Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/130615

Adaptive Learning and Game Theory Based Cognitive Radio Networks

P. Arivazhagi[1,*] *and P. Karthigaikumar*[2]

[1] Electronics & communication Engineering, Ariyalur Engineering College, Ariyalur, India
[2] Electronics and communication Engineering, Karpagam College of Engineering, Coimbatore, India.

Received: 12 Mar. 2019, Revised: 22 May 2019, Accepted: 24 May 2019
Published online: 1 Nov. 2019

Abstract: In this paper, we propose the optimized adaptive spectrum sensing method employing Game Theory Model for Cognitive Radio Networks. In the game theory model, the secondary user (SU) decide the sensing technique applicable relative to the utility function. Prior to this, SU estimates the SNR (Signal-to-Noise Ratio) of each channel and thus forms the utility function in terms instead of energy and throughput. Then the sensing method is adaptively determined on the basis of the SNR value. At low SNR values, the one-order cyclostationary detection technique is applied whereas at high SNR values, the energy detector is used. The decision thresholds λ_1 and λ_2 of the energy detector and the one-order cyclostationary detector, respectively, are adjusted to maximize the utility. Depending on the results of simulation, it is evident that the proposed technique increases both the energy efficiency and the recognition accuracy.

Keywords: Cognitive Radio Networks, Spectrum sensing, Game theory, Energy detection, Utility function

1 Introduction

Cognitive Radio (CR) is employed for resolving the spectrum deficiency and is a highly robust means of communication for network users which is available at any location and at any moment. CR networks (CRN) enables and optimizes the radio spectrum implementation. The parameters of the CR transmitter may differ functionally based on the operational environment situations and interaction [1]. One of the CR's most important applications is the identification of the licensed/primary user (PU). Supposing that PU does not exist, the spectrum is made accessible to the CR/secondary user (SU), and this is called the spectrum hole or white space.

In the process of PU detection, the process of PU implementing the sensing radio environment is called spectrum sensing. Spectrum sensing suffers from two intrinsic problems: (1) There should not be any form of interference from the SU communication to the primary system and (2) the detection of the spectrum holes has to be targeted for the deduction of a better throughput along with the factor of service quality (QoS) [2]. Cognitive radio consists of 4 functional blocks shown in Fig. 1.

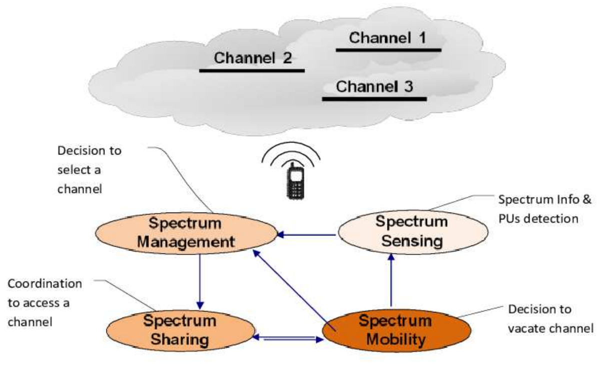

Fig. 1: Functional diagram for cognitive radio networks

1. Spectrum sensing is useful in determining the licensed users or PUs and the corresponding spectrum availability.
2. Spectrum management provides the prediction of the time duration for which the spectrum holes are available for use to the unlicensed users or SUs.
3. Spectrum sharing facilitates the distribution of the spectrum holes in a more uniform way amongst the SUs by taking the usage cost into consideration.

* Corresponding author e-mail: arivu013@outlook.com

4. Spectrum mobility make it possible to consistently maintain the seamless communication demands and facilitates the transition towards an enhanced spectrum [1].

1.1 Spectrum sensing in CRN

Identification of spectrum holes through the sensing of the CR receiver's local neighborhood radio spectrum in random is called spectrum sensing. The holes of the radio spectrum are underutilized sub-bands existing at a geographic place at a certain point of time [2]. Particularly, spectrum sensing consists of the subtasks as below:

1. Identification of spectrum holes.
2. Spectral resolution of every spectrum hole.
3. Estimation of the spatial orientations of inward moving interferences.
4. Categorization of the signal.

Spectrum sensing is faced with few challenges related to the processes listed below:

1. Uncertainty of the channel in the received signal strength due to channel fading or shadowing.
2. Noise uncertainty exists during the estimation of noise power.
3. Sensing interference caps or bounds the identification of the spectrum state.

2 Related Works

Vamsi Krishna Tumuluru et al. [3] suggest a spectrum scheduling scheme for multichannel CRNs wherein scheduling is conducted in the onset of each frame and bears multiple slots. Thereafter, the expected number of packets transferrable for each frame using each SU via a licensed channel may be computed using the Markov chain design. Here, the central scheduler, based on anticipatory packet transmissions, designates licensed channels to the SUs. Scheduling algorithm then designates licensed channels which enables maximizing SUs aggregate throughput, though there can be a possibility of scheduling overheads.

In their approach, Li Zhang et al. [4] suggest a general scheduling framework to cross impediments that occur like maximum throughput channel scheduling problem (MTCS). In this framework, two polynomial time optimal algorithms are taken to resolve MTCS in scenarios pertinent to both homogeneous and heterogeneous traffic load. Thus the algorithms perform better than greedy algorithm by a percentage as high as 21.6%.

Wael Guibene et al. [5] in their study, show the outcome of a new standpoint for spectrum sensing deciphered based on the principle detection theory by deriving results from differential algebraic computations, non-commutative ring theory, and operational calculus. Spectrum sensing is evaluated using this algebraic-based algorithm changed point detections while pointing out spike-like portions of the mentioned noisy amplitude spectrum. The obtained results have clearly shown that this technique is especially effective during the process of detection of filled sub-bands used in the PU transmissions.

Waleed Ejaz et al. [6] through their research and study of the adaptive local spectrum sensing approach, where the CR can implement a one-order cyclostationary or an energy detector for carrying out spectrum sensing based on the SNR estimated. SNR here is computed for existing channels. There are conclusive outcomes that prove that this scheme offers fast detection by the deployment of the energy detector. Though, total mean detection time is reduced considerably for acquiring the same accuracy.

Juan Andrés Bazerque et al. [7] in their study, used an introductory collaborative approach for wireless CRNs sensing by deploying an expansion model of the power spectral density (PSD) which is mapped with parameters for both space and frequency. Joint estimation on the model parameters facilitates detection of frequency bands that are unused at random places and reestablishment and usage of spatial frequency. This methodology takes in to account and capitalizes on two variants of sparsity. Firstly, narrowband characteristic of transmit-PSDs associated with the broad sets of useful spectrum is introduced, whereas the latter is coming from sparsely placed active radios present in the operational space. Based on the Lasso algorithm, model estimator is deployed to extract various types of sparsity and disclose the unknown places of transmitting CRs. Results show that CR sensing decreases spatial and frequency spectrum leakage by 15 dB associated with least-squares alternates.

Feng Lin et al. [8] suggest covariance matrix-based spectrum sensing technique to enhance the functionality of CR systems. In this work, a collaborative sensing scenario uses every sensor to fulfill the requirement to restrict sample data for computation and transmits the results obtained to the fusion center. They provide the performance comparison carried out for various rational functions. This indicates that various functions used in this algorithm have either an identical or a different performance. Therefore, it becomes necessary for a suitable function to be selected. Results show that, during very less signal-to-noise ratio (SNR) scenarios, the above technique will deliver better results and is reliable and also has a better performance when compared to estimator-correlator approach.

In [9] and [11], compressive wideband power spectrum estimation technique and dynamic compressive spectrum sensing techniques have been proposed and proven to be effective. In [10], utility-based cooperative spectrum sensing technique has been introduced.

Waleed Ejaz1 et al. [12] extensively evaluate the trade-off involving energy-throughput that is for the collaborative spectrum sensing and deduct issue related to the optimization issue for secondary users that is deduced for attaining spectrum sensing efficiency. Energy detector model has been deployed to enable spectrum sensing and applied k-out-of-N rule for decision fusion rule.

Detection exhibits a shorter sensing time and is simple, its performance is not commendable under low Signal to Noise Ratio (SNR) scenarios [6]. Whilst, focusing on achieving minimization of energy consumption and optimizing the parameters of the fusion rule throughput value is degraded [13]. Thus, it is proposed to structure an adaptive spectrum sensing method applicable for CR networks using game theory.

3 Optimized Adaptive Spectrum Sensing Technique

Cognitive Radio Networks include the application of the energy detection technique that is convenient to adopt and its sensing time is also short. But, the network performance employing this method is not mentionable due to the conditions arising owing to a lesser Signal-to-Noise Ratio (SNR). Hence, in the following research work, an optimized adaptive spectrum sensing method employing Game Theory Model developed especially for Cognitive Radio Networks is proposed. Initially, the primary users decide on the sensing technique that is applicable based on the utility function taking energy and throughput into consideration.

3.1 Basics of Game Theory

Rationality is the most basic presumption made in game theory. Rational players are supposed to increase their payoff, that implies motivation inspired selfishly. In the case of game theory, outcome forms the game's solution. In the case of WSN, Intrusion Detection System (IDS) acts as one player and the attacker plays as an opponent player. As with the problem of WSN, the huge WSN is classified into clusters and IDS protects a cluster at any point of time when the attacker interferes with the usual functionalities.

Vital aspects of the game theory applications are as under:

1. Enables decision making for economic issues like bidding.
2. Ensuring maximization of the nodes' Signal-Interference-to-Noise Ratio (SINR), their choice of path by source node to reduce delay, and their co-ordination among the nodes to detect the service and then forwarding the packets towards their destination.

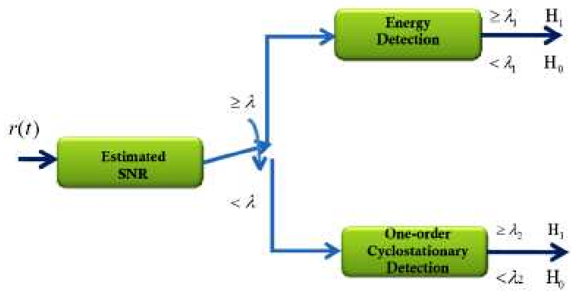

Fig. 2: Adaptive spectrum sensing scheme

3.2 Detection Technique

We consider the following two detection techniques:

1. Energy Detection
2. One-order Cyclostationary detection

Energy Detection: This may be considered as an estimation of the received signal's power. Nodes utilize the energy detection technique when the estimated received signal is higher compared to the threshold.

One-order cyclostationary: Primary-modulated waveforms and patterns defined as cyclostationary features include sine-wave carriers, pulse trains, repeating distribution, hoping sequences or cyclic prefixes that includes periodicity. Using periodic statistics such as mean and auto- correlation of the primary waveform, the CR detects a random signal bearing a particular type of modulation with the randomized stochastic noise present. The cyclostationary detection depends on the auto-correlation function. However, one-order cyclostationary detection is considered to enhance the channel sensing in time domain. This helps in minimizing complexity and power consumption.

We detect the optimal spectrum sensing technique by applying game theory that has elucidated upon in the following section. Fig. 2 shows the basic functional block diagram for adaptive spectrum sensing scheme.

3.3 Game Theory Based Spectrum Sensing Technique Decision

Based on the utility function in the game theory model, the secondary user (SU) concludes on the sensing technique applicable. SU beforehand estimates SNR for each channel and formulates the utility function as energy and throughput.

Let ST be the sensing technique.

$ST : \{x, y, \lambda_1, \lambda_2\}$

ST represents the rule that selects four-tuple $\{x, y, \lambda_1, \lambda_2\}$ to transmit at time slot t,

where $\{\lambda_1, \lambda_2\}$ = sensing technique thresholds (energy detection and one-order cyclostationary detection respectively).
$\{x, y\}$ = primary and secondary nodes.
Let $T^p(t)$ and $T^s(t)$ be the throughput level of primary and secondary nodes.
Let $T^r(t)$ be the throughput matrix.
The steps involved in detecting the sensing technique are as follows:
During $(1-\lambda_1)$, $0 \leqslant \lambda_1 \leqslant 1$ of time slot, x transmits the data to y.

1. In the rest of the segment of time slot, the scheduled y node makes use of the channel for relaying the data of the primary user over a $\lambda_1$fraction, $0 \leqslant \lambda_1 \leqslant 1$.
2. Then y transmits its own data during the remaining time slot i.e. $\lambda_2 (1-\lambda_1)$ fraction.
3. The signal to noise ratio (SNR) of the node is estimated based on the utility function $\left(UF_{x',y'}(ST,t)\right)$ at time t.

Utility function for primary nodes:

$$UF^p_{x',y'}(R,t) = \begin{cases} s_1\left(T^p_{x'}(t)\right); \text{ if } y' = 0 \\ s_1\left((1-\sigma)T^r_{x',y'}(t)\right), \text{ otherwise} \end{cases} \tag{1}$$

Utility function for secondary nodes:

$$UF^s_{x',y'}(R,t) = \begin{cases} 0 \text{ if } y' = 0 \\ s_2\left(\sigma(1-\tau)T^s_{y'}(t)\right), \text{ otherwise} \end{cases} \tag{2}$$

For every primary and secondary node $\{x, y\}$ so that $x \neq x'$ and $y \neq y'$.

4 Simulation Results

4.1 Simulation Parameters

MATLAB version 7.12(R2011a) has been deployed for simulation of the suggested Optimized Adaptive Spectrum Sensing Technique Employing Game Theory Model (OASST) protocol. Through the process of simulation, the number of nodes is considered 50. Area size becomes 100 meter × 100 meter area.

$$UF^p_{x,y'}(R,t) = UF^s_{x,y'}(R,t) = 0 \tag{3}$$

4. The optimal value of λ_2 is estimated using following equation

$$\lambda_2^* = \frac{(1-\lambda_1)T^r_{xy}}{\lambda_1 T^s_y} \tag{4}$$

If $\lambda_2^* > \frac{(1-\lambda_1)T^r_{xy}}{\lambda_1 T^s_y}$,
Then
Y uses the energy detecting technique (described in Section 3.3)
End if

Table 1: Simulation parameters

No. of nodes	50
Area	100×100
SNR	-10 dB

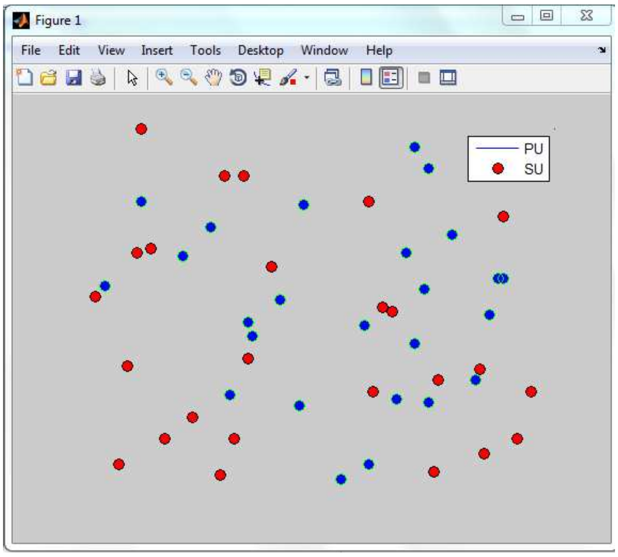

Fig. 3: Simulation topology

If $\lambda_2^* < \frac{(1-\lambda_1)T^r_{xy}}{\lambda_1 T^s_y}$
Then
Y uses the one-order cyclostationary detection technique (described in Section 3.3)
End if
When low SNR values exist, the one-order cyclostationary detection technique is applicable and when SNR values are high, the energy detector is applicable.
Thus, the notation $R = \{x, y, \lambda_1, \lambda_2\}$ is used for the decision of the sensing technique.

5. Maximizing overall expected utility of both the primary and secondary systems necessitates the decision thresholds λ_1 and λ_2 of energy detector and one-order cyclostationary detector adjustment:

$$O(ST,t) = \sum_{x=}^{X}\sum_{y=}^{Y} UF^p_{xy}(t) + UF^s_{xy}(t) \tag{5}$$

Both simulation settings and parameters have been tabulated as below in Table 1. Fig. 3 shows the simulation topology.

Fig. 4 exhibits corresponding Receiver Operating Characteristic (ROCs) of the existing adaptive spectrum sensing approach, energy and one-order cyclostationary detection. The probability of false-alarm is plotted along the X-axis and the probability of mis-detection is plotted along the Y-axis.

Fig. 5 exhibits the proposed game theory-based spectrum sensing as a comparative better option than existing adaptive spectrum sensing, one-order

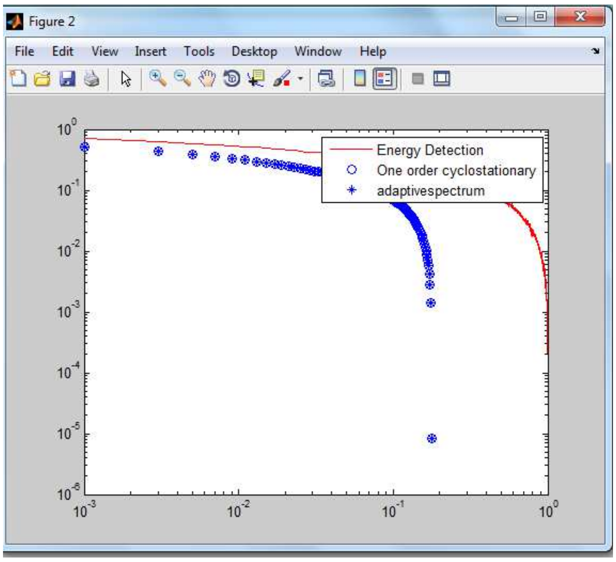

Fig. 4: ROC curves of the current adaptive spectrum sensing, one-order cyclostationary and energy detection

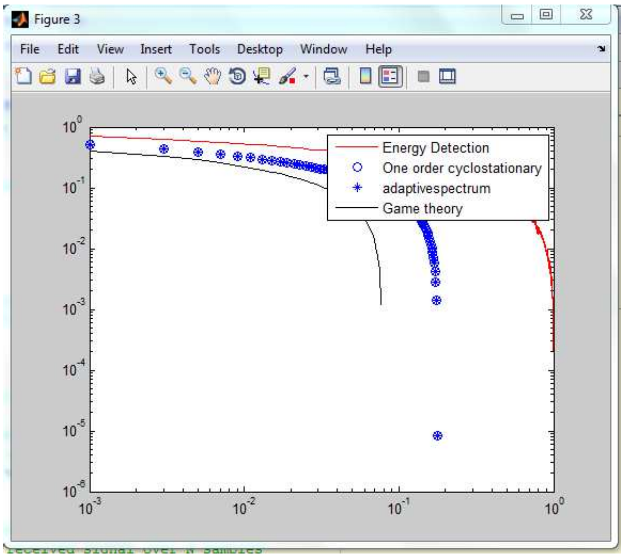

Fig. 5: ROC here shows suggested game theory's curves, the adaptive spectrum sensing, one-order cyclostationary as well as energy detection

cyclostationary detection and energy detection techniques. (ie) The probability of mis-detection is lesser in the case of the technique suggested herein.

In this condition, it is supposed that the average SNR arrives to -10 dB. Existing adaptive scheme performance as per obtained results clearly indicates that energy detector is better but its performance is equivalent to that of the one-order cyclostationary detector.

5 Conclusion

In this paper, we claim that designing an optimized adaptive spectrum sensing technique employing Game Theory Model for Cognitive Radio Networks is the most probable solution. Initially, application of the sensing technique is decided by the secondary users depending on the utility function instead of both energy and throughput. The results drawn on the basis of simulation show that the technique proposed here is not only efficient but it also maximizes and optimizes both energy efficiency as well as detection accuracy.

References

[1] Mansi Subhedar and Gajanan Birajdar, Spectrum Sensing Techniques in Cognitive Radio Networks: A Survey, International Journal of Next-Generation Networks (IJNGN), **3**, 2 (2011).
[2] Simon Haykin, David J. Thomson and Jeffrey H. Reed, Spectrum Sensing for Cognitive Radio, Proceedings of the IEEE 97.5 (2009).
[3] Vamsi Krishna Tumuluru, Ping Wang, Member and Dusit Niyato, A Novel Spectrum Scheduling Scheme for Multi-channel Cognitive Radio Network and Performance Analysis, Vehicular Technology, IEEE Transactions on 60.4 (2011).
[4] Li Zhang, Kai Zeng and Prasant Mohapatra, Opportunistic Spectrum Scheduling for Mobile Cognitive Radio Networks in White Space, Wireless Communications and Networking Conference (WCNC), IEEE (2011).
[5] Wael Guibene, Monia Turki, Bassem Zayen and Aawatif Hayar, Spectrum sensing for cognitive radio exploiting spectrum discontinuities detection, EURASIP Journal on Wireless Communications and Networking (2012).
[6] Waleed Ejaz, Najam ul Hasan and Hyung Seok Kim, SNR-Based Adaptive Spectrum Sensing For Cognitive Radio Networks, International Journal of Innovative Computing, Information and Control ICIC International 2012 ISSN 1349–4198 **8**, 9 (2012).
[7] Juan Andrés Bazerque and Georgios B. Giannakis, Distributed Spectrum Sensing for Cognitive Radio Networks by Exploiting Sparsity, IEEE Transactions on Signal Processing, **58**, 3 (2010).
[8] Feng Lin, Robert C. Qiu, Zhen Hu, Shujie Hou, Lily Liy, James P. Browningz and Michael C. Wicks, Cognitive Radio Network as Sensors: Low Signal-to- Noise Ratio Collaborative Spectrum Sensing, Proceeding of IEEE International Waveform Diversity & Design Conference (2012).
[9] Dyonisius Dony Ariananda and Geert Leus, Compressive Wideband Power Spectrum Estimation, IEEE Transactions on Signal Processing, **60**, 9 (2012).
[10] Hongjuan Li, Xiuzhen Cheng, Keqiu Li, Xiaoshuang Xing, Tao Ji, Utility-Based Cooperative Spectrum Sensing Scheduling in Cognitive Radio Networks, Proceedings of IEEE Inforcom. (2013).
[11] Wotao Yin, Zaiwen Wen, Shuyi Li, Jia (Jasmine) Meng, and Zhu Han, Dynamic Compressive Spectrum Sensing for Cognitive Radio Networks.

[12] Waleed Ejaz, Ghalib A. Shah, Najam ul Hasan and Hyung Seok Kim, Energy and throughput efficient cooperative spectrum sensing in cognitive radio sensor networks, Transactions on Emerging Telecommunications Technologies, Trans. Emerging Tel. Tech. (2014)
[13] Saud Althunibat, Marco Di Renzo and Fabrizio Granelli, Optimizing the K-out-of -N Rule for Cooperative Spectrum Sensing in Cognitive Radio Networks, IEEE Global Communications Conference (GLOBECOM) (2013).

P. Arivazhagi she is currently working in Electronics and Communication Engineering, she is now Assistant Professor and Head in Electronics and Communication Engineering in Ariyalur Engineering college ariyalur, India. She received the B.E degree in Electronics and communication engineering from Dhanalakshmi Srinivasan engineering College of Anna University, India, in 2007, and the M.E. degree with distinction in communication systems from SSN College of engineering of Anna University India, in 2010. She is currently pursuing the Ph.D. degree with the Division of information and communication Engineering, Anna University, India. She research interests include wireless networks, Cognitive radio networks.

P. Karthigaikumar received his Bachelor of Engineering degree in Electrical and Electronics Engineering from the Bharathiar University, India in 1999 and his Master of Engineering degree with Distinction in Applied Electronics from Bharathiar University, India in 2002. He completed Ph. D degree in Information and Communication Engineering under Anna University, India in 2011, focusing on FPGA and ASIC implementation of Media Security processor. He is a member of IEEE (MIEEE), senior member of Association of Computer Electronics and Electrical Engineers (ACEEE), member of International Association of Engineers (MIAENG) and member of International Association of Computer sciences and Information Technology (MIACSIT). He joined Karunya University; Coimbatore, India in 2000 and worked for 13 years. He is now Professor and Head in Electronics and Communication Engineering in Karpagam College of Engineering, Coimbatore, India. He has published more than 60 papers in in journals and conferences. He received IETE K S Krishnan award for the best system oriented research paper in the year 2010. He applied for 2 Indian patents and is published in Indian Patent Journal. He is a reviewer for different reputed journals like Elsevier, Wiley, Inderscience etc., and he has been the Guest editor for few special issues in Hindawi, Elsevier, Inderscience, Springer. His research interest includes FPGA implementation of Media security algorithm and Signal Processing algorithm.