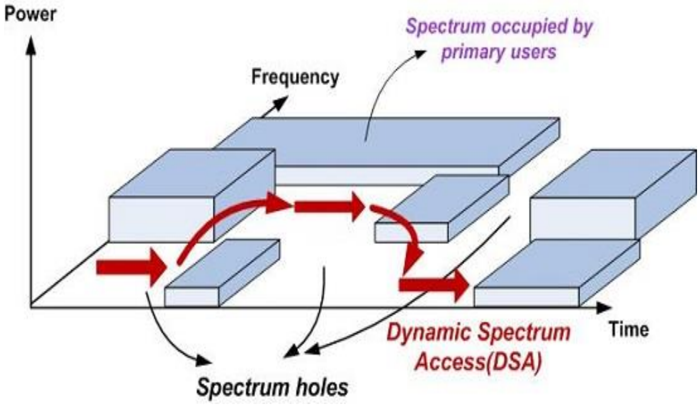

Fig. 5: Dynamic Spectrum Access [7]

In dynamic spectrum access as shown in "Fig. 5," a secondary user may share the spectrum resources with primary users, other secondary users, or both. Hence, a good spectrum allocation and sharing mechanism is necessary to achieve high spectrum efficiency. Since primary users own the spectrum rights, when secondary users co-exist in a licensed band with primary users, the interference level due to secondary spectrum usage should be limited by a certain threshold. When multiple secondary users share a frequency band, their access should be coordinated to avoid collisions and interference [1].

III. Spectrum Sensing in Cognitive Radio

This section describes energy detector and cyclostationary based detection methods. This paper focuses on spectrum sensing, it is defined as the task of finding spectrum holes by sensing the radio spectrum in the local neighbourhood of the *CR* user. The task of spectrum sensing involves

- Detection of spectrum holes
- Spectrum resolution of each spectrum hole
- Estimation of direction incoming interferer
- Signal classification

It is done across frequency, time, geographic space, code and phase. A number of different methods are proposed for identifying the presence of signal transmission [8]. They are as follows

- Energy detection based
- Wavelet based
- Cyclostationary based
- Radio identification based
- Matched filtering based

In this paper we focus on energy detection and cyclostationary based spectrum sensing [9].

A. Energy Detection based Spectrum Sensing

This is one of the simplest method for spectrum sensing. This method does not require pre- knowledge of primary user. This method is simply based on energy of received signal and its comparison with threshold.

1) Block Diagram

"Fig. 6," shows block diagram of energy detector. In this method signal is first captured and then it passes through the bad pass filter in order to select desired band. Following block is squaring device. The squared samples then integrated over captured time interval. These two blocks actually compute average energy contained in signal. This is called test statics and then it is compared with threshold if it is above threshold then signal is detected and if it is below threshold primary signal is assumed to be absent. This is opportunity for secondary user to use the spectrum.

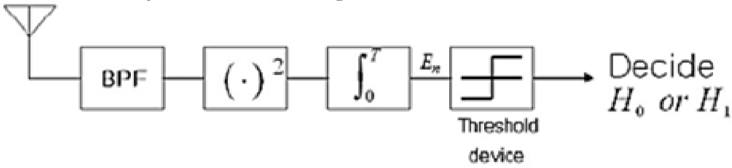

Fig. 6: Energy detector [10]

2) Algorithm

Sensing algorithm consist of following steps

- Primary user signal *x(t)* is basically QAM modulated signal of 50Hz with carrier frequency of 1KHz.
- Depending on two hypothesis received signal at detector is [11]

$$y(t) = n(t) \qquad 0 < t < T \quad \text{under H0} \qquad (2.1)$$

$$y(t) = x(t) + n(t) \qquad 0 < t < T \quad \text{under H1} \qquad (2.2)$$

Where y(t) – Received signal from CR

n(t) – Additive white Gaussian noise (AWGN)
x(t) – Transmitted signal from Primary user
H0 – Spectrum is not occupied by Primary User
H1 – Spectrum is occupied by Primary User
T – Observation time interval

- y(t) is sampled at 3KHz to obtain y(n), N=1000 samples taken for detection.
- Power spectrum of y(n) is computed to obtain test statics.
- Threshold λ for detection can be obtained by using formula as in "(2.3)" [11].

$$\lambda = \sqrt{2N(\sigma_n^4)}\ Q^{-1}(P_f) + N\,(\sigma_n^2) \qquad (2.3)$$

Where

σ_n= Noise variance
σ_s = Signal Variance

There are basically two important parameters which measure the performance of spectrum sensing methods. The first is called probability of detection (P_d) which is defined as probability that primary signal is present and detected correctly by cognitive radio spectrum sensor. The second parameter is called probability of false alarm (P_f) which is defined as probability that primary user is absent but cognitive spectrum sensor detect that primary user signal is present, this can be due to noise or other interference. Theoretically probability of false alarm should be as low as possible. Apart from these two one more parameter can be defined called probability of missed detection (P_{md}). It can be defined as probability that primary signal is present but CR missed to detect it.

The detection probability and the false alarm probability can be expressed as in "(2.4)" and "(2.5)" [12].

$$P_d = P(y(n) > \lambda|H0) = Q\left(\frac{\lambda - N\,\sigma_n^2}{\sqrt{2N\,\sigma_n^4}}\right) \qquad (2.4)$$

$$P_f = P(y(n) > \lambda|H1) = Q\left(\frac{\lambda - N(\sigma_n^2+\sigma_s^2)}{\sqrt{2N(\sigma_n^2+\sigma_s^2)^2}}\right) \qquad (2.5)$$

B. Cyclostationary based Spectrum Sensing

Most of our communication and control systems employ signal formats that involve some form of periodicity. This information signals are modelled by random processes that are Cyclostationary, that is whose mean and autocorrelation have some form of periodicity.

1) Block Diagram

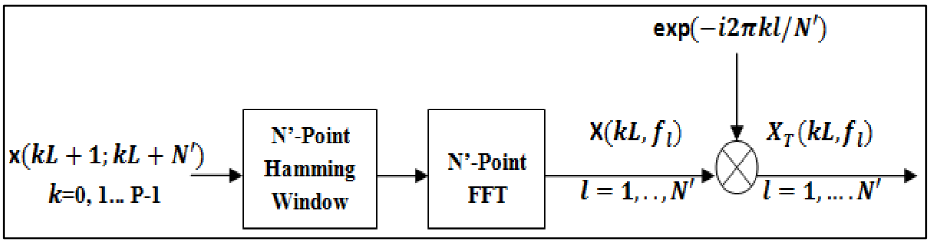

Fig. 7: Cyclostationary based detector [13]

The essence of this Cyclostationary method is the fact that periodicity can be extracted from random data by applying certain non-linear transformation. Mathematically it can be seen that sinusoidal signal is extracted by applying transformation like auto-correlation function.

But as signals usually have distinctive feature in the frequency domain that is not easily seen in the time domain. Those features are generally used for detecting the presence of primary signal embedded in noise. Hence, Spectral Correlation density function (*SCD*) which is Fourier transform of autocorrelation is utilized.

The widely used algorithm in it is FFT accumulation method (*FAM*) which is implemented as shown in "Fig. 7."

2) Algorithm

- The signal operation takes place in terms of samples which are passed through hamming window serving as input band pass filter.
- Then having a Fourier transform with exponential multiplication to generate complex demodulates of original signal.
- This demodulates as seen in Fig. 8. undergoes autocorrelation (Multiplication of signal with its conjugate serve as ACF) and its Fourier transform leads to Spectral Correlation Density (SCD).

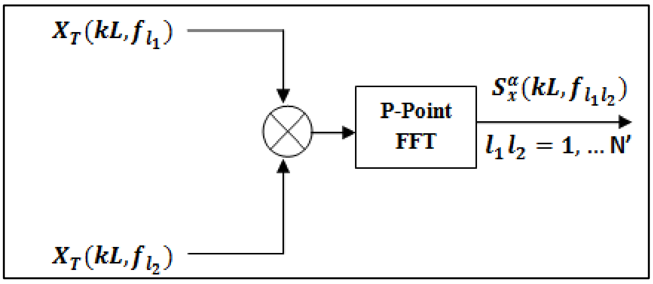

Fig. 8: Demodulation [13]

The extracted periodic signal has certain frequency which is called as cyclic frequency which can be viewed as a peak in “Fig. 13,” that is frequency domain representation.

IV. RESULTS

A. Energy Detector

All the simulations are done in MATLAB for two cases. In first case signal is passed through AWGN channel and in second case signal is passed through Rayleigh fading channel.

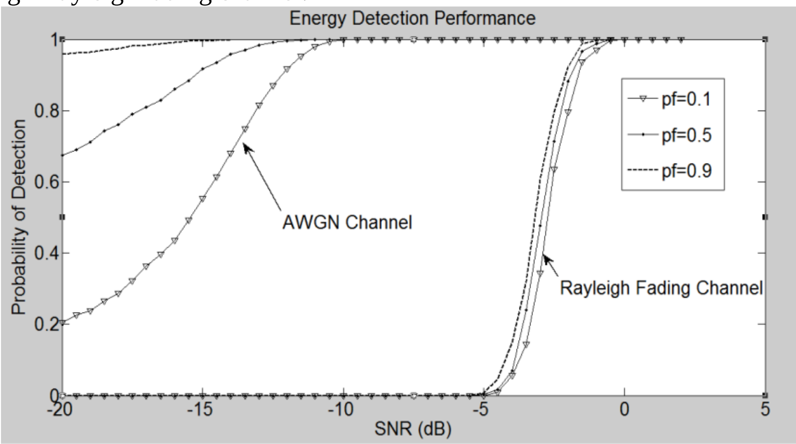

Fig. 9: SNR Versus Probability of detection

“Fig. 9,” illustrates plot of SNR (dB) versus probability of detection (P_d) for different values of probability of false alarm (P_f). We observe that as SNR of signal increases probability of detection also increases. Probability of detection also increases with increase in probability of false alarm which is actually to be minimized. We also observe from “Fig. 9,” that SNR wall for AWGN channel is -10 dB for probability of false alarm equal to 0.5 whereas for same value of probability of false alarm for Rayleigh channel SNR wall is -1dB. So, Rayleigh channel requires improved SNR than AWGN channel for detection of signal.

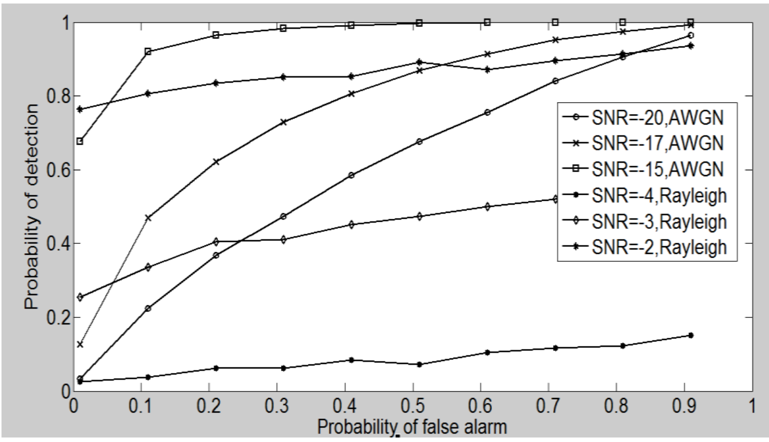

Fig. 10: Probability of false alarm versus probability of detection

For the given probability of false alarm (P_f) say 0.1 it can be observed from “Fig. 10,” that probability of detection (P_d) is more in case of SNR value equal to -15dB in comparison to SNR value equal to -20dB under AWGN channel. Whereas for Rayleigh fading channel under these SNR condition probability of detection is equal to zero. The signal can be detected if SNR value of signal is greater than -4dB. This graph gives information about SNR requires for correct detection.

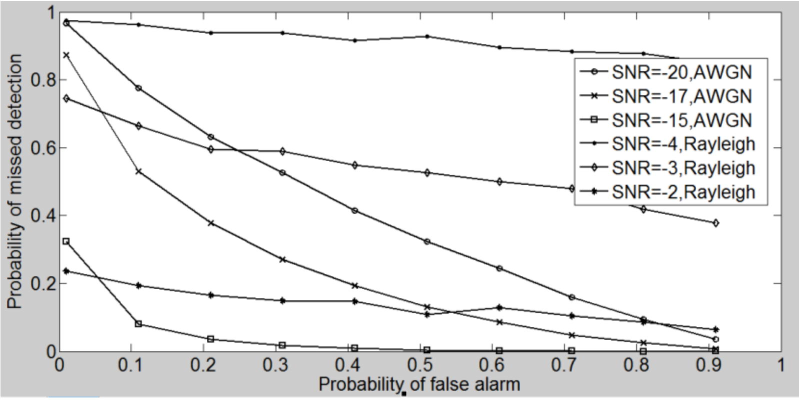

Fig. 11: Probability of false alarm versus probability of missed detection

The plot of probability of false alarm *(P_f)* versus probability of missed detection (P_{md}) for different values of SNR (dB) is shown in "Fig. 11." It can be observed that as probability of false alarm increases probability of missed detection decreases. As SNR of signal is go on increasing the possibility that *CR* missed to detect it becomes less. For Rayleigh fading channel missed detection is more than AWGN channel at particular value of SNR of signal.

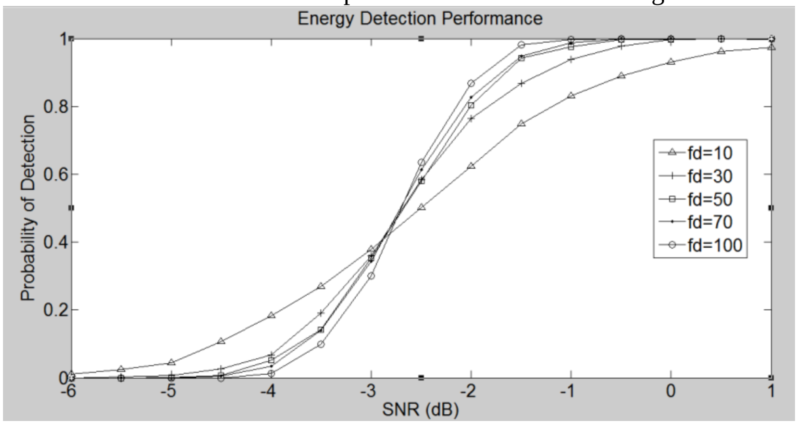

Fig. 12: SNR versus probability of detection for Rayleigh fading channel

"Fig. 12," illustrates the plot of SNR (dB) versus probability of detection (P_d) for different values of Doppler shift (fd) under Rayleigh fading channel. It can be observed that in low SNR range that is less than -3dB as Doppler spread increases probability of detection decreases. But after SNR equal to -3dB as Doppler spread increase the probability of detection improves. It is due to improved SNR which overcome the problem of Doppler spread and hence detection of signal increases.

B. Cyclostationary Detector

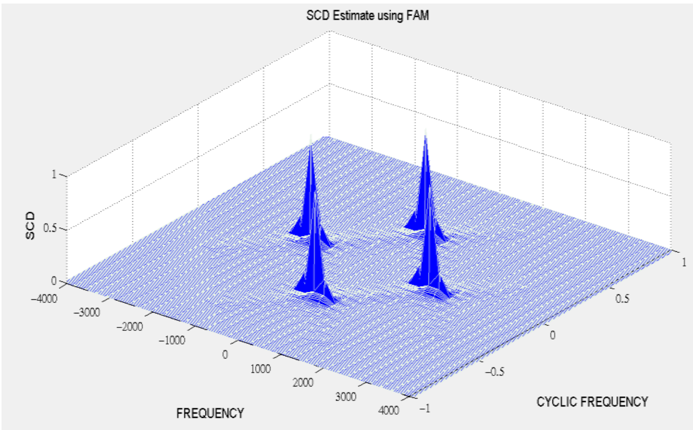

Fig. 13: Frequency domain representation

"Fig. 13," illustrates the magnitude of the SCD function estimates for an 'AMSSB' signal in each region of the bi-frequency plane with co-ordinates f and cyclic frequency. This peak resembles the presence of primary user and also it is useful for estimating the amount of energy and its distribution across different frequencies, channel bandwidth, its shape, transmission technology, centre frequency etc. It is also possible to distinguish primary user from secondary user by having prior information about primary user.

Parameters	**Energy Detector**	**Cyclostationary Detector**
Reliability and Accuracy	Poor	Medium
Prior Signal Information	No	Some
Ability to differentiate signals	Poor	Medium

Sensing Time	Medium	High
Complexity	Low	High

Table 1: Results of Energy Detector and Cyclostationary Based Detector [14]

V. CONCLUSION

In this paper energy based and cyclostationary based spectrum sensing methods for cognitive radio networks are analysed. The analysis is performed under two channel conditions. It is observed that cyclostationary based method has more ability to differentiate signals in comparison to energy detector, however due to complex nature cyclostationary method requires more sensing time. In case of energy detector, it is observed that probability of detection increases with more SNR and this method perform better in AWGN channel than Rayleigh fading channel.

REFERENCES

[1] Beibei Wang and K. J. Ray Liu "Advances in Cognitive Radio Networks: A Survey," IEEE Journal of Selected Topics in Signal Processing, Vol. 5, No. 1, February 2011.
[2] http://money.cnn.com/2012/02/21/technology/ spectrum_crunch/
[3] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey," Comput. Netw., vol. 50, pp. 2127 –2159, May 2006.
[4] Joseph. Mitola, Ed.,"Special issue on software radio", IEEE Communication Magazine, May 1995.
[5] "Spectrum Policy Task Force Report," FCC, Nov. 2002, FCC Doc. ET Docket No. 02-135.
[6] George Fortetsanakis, "Introduction to cognitive radios part one", Presentation.
[7] Goutam Ghosh, Prasun Das and Subhajit Chatterjee, "Simuation and analysis of cognitive radio system using Matlab", International Journal Next Generation Networks(IJNGN), Vol 6, No 2,June 2014.
[8] Tevfik Yucek and Huseyin Arslan, "A survey of Spectrum Sensing Algorithms for Cognitive Radio Applications", Communication Surveys and Tutorials, IEEE 2009.
[9] MahsaDarakhshani, Masoumah Nasiri Kenari, "Cooperative Cyclostationarity Spectrum Sensing in Cognitive Radio at low SNR regimes", IEEE conference ICC 2010.
[10] https://www.researchgate.net/publication/4325123_Improved_Reliability_of_Spectrum_Sensing_using_Energy_Detector_in_Cognitive_Radio_System
[11] Sun Yuhang, "Spectrum Sensing in Cognitive Radio Systems using Energy Detection", University of Gavle, 09/2011.
[12] Zhai Xuping, Pan Jianguo," Energy-Detection Based Spectrum Sensing for Cognitive Radio", Key Laboratory of Special Fiber Optics and Optical Access Networks, Ministry of Education, School of Communication and information engineering, Shanghai University, 200072, China.
[13] Evandro Luiz da Costa "Detection and Identification of Cyclostationary Signals", Naval Postgraduate School, March 1996.
[14] Adrish Banerjee, "Spectrum Sensing: How to cooperate for better sensing", Department of Electrical Engineering, Indian Institute of Technology Kanpur.