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Energy Efficient and Interference-aware Spectrum Sensing Technique for Improving the Throughput in Cognitive Radio Networks

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Abstract Cognitive Radio network (CRN) depends on opportunistic spectrum access and spectrum sensing for improving the wireless networks' spectrum efficiency. Since throughput maximization can result in high energy consumption, the spectrum sensing technique should address the energy-throughput trade off. The spectrum sensing time has to be determined by the considering the residual battery energies of each secondary user (SU).The Primary User (PU) interference degrades the throughput of the entire network. Hence the transmit power level should be determined considering the PU interference and SU battery energy. This paper proposes Energy Efficient and Interference-aware Spectrum Sensing (EEISS) technique for improving the throughput in CRN. In this work, the sensing time is dynamically estimated based on the battery energy levels of SUs and the transmit power is determined depending on PU signal and battery energy levels of SUs. A Game theory model is formulated to maximize the throughput based on these constraints. Experimental results show that EEISS attains improved throughput, higher probability of detection and higher residual energy.

Keywords: Cognitive Radio network (CRN), Spectrum sensing, Residual Energy, Throughput, Game theory model

1. Introduction

Cognitive radio network (CRN) is a network that relies on unscrupulous spectrum access and spectrum detecting for enhancing the wireless networks' spectrum competence. In CRN, the spectrum is fundamentally predefined and approved for the primary users (PU).On the other hand, whenever the spectrum is not being used by the PUs, then the SUs are allowed to utilize it. This method of allowing the SUs to access the spectrum whenever likely permits the supreme and effectual use of the restricted radio sources.

But, in order to attain this, the secondary users must proficientlyidentify the network spectrum to perceive if the spectrum is used or not by the primary users. The primary users should also be able to determine the noise modification and discriminate it from being the primary users. The secondary users ought toexecute spectrum detectingdeprived ofdistressing the PU's broadcastprocedure. The chieffeatures of cognitive radio (CR) are that the SUs ought toacclimate to the activevariations of the channel obtainability and the actions of PUs varyvigorously.

1.1 Proposed Contributions

Based on the identified research gaps (presented in the next section), this paper proposesEnergy Efficient and Interference-aware Spectrum Sensing (EEISS) technique for improving the throughput in CRN.

The main contributions of this work include:The sensing time is adaptively determined based on the residual battery energy of SUs.The transmit power is determined depending on the PU signal and energy level of SUs.

This paper is arranged as given: In section 2, related works are presented and in section 3 the details of EEISS are explained. In section 4, the results and discussion are presented. Section 5 contains the conclusion.

1.2 Related Works and Research Gaps

Asthroughput maximization can effect in huge energy depletion, the spectrum detectingmethod should address the energy-throughput tradeoff.So as toconserve the absolute right of the PU, the SU is confronted with the encounters of when to notice a channel, how long should the identifyingaction take, when to shift from the network and when to diffuseby means of a offered accessible channel. Besides the tasks of spectrum sensing, there are certainexclusivetasksassociated to CR channels like channel accessibility, channel excellence, control channel consignment and data channel consignment.

A joint channel, power and routing consignment are deliberated in the structure of [1]. It undertakes a group of ideal power levels of SU for attainingimprovedact. But, maintaining those power levels and defining the appropriate power which maximizes the throughput is yet again perplexing. In mutual channel assortment and routing protocol [2], the channel availability and channel swappinglatency are deliberated for channel assortment. On the other hand, energy and throughput factors are not taken into consideration.

The reinforcement learning-based transmission power and spectrum assortment system [3] permit every transmitter and receiver to indigenously alter its option of spectrum and transmit power, bearing in mind the connectivity and interference restraints. However, the reward function loads the improvement got by fruitful transmissions only thus parting the unsuccessful and retransmission efforts. Furthermore, it did not deliberate the throughput degradation in the course of PU impact.

In new generalized energy detector (GED) system [4], the sensing period is enhanced for exploiting the throughput of the CRN, by means of possibility of detection and false detection. However the sensing period has to be resolute by bearing in mind the residual energy levels of every SU too. The definite constant throughput at the SUs [5] enhances the detection possibility for cooperative sensing. Yet again, this research did not deliberate the remaining energies of SU while maximizing the throughput..

The idealsensingfactors of defectivesensing [6],consider only the Energy Detection process for spectrum sensing which tends to advanced false detection prospect. In the structure of spectrum sensing with a multi-class postulate [7], the SU communicates with the power level depending on the dynamic level of the identified signaland the remaining energy. However, the feature extraction method of SVM still has substantial computational and time overhead.

The trade off amid the spectral and energy efficiency has been addressed in [8] by bearing in mind the diversesorts of power utilized in CRN. But only the power of emission is considered for assessing the EE. The energy and throughput tradeoff managed in [9] such that the hybrid CRN energetically regulates its process manner for every time period and regulates the sensing period. But it deliberates only the Energy detection technique for spectrum sensing which tends to higher false detection probability.

2.Proposed Methodology

2.1 Overview

This paper proposes Energy Efficient and Interference-aware Spectrum Sensing (EEISS) technique for improving the throughput in CRN. In this work, the sensing time is adaptively determined depending on the energy level of SUs and the transmit power is determined depending on the PU signal and battery energy level of SUs.

2.2 Determination of Transmission Power Level (TPL)

The energy level (Eg_r) of the SU at period $t+1$ is found as

$$Eg_r(t+1) = Eg_r(t) - eg^{con}(t) \qquad \le B, \tag{1}$$

where $eg^{con}(t)$ denotes the expended energy at period t, and B denotes battery capability of the SU .

We signify the broadcast power of the i^{th} node as Q^i_{tx}. The broadcast range and interference range of the i^{th} node are specified by S^i_{tx} and S^i_{if}, correspondingly.

The lessened power occurrence as Q^j_{rx} at the j^{th} receiver can be evaluated by,

$$Q^j_{rx} = \alpha . Q^i_{tx}\{d^i\}^{-\beta} \tag{2}$$

Where
d^i - the definite distance amid the j^{th} receiver and the i^{th} node
B – the proponent factor of path-loss

α - the function of frequency f^I chosen by the broadcast node i
c – the speed of light

Let Min_P and Max_P are the minimum and maximum limits for the transmission power Q_{tx}
Let EPU_r be the energy of the received PU signal and EPU_{max} is the maximum limit for EPU_r
Let Eg_{max} and Eg_{min} be the minimum and maximum limits of Eg_r
Then the condition for selecting the transmission power level (TPL) is given by
TPL =MinP , when $EPUr > EPU_{max}$ or $Eg_r < Eg_{min}$
= MaxP, when $EPUr < EPU_{max}$ or $Eg_r > Eg_{max}$ (3)
The aim is to select the TPL of the SU depending up on the detected PU signal and the Eg_r in the SU battery.

The greater the PU energy level, the inferior the transmit power of the SU. In disparity, the greater the SU remaining energy, the greater the SU transmit power. It is due to fact that the greater the sensed energy due to advanced possibility of the PU's occurrence, and therefore, the transmit power ought to be chosen to lessen the PU interference. When the SU energy level is lesser, the transmit power ought to be lesser to upsurge the energy efficacy of the system.

2.3 Determination of Spectrum Sensing Interval

The spectrum sensing interval (SI) is adaptively adjusted based on the remaining energy (Eg_r) of SU.
So the main constraint for adjusting the sensing interval is
SI = SI + Δi, if $Eg_r > Eg_r >= Eg_{max}$
SI – Δi, if $Eg_r < Eg_r < Eg_{min}$ (4)
If the Eg_r is high, the sensing interval can be slightly increased by the factor Δi. On the other hand, if Eg_r is less, it should be decreased by the same factor.

2.4 Throughput Estimation

Each CR user collects N samples during periodic sensing and broadcast frame period of every Tf; if Ts is the specimen period, then $Tf = N \cdot Ts$ .The frame includes sensing period ρ that has n detection values utilised for sensing PU. The second portion of the frame is the data broadcast period of (Tf −ρ) with (N-n) samples, where $1 \leq n \leq N$.
Hence the expected throughput of the i^{th} SU can be estimated by

$$TH_n(\rho) = \frac{T_f - \rho}{T_f}(1 - Q_{f,i}) \tag{5}$$

2.5 Estimation Utility Function for theGame Theory Model

An utility function is derived to maximize the normalized throughput while considering the constraints presented in Eq.(3) and Eq.(4).
$UF_i = w_1 . EPU_{max} - w2 . Eg_r$ (7)
where $w_1$and w_2 are weight factors such that $w_1 + w_2$ 1.

According to Eq.(7), if UF is high , it assigns MinP for TPL and SI $-$ **Δi** for sensing interval. On the otherhand, if UF is low, it assigns MaxP for TPL and SI**+Δi** for sensing interval. In both the cases, the throughput should be maximized.

2.6 Game Theory Model for the Optimization Problem

In a game, as defined in game theory (GT), number of performers interrelate based on the instructions provided. Those performers might be singles, teams, corporates, associations and so on. Their collaborations will affect every performer and on the entireset of performers, i.e. they are mutually dependent.

So GT can be expressed in its common form as

$$G = [\ \{S_j, R_j\}, \{A_j\}, \{UF_j\}\ ]$$

where $\{S_j, R_j\}$ is the set of players which represents the SUs , $\{A_j\}$ is the group of activities of the performers which represents the estimation of sensing interval and $\{UF_j\}$ represent their utility functions.

The model is a non cooperative game, where players make independent decisions to optimize their utility functions.

T is the total time taken for number of iterations for actions taken by the players. Let $A_{j,1}$, $A_{j,2}$ .... denote the actions performed by the jth players in iterations 1,2....

Let $R(A_{j,1})$. $R(A_{j,2})$ ....denotes the responses of the corresponding actions performed and $R'(A_{j,1})$. $R'(A_{j,2})$ ....denotes the responses of the corresponding actions performed at the next iterations.

For each pair of players (S_j,R_j) the action A_j selected affects the actions of all other players.

In the proposed game theory model, each SU acts as the player, playing a non cooperative game between other players. For each player P_i, a utility function UF is formed using Eq. (7).

The following algorithm illustrates game theory model for improving the throughput based on TPL and SI.

Algorithm-2: Game theory based Spectrum Sensing

Input: Pair of Players (S_j, R_j), j=1,2....N
Initialize SIand TPL for all players
Output: Improved Throughput (TH_n)

```
1. t=1
2. k=1
3. While (t < T)
4. Do
5. for each pair of players <S_j, R_j>, ,j=1,2....N
6.  Initialize A_{j,k}=0
7.          Initialize R(A_{j,k})=0
8.          Initialize R'(A_{j,k})=0
```

```
$P_j$ estimates $Egr_j$
$P_j$ estimates EPUr
if ($R'(A_{j,k}) > R(A_{j,k})$)
        Compute $U_{Fj}$ using Eq.(7)
        if ($UF(P_j)$ = Maximum)
SI = SI – Δi
            TPL = MinP
            Estimate $TH_n(t)$ using (6)
if( $TH_n(t) > TH_n(t-1)$)
               break
else
        Form $A_{j,k+1}$
Compute $R'(A_{j,k}) = R(A_{j,k+1})$
t=t+1
end if
elseif (UF(Pj) = Minimum)
            SI = SI+Δi
            TPL = MaxP
            Estimate $TH_n(t)$ using (6)
if( $TH_n(t) > TH_n(t-1)$)
              break
else
Form $A_{j,k+1}$
Compute $R(A_{j,k+1})$
t=t+1
end if
   end if
 end for
end while
```

3. Experimental Results

The performance evaluation of EEISS is conducted using NS2 [10] against the Sub-channel Activity Index (SAI) based [8] scheme.

The experimental settings are listed out in Table 1

.Simulation parameter	**Value**
CR users	50 to 250
Size of the topology	1000m X 1000m
Distance between transmitter and receiver	300m
Path loss exponent (η)	4
Propagation Model	Two Ray Ground

Type of the Channel	Rayleigh Fading
Probability of Detection (P_d)	0.4 and 0.5
Probability of Miss detection (P_f)	0.01
Modulation used	BPSK
Energy Level	15 μJ
Transmit power	66 mW
Receive power	39 mW
Assigned Channels	12

Table -1Experimental parameters

4. Results

The experiments are conducted by increasing the SUs from 50 to 250. The parameters average delivery rate, Normalized throughput,average residual energy, probability of detection and probability of successful deliveryare measured for both the schemes.

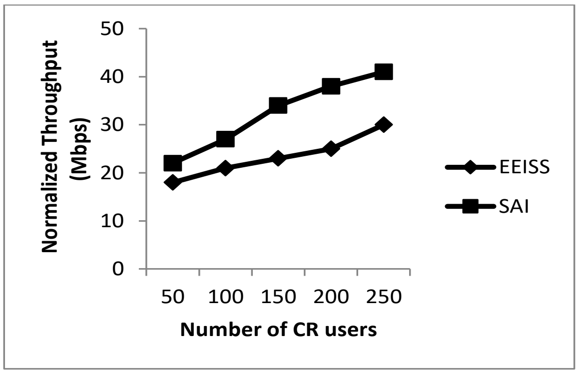

Figure 2 Throughput obtained at the receivers for CR users

Figure 2 shows the throughput obtained at the receivers for both the techniques in case of varying users. Since SAI did not consider the PER arising due to bad channel conditions, EEISS has 26% higher throughput, when compared to SAI scheme.

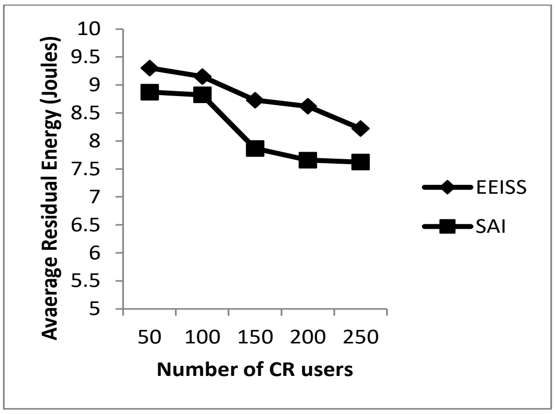

Figure 3 Average Residual Energy for CR users

Figure 3 exhibits the average battery energy level measured for both the techniques in caseof varying users. Since the sensing time is adaptively tuned based on the residual energies of SUs in EEISS, it has 7% higher residual energy than SAI scheme.

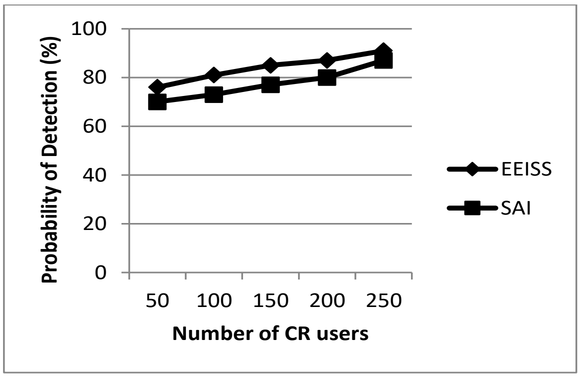

Figure 4 Probability of Detection (%) for CR users

Figure 4 shows the probability of detectionfor both the techniques in case of varying users. Since the sensing time is adjusted based on the residual energy, EEISS has 9% higher detection rate, when compared to SAI scheme.

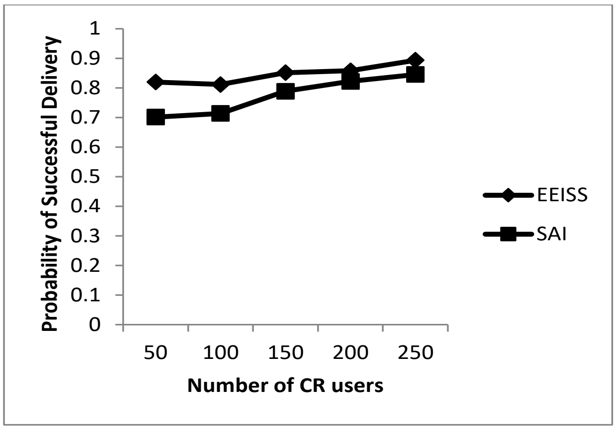

Figure 5 Possibility of Effective delivery for CR users

Figure 5 expresses the possibility of effective delivery for both the methods. As SAI did not deliberate the PER rising owing to bad channel situations, EEISS has 9% greater delivery rate, when associated to SAI system.

5.Conclusion

This paper proposes Energy Efficient and Interference-aware Spectrum Sensing (EEISS) techniquefor improving the throughput in CRN. In this work, the sensing time is adaptively determined based on the residual battery energy of SUs and the transmit power is determined depending on the PU signal and battery energy levels of SUs. A Game theory model is formulated in order to maximize the throughput. The results of EEISS are validated by means of NS2 and compared with the Sub-channel Activity Index (SAI) based scheme. Results show that EEISS attains improved throughput, higher probability of detection and higher residual energy.

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