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# Optimized Adaptive Spectrum Sensing Technique Using Game Theory Model for Cognitive Radio Networks

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**Abstract:** In Cognitive Radio Networks, though energy detection technique is simple with short sensing time, its performance is poor under low Signal to Noise Ratio (SNR) conditions. Hence in this study, we propose to design an optimized adaptive spectrum sensing technique Using Game Theory Model for Cognitive Radio Networks. Initially, the secondary users decide the sensing technique to be applied based on the utility function in terms of the energy and throughput. By simulation results, we show that the proposed technique maximizes the energy efficiency and detection accuracy.

**Key words:** Cognitive radio networks, spectrum sensing, game theory, energy detection, utility function

## INTRODUCTION

**Cognitive Radio Networks (CRN):** Cognitive Radio (CR) is an emerging technology for mitigating spectrum scarcity and providing highly reliable communication for all the users in the network at any time and any place. CR Networks (CRN) enables an effective utilization of radio spectrum. CR can vary its transmitter parameters according to the interaction with the operating environment (Subhedar and Birajdar, 2011; Ejaz *et al*., 2012, 2015).

CR's major task is to identify the licensed/Primary User (PU). If PU is absent then, the spectrum will be available for CR/Secondary User (SU) which is called as spectrum hole or white space. The process of detecting PU using sensing radio environment is termed as spectrum sensing. Two primary concerns of spectrum sensing are as follows: the primary system should not be disturbed by SU communication and spectrum holes must be efficiently identified for obtaining better throughput and Quality of Service (QoS). CR comprises four main functional blocks. They are as follows:

- Spectrum sensing is used to determine the presence of the licensed users or PUs and spectrum availability
- Spectrum management predicts the duration up to which the spectrum holes are likely to remain available for use to the unlicensed users or SUs
- Spectrum sharing helps to fairly distribute spectrum holes among the SUs by considering usage cost
- Spectrum mobility maintains seamless communication requirements during the transition for better spectrum (Subhedar and Birajdar, 2015)

**Spectrum sensing in CRN:** The task of finding spectrum holes by sensing the radio spectrum in the local neighborhood of the CR receiver in an unorganized fashion is termed as spectrum sensing. Spectrum holes are the sub-bands of the radio spectrum that are underutilized at a particular time and geographic location. Specifically, the task of spectrum sensing comprises the following subtasks:

- Detection of spectrum hole
- Spectral resolution of each spectrum hole
- Estimation of the spatial directions of incoming interferences
- Classification of signal (Haykin *et al*., 2009)

**Issues in spectrum sensing:** Some of the issues in spectrum sensing are as follows:

- Channel uncertainty in received signal strength arises due to channel fading or shadowing
- Noise uncertainty occurs due to noise power estimation
- Sensing interference limits the detection of spectrum status (Subhedar and Birajdar, 2011)

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**Classification of spectrum sensing:** The spectrum sensing can be classified as:

- Interference-based sensing
- Cooperative sensing
- Non-cooperative sensing
- Energy detection
- Matched filter detection
- Cyclostationary feature detection (Subhedar and Birajdar, 2011)

**Problem identification:** Ejaz *et al.* (2015) examines the energy-throughput trade-off for cooperative spectrum sensing and formulates an optimization problem for secondary users based on spectrum sensing efficiency. They have used the energy detector model for spectrum sensing and applied k-out-of-N rule for decision fusion rule. Though energy detection is a simple technique that has short sensing time, its performance is poor under low Signal to Noise Ratio (SNR) conditions. Also, considering the minimization of energy consumption as an objective for optimizing the parameters of the fusion rule will degrade the throughput (Althunibat *et al*., 2013).

In order to solve these issues, we propose to design an adaptive spectrum sensing technique for CR networks using game theory.

**Literature review:** Tumuluru *et al.* (2011) have proposed an opportunistic spectrum scheduling scheme for multichannel CRNs in which scheduling is done at the beginning of each frame with multiple slots. After that, the expected number of packets which can be transmitted over the frame by each SU for each licensed channel can be estimated using a Markov chain formulation. A central scheduler allocates the licensed channels to the SUs based on these expected packet transmissions. Scheduling algorithm allocates the licensed channels, thereby maximizing the aggregate throughput of the SUs. However, scheduling overheads may occur.

Li *et al.* (2013) and Zhang *et al.* (2011) have proposed a general scheduling framework in order to overcome the Maximum Throughput Channel Scheduling problem (MTCS). According to this framework, two polynomial time optimal algorithms are presented that solve the MTCS in both homogeneous and heterogeneous traffic load scenario, respectively. Results show that these algorithms outperform a greedy algorithm by 21.6%.

Guibene *et al.* (2012) have presented a new standpoint for spectrum sensing emerging in detection theory by deriving differential algebra, non-commutative ring theory and operational calculus. This algebraic-based algorithm for spectrum sensing changes point detections for emphasizing “spike-like” parts of the given noisy amplitude spectrum. Results show that this approach is very efficient for detecting the occupied sub-bands in the PU transmissions.

Ejaz *et al.* (2012) have proposed an adaptive local spectrum sensing scheme where CR can implement one-order cyclostationary or energy detector for spectrum sensing based on the estimated SNR. SNR is estimated for all available channels. Results show that this scheme provides fast detection using the energy detector. However, the total mean detection time is reduced considerably in order to achieve the same accuracy.

Bazerque and Giannakis (2010) have introduced a cooperative approach for sensing in wireless CRNs using a basis expansion model of the Power Spectral Density (PSD) map in space and frequency. Joint estimation of the model parameters allows identification of the unused frequency bands at arbitrary locations and spatial frequency reuse. This scheme capitalizes on two forms of sparsity. The former is introduced by the narrowband nature of transmit-PSDs relative to the broad swaths of usable spectrum, whereas the latter is emerging from sparsely located active radios in the operational space. Based on the Lasso algorithm, an estimator of the model coefficients is developed to exploit these forms of sparsity and reveal the unknown positions of transmitting CRs. Results show that CR sensing decreases spatial and frequency spectrum leakage by 15 dB relative to least-squares alternatives.

Lin *et al.* (2012) have proposed a function of covariance matrix-based spectrum sensing approach for CR systems. In this, a collaborative sensing scenario is used where each sensor requires limited sample data for calculation and sends mediate result to fusion center. They provide the performance comparison of different rational functions. This shows different functions used in this algorithm have similar or distinct performance. Therefore, an appropriate function must be selected. Results prove the reliable performance in very low Signal-to-Noise Ratio (SNR) condition and better performance when compared to estimator-correlator approach.

Ariananda and Leus (2012) and Yin *et al.* (2011) compressive wideband power spectrum estimation technique and dynamic compressive spectrum sensing techniques are proposed, respectively. In utility-based cooperative spectrum sensing technique has been proposed.

## MATERIALS AND METHODS

### Optimized adaptive spectrum sensing technique

**Overview:** In this study, we propose to design an optimized adaptive spectrum sensing technique. Using game theory model for cognitive radio networks. In the game theory model, the Secondary Users (SU) can decide the sensing technique to be applied based on the utility function. The SU estimates the SNR of each channel in advance and forms the utility function in terms of the energy and throughput.Then the sensing technique is adaptively determined based on the SNR value, i.e.. At low SNR values, the one-order cyclostationary detection technique is applied whereas at high SNR values, the energy detector is applied. The decision thresholds $\lambda_1$ and $\lambda_2$ of energy detector and one-order cyclostationary detector, respectively, are adjusted such that the utility is maximum.

**Basics of game theory:** The game Z is defined as Z = (N, S, {$Uf_i$}). where N = finite set of players S = action space formed as Cartesian product. i.e., $S = S_1 \times S_2 \times S_3 \times S_4 \times S_n$ $Uf_i$ = utility functions. $UF_{i =}$ {$UF_1$, $UF_2$,.., $Uf_n$} The outcomes are selected by a particular player i with $S_i$ as $UF_i$ and the particular actions selected by other players is $S_{-i}$.

Rationality is the most basic assumption in game theory. Rational players are assumed to maximize their payoff, which is selfish motivation. In game theory, outcome is the solution of a game. In WSN, Intrusion Detection System (IDS) acts as one player and intruder plays as opponent player. In the WSN problem, the large WSN is divided into clusters and IDS defends a cluster at any given time while the attacker disturbs the normal operations. The main applications of game theory are as follows :

- Decision making in many economic problems especially during bidding.
- Power control to set the power level of nodes. This is performed to maximize their Signal Interference to Noise Ratio (SINR), their selection of path by source node to minimize delay and their cooperation among the nodes to identify the service and forwarding of the packets to their destination.

**Detection technique:** We consider the following two detection technique

- Energy detection
- One-order cyclo-stationary detection

**Energy detection:** It represents the estimation of received signal's power. The nodes utilize the energy detection technique when the estimated received signal is greater than the threshold.

**One-order cyclo-stationary:** The primary-modulated waveforms are coupled with patterns characterized as cyclo-stationary features such as sine-wave carriers, pulse trains, repeating spreading, hoping sequences or cyclic prefixes inducing periodicity. By using the periodic statistics such as mean and auto-correlation of the primary waveform, CR can detect a random signal with a specific modulation type in the presence of random stochastic noise. The cyclostationary detection depends on auto-correlation function. However, we consider one-order cyclo-stationary detection to improve the channel sensing in time domain. This can minimize the complexity and power consumption.

We detect the optimal spectrum sensing technique by applying game theory which is described in following section.

**Game theory based spectrum sensing technique decision:** In the game theory model, the Secondary User (SU) decides which sensing technique can be applied based on the utility function. The SU estimates the SNR of each channel in advance and forms the utility function in terms of the 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 cyclo-stationary detection respectively). {x, y}= primary and secondary nodes.

Let $T^p$ 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-$\lambda_1$), $0 \le \lambda_1 \le 1$ of time slot, x transmits the data to y:

- In remaining portion of time slot, the scheduled y node uses the channel to relay the primary user's data over a $\lambda_1$ fraction, $0 \le 1$ $\lambda_1 \le 1$
- Then y transmits its own data during remaining time slot i.e. $\lambda_2(1-\lambda_1)$ fraction
- The signal to noise ratio (SNR) of the node is estimated based on the utility function ($Ud_{x'y'}$(ST, t)) at time t

Utility function for primary nodes:

$$UF^{p}{}_{x',y'}(R,t)=\begin{cases} s_1\left(T^{p}_{x'}(t)\right) & ;\text{if } y'=0 \\ s_1\left((1-\sigma)T^{r}_{x',y'}(t)\right), & \text{otherwise}\end{cases} \quad (1)$$

Utility function for secondary nodes:

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

For all primary and secondary nodes {x, y} such that x ≠x' and y≠y':

$$UF^{p}{}_{x,y'}(R,t)=UF^{s}{}_{x,y'}(R,t)= \quad (3)$$

The optimal value $\lambda_2$ of is estimated using following Eq. 4:

$$\lambda_2{}^{*}=\frac{(1-\lambda_1)T^{r}_{xy}}{\lambda_1 T^{s}_{y}} \quad (4)$$

If

$$\lambda_2{}^{*}>\frac{(1-\lambda_1)T^{r}_{xy}}{\lambda_1 T^{s}_{y}}$$

Then, Y uses the energy detecting technique (described in study). End if:

$$\lambda_2{}^{*}<\frac{(1-\lambda_1)T^{r}_{xy}}{\lambda_1 T^{s}_{y}}$$

Then, Y uses the one-order cyclo-stationary detection technique (described in study). End if this reveals that at low SNR values, the one-order cyclo-stationary detection technique is applied whereas at high SNR values, the energy detector is applied. Thus, the notation R = {x, y, $\lambda_1$, $\lambda_2$} is used for decision of sensing technique.

In order to maximize the total expected utility of both primary and secondary systems, the decision thresholds $\lambda_1$ and $\lambda_2$ of energy detector and one-order cyclo-stationary detector, respectively are adjusted.

$$O(ST,t)=\sum_{x=}^{X}\sum_{y=}^{Y}UF^{p}_{xy}(t)+UF^{s}_{xy}(t) \quad (5)$$

## RESULTS AND DISCUSSION

**Simulation parameters:** We use MATLAB version 7.12(R2011a) to simulate our proposed Optimized Adaptive Spectrum Sensing Technique Using Game Theory Model (OASST) protocol. In our simulation, the number of nodes is taken as 50. The area size 100×100 $m^2$ region. Our simulation settings and parameters are summarized in Table 1 and Fig. 1.

Figure 2, it shows the complementary Receiver Operating Characteristic (ROCs) of the existing adaptive spectrum sensing scheme, energy detection and one-order cyclostationary detection. X-axis shows the probability of false-alarm and Y-axis gives the probability of miss detection.

In this scenario, it is assumed that the average SNR is -10 dB. The result shows that the existing adaptive scheme performs better than the energy detector but equally to the one-order cyclostationary detector.

Figure 3, it represents that our proposed game theory based spectrum sensing is better than the existing adaptive spectrum sensing, one-order cyclostationary detection and energy detection techniques, i.e., the probability of probability of miss detection is less in the proposed technique.

Table 1: Simulation parameters

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

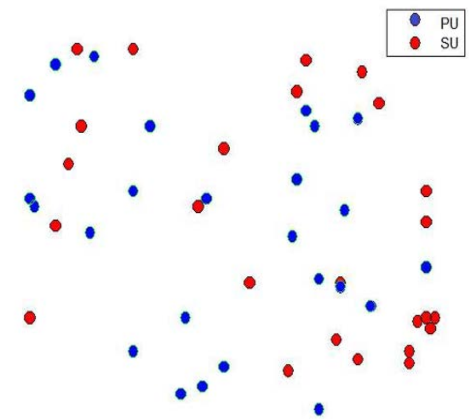


Fig. 1: Simulation topology

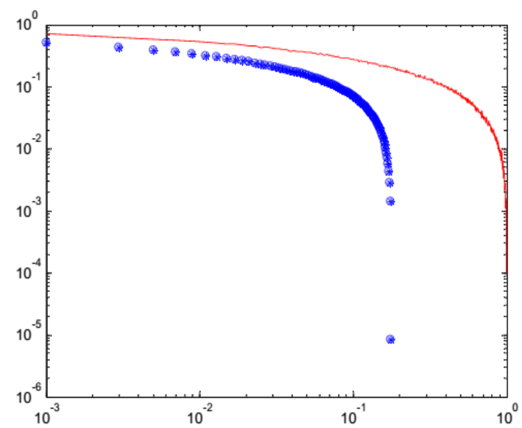


Fig. 2: ROC curves of existing adaptive spectrum sensing, one-order

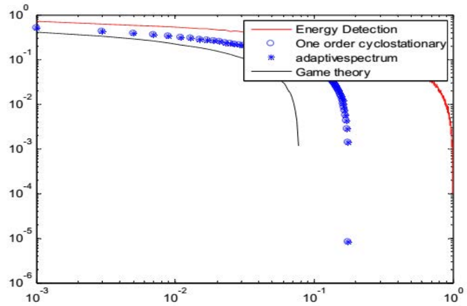


Fig. 3: ROC curves of proposed game theory, existing adaptive spectrum sensing, one-order

## CONCLUSION

In this study, we have proposed to design an optimized adaptive spectrum sensing technique using game theory model for cognitive radio networks. Initially, the secondary users decide the sensing technique to be applied based on the utility function in terms of the energy and throughput. By simulation results, we have shown that the proposed technique maximizes the energy efficiency and detection accuracy.

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