A Novel Method of Cognitive Spectrum Sensing in DWT based MIMO-OFDM

Patel Hirenkumar Sureshbhai[1], Akant Kumar Raghuwanshi[2]
[1]M.Tech Scholar [2]Assistant Professor
Vedica Institute of Technology
RKDF University, Bhopal

ABSTRACT

Spectrum sensing is an important part of cognitive radio systems to find spectrum hole for transmission which enables cognitive radio systems coexist with the authorized radio systems without harmful interference. The resource of radio frequency spectrum is not efficiently managed, and the increased dependence on wireless devices in the modern era just adds to the problem. The concept of cognitive radio aims to overcome the problem of limited radio frequency spectrum by helping to achieve improved spectral management, utilization, and efficiency. One of the ways to improve the efficiency and utilization of an available frequency spectrum is to share it between the users. One of the most important step for spectrum sharing is spectrum sensing. There are many spectrum sensing algorithms available for cognitive radio. For detection purpose, MIMO OFDM transmitter serves as a primary user to represent busy channel or a secondary user to represent idle channel. For reconstruction purposed, MIMO_OFDM transmitter is considered to be another CR user trying to communicate with MIMO OFDM CR receiver. The proposed MIMO-OFDM CR receiver, signals go through the IDWT block first and transmitted by multiple antennas. Then cyclic prefix will be added after IDWT block. Then Cyclostationary features of the signal are estimated to check whether the received signal is from primary user or from secondary user. If the signal is from primary user, CR user leaves the channel immediately. Id the received signal is intended for the CR receiver from the transmitter, it reconstruct the signal. This research analyses the Cyclostationary Detection based method of cognitive spectrum sensing in DWT based MIMO-OFDM under different modulation scheme. The simulation result used the probability of false alarm while evaluating spectrum sensing. Similarly, BER and MSE is also evaluated using different modulation scheme.

1. Introduction

Modern wireless systems are capable of offering a wide variety of high data-rate applications to various users at the same time. In order to realize this objective, they have to overcome the practical constraints imposed by the resources they need such as power and spectrum. But, these resources are quite limited in nature. The rapid increase in the number of wireless systems and the scarcity of these resources, especially of the frequency spectrum, continues to be a problem. Cognitive radio is a concept that aims to overcome these very problems by proposing an opportunistic spectrum usage approach, in which the frequency bands that are not being used by their licensed users can be utilized by cognitive radios [1].

The basic function of a cognitive radio is to accurately sense the spectrum by evading any chances of obstruction or interference to the primary or licensed users. By using spectrum sensing, cognitive radios can adapt themselves to the external wireless network. The cognitive radio users can be divided into primary users (PU) and secondary users (SU). The users who has the license to use a specific band of the spectrum are known as the primary users. On the other hand, secondary users (SU) do have license to use the spectrum but can use the spectrum when the PU is absent [2]-[5].

In a cognitive radio (CR) network, secondary users (SUs) are allowed to utilize frequency bands of primary users (PUs) for communication whenever the communication channel is not engaged by PUs. To reuse the available spectrum in the network, the SUs sense the signals in the communication channel and detect whether the PUs are using the channel. Whenever a PU is transmitting a signal in a given channel in the network, the SUs are required to vacate the channel within a certain amount of time. If the PUs are not using it, the SUs are allowed to communicate using the channel. Cognitive radios are required to detect the PU signals even at low signal-to-noise ratio (SNR) conditions and in fading environments efficiently [6]-[10]. Spectrum Sensing is a key aspect of cognitive radio (CR). The objective of cognitive radio is to utilize the empty channels in the spectrum to reduce the traffic in congested areas. Proper sensing of the spectrum is the integral part of this software defined radio. Also, communication should not be obstructed or hindered by fading. Spectrum sensing in cognitive radio is applicable to radio frequencies only. Observing the unused spectrum of a licensed user is crucial for the concept of cognitive radio to be a success [11]-[15]. So, the primary user is sensed perpetually to allow channel mobility of SU to another part of the spectrum; in case the primary user initiates to transmit. This requires an efficient hardware with minimum possible error. The threshold for detection forms the crux. This should be in consideration of the interference in the worst-case scenario. Future spectrum analysis and decision-making processes are dependent on sensing the primary user correctly [16]-[20]. This is defined as managing the spectrum dynamically. There are various spectrum sensing techniques which are employed for spectrum sensing; such as:

Matched-Filter Detection: The matched-filter (also known as coherent detector), can be considered as a best sensing technique if CR has prior knowledge of the PU. It is very accurate because it maximizes the received signal-to-noise ratio (SNR). Matched-filter correlates the received signal with its time shifted version. Comparison between the final output of the matched-filter and a pre-determined threshold will determine the presence of primary user. Hence, if this information is not accurate, then the matched-filter will operate weakly [21].

Cyclostationary Feature Detection: Implementation of a Cyclostationary feature detector is a spectrum sensing technique which can differentiate the modulated signal from the additive noise. A signal is said to be Cyclostationary if its mean and autocorrelation are a periodic function. Cyclostationary feature detection can distinguish PU signal from noise, and used at very low Signal to Noise Ratio (SNR) by using the information present in the PU signal that are not present in the noise [22]-[24].

Energy Detection: Energy detection is the most popular way of spectrum sensing because of its low computational and implementation complexities. The receivers do not need any previous knowledge about the primary users. An energy detector (ED) simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal [25]-[27]. Table I shows the comparative study of different research work performed in cognitive radio spectrum sensing.

Table I: Comparative Chart of Cognitive Radio Using Cyclostationary based Spectrum Sensing

Author	**Technique**	**Conclusion**
Yan Jiao and Inwhee Joe (2014) [29]	Focused on energy consumption because of spectrum sensing. establish a Markov model-based mathematical modeling for analyzing the relationship between spectrum sensing time interval.	Result demonstrate that the proposed strategy with dynamic adaptive spectrum sensing time interval exceeded listen before talk (LBT).
Goutam Ghosh (2014) [2]	Energy detection method of spectrum sensing	Spectrum Access in Cognitive Radio demonstrated successfully without interfering with the other frequency bands used by the primary user (PU). In the low SNR the performance of the system degrades.
Yang Mingchuan (2015) [8]	An algorithm based on the cyclostationary feature detection and theory of Hilbert transformation is proposed	Comparing with the conventional cyclostationary feature detection algorithm, this approach is more flexible.
B. Senthil kumar (2015) [30]	Proposed An Efficient Spectrum Sensing Framework and Attack Detection in Cognitive Radio Networks using Hybrid ANFIS.	The proposed approach minimizes Linear Minimum Mean-Square Errors
Danda B Rawat (2016) [7]	Evaluated the performance of the MIMO-OFDM cognitive radio (CR) system where CR devices continuously sense the channel to check whether it is idle or not using compressed sensing with cyclostationary detection.	Found that the reconstruction depends directly on the number of sub-carriers in MIMO-OFDM.
Tejaskumar M. Gojariya (2016) [19]	The popular cyclostationary beam formers which has two algorithms namely the adaptive cross self-coherent- restoral (ACS) and cyclic adaptive beam forming (CAB), algorithms that provide good performance in the case of medium or weak interference.	The method proposed not only achieves much higher sensing accuracy with fewer samples at a low SINR but also has a far more implementation complexity than the conventional cyclic spectrum estimation based cyclostationary feature detectors.

F. Rahimzadeh (2017) [28]	Proposed a sensing algorithm for secondary users (SUs) that uses a set of normalized least mean square (NMLS) adaptive filters in order to estimate the signal in the communication channel from its frequency shifted samples.	low computational complexity and requires a very small number of signal samples for sensing.

2. Proposed Methodology

The System model for MIMO-OFDM based transmitter with M_t antenna and receiver with M_r antenna as shown in figure 1.

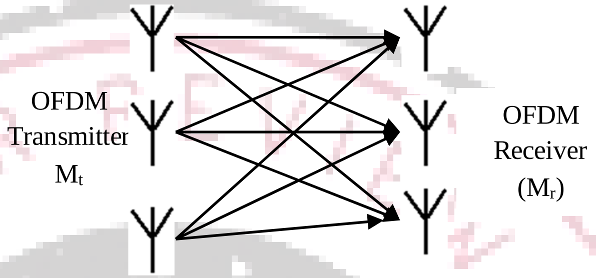

Figure 1: MIMO-OFDM Transmitter and Receiver

For detection purpose, MIMO-OFDM transmitter serves as a primary user to represent busy channel or as a secondary user to represent idle channel. For reconstruction purpose, MIMO-OFDM transmitter is considered to be another CR user trying to communicate with the MIMO-OFDM transmitter CR receiver. In conventional model of MIMO-OFDM based CR, signal go through the IFFT block first and transmitted by multiple transmitting antennas. In this research work the IFFT block is replaced with IDWT block because wavelets are localized in both time and frequency whereas the standard Fourier transform is only localized in frequency. Then cyclic prefix is added after the signal goes through the IDWT block and then the signal is transmitted. In the proposed model, the received signal at antennas are first recombined using combining vector and send for demodulation. In this proposed model a cyclostationary model is also added in order to detect whether the received signal is from primary user or from the secondary user. If the signal is from primary user, CR user leaves the channel immediately. If the received signal is intended for the CR receiver from its transmitter it reconstructs the signal. The model shown for figure 2 has basically two essential parts that is MIMO-OFDM based transmitter and MIMO-OFDM based receiver.

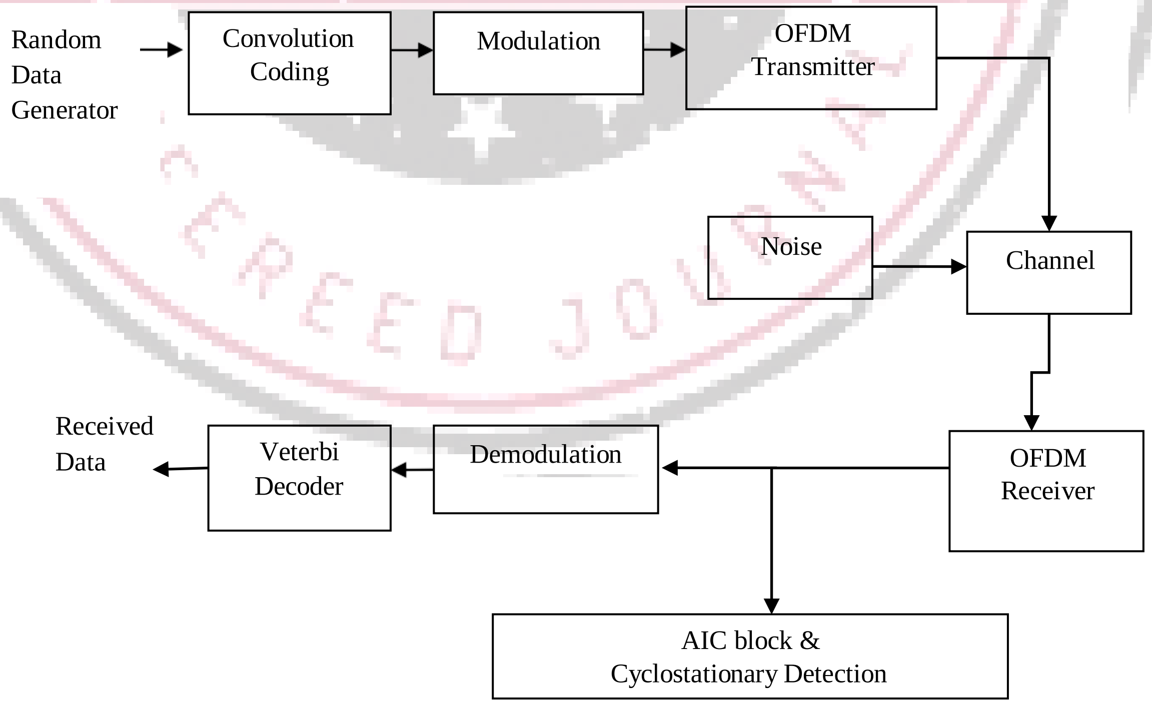

Figure 2: Flow diagram for transceiver of MIMO-OFDM

OFDM Transmission:

Let x be the baseband signal that is to be transmitted over MIMO with M_t and M_r antennas. The signal x can be expressed as $x=[x_1(m), x_2(m)\ldots\ldots x_{Mt}(m)]$ for mth subcarrier and for ith transmitting antenna $x_i=[x_i(1), x_i(2), \ldots\ldots\ldots x_i(N_s)]$.

After data signals are modulated using QPSK, BPSK and 64-QAM modulation scheme.

After IDWT is applied using equation that is represented as:

$$(k) = \sum_{m=0}^{\infty} D_m^n 2^{\frac{m}{2}} \psi(2^m k - n)$$

Where D_m^n are the wavelet coefficients and ψ(t) is the wavelet function with compressed factor m times and shifted n times for each subcarrier (number k, $0 \leq k \leq N-1$).The wavelet coefficients are the representation of signals in scale and position or time. At the receiver side, the process is inversed. The data is transmitted in noisy channel. The channel is Rayleigh fading with AWGN noise. The equation for this transmission is given below:

$$x' = x + n$$

Where, x is transmitting signal and n is noise added in the channel. The new signal is modified with noise. So, the receiving M_r will receive x'.

OFDM Receiver:

The received signal is then processed by the combining vector of the j-th receive antenna. Let the combined vector be represented as s(j). Then the s(j) is sent to AIC block, as shown in figure 4, that is used to compress the sparse signal where LFSR generates a pseudorandom sequence to use it as a modulator.

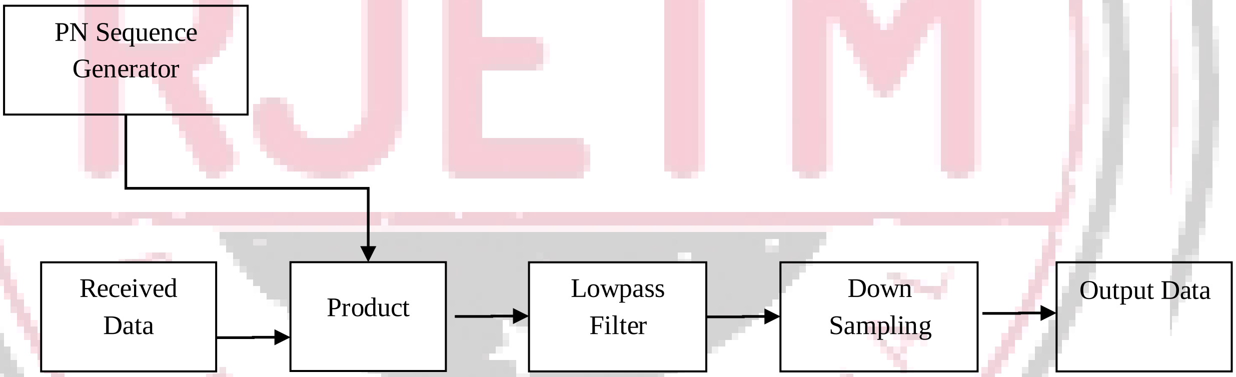

Figure 4: AIC Block Diagram

The modulated signal is then passed through low pass filter. The signal after low pass filter is then passed through a down sampler to gather the non-zero discrete values from the sparse signal. The AIC block works as a compressive sampler and the complexity of the optimization problem that grows exponentially with signal length.

Cyclostationary Detection:

The signal output from AIC block is considered to be as cyclostationary signal. Cyclostationary feature detection method is also called as spectral correlation method because it uses cyclic correlation function for detecting present of signal in a given spectrum. These process having periodicity in statistical property like mean, autocorrelation are cyclostationary. By using periodic statistics of primary user waveform, CR can detect random signal in presence of noise. And these features are extracted using spectral correlation function. Fig.4 represent basic block diagram of cyclostationary based detection method.

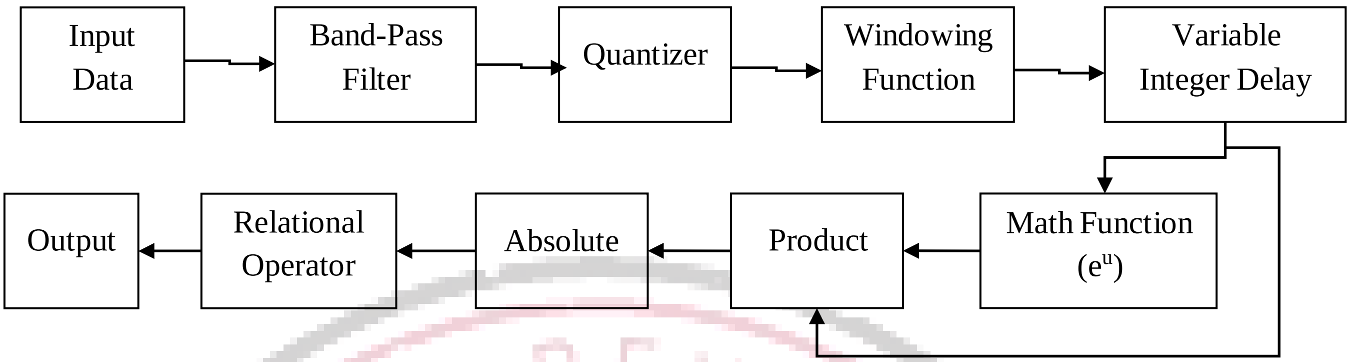

Figure 4: Cyclostationary Detection Model

In cyclostationary detection block the signal is passed through filter. Here band pass filter is used to pass particular band of frequency and reject the frequencies outside that range. The primary 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 DWT 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. Now absolute value of signal is compared with constant value for detecting the primary user.

3. Result Analysis

Relation between False Alarm and decision threshold: The false alarm P_f and the decision threshold value holds the following relationship.

$$P_f=(1-\lambda_t)^{M-1} \quad (1)$$

Proof: When noise is additive white Gaussian noise in the system, Cumulative Distribution Function (CDF) of the detection threshold λ is as:

$$F_\lambda = 1-(1-\lambda)^{-1}, 0 \le \lambda \le 1 \quad (2)$$

The false alarm P_f is calculated as

$$P_f = P[\lambda \ge \lambda_t | H_o] = 1 - F_\lambda \quad (3)$$

Where H_o represents the absence of primary user.

By substituting the value of F_λ into equation 3, it has been proved the relationship between false alarm and decision threshold.

So, threshold can be computed as:

$$\lambda_t = P_f^{\frac{1}{M-1}} \quad (4)$$

Relation between Probability (P_m) of misdetection and probability of detection (P_d): For the MIMO-OFDM based cyclostationary detection, Probability of misdetection (P_m) is calculated as:

$$P_m = 1 - \left(\frac{\lambda_t \sqrt{N_s(M_r-1)}\left(1-\frac{1+\gamma}{N_s\gamma}\right)}{1+\gamma} - \frac{\sqrt{N_s}}{1+\frac{M_r-1}{N_s\gamma}} \right) \quad (5)$$

Proof: Probability of detection (P_d) is calculated as:

$$P_d = P[[\lambda \geq \lambda_t | H_1]$$

$$= Q(\frac{\lambda_t\sqrt{N(M_r-1)(1-\frac{1+\gamma}{N_s\gamma})}}{1+\gamma} - \frac{\sqrt{N_s}}{1+\frac{M_r-1}{N_s\gamma}}) \quad (6)$$

Where Q(.) is the q-function and λ is the signal-to-noise ratio (SNR) at the receiver and H_1 represents the presence of primary user.

The probability of misdetection(P_m) is:

$$P_m = 1 - P_d \quad (7)$$

Relation between Cumulative Distribution Function (CDF) and decision threshold: The Cumulative Distribution Function (CDF) and the decision threshold value holds the following relationship.

$$CDF=1-(1-\lambda_t)^{M-1}, \; 0\leq \lambda_t \geq 1 \quad (8)$$

The graph of probability of false alarm i.e. P_f is plotted versus decision threshold i.e. λ_t in figure 5. From figure it is analyzed that the probability of false alarm reduces with increasing samples.
The graph of Cumulative Distribution Function i.e. CDF is plotted versus decision threshold i.e. λ_t in figure 6. From figure it is analyzed that the probability of CDF increases with increasing samples.

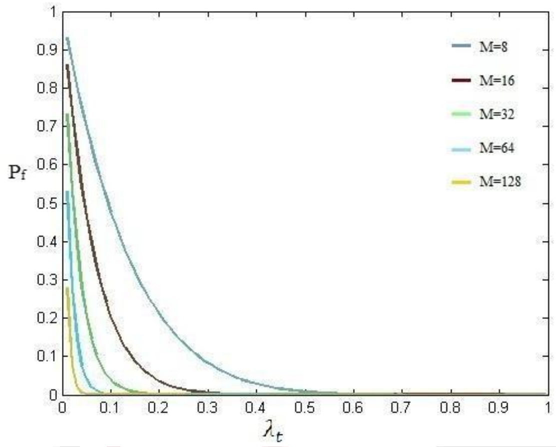

Figure 5: P_f vs λ_t

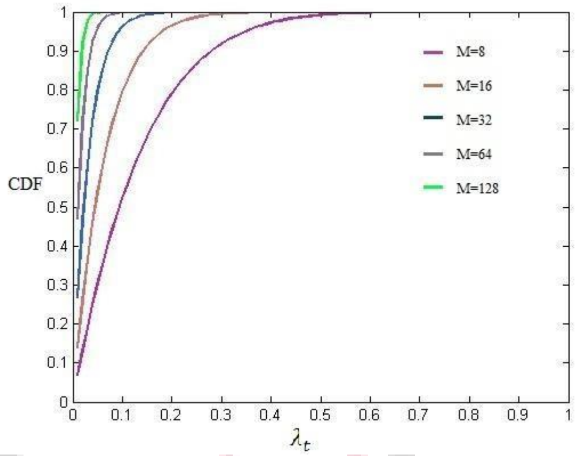

Figure 6: CDF vs λ_t

A. Probability of Detection (P_d)Evaluation

Table II: P_d versus SNR Ratio

SNR (in db)	Proposed	Existing [1]
-15	0.9583	0.1
-10	1	0.3
-5	1	1
0	1	1
5	1	1
10	1	1

Table II illustrates Pd versus SNR ratio for performance evaluation. From comparative analysis is concluded with existing work in [1]. It has been observed that with increasing SNR value the proposed work achieves highest probability of detection.

B. MSE Evaluation with Different Modulation Scheme

The mean squared error (MSE) of signal $\bar{x}$ and its estimate $\bar{x}'$ as:

$$MSE = [(\bar{x} - \bar{x}')^2]$$

Where E[.] is the expectation operator.

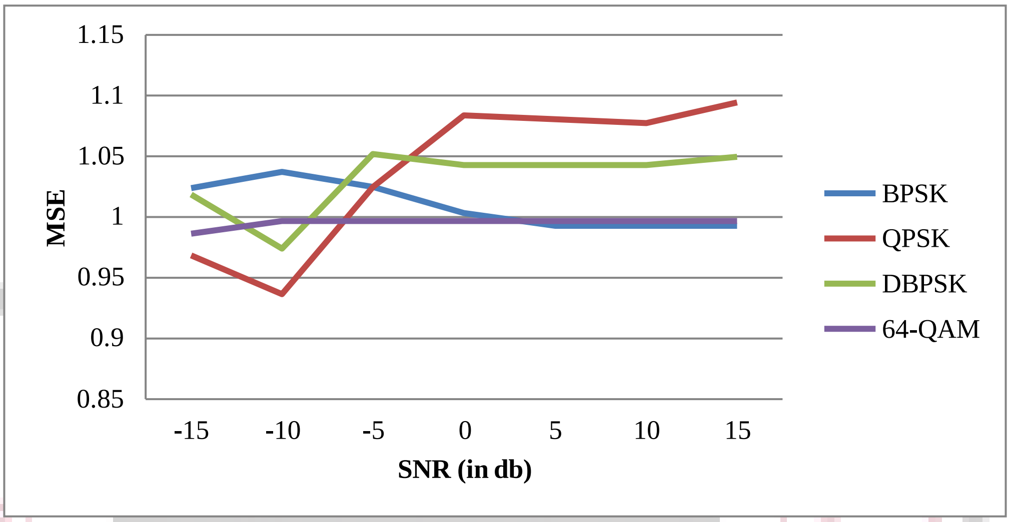

Figure 7: MSE Vs SNR for 2*2 MIMO OFDM

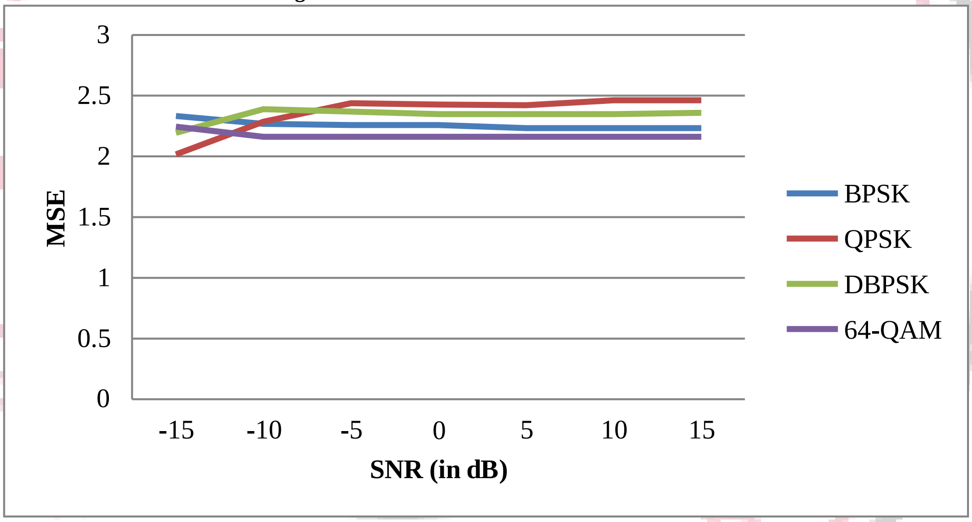

Figure 8: MSE Vs SNR for 3*3 MIMO OFDM

Figure 7 and 8 illustrates MSE Vs SNR for 2*2 and 3*3 MIMO OFDM respectively. From comparative analysis it is concluded that the minimum error is achieved by BPSK and 64-QAM modulation scheme.

4. Conclusion

In this paper cyclostationary based detection method for spectrum sensing is implemented in Simulink. Here use of Rayleigh fading and AWGN noise is efficiently detecting presence of primary user by comparing it to decision threshold. Minimum noise is affected by AWGN noise model. The practical network can be designed for maximum utilization of available spectrum using cyclostationary based detection method. This method has its own advantage because other method i.e. matched filter and energy based detection method requires prior knowledge of primary user while this method do not require it. In this paper work, performance of DWT based MIMO-OFDM CR system is analyzed where the CR device continuously sense the channel to check whether channel is idle or not using cyclostationary detection and reconstruct the signal if communication is for the given

CR receiver from its intended CR transmitter. In this research probability of false alarm is used while evaluating spectrum sensing. Similarly, BER and MSE is also evaluated using different modulation scheme.

The purpose of the paper is to detect and classify the spectrum sensing techniques for cognitive radio networks by using signal processing techniques. The sensing has been analyzed for a few identified situations and then these behaviors have been reported to the operator for further action. In future bit error rate can be measured for different sensing method and compared for better results.

References

[1] R. Verma and A. Mahapatro, "Cognitive Radio: Energy detection using wavelet packet transform for spectrum sensing," 2017 Third International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), Chennai, 2017, pp. 168-172.
[2] Goutam Ghosh, Prasun Das & Subhajit Chatterjee, Simulation and Analysis of Cognitive Radio System Using Matlab, International Journal of Next Generation Networks (IJNGN) Vol.6, No.2, June 2014, pp-31-45.
[3] Ashutosh Singh &Varsha Saxena, Different Spectrum Sensing Techniques Used In Non Cooperative System, in International Journal of Engineering and Innovative Technology Vol.1, Issue 2, February 2012, pp.11-15.
[4] Shital Vachhani, Arjav Bavarva, “Cyclostationary Based Detection Method of Spectrum Sensing for Cognitive Radio,” International Journal of P2P Network Trades and Technology (IJPTT), vol. 7April 2014, pp-26-28.
[5] Pradeep Kumar Verma, SachinTaluja, “Performance Analysis of energy Detection, Matched Filter Detection, Cyclostationary feature Detection Spectrum Sensing,” International journal of Computational Engineering Research (IJCER), vol2, issue-5, September 2012, pp-1296-1301.
[6] K.L. Du & Wai Ho Mow, Affordable Cyclostationary Based Spectrum Sensing for Cognitive Radio with Smart Antennas, IEEE transactions on vehicular technology, vol.59, no.4, May2010, pp.1877-1886.
[7] Danda B. Rawat, “Evaluating Performance of Cognitive Radio Users in MIMO-OFDM-Based Wireless Networks”, IEEE, 2016.
[8] Yang Mingchuan, Li Yuan, Liu Xiaofeng, Tang Wenyan, “Cyclostationary Feature Detection Based Spectrum Sensing Algorithm under Complicated Electromagnetic Environment in Cognitive Radio Networks”, Synergetic Radio Cooperative and Collaborative Radio, 2015.
[9] J. Mitola and G. Q. Maguire, Jr., “Cognitive radio: Making software radios more personal,” IEEE Pers. Commun., vol. 6, no. 4, pp. 13–18,Aug. 1999.
[10] S. Haykin, D. J. Thomson, and J. H. Reed, “Spectrum sensing for cognitiveradio,” Proc. IEEE, vol. 97, no. 5, pp. 849–877, May 2009.
[11] W. S. Jeon, D. G. Jeong, J. A. Han, G. Ko, and M. S. Song, “An efficientquiet period management scheme for cognitive radio systems,” IEEETrans. Wireless Commun., vol. 7, no. 2, pp. 505–509, Feb. 2008.
[12] D. Cabric and R. Brodersen, “Robust spectrum sensing techniques for cognitive radio networks,” in Cognitive Wireless Networks.
[13] F. H. P. Fitzek and M. D. Katz, Eds. Berlin, Germany: Springer-Verlag,2007, pp. 373–394.
[14] Y.-C. Liang, Y. Zeng, E. C. Y. Peh, and A. T. Hoang, “Sensing-throughput trade-off for cognitive radio networks,” IEEE Trans. Wireless Commun.,vol. 7, no. 4, pp. 1326–1337, Apr. 2008.
[15] W. A. Gardner, Statistical Spectral Analysis: An Non-probabilistic Theory.Englewood Cliffs, NJ: Prentice-Hall, 1987.
[16] B. G. Agee, S. V. Schell, and W. A. Gardner, “Spectral self-coherentrestoral: A new approach to blind adaptive signal extraction using antennaarrays,” Proc. IEEE, vol. 78, no. 4, pp. 753–767, Apr. 1990.
[17] K.-L. Du and M. N. S. Swamy, “A class of adaptive cyclostationary beamforming algorithms,” Circuits Syst. Signal Process., vol. 27, no. 1,pp. 35–63, Jan. 2008.
[18] D. Z. Vucic, M. M. Obradovic, and D.M. Obradovic, “Spectral correlationof OFDM signals related to their PLC applications,” in Proc. 6th ISMPLC,Athens, Greece, Mar. 2002.
[19] Tejaskumar M. Gojariya, , Rajesh S. Bansode, “Cyclostationarity-Based Spectrum Sensing using Beamforming Algorithm in Cognitive Radio Networks”, IEEE, 2016.
[20] Treeumnuk, D., & Popescu, D. C., “Enhanced spectrum utilisation in dynamic cognitive radios with adaptive sensing” IET Signal Processing, 8(4), 339–346, 2014.
[21] Lo´pez-Benitez, M., & Casadevall, F., “Improved energy detection spectrum sensing for cognitive radio”, IET Communications, 6(8), 785–796, 2012.
[22] Lunden, J., Koivunen, V., Huttunen, A., & Poor, H. V., “Collaborative cyclostationary spectrum sensing for cognitive radio systems”, IEEE Transactions on Signal Processing, 57(11), 4182–4195, 2009.
[23] Lunden, J., Koivunen, V., Huttunen, A., and Poor, H.V. , “Spectrum sensing in cognitive radios based on multiple cyclic frequencies”, In 2nd International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom) (pp. 37–43), 2007.

[24] Zhong, G., Guo, J., Zhao, Z., and Qu, D., “Cyclostationarity based multi-antenna spectrum sensing in cognitive radio networks”, In IEEE 71st Vehicular Technology Conference (VTC) (pp. 1–5), 2010.
[25] Huang, G., & Tugnait, J. K., “On cyclostationarity based spectrum sensing under uncertain Gaussian noise”, IEEE Transactions on Signal Processing, 61(8), 2042–2054, 2013.
[26] Du, K.-L., & Mow, W. H., “Affordable cyclostationarity-based spectrum sensing for cognitive radio with smart antennas”, IEEE Transactions on Vehicular Technology, 59(4), 1877–1886, 2010.
[27] Chopra, R., Ghosh, D., & Mehra, D. K., “Spectrum sensing for cognitive radios based on spacetime FRESH filtering”, IEEE Transactions on Wireless Communications, 13(7), 3903–3913, 2014.
[28] Fatemeh Rahimzadeh, Kamal Shahtalebi, Farzad Parvaresh, “Using NLMS Algorithms in Cyclostationary-Based Spectrum Sensing for Cognitive Radio Networks”, Springer, 2017.
[29] Jiao, Yan, and Inwhee Joe. "Markov model-based energy efficiency spectrum sensing in Cognitive Radio Sensor Networks." Journal of Computer Networks and Communications, 2016.
[30] Kumar, B. Senthil, and S. K. Srivatsa. "An efficient spectrum sensing framework and attack detection in cognitive radio networks using hybrid ANFIS." Indian Journal of Science and Technology 8, no. 28, 2015.