Performance Evaluation of Cognitive Radio in Cyclo-stationary CS MIMO-OFDM

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Abstract- In this paper, the performance of Energy and Cyclo-stationary spectrum detection in Rayleigh, Nakagami, Rician, and additive white gaussian noise (AWGN) channel environments is investigated for spectrum sensing in cognitive radio networks. MIMO-OFDM cognitive radio (CR) system is used where CR devices continuously sense the channel to check whether it is idle or not using compressed sensing with cyclo-stationary detection, and reconstruct the signal if communication is available for the given CR receiver from its transmitter. Moreover, collaborative spectrum sensing improves performance degradation caused by multipath and shadowing.
Keywords—Cooperative Cognitive Network, Nakagami Channel, AWGN, Probability of False Alarm, Probability of Detection, Rayleigh Channel

I. INTRODUCTION

The radio spectrum is a valuable resource that is inefficiently allocated among licensed users. Service providers must receive a license from the Federal Communications Commission (FCC), for example, in order to access any band of radio spectrum. These policies must be carefully amended due to the infeasible distribution of radio spectrum. One option is to share allocated spectrum among several users as long as there is no interference between primary and secondary (unlicensed) users. These difficulties are becoming more serious as the number of wireless applications and services grows. To accommodate a variety of wireless applications using unlicensed bands, the FCC was convinced to open more unlicensed bands, and CR is capable of accessing spectrum without interference [1] [2]. CR is a new trend in future communication that solves spectrum constraints through shared utilization. Unlicensed cognitive users can use unused licensed frequencies without interfering with primary users. Spectrum sensing is required in CR to determine whether any region of the spectrum is in use. As a result, the advantage of opportunistic exploitation of idle bands is provided. With the rapid expansion and advancement in the field of wireless communication, the demand for the radio spectrum is increasing, which is a restricted resource that is becoming scarce due to the fixed allocation by the spectrum assignment policy [2]. Fixed spectrum is only available to licensed users, yet it is underutilized, resulting in "spectrum holes," or unused spectrum. The Software Defined Radio (SDRCRs) technology has been created to solve spectrum shortages and pave the way for upcoming wireless technologies [3]. This method of utilizing spectral holes increases spectrum utilization. Identification of spectrum gaps is one of the main and major challenges in the deployment of Cognitive Radios in order to detect and feel the presence of primary users (PUs) efficiently and accurately. Spectrum holes and PUs are mainly detected using energy and cyclo-stationary detection techniques [4]. Because of its simplicity, non-dependency on prior knowledge of the PU signal, and low implementation and complexity, the energy detection technique is a widely used technique for spectrum sensing. It also indicates the likelihood of detection in a short time frame with a high signal to noise ratio (SNR) [5, 6]. The cyclo-stationary detection technique takes advantage of the received signal's cyclo-stationarity qualities in terms of mean and auto-correlation. Due to the learning capabilities about the modulation type employed in Primary Base Station (PBS), it has been demonstrated that this technology delivers higher performance with probability of detection in low SNR. Furthermore, because the signal in the spectrum has certain non-arbitrary components, it can distinguish between noises, channel interference, and PBS signal.

In this paper, we evaluate the performance of compressed sensing (CS) with cyclo-stationary detection in MIMO-OFDM based CR system where CR devices continuously sense the channel to check the status (idle or occupied) of the channel and reconstruct the signal for CR communications. The performance of the spectrum sensing is evaluated using probability of misdetection and probability of false alarm [7].

II. COGNITIVE RADIO CONCEPTS

A. Cognitive Radio

CR permits unlicensed users additionally known as a secondary user (SU) to operate in the licensed band. It can solve the problem of spectrum underutilization in the wireless communication. The licensed users are known as PUs who have higher priority to apply the spectrum than SUs. The SU should be able to identify the presence of vacant spectrum through spectrum sensing. This spectrum sensing may be completed through individual SUs known as non-cooperative spectrum sensing or it can be conducted by a group of SUs which performs spectrum sensing by collaboration known as cooperative spectrum sensing. Among all strategies, energy detection is preferable method for spectrum sensing because of its low complexity and simplicity.

B. Energy Detector

A popular way for detecting unknown signals is to monitor energy over time. Processing is used to detect a signal in the presence of noise, and it is dependent on the signal's noise characteristics. When the signal's form is uncertain, it's regarded as a sample function of a random process. When the noise is Gaussian and the signal has a known form with unknown parameters, the "Matched Filter" is used in the processing approach. When signal statistics are available, it is typically possible to create detectors using this information. In the absence of much knowledge concerning the signal, it is appropriate to use "energy detector" to determine the presence of signal [8].

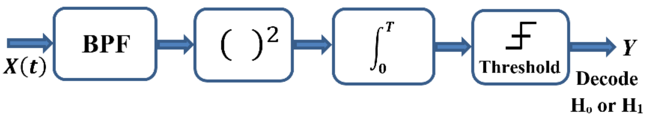

Fig.1. Block diagram of energy detector.

The block diagram of an energy detector is shown in Figure 1. The input signal is filtered using band pass filter (BPF) in order to limit the noise and to select bandwidth of interest. Band limited flat spectral density is the output of the filter. The presence of a signal is determined by comparing the output *Y* to a statistically determined threshold. Signal transmission is modelled as an unknown deterministic signal when only noise is present. The purpose of spectrum sensing is to detect the presence of an unknown deterministic signal in the radio band.

C. Spectrum Sensing

The major purpose of spectrum sensing is to deduce whether the received signal by SU is H_0 or H_1, according to [2]

$$X(t) = n(t) \text{ .... } H_o \quad (1)$$
$$X(t) = hs(t) + n(t) \text{ . .. . } H_o \quad (2)$$

Where *X(t)* is called the signal received by SU , *n(t)* is the AWGN , *s(t)* is the transmitted signal by PU and *h* is called the channel gain. The input to the threshold device of energy detector is indicated by *Y*, and it follows chi-square distribution.

$$Y = \sim X^2_{2TW} \text{ Central}$$
$$Y = \sim X^2_{2TW^{2(Y)}} \text{ Non-Central}$$

For simplicity, TW is considered as an integer number which is denoted by *u*.

D. Probability of False Alarm

$$p_f = \frac{\Gamma\left(u,\frac{1}{2}\right)}{\Gamma(u)} \quad (3)$$

Where u is identified by time to bandwidth product and λ is the threshold. Moreover, $\Gamma(u)$ is named by complete gamma function and $\Gamma\left(u,\frac{1}{2}\right)$ is the incomplete gamma function. It is obvious from equation (3) that p_f is independent of SNR, therefore p_f is independent of the nature of the channel and the amount of fading and shadowing degrading the performance.

E. Probability of Misdetection

The probability of misdetection is proportional to the probability of detection; once the probability of detection is known, *Pm* can be easily calculated by subtracting *Pd* from (1). It is written as follows:

$$p_m = 1 - p_d \quad (4)$$

F. Probability of Detection

This method can be used to determine the probability of detection. The paper is based on channel modeling and determining its pdf, as shown in [1]

$$p_d = \int_x^1 Q_m\,(2\gamma, \lambda) f_\gamma(x) \quad (5)$$

Where, $f_\gamma(x)$ is the pdf of the channel used, Q_m is the Marcum Q function, and γ is the SNR. The method makes use of closed forms for the calculation of *Pd.* Closed forms for each of the channel are given below. When there is no fading channel is considered as ideal AWGN channel, the formula for probability of detection for AWGN channel is given as [9]:

$$P_d = Q_m(2\gamma, \sqrt{2\lambda}) \quad (6)$$

Since for Rayleigh channel γ follows exponential distribution, therefore the closed form that is derived for p_d using (6) is given as [9]:

$$p_{d,ray} = e^{-\frac{\lambda}{2}} \sum_{k=0}^{u-2} \frac{1}{k!}\frac{\lambda^k}{2} + \left(\frac{1+\gamma}{\gamma}\right)^{u-1} \times \left[e^{-\frac{\lambda}{2(1+)}} - e^{\frac{\lambda}{2}} \sum_{k=0}^{u-2} \frac{1}{k!}\left(\frac{\lambda}{2(1+)}\right)^k\right] \quad (7)$$

Similarly, for Nakagami channel with *m* parameter, the closed form that is derived for p_d using (7) is shown as [9]:

$$p_{d,NAK} = A_1 + \beta^m e^{-\frac{\lambda}{2\sigma^2}} \sum_{i=1}^{\frac{N}{2}-1} \frac{\left(\frac{\lambda}{2\sigma^2}\right)^i}{i!} 1F_1\left(m; i+1; \frac{\lambda(1-\beta)}{2\sigma^2}\right) \quad (8)$$

Where, $\beta = \frac{2m\sigma^2}{2m\sigma^2 + \gamma\alpha}$ and $A_1 = e^{-\frac{\lambda\beta}{2m\sigma^2}}\left[\beta^{m-1} L_{m-1}\left(-\frac{\lambda(1-\beta)}{\sigma^2}\right) + (1-\beta)\sum_{i=0}^{m-2} \beta^i L_i\left(-\frac{\lambda(1-\beta)}{3\sigma^2}\right)\right]$

Allowing users to collaborate is one way to improve spectrum sensing due to fading. Let *N* denotes the number of users collaborating, and the detection and false alarm probabilities are given as [9]:

$$Q_d = 1 - (1 - p_d)^N \quad (9)$$
$$Qf_a = 1 - \left(1 - p_f\right)^N \quad (10)$$

N is indicated by the number of users and Q_d is denoted by Collaborative probability of detection. To obtain the result of Qf_a which is named by Collaborative probability of false alarm, p_d is called an individual probability of detection and p_f is the individual probability of false alarm

III. MIMO-OFDM FOR COGNITIVE RADIO SYSTEM MODEL

The MIMO-OFDM system model includes a transmitter with M_t antenna and a receiver with M_r antenna. MIMO-OFDM transmitter serves as a primary user to represent a busy channel or as a SU to represent an idle channel for detection purposes. MIMO-OFDM transmitter is regarded as another CR user attempting to communicate with MIMO-OFDM CR receiver for reconstruction purposes. In the conventional approach of MIMO-OFDM-based CR, signals are transmitted through an IFFT block before being transmitted by multiple transmitting antennas. The proposed MIMO-OFDM methodology uses transmit beamforming along with receive combining. Consequence, all subcarriers in a given channel pass through the beamforming vector block at the transmission end. Supposing the number of total sub-carriers to be *N*, the *m*-th sub-carrier modulates a signal using a beamforming vector. After the signal has passed through the IFFT block, a cyclic prefix (CP) is added before the signal is transmitted [10]. In the proposed method, received signals at antennas are first recombined using a combination vector for the *m*-th sub-carrier, and then the signal is demodulated using a pseudo-random sequence. Without sacrificing generality, the value of any point in the sequence can be generated using a linear feedback shift register (LFSR) [11, 12].

In MIMO–OFDM System, the probability is calculated as follow:

$$p_f = (1-\lambda_t)^{M-1} \quad (11)$$

$$p_m = 1 - Q\left(\frac{\lambda_t\sqrt{N_S}(M_r-1)\left(1-\frac{1+\gamma}{N_S\gamma}\right)}{1+\gamma} - \frac{\sqrt{N_S}}{1+\frac{M_r-1}{N_S\gamma}}\right) \quad (12)$$

$$p_d = Q\left(\frac{\lambda_t\sqrt{N_S}(M_r-1)\left(1-\frac{1+\gamma}{N_S\gamma}\right)}{1+\gamma} - \frac{\sqrt{N_S}}{1+\frac{M_r-1}{N_S\gamma}}\right) \quad (13)$$

VI. SIMULATION RESULTS

The receiver-operating characteristic (ROC) curve is a basic plot in signal detection theory. They are advantageous in that sense that all phase of signal detection theory can be represented in one graph. The curve results in plotting the true positive rate against the false positive rate at various thresholds. The system model for MIMO-OFDM based transmitter with *M* antenna, and receiver with *M* antenna. For detection purpose, MIMO-OFDM transmitter serves as a PU to represent busy channel or as a SU to represent idle channel.

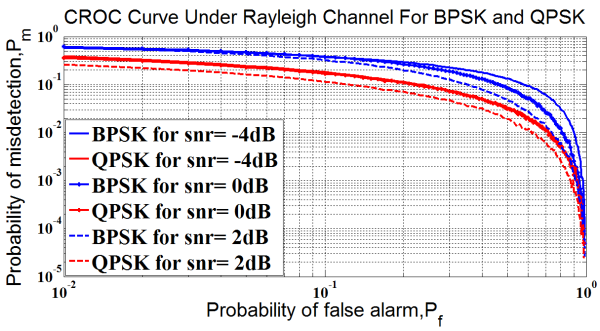

Fig.2. Comparison between p_f and p_m for Rayleigh channel with QPSK and BPSK Modulation.

Figure 2 illustrates the probability of false alarm versus probability of misdetection for energy detection method under Rayleigh channel. It can be seen that, the values of p_f are low at high threshold p_m . Only signals with high amplitudes can exceed the threshold and are considered noise at high thresholds; those that cannot exceed the threshold are considered noise. Signals with low amplitudes can be easily misdirected due to the high SNR, sop_m remains high for high threshold. For the same reason, the probability of mistaking noise for signal decreases, and thus p_f is low. As the threshold decreases, more signals pass through it, increasing the probability of inability to detect the presence of a signal despite the reduced signal. Meanwhile, as more signals cross the threshold, noise might exceed the threshold and assumed as signal, so p_f increases. Therefore, p_f and p_m are inverse to each other. Figure 2 also shows that for lower value of SNR, the performance of Rayleigh model performs better with increasing p_f values. Consequently, as the value of SNR increases, the performance increases.

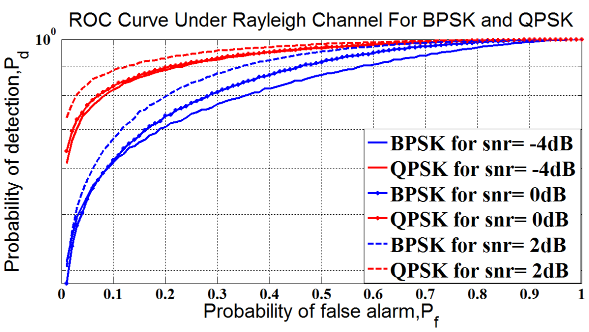

Fig.3. Comparison between p_d and pf for Rayleigh Channel with QPSK and BPSK Modulation.

As shown in Figure 3 the ROC curve shows the increasing value of p_f , the value of p_d also increases which means if the high probability of false alarm is tolerable, the probability of detection would be high. Again, the probability of detection for higher value of SNR outperforms the result for low SNR as expected and also ROC curve is improved for QPSK modulation than BPSK modulation.

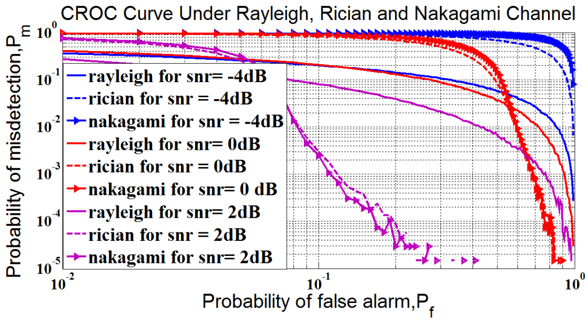

Fig.4. Comparison between p_f and p_m for AWGN, Rayleigh and Nakagami, Rician channels with different signal to noise ratio.

The comparison of Rayleigh, Rician and Nakagami channels considering the probability of misdetection versus the probability of a false alarm is shown in Figure 4. Comparing these channel models, it can be seen that the Rayleigh channel has lower possibility of misdetection for -4dB than Rician and Nakagami channel. But for higher value of SNR, the performance of Rayleigh model is degraded rapidly. When comparing the Rician and Nakagami channel to each other, it can be observed that the Rician channel model works better in lower SNR but in higher value of SNR Nakagami channel shows slightly better result than Rician model. Consequently, it can be concluded that Rician and Nakagami channel models are greater than Rayleigh model and Nakagami becomes severe than both the models in higher value of SNR for energy detection method.

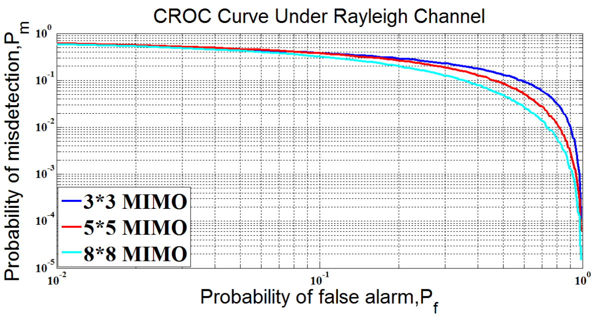

Fig.5. The probability of misdetection p_m versus false Alarm p_f.

The variation of probability of misdetection against false alarm for ROC using different MIMO sizes is presented in Figure 5. It can be observed that the larger size of MIMO results in lower probability of false alarm and misdetection.

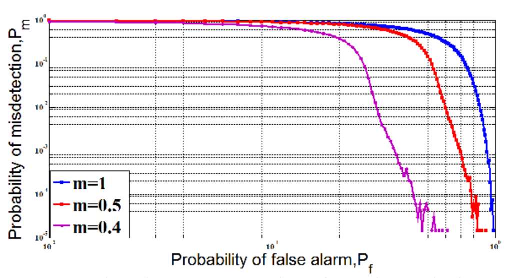

Fig.6 Comparison between p_f and p_m for Nakagami Channel (m= 1, 0.5, 0.4)

Figure 6 shows a comparison between the Probability of misdetection and the Probability of false alarm under Nakagami channel. It can be seen that the Probability of false alarm increases with decrease in fading parameter m.

V. CONCLUSION

In this paper, the CR ROC curves under Rayleigh, Rician and Nakagami channel models are discussed. The individual performance of each model for energy detection method at different values of SNR is investigated. Furthermore, the performance of MIMO OFDM CR system is evaluated, where CR device continuously senses the channel to check whether the channel is idle or not by using compressed sensing with cyclo-stationarity detection, and then reconstructs the signal if communication is available for the given CR receiver from its intended CR transmitter. The probability of misdetection and probability of false alarm while evaluating spectrum sensing for different SNR and channels are compared and the results show the outstanding performance of Rayleigh channel model.

REFERENCES

[1] W. Abd Ellatif, D. Abd El Aziz and R. Mahmoud, "A 4-elements performance analysis of compact UWB antenna for MIMO-OFDM systems," *2016 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE)*, 2016, pp. 135-139, doi: 10.1109/WiSEE.2016.7877318.

[2] R. M. Thabet, W. A. E. Ali and O. G. Mohamed, "Synchronization Error Reduction Using Guard-Band Allocation for Wireless Communication Systems," *2020 International Conference on Innovative Trends in Communication and Computer Engineering (ITCE)*, 2020, pp. 308-312, doi: 10.1109/ITCE48509.2020.9047789.

[3] J. Yang, Y. Chen, W. Shi, X. Dong, T. Peng, â Sensing Against attacks in Cognitive Radio Networkâ ˘A˘AIJ IEEE Interna-tional Conference on Information and Automation 2014.Spectrum Sensing Technique in Cognitive Radio.

[4] Theodore .S. Rappaport, (1996), "Wireless Communications Principles and Practice", Prentice Hall, led. 978-1-5090-3310-2/17/$3\.00 ©2017 IEEE.

[5] R. Ali, B. Hussain, A. Ahmad, I. Khan, S. Jan, I.A. Shah, M. A. Mahmood, " Cyclostationary Spectrum Sensing in Cooperative Cognitive Networks", Bahria University Journal of Information & Communication Technologies, (BUJICT), vol. 6, Iss. 1, December 2013.

[6] M.K. Dhaka, P. Verma, â˘AIJA Relay based Cooperative Spectrum Sensing Selecting Maximum Value of SNR in Multi-Channel Cognitive Radioâ˘A˙I, IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE2014).

[7] E. Rebeiz, V. Jain, and D. Cabric, "Cyclostationary-based low complexity wideband spectrum sensing using compressive sampling," in *Proc. IEEE ICC*, Ottawa, ON, Canada, 2012, pp. 1619–1623.

[8] X. Fu, Y. Zhu, J. Yang, Y. Zhang, and Z. Feng, "Simplified cyclostationary detector using compressed sensing," in *Proc. IEEE WCNC*, New Orleans, LA, USA, 2015, pp. 259–264.

[9] Maria Ashrafl, Junaid Khan, Haroon Rasheed, Farhana Ashrafl, Muhammad Faizan, Muhammad Irfan Anis," Demonstration of Energy Detector Performane and Spectrum Sensing in Cognitive Radio using A WGN, Rayleigh and Nakagami Channels", 978-1-5090-3310-2/ 17/$3 1.00 ©2017 IEEE.

[10] R. Mahmoud, W. Abd Ellatif, O. Gaafar and D. Abd El Aziz, "A calibration method for hybrid technique based on CMA with clipping in MIMO-OFDM system," *2018 11th German Microwave Conference (GeMiC)*, 2018, pp. 203-206, doi: 10.23919/GEMIC.2018.8335065.

[11] J. Xu and G. Choi, "Compressive sensing and reception for MIMO-OFDM based cognitive radio," in *Proc. Int. Conf. Comput. Netw.Commun.*, Garden Grove, CA, USA, 2015, pp. 884–888.

[12] Danda B. Rawat, *Senior Member, IEEE,"* Evaluating Performance of IEEE WIRELESS COMMUNICATIONS LETTERS, VOL. 5, NO. 5, OCTOBER 2016 Cognitive Radio Users in MIMO-OFDM-Based Wireless Networks",2016, 10.1109/LWC.2016.2587262.