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Energy Efficient Design for External Cooperative Sensing in Cognitive Radio

Hemlata Patil
Ramrao Adik Institute of Technology,Nerul
Navi Mumbai, India

A.J. Patil, PhD
Shri Gulabrao Deokar College Of Engineering, Jalgaon
India

S.G. Bhirud, PhD
Veer Jijamata Technological Institute, Mumbai
India

ABSTRACT
In this paper, the energy efficiency of cooperative sensing in cognitive radio networks is investigated. In cooperative sensing, more energy is consumed in sensing the channel and reporting the results to the fusion detector. To address this issue a very innovative design called External Sensing Energy Efficient technique is proposed in this literature. Analytical studies show that sensing time is a key factor to determine the energy efficiency. The approach is to outsource the sensing work to external network. Simulation results show the comparison between the internal sensing and the external sensing which says that ESEET performs significantly better than that of internal sensing.

General Terms
Cognitive Radio, Cooperative Sensing.

Keywords
External Cooperative Sensing, Energy Efficiency

1. INTRODUCTION
In recent years there is remarkable growth in wireless communication industry. Every single individual is endeavoring to get a share of spectrum. As electronic devices are becoming smarter and bandwidth hungry, to address such type of situation where a spectrum can be offered spatially and temporally cognitive radio comes up as an effective solution. This can be accomplished without disturbing the operation of primary users. Cognitive radio (CR) is a wireless device which tries to address a spectrum scarcity problem. Spectral efficiency is improved by locating the vacant slots in primary user (PU) spectrum thereby preventing the harmful intervention caused by secondary users (SU). The main spectrum sensing techniques are Energy Detection, Cyclostationary Detection and Matched Filter Detection [1] [2].

Energy detection is the most-used technique as it does not require any information about the primary user. However, in practice detection, performance is affected by multipath fading, shadowing and receiver uncertainty issues. To overcome this issues cooperative spectrum sensing has come up as a promising solution [1]. In cooperative spectrum sensing each secondary node sense the spectrum individually and depending on the type of sensing technique used the results are either distributed among each secondary user or sent to the fusion center where the decision is taken whether the spectrum is empty or not. As the number of secondary users increase the cooperation overhead increases thereby putting up the limit of an optimal number of secondary users taking part in sensing process. The sensing results are sent to fusion center where they are combined in one of these three ways Hard Combined rules, Soft combined and softened hard rule. In hard combined rule AND, OR and MAJORITY OR logic is used. CR tries to sense the PU individually and sends its result to FC where the decision is taken up depending on the logic, whether the PU is present or not.

Hard combining rule is demonstrated in [3] where as soft combining rule is studied in [4] which use equal gain combining rule and maximal ratio combining rule. The soft combining rule gives better result than hard combining rule. K out of N rule is proposed in [5] which shows that the majority of the users send the result of PU as vacant, then FC declares the PU spectrum to be vacant or vice versa. In [6] the sensing time of SU is analyzed under two operational modes, namely, the constant primary user protection and constant secondary user spectrum usability situations, where the targeted probability of detection is kept high to protect the PU and in second situation the probability of false alarm is kept low so that the secondary users get the maximum chance to use the spectrum. The main objective of CR networks is efficient spectrum utilization. Thus, the spectrum sensing functionality should provide more transmission opportunities to CR users. However, during the observation period, the transmission of CR users is not allowed, which inevitably decreases the transmission opportunities of CR users, leading to the so-called sensing efficiency issue [7]. Since spectrum sensing process consumes lots of energy while trying to find out vacant channel, energy efficiency is a crucial part which has to be addressed effectively. Many researchers have worked on energy improvement techniques for internal cooperative sensing. If the number of cooperating secondary user are more, then sensing time required is also more. The detection performance can be improved but at the same time energy consumption is increased. Therefore the different ways to select the cooperating secondary users is studied in [6] which consider the local sensing performance, the sensing result and the transmission of data. The network energy consumption is an essential parameter which is well addressed and minimized in these papers [8] [9]. In practical situations performance is degraded by multipath fading and shadowing in internal sensing. To combat these issues cooperative external sensing methods are gaining attention. In [10] secondary users access spectrum through Radio Environment Map(REM)and geo location database, the results says that Live REM outperforms in terms of root mean square error detection zone ratio. So far external sensing is not implemented and has not been exploited and thus External Sensing Energy Efficient technique (ESEET) method has been proposed which addresses the energy efficiency problem.

The rest of this paper is organized as follows. In Section 2, the system model is introduced. Section 3 is devoted to the analysis of proposed ESEET method. In Section 4 Simulation results are provided, followed by concluding remarks in Section 5.

2. SYSTEM MODEL

Consider a cognitive radio network of k number of secondary users and 1 primary user channel. The external network (EN) consists of only one node and is continuously sensing the primary users channel via periodic sensing, as soon as it finds the empty space it transmits a one bit message to all secondary users conveying the message that channel is vacant. We assume the decision given by EN is error free. The design of external network is out of focus of this literature, here we are going to concentrate on how the energy efficiency, throughput and sensing efficiency is achieved by outsourcing the spectrum sensing work. The secondary users are in wake up mode if they have some data to transmit else they are in sleep mode saving energy consumed in listening to external network. Each frame of external node consists of a sensing slot and a reporting/transmission slot. Primary user is assumed to be in on-off traffic model [7],

Hypothesis model for energy detection can be given as [2];

$x_r(t) = n_c(t), \quad 0 < t < T$ under H_0 (1)

$xr(t) = h_c s_p(t) + n_c(t), \quad 0 < t < T$ under H_1 (2)

where $x_r(t)$ – received signal at the external node, $n_c(t)$ is zero mean additive white Gaussian noise (AWGN), h_c is the channel gain of the sensing channel and $s_p(t)$ is transmitted primary user signal. The external network uses two hypotheses

H_0: Spectrum is idle i.e. primary user is absent

H_1: Spectrum is occupied: primary user is present

Fig 1 demonstrates the cooperative external sensing system. The energy detection method is used to sense the channel, the average received signal to noise ratio SNR of the PU signal is γ .The false alarm probability and detection probability are given by [11].

$$Pfn(\tau_{sn}) = Q\left(\sqrt{2\gamma+1}\,Q^{-1}(Pdt) + \gamma\sqrt{\tau_{sn} fs}\right) \qquad (3)$$

$$Pdn(\tau_{sn}) = Q\left(1/\sqrt{2\gamma+1}\,Q^{-1}(Pft) - \gamma\sqrt{\tau_{sn} fs}\right) \qquad (4)$$

where *Pfn* and *Pdn* are the false alarm probability and detection probability of the external node in the design. τ_{sn} is the sensing time of the external node. Pft is the targeted probability of false alarm, Pdt is the targeted probability of detection. Q is complementary distribution function of standard Gaussian. The value of Pdt is kept high in order to protect primary user and Pft is kept low in order to allow secondary user to use maximum spectrum.

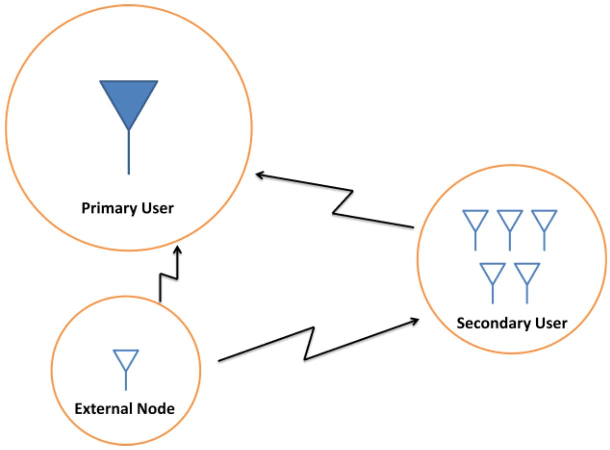

Fig 1 Demonstration of Cooperative External Sensing

3. ANALYSIS OF PROPOSED ESEET

In this section the overall throughput and energy efficiency of the system with respect to sensing time of the external network is analyzed. A TDMA slot is considered with a frame which has a τ_{sn} as sensing slot, T- τ_{sn} as reporting/transmission slot with T as total frame duration.

The secondary users access the primary user's channel. Let β be the probability that the channel is occupied and $1-\beta$ is the probability that the channel is vacant. The different circumstances under channel sensing are [12]; the probability of the channel that it is used by primary user is βPdn. The probability of the channel that it is used by primary and secondary user is $\beta.\ (1-Pdn)$. The probability of the channel that it is used by secondary users is $(1-\beta)\ (1-Pfn)$. The probability of the channel that neither one is using $(1-\beta)Pfn$. Thus, the average channel throughput Cavg is given by

$$Cavg = \beta Pdn.(Cp + Cn) + \beta\,(1 - Pdn).(Cps + Csp + Cn) + (1-\beta)(1-Pfn).(Cs + Cn) + (1-\beta)PfnCn \qquad (5)$$

where *Cp, Cs, Cn* is the throughput of primary user, secondary user and external node respectively. *Cps* is the throughput of PU when SU is present and *Csp* is the throughput of SU when PU is present

Simplifying equation (5)

Let $C_1 = \beta Pdn.(Cp + Cn)$, $C_2 = \beta\,(1 - Pdn).(Cps + Csp + Cn)$, $C_3 = (1-\beta)(1-Pfn).(Cs + Cn)$, $C_4 = (1-\beta)PfnCn$

Therefore

$$Cavg = C_1 + C_2 + C_3 + C_4 \qquad (6)$$

Secondly the average energy consumption by the network is considered. The different scenarios are

- P (H_1/ H_1) i.e. the probability that PU was busy and it is correctly detected as busy .The probability of this is $\beta.Pdn$. In this case the energy consumed is *Ens+Enr+Ep*
- P (H_0/ H_1) i.e. the probability that PU was busy and it is falsely detected as vacant. The probability of this $(1-\beta)\ (1-Pdn)$. In this case the energy consumption is *Ens+Enr+Eps+Esp*
- P (H_1/ H_0) i.e. the probability that PU was inactive and it is falsely detected as busy .The probability of this is $\beta.Pfn$. In this case the energy consumption is *Ens+Enr*

- P (H_0/ H_0) i.e. the probability that PU was inactive and it is correctly detected as vacant. The probability of this is *(1-β)(1-Pfn)*.In this case the energy consumption is *Ens+Enr+Es*

Where *Ens*, *Enr* is the energy required by the external node for sensing the PU and reporting the information to SU's respectively. *Ep* is the energy required by the PU for data transmission .*Es* is the energy required by the SU for data transmission .*En* is the energy required by external node i.e. *En =Ens+Enr*

Thus the average energy consumption is given as; Energy consumed in the network equals to energy consumed by listening to external network and energy consumed by transmitting the message by secondary user .As external sensing node is not going to transmit data to primary network, the throughput of this network will be very small.

$$Eavg = \beta Pd.(Ens + Enr + Ep) + \beta(1 - Pdn)(Ens + Enr + Ep + Es) + (1 - \beta)(1 - pfn).(Ens + Enr + Es) + (1 - \beta).Pfn.(Ens + Enr) \quad (7)$$

Equation (7) can be simplified as

$$Eavg = En + 1 - [(1 - \beta).Ep] + [Pfn - Pdn].\beta Es \quad (8)$$

Energy efficiency η is defined as throughput of a network upon energy consumed by a network. [12] ie Average no of bits transmitted upon average energy consumed

$$\eta = Cavg/Eavg \quad (9)$$

$$\eta = \frac{C1 + C2 + C3 + C4}{En + 1 - [(1-\beta).Ep] + [Pfn - Pdn].\beta Es} \quad (10)$$

Thus comparing equation (10) with the energy efficiency equation in [9] analytically as well as with performed simulations we can justify that if external sensing technique is used for cooperative network, the energy efficiency is improved.

4. SIMULATION RESULTS

The simulations are done on Matlab 2013a to verify the above energy efficiency equation. The values of some parameters are taken from [9] for fair comparison. The energy detector is used and the primary user is considered to have BPSK modulated wave with bandwidth of 2MHz .The sampling frequency is same as bandwidth and sensing duration to be 5ms, therefore the time bandwidth product *u* comes out to be 10.The value of β is taken as 0.5. As the transmission energy of primary user will be more compared to secondary so *Cp* is assumed to be greater than *Cs*. Let *Cp* be 20 and *Cs* be 10. *Cps* and *Csp* is taken up as 10 and 5.As the throughput of external node will be very less as it only has to report the information regarding the status of the channel it is considered as 0.5.*Ep* is taken up as 40 and *Es* to be 10.The sensing energy required is taken as 0.1 and reporting energy to be 0.05.

Table 1 shows the tabular data of comparison of proposed ESEET and EEOS. It is evident that the energy efficiency obtained by ESEET for all threshold values is better than that of EEOS. It is obvious to get efficient results with ESEET as the sensing time is reduced thereby reducing the energy consumption which in turn increases energy efficiency.

Threshold	Energy Efficiency of ESEET	Energy Efficiency of EEOS
20	0.632	0.5887
22	0.6286	0.5873
24	0.6282	0.5869
26	0.6249	0.5839
28	0.6282	0.5871
30	0.6290	0.5879
32	0.6274	0.5866
34	0.6267	0.5860
36	0.6326	0.5916
38	0.6352	0.5941
40	0.6326	0.5918

Table 1 Energy Efficiency comparison of ESEET and EEOS

The Fig 2 has a comparison of energy efficient optimization strategy (EEOS) method and our proposed ESEET method with respect to threshold and energy efficiency. The threshold is varied from 20 to 40, average snr is kept at 10dB the time bandwidth product u is 10. The η of EEOS is 0.5626 and that of ESEET is 0.618.This clearly indicates that the proposed method improves the energy efficiency.

Fig 3 illustrates the energy efficiency versus SNR .The number of cooperating SU's for EEOS method is 10 and the threshold is kept at 20.Energy efficiency for EEOS at 8dB under awgn is 0.553 and for proposed ESEET its 0.6136.Thus it can be seen that the energy efficiency of ESEET is significantly more than the EEOS

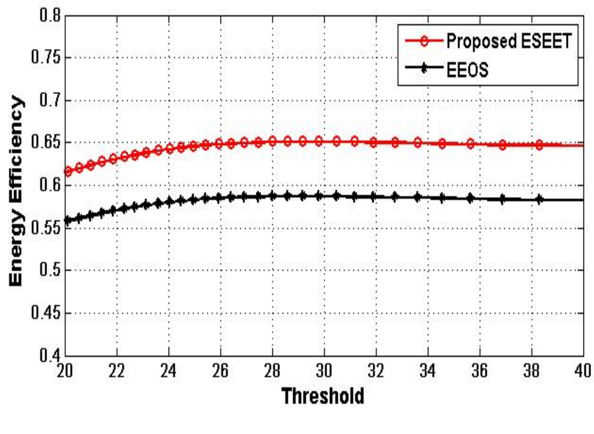

Fig 2 Comparison of Energy Efficiency of EEOS and proposed ESEET

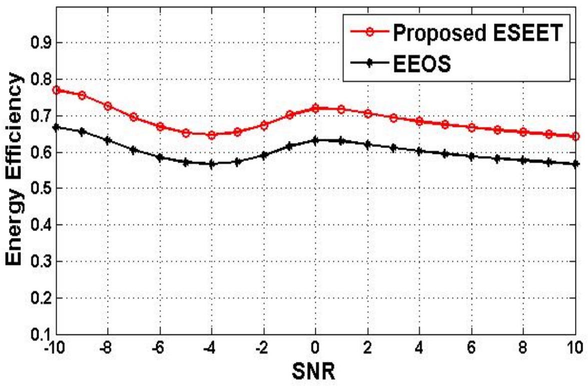

Fig 3 Energy Efficiency versus SNR

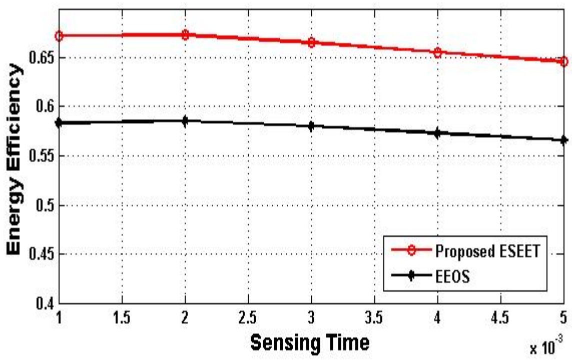

Fig 4 Energy efficiency versus sensing time

Fig 4 is the illustration of proposed method; it shows the relationship between sensing time and energy efficiency. As we know increasing sensing time gives better detection probability. We can verify the result of this fig with our previous ones. Keeping average SNR at 10dB, number of SU's 10 and varying sensing time from 1 ms to 5 ms we can observe that at 5 ms we get the energy efficiency of 0.5656 and of ESEET is 0.62 .Thus it has again proved that the ESEET performs outstandingly compared to EEOS

5. CONCLUSION

In this paper, a new technique to improve the energy efficiency of the system is proposed .The results of ESEET are verified analytically as well as by simulations by comparing them with EEOS. The impact of signal to noise ratio, threshold and sensing time on the technique is illustrated. It is shown that the energy consumption is reduced by external sensing, thereby increasing the energy efficiency. Simulation clearly indicates that the proposed method outperforms in terms of energy efficiency .The energy efficiency with the proposed ESEET technique is improved by 5.7 % which is very distinctive. In future work we are going to investigate the same problem with more realistic view in multichannel cognitive radio network.

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