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Energy-Decisive and Upgrade Cooperative Spectrum Sensing in Cognitive Radio Networks

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Abstract

In recent year energy efficiency and sensing time are become disparaging corner for cognitive radio (CR) networks, as network become deliberately energy-onerous. Cognitive radio intensify the pliability of personal services through language that illustrate knowledge of radio protocol, software module, proliferations, networks, user needs, and application scenario in a way that supports automated reasoning about the requirements of users [1]. As fast growing wireless applications are consuming more and more energy, and impersonate big challenges to operators in terms of energy footprint. Energy efficiency is not only includes the greenhouse problem and operational outlay, but is an obligatory to limit the power consumption demand in spectrum sensing and signal overhead, so it is of preeminent priority for a CR scenario compared to non-CR ones. Short while ago cooperative spectrum sensing is presented as a productive way to achieve superior sensing precision and bring down energy depletion by harnessing spatial diversity. So here we discussed the implications of facilitating higher energy efficiency in cognitive radio network from the perspective of fundamental trade-offs (i.e. what need to sacrifices to be energy efficient). In this review paper we have modelled given optimization problem with two different strategies. In first strategy only one phase of coarse spectrum sensing is activated in situation of absence of primary user or Signal-to-Noise Ratio (SNR) quantity is quite large. The second strategy accomplished for quality spectrum sensing. Here only single bit result send to the fusion center (FC), which overcome the consumption. And next algorithm finely exploit the local outcomes of coarse detection. It conserves the energy and improves a detection performance in noticeable amount. Simulation results shows that proposed strategies can achieve goal of minimum energy, less sensing time and better performance.

Keywords: Cooperative spectrum sensing; Energy-Efficiency; Sensing time; Cognitive radio network

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1. Introduction

The spectrum become progressively scarce with rapid emerge in wireless communication calls for efficient spectrum utilization. A Smart wireless communication system which familiar with surrounding environmental activities and tackle the change by edifice to accept the variation in upcoming Radio Frequency which cause by certain deviation in operating modules like modulation schemes, power-transmit and frequency of carrier in real scenario. To facilitate economical green wireless networks, energy efficient CRNs reduces the environmental impact and also cuts deployment costs. To assure that the unlicensed user can recognize the unoccupied spectrum quick and precisely without impeding the licensed users, cooperative sensing is considered to improve the performance of sensing by leveraging spatial diversity [2]. It was theory of ultimate goal in which a software radio platform should develop a fully adaptive and intelligent network that adopt its communication parameters accordingly as response of user and network requirement and without interfering primary users (PUs).

As whole execution of a cognitive radio is regulate combine by the precision of two task, and so it is mandatory to achieve better detection accuracy and accessing capability at the same moment. However, as there is a deficiency in detection potential, detection accuracy may not be achieve at much extent. Furthermore, the amount of resources is finite and they mostly reserved by detection stages, so accessing task leftover with scanty of resources. In overall, the interpretation of cognitive radio is finite by the condition of interference channel and the movement of primary network. Especially, in intertwine systems, the cognitive network can retrieve the spectrum only when the primary network is disable.

There are multiple technique for realization of spectrum sensing. As described in [3], the matched filter detection (coherent detection by way of gain in the signal-to-noise ratio (SNR)), the cyclostationary feature detection (oppression of the intrinsic periodicity of primary signals), entropy based detection (require a preceding knowledge of primary signal) can solve the noise uncertainty of the spectrum sensing through information entropy, and energy detection is the most popular method. It is consider being a most competent technique among all others.

To assured the service quality of primary user (PUs) as well as the spectrum availability of the secondary users (SUs), authentic and expeditious detection of spectrum vacancy is challenging issue. Although multipath fading, noise suspicious, and obscurity are always present in detection performance. Cooperative sensing is the moderate solution to attenuate such influences [4]. In Cooperative spectrum sensing (CSS), all secondary user observe the spectrum separately and their determination monitor by fusion center to establish the final decision.

In hard combination CSS only single bit outcome received by fusion center from every SU, which diminish the disbursement. But in soft combination CSS technique by way of precise sensing results from separate SUs, overall performance has been improved. Nevertheless its fulfilment in real scenario is inconvenient because of immense overhead [5]. In our paper we have elaborate single bit decision CSS strategy to conserve energy, and sensing duration minimize at some extent which finally improved the performance of CSS technique for secondary users (SUs).

In optimal multiple channel sensing scheme, channel sensing duration overcome by concentrating the spectrum detector on the channels that are possibly unoccupied [5]. A two-stage sensing approach discussed in [6] based on energy detection and cyclostationary detection. In this article, based on certain threshold first stage performed the coarse energy detection and if condition not satisfied, a next stage is executed with precise cyclostationary detection. This technique improved the detection performance.

As per the previous researches, works about the energy efficiency transmission with cooperative sensing are still lacking at present. The concept of cooperative sensing upgrade the sensing interpretation and wisely uses the spectrum. Though, ample of energy depleted in CSS as compare to single user sensing. So, preservation of energy is prerequisite at this moment. If spectrum sense for longer duration with big amount of cooperative SUs, result achieves accurate sensing outcomes. But with the vast amount of energy and transmit in short time. Therefore, it is necessary to make a balance between them. As we discussed, sensing process in CSS also affect mainly by number of bit employ in it. Hence, in our paper we concentrate on all above factors simultaneously to attain an ideal model with minimal energy utilization in cooperative environment.

2. Fundamentals

In this article we review the work in [5] and by adding few more equations we elaborate our work. Here we present two time saving and energy efficient one bit CSS (TSEEOB-CSS) strategies, in which spectrum sensing task
done with two different phases. In some conditions (when PU inactive/SNR is high) only single phases of sensing is utilized, which conserve the energy and cut the time of sensing. Also, all cooperative CR users report their sensing outcome to fusion center via single bit, which additionally save the disbursement. Various feature and techniques covered in this article are listed below:

- We present a same TSEEOB-CSS algorithm as used in [5] with some variation for cooperative spectrum sensing instead of conventional CSS schemes which enhance the energy efficiency with better detection performance.
- First algorithm conduct for the scatological detection.
- Second algorithm presents with support of first algorithm. It exploit the confined outcomes of previous stage, and explore the consequences. It furthermore retain the energy.
- The variables used in both the algorithm discussed above are adjusted carefully to meet the goal, and for this, some rules are described in the article to help it.
- Prevalent simulation results show the fulfilment of the algorithms and diminish the energy consumption at great extent.

3. System Model

As shown in Fig. 1, the PU networks and CR networks perform together in similar band of frequencies. Hence, there may be chances of interference between different PUs and CR users. System first search for a spectrum opportunity in the given frequency slot and then begin communications in it. Based on this criteria, main purpose of cooperative sensing is to achieve two goals. First to avoid any interference, CR user should keep track on primary user when spectrum is busy. Second to enhance its overall spectrum efficiency, CR user should detect accessing opportunities when spectrum is idle.

![Fig. 1. Model for spectrum sensing in CRN [7]](image)

3.1. Energy based Detection for Spectrum Sensing

The key of an interlace cognitive network is to have a powerful spectrum sensing capability. Energy detection is execute by measuring the threshold value with energy intensity of incoming signal from a PU [7]. This method does not need a foregoing perception of transmitted signal and its noise behaviour, which make its practical realization simple. In moderate SNR zone, its execution may corrupt. Here in cooperative sensing, all participating CR users separately operate local sensing and outcomes of all CR users accumulate by fusion center to monitor the PU activity. Let the model contains N number of CR users. The spectrum sensing essence can be expressed with binary hypothesis-testing notation:

\[ H_0: \text{Channel is idle (PU is inactive)} \]
\[ H_1: \text{Channel is busy (PU is active)} \]
Now sensing method is to be decided on the basis of this test according to [8]. For simplification, the impulse response of channel is contemplate as consistent while sensing task.

\[ y(m) = \begin{cases} w(m) & H_0 \\ h(m)x(m) + w(m) & H_1 \end{cases} \]  

where \( y(m) \) is received signal, \( x(m) \) is primary signal transmitted via wireless channel, \( h(m) \) is impulse response of the sensing channel, \( w(m) \) is additive white Gaussian noise (AWGN), and \( m = 0,1,2,\ldots,K \); where \( K \) is number of samples. The test module can be expressed as [5]:

\[ Z = \frac{1}{K} \sum_{m=1}^{K} |y(m)|^2 \begin{cases} > \lambda & H_1 \\ < \lambda & H_0 \end{cases} \]  

where \( Z \) is the testing quantity, and \( \lambda \) is fixed known threshold. Let, \( \sigma_w^2 = 1 \) and \( \gamma_p = \sigma_x^2/\sigma_w^2 \) as the received SNR of primary user signal (\( \sigma_x \): power of transmitted signal, \( \sigma_w \): power of noise). By using energy detection, the false alarm and detection probability of the secondary user respectively can be computed according to [5]:

\[ P_f = Pr(Z > \lambda | H_0) = Q\left(\lambda - 1 - \frac{1}{2}\sqrt{\frac{K}{2}}\right) \]  

\[ P_d = Pr(Z > \lambda | H_1) = Q\left(\lambda - \gamma_p - 1 - \frac{K}{2\gamma_p + 1}\right) \]  

where \( Q(.) \) is Q function.

### 3.2. Energy Efficient Cooperative Sensing

Energy efficiency is basically described as the number of data bits transmitted in unit of energy. Here, the objective is to improve the energy efficiency in cooperative sensing, communicating cooperative outcome to central module (FC) by fulfilment of authenticity constrain and impart specific throughput to secondary users. Also the optimization of CR performance can be achieved with energy limitation by detection accuracy control [3]. Particularly, this technique explore the trade-off among two feature of sensing time. First, a long lasting spectrum sensing expend much more energy of every CR users. Second, if spectrum sensing last for lengthy duration, detection performance enhance at every CR user and side by CR user count and relevant energy reduced. Thus, to compensate between energy depletion and its overhead owing of expected detection performance, this technique attain most favourable sensing duration and quantity of CR users.

Furthermore, in CR network a sleep mode is always present while transmission. So during sleep mode if sensing transceiver switches off, observation and transmission energy can be saved additionally [9].

### 4. Algorithm Design: TSEEOB-CSS

It is generally considered that the secondary users can only transmit if the primary network is inactive or if the secondary users are located outside a forbid region surrounding the primary transmitter. The algorithm describe in [10] (time saving two bit CSS) attain a superior interpretation of CR design than hard combination cooperative sensing scheme. In extension of this work, other concept presented in [5] is one-bit time saving energy efficient scheme. We have review the same strategy and in addition of some more facts, energy optimization and shorter sensing duration criteria fulfilled.

To implement both phases of TSEEOB cooperative scheme, we consider the total \( K \) number of samples. Out of which only \( \beta K \) samples manipulate in first phase of detection and \( (1- \beta) K \) samples employ in next phase of quality sensing.
To facilitate clearness, we suppose that in these procedure active/inactive position of primary user does not modify i.e. received signal is consistent with observation time [5].

4.1. The First Algorithm

The two phase one bit energy efficient scheme is presented in fig. 2. It accomplished by series of subsequent steps and Equations [5]:
Step 1: In first phase of local detection process, at every SU detection is done by $\beta K$ samples (here $0 < \beta < 0.5$).

$$Z_{L1} = \frac{1}{\beta K} \sum_{m=1}^{\beta K} |y_i(m)|^2$$  \hspace{1cm} (5)

$y_i(m)$ is $m$th sample of the signal to be sensed at $i$th secondary user ($i=0,1,2,...,M$). Local result ‘$L1_i$’ received as:

$$L_{1i} = \begin{cases} 
0, & 0 < Z_{L1i} < \lambda_1 - \delta \\
\text{no decision,} & \lambda_1 - \delta \leq Z_{L1i} \leq \lambda_1 + \delta \\
1, & Z_{L1i} > \lambda_1 + \delta 
\end{cases}$$  \hspace{1cm} (6)

Step 2: Once the central module (FC) receive the local result $L_{1i}$, the final result $F$ can be obtained as,

$$F = \begin{cases} 
1, & \text{More than half SUs indicate presence of primary user} \\
0, & \text{More than half SUs indicate absence of primary user} \\
\text{Elsewhere, Final result cannot be send}
\end{cases}$$  \hspace{1cm} (7)

Step 3: If final result $F$ is received by the SUs, detection is complete. Otherwise, about $\tau$ interval next phase of prime energy detection is executed by $(1-\beta) K$ samples. Let the value of $\tau$ in fig. 2 follows; $\tau < T_1 < T_2$, then $\tau$ can be neglected.

Step 4: After prime energy detection done in next phase, local result $L_{2i}$ formulated as

$$L_{2i} = \begin{cases} 
1, & Z_{L2i} \geq \lambda_2 \\
0, & Z_{L2i} < \lambda_2 
\end{cases}$$  \hspace{1cm} (8)

Step 5: Once the central module (FC) receive the local result $L_{2i}$, the final result $F$ can be express as Equation (9) and it finally send to central module.
The first TSEEOB-CSS algorithm deliberates near about same interpretation as achieve from hard combination CSS. But in absence of PU or SNR is prominent, sensing time can be cut and energy efficiency perhaps enhance productively.

4.2. The Second Algorithm

The Second presented algorithm completely utilize the energy detection scheme and prevent some more energy. This algorithm implemented near about similar steps as of first algorithm. For step 1 to 3 we have follow the same logic of previous algorithm. The furtherance is done as below.

Step 4: In elapse of τ interval, if the CR users does not acknowledge local result L1i in first algorithm, then by using (1-β) K samples prime energy detection perform. Local result L2i=L1i (if L1i acknowledge), else L2i calculated by similar expression as in Equation (8).

Step 5: Now, Final result F was formulated by Equation (10).

\[
F = \begin{cases} 
1, & \text{More than half SUs indicates presence of PUs} \\
0, & \text{elsewhere} 
\end{cases}
\]

If we summarize above two TSEEOB-CSS algorithms, by using local result of the coarse detection in second algorithm level of performance of detection raised and energy was reserved greatly. By using same number of samples whole cognitive network deliberate energy efficient model.

5. Optimization Model

5.1. Energy Consumption Model

Most of energy utilization done by samples of received signal at every SUs in detection process. Thus, with number of samples energy utilization in ordinary cooperative sensing (CS) scheme can be calculated as [5]:

\[
E_{CS} = MKe_0
\]

Here, M is count of total CR users present in cooperative sensing, K represent the count of total samples taken in detection process at every SU, and energy depletion for single sample in detection is expressed as e_0. The energy of the first and second presented TSEEOB_CSS algorithm can be elaborate as [5]:

\[
E_1 = M\beta Ke_0 + M ((1-\beta) K) e_0 \left(1 - \sum_{i=\lceil M/2 \rceil+1}^{M} \binom{M}{i} P_1^i (1 - P_1)^{M-i} \right) - \sum_{i=\lceil M/2 \rceil+1}^{M} \binom{M}{i} P_0^i (1 - P_0)^{M-i} 
\]

\[
E_2 = M\beta Ke_0 + M ((1-\beta) K) e_0 \left(1 - \sum_{i=\lceil M/2 \rceil+1}^{M} \binom{M}{i} P_1^i (1 - P_1)^{M-i} \right) - \sum_{i=\lceil M/2 \rceil+1}^{M} \binom{M}{i} P_0^i (1 - P_0)^{M-i} \right) (1-P_1-P_0) 
\]

From above three equations (11-13), we can observe that
So, we can conclude from scenario that energy required in second TSEEOB-CSS algorithm is considerably less than first and ordinary cooperative sensing algorithms. As energy conserved in plentiful amount, we can represent it as green network for CR.

5.2. Model for EE Sensing time

The sensing time is a remarkable variable in system which illustrate how frequently and how lengthy the CR network retrieve the spectrum. To strengthen the performance, accumulation of the sensing time is crucial, as it can expand detection probability of idle spectrum although probability of false alarm drop [12].

By mean of count of total samples taken for spectrum sensing, the sensing time in ordinary cooperative sensing algorithm can be expressed as [5]:

\[ T_{CS} = Kt_0 \]  

\[ T_1 = T_2 = \beta Kt_0 + ((1-\beta) K) t_0 \]

From equation (15) and (16), we can observe that,

\[ T_1 = T_2 < T_{CS} \]

The general equation for sensing time is represent as:

\[ \tau_s \geq \frac{2}{\gamma_f} \left( Q^{-1}(p_f) - Q^{-1}(p_d) \right)^2 \]  

where \( \tau_s \) is sensing time, \( \gamma_p \) is received SNR of primary user signal, and \( f_s \) is sampling frequency. From Equation (18), we can derived the minimum sensing time equation that can be express as per [13]:

\[ \tau_s^{min} = \frac{2}{\gamma_f} \left( Q^{-1}(p_f) - Q^{-1}(1 - P_d) \right)^2 \sqrt{T + 2\gamma_p} \]

where \( \tau_s^{min} \) is minimum sensing time required by secondary user. Later we discussed about the design criterion for minimum sensing time.

From the throughput( energy efficiency) point of view, if sensing exhausted for longer time the extra energy is expend for overhead and only few time left for transmission. Simultaneously, the detection precision (\( P_d \) and \( P_f \)) may fluctuate the throughput of CR network [14].

From the whole study, we observe that by use of TSEEOB sensing algorithm in the situation of absence of PU or prominent SNR region of PU, the energy efficiency enhance in noticeable amount and also the sensing time diminish.

6. Simulation Results and Performance Analysis

In the following section the performance of the discussed algorithms has designed using simulation software. The sampling frequency \( f_s \) at SUs is taken to be 64MHz, and the baseband symbol rate (\( fb \)) consider to be 1Mbps. In
presented two phase algorithm value assign to all variable as, $\beta = 0.33$, the total count of samples = 763, and $\delta = 0.1$.

Here we begin the resemblance of detection performance in first algorithm of TSEEOB cooperative sensing scheme at distinct value of $\lambda_1$ i.e. 1.125, 1.100, and 1.050. The resemblance is shown in fig. 3(a). With value of $P_f = 0.1$, in first presented algorithm the performance of detection at $\lambda_1 = 1.050$ is superior to $\lambda_1 = 1.100$.

The energy efficiency enhance in second TSEEOB algorithm as measure of previous algorithm. So the performance of detection in both algorithm is present in fig. 3 (b). From this simulation plot, we can conclude that the detection performance of the second TSEEOB algorithm is close to that of first TSEEOB algorithm with 768 samples and background noise power is consider to be unity.

With prime energy detection in second phase the energy consumption overcome and sensing is improved. The second phase detection probability for both algorithm is shown in fig. 4 (a). By selecting the appropriate value of $\delta$, the system model can exhibit balance among detection precision and energy efficiency.

Now if we consider the sensing time effect, if more time spent in spectrum sensing by SUs, more energy...
consumption occurs. Consequently, its trade-off among transmission and sensing time for both energy efficiency and throughput. So we try to implement the best model with minimal energy and sensing time with better signal detection performance. From Equation (18) we can elaborate the correlation among probability of detection and sensing duration. With more sensing span of time, detection probability strengthen and false alarm probability diminished. We conclude the same from fig. 4 (b).

Plenty of simulation results discussed in this section, they shows that the algorithm can achieve significant detection performance with lower energy consumption and minimum sensing duration.

7. Conclusion and Future Work

In this article, the numerical outcomes express the effectiveness of the presented cooperative schemes by comparing with the traditional schemes. As our main goal in this article is to design energy efficient CR network, and we achieve it first by using one-bit decision instead of two, which reduces the overhead prominently. Second we have done the spectrum sensing in two phases, in which prime energy detection executed when first stage failed to deliver the sensing result.

It explore the cooperative sensing with energy detection because of its low computational difficulties. With rapid swing in background noise, the performance of the presented algorithm leads to intolerance. So we have utilize one-bit energy efficient algorithm in two phases. As only one bit used in acknowledgement process and with prime energy detection in second phase, fulfilled the goal of optimized energy and sensing duration.

The energy efficiency of spectrum sensing is mainly affected by how frequently the primary channel sensed by secondary users. By keeping this point in mind we have tried to reduce sensing time and also improves the detection precision by quality energy detection. By concluding all our work, we have presented a model which provide green cognitive radio network which deliberates minimum energy consumption with better accuracy.

In our future work, we try to elaborate our work with one-bit decision to optimize the sensing time and also improving the detection performance with minimal energy by using more advance optimizing parameter that effect the overall performance of the system.

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