Improvement of Energy Consumption in Cognitive Radio Networks using an Efficient Coarse – Fine Sensing Method

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Abstract. Cognitive radio (CR) is a technology to solve the sacristy problem in the spectrum. One of the major problems is such technology is the high energy consumption especially during spectrum sensing. In this paper a method to improve energy consumption in sensing process is proposed. Theoretical analysis to compute the amount of energy consumed using the proposed as well as in the transmission stage during transmitting a local decision to the fusion center FC method are derived. The proposed sensing method is based on energy detection to detect the presence or absence of the primary user (PU). The proposed method consists of two stages: coarse sensing stage and fine sensing stage. In coarse sensing stage, all the channels in the band are sensed shortly and the channel that have maximum (or minimum) energy is identified to make intensive fine sensing for verifying the presence of PU signal (or hole). The performance of the proposed method is evaluated in two scenarios: non-cooperative, and cooperative in both AWGN and Rayleigh fading channels. The simulation results in cooperative scenario at SNR equals 0 dB showed that the proposed method reduces the energy consumption by 72% as compared with the traditional method based on single sensing stage. The result also showed that 57%, 54% reductions in energy consumption are obtained using the proposed method as compared with TSEEOB-CSSS and CC4C methods that are based on two sensing stages respectively.

Keywords: Cognitive radio, spectrum sensing, energy detection energy consumption, cooperative sensing, non-cooperative sensing, coarse-fine sensing.

1 INTRODUCTION

The concept of cognitive radio is that unlicensed users (cognitive radio users) can access the spectrum owned by licensed users (primary users) while they cannot interfere with primary users when exploiting spectrum. Thus to realize the technique of cognitive radio, a cognitive radio user must have the ability to measure, sense and learn channel characteristics and availabilities [1]. One of the main challenges in CR networks is the high energy consumption, especially in battery-powered terminals. In order to identify the unused spectrum portions, the unlicensed users, also called cognitive users (CUs), are enforced to sense it for specific period, inducing energy consumption [2]. Different spectrum sensing techniques are available such as energy detection, matched filter detection, waveform-based sensing, and cyclostationarity-based sensing. Energy detection is a simple method for spectrum sensing, and is one of the most commonly employed spectrum sensing schemes. It does not require any prior knowledge of the structure of the primary users (PUs) signals [3]. Two scenarios of sensing spectrum are usually used, non-cooperative scenario and cooperative scenario (CSS). In non-cooperative scenario single user is used to make the sensing while in cooperative scenario multiple cognitive users sense in cooperation to reduce the effect of fading [3]. In

CSS, the local sensing results are reported to a central entity, called fusion centre (FC). The FC is in charge of making a global decision regarding the spectrum occupancy by applying a specific fusion rule (FR) [2] . There are two popular schema used to represent the local result: hard-based scheme and soft based scheme. In hard scheme, all CUs convey their local decisions as a single bit per CU towards the FC consecutively: bit "1" indicates the PU presence and bit "0" indicates the PU absence. In soft scheme the sensing result is usually quantized by a large number of bits [4]. In this work hard scheme is used because it consumes less energy. The rule that is employed by the FC is OR rule, which implies that if at least one CU makes a local decision of busy (or 1), the global decision will be busy (or 1). Otherwise; the global decision will be free (or 0) [4].

Many works have investigated the reduction of energy consumption. Sequential sensing as an approach to reduce the average number of sensors required to reach a decision is studied comprehensively in [5-9]. In [10], the CUs are divided into non-disjoint subsets in a way that only one subset senses the spectrum while the other subsets stay in a low power mode. In [11], censoring and sequential censoring methods are presented to improve energy consumption. However, although these methods improve the energy consumption but they have some drawbacks. These methods uses two thresholds and this increases the complexity. In censoring method all the spectrum is sensed intensively which increases the energy consumption. The sequential censoring methods has a weakness in the performance of detection since they stop the sensing process once the accumulated energy crosses the upper threshold without sensing other channels which may have higher accumulated energy i.e. more probable existence of PU signal.

In [12] , coarse-fine sensing method called CC4C (Cooperative Coarse sensing scheme For Cognitive radio network) is presented where coarse sensing is used to find the available channel together with sequential sensing scheme. Although this method reduces the sensing time but it also has a problem that it uses sequential sensing which does not select the optimal channel available since the sensing is stopped quickly as soon as available channel is found without checking other channels. Furthermore, for low values of SNR (less than 4 dB) this method consumes high energy, because it cannot produce a local decision early, and continue to take more samples. In [13], a coarse - fine sensing method called TSEEOB-CSSS (Time Saving Energy Efficient One Bit based – Cooperative Spectrum Sensing) where the PU presence or absence may declared in coarse sensing stage without using fine sensing stage. This method it has two problems: first; it uses two thresholds comparison process at coarse sensing which increases the complexity, second; once the upper threshold is crossed the sensing process stops without performing fine sensing which may led to either selecting the channel of less probability to be vacant or false alarm state is happened when SNR is low which as a result increases the energy consumption. In [14] also a two stage coarse-fine sensing is proposed to improve detection performance. In this method energy detection technique is applied in the coarse stage, while first order cyclostationary technique is applied in the fine stage. Although this method gives good detection performance than the previous ones, but the cyclostationary sensing technique is complex in implementation and needs a higher sensing time which imply increasing the energy consumption.

In this paper we proposed a sensing method overcomes the problems mentioned in the previous works. It makes sensing in two stages: the first stage is to vastly sense all the channels in the spectrum with low number of samples and then identify the channel that have the maximum accumulated energy (the channel that is more likely to have a PU signal). Then a fine sensing is done only on this channel with higher number of samples for verification. The main contributions in this paper are: 1) the improvement of energy consumption is based on increasing the detection probability since all channels will be sensed without exclusion and the best one is selected for further verification which makes the method very efficient at low SNR values. 2) Multi-primary user scenario is assumed which is not considered in many previous works, 3) Analytical expression for the energy consumption of the proposed method is derived for both sensing and transmission stages assuming the use of zigbee as a CU.

2 ENERGY DETECTION BASED SPECTRUM SENSING

Energy detection is considered as one of the widely used spectrum sensing techniques due to its simplicity as it does not need any information about the structure of the PUs signals. In CR networks, the SU checks the spectrum allocated to PU and when it detects the absence of PU transmission, it starts data transmission to its receiver. The received samples at CU receiver are [3]:

$$Y(n) = h_{ps}\,\theta\, X_p(n) + W(n) \qquad (1)$$

Where $X_p(n)$ is the signal of the PU, h_{ps} is the channel gain between PU and SU, $W(n)$ is the Additive White Gaussian Noise (AWGN) at the CU receiver, and θ is the PU activity indicator which can take one out of two value as in the following Eq:

$$\theta = \begin{cases} 0 & for \quad H_0\, hypothesis \\ 1 & for \quad H_1\, hypothesis \end{cases} \qquad (2)$$

When the PU is active is referred to as hypothesis H_1, while the case of inactive PU is referred to as hypothesis H_0. The false alarm and detection probabilities are evaluated by comparing the detector decision metric with a pre-set threshold λ. The decision metric (DMED) is defined by the energy of the captured samples during the observation window t.

$$DMED = \frac{1}{N}\sum_{n=1}^{N}|Y(n)|^2 \qquad (3)$$

Where N is the number of sensing samples $N = tF_s$, where F_s is the sampling frequency. The probabilities of false alarm and detection are evaluated by:

$$P_f = P_r(DEMD > \lambda \mid H_0) \qquad (4)$$
$$P_d = P_r(DEMD > \lambda \mid H_1) \qquad (5)$$

3 THE PROPOSED METHOD

The spectrum sensing process consumes energy in both sensing and transmission stage. The proposed method achieves energy saving in the sensing stage, besides it improves the detection performance. Fig.1 shows the flowchart of the proposed method. This method consists of two stages: coarse sensing stage and fine sensing stage. In coarse stage the CU senses a fixed spectrum length and fixed number of channels with small number of sensed samples (e.g. 16% of the number of samples is used in proposed sensing process). The energies obtained from all channels during the coarse sensing are collected (each channel may have a PU signal at the same time) and then a fine sensing is performed to the channel that has maximum energy. Fine sensing senses all samples in the channel selected to confirm. In order to ensure that this signal is a PU signal (not noise), the accumulated energy in the channel is compared with a threshold λ to produce a final decision about PU signal presence or absence. If the requirement is detecting a hole in the spectrum, the same procedure is repeated but fine sensing is employed to the channel that has minimum energy. In general, the amount of energy consumption achieved by jth cognitive user C_j is given by:

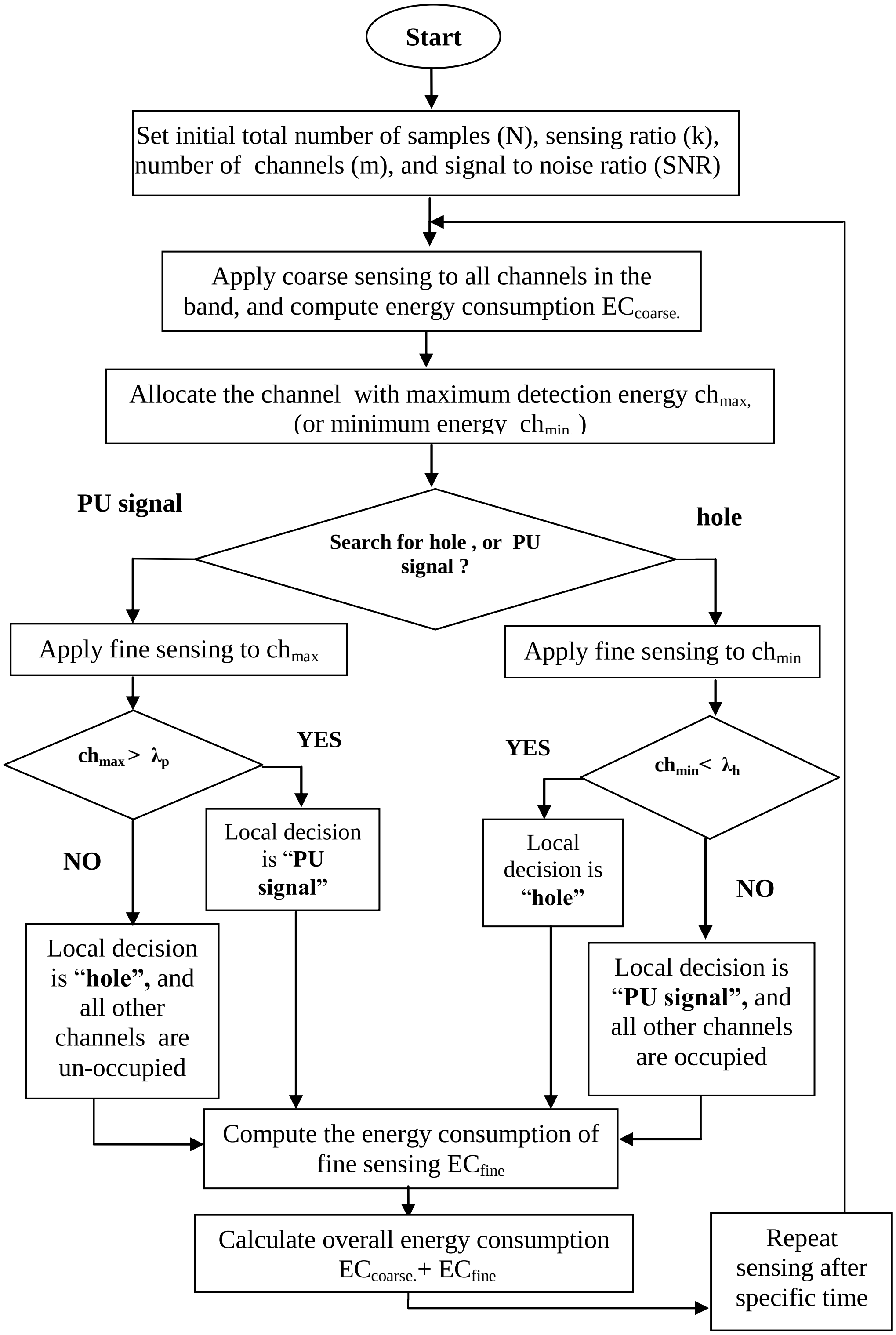

Fig. 1. Flow chart of the proposed sensing method.

$$C_j = C_{sj} + C_{tj} \quad (6)$$

with

$$C_{sj} = N\, C_{ssj} \quad (7)$$

Where C_{sj} and C_{tj} are the energies consumed by the jth CU in sensing and transmission (per bit) stages respectively, N is the number of sensed samples, and C_{ssj} is energy consumption per sample. As stated in [11], C_{ssj} is fixed and depends only on the sampling rate and energy consumption of the sensing module, and computed assuming $P_d = 1$,(i.e. $C_{ssj}|_{Pd=1}$). When P_d is decreased C_{ssj} is increased since the energy detector will produce false decision which leads to repeat the sensing process. According to this discussion C_{ssj} will be written as:

$$C_{ssj} = C_{ssj}|_{Pd=1} + C_{ssj}|_{Pd=1}(1 - P_d) \quad (8)$$

Considering a sensor used by CU based on IEEE 802.15.4/ZigBee radios. The sensing energy for each decision consists of two parts: the energy consumption involved in listening over the channel and in making the decision and the energy consumption of the signal processing part for modulation, signal shaping,..etc. The number of samples per detection interval used in our simulation is chosen to be 5 according to [15]. This interval corresponds to a detection time of 1µs. Considering the fact that the typical circuit power consumption of ZigBee is approximately 40 mW, the energy consumed for listening is approximately 40 nJ. Therefore, we conclude that energy consumption per sample is 40 nJ/5 =8nJ. So, C_{ssj} =8 nJ will be used. According to the proposed algorithm, Eq. (7) can be written as:

$$C_{sj} = C_{coj} + C_{f\,ij}, \quad (9)$$

Where C_{coj} and C_{fij} are the energy consumptions in the coarse and fine stages respectively, with:

$$C_{coj} = N\, k C_{ssj} \quad (10)$$
$$C_{fij} = N/m\, C_{ssj} \quad (11)$$

Where k is the sensing ratio which is defined as the number of sensed samples to the total number of samples N, and m is the number of channels in the spectrum. Fig.2 explains the division process of the spectrum used in the proposed coarse-fine sensing method.

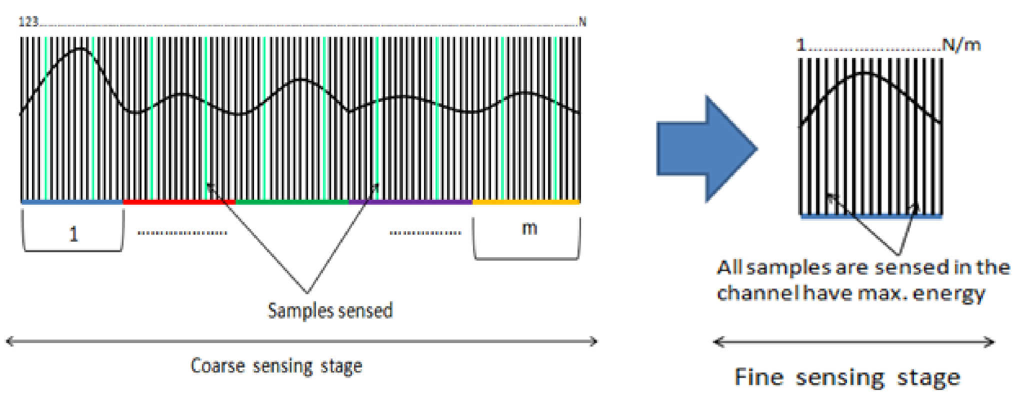

Fig. 2 The division of spectrum using the proposed coarse-fine sensing method.

So, the total energy consumption per sensor in both coarse and fine stages is:

$$C_{sj} = C_{coj} + C_{f\,ij.} = (k + 1/m)\, N\, C_{ssj} \qquad (12)$$

The amount of energy consumption per bit in the transmission stage is computed as follows: according to [15], the consumed energy related to the signal processing part in the transmission mode for a data rate of 250 kb/s, a voltage of 2.1 V, and current of 17.4 mA is approximately 150 nJ/bit. The transmitter dissipates energy to run the radio electronics and the power amplifier. To transmit one bit over a distance d, the radio spends:

$$C_{tbj}=C_{t\text{-}elec\,j}+ e_{ampj}\, d^2 \qquad (13)$$

Where $C_{t\text{-}elec\,j}$ is the transmitter electronics energy and e_{ampj} is the amplification required to satisfy a given receiver sensitivity level. Assuming a data rate of 250 kb/s and a transmission power of 20 mW, $C_{t\text{-}elec\,j}$ = 80 nJ. To satisfy a receiver sensitivity of 90 dBm at an SNR of 10 dB, e_{ampj} is 40.4 pJ/m^2. So, the transmitted energy per bit per for the jth CU would be:

$$C_{tj} = C_{tbj}+ 150 \text{ nJ/bit} \qquad (14)$$

Substituting (14) & (12) in (6) we get

$$C_j =(k + 1/m)\, N\, C_{ssj} + C_{tbj} + 150 \text{ nJ/bit} \qquad (15)$$

This Eq. represents the target function with which we can adapt the energy consumed by changing the design parameters k and *N*.
In this work, OR rule is used in FC to make the final decision. This way, the global probability of detection Q_d is [11].

$$Q_d = 1-\prod_{j=1}^{M}(1 - P_d) \qquad (16)$$

Where P_d is the local probability of detection and M is the number of cognitive users.

4 SIMULATION RESULTS AND DISCUSSION

This section presents the simulation results of energy detector performance and energy consumption of the proposed scheme under cooperative and non-cooperative scenario. The performance is tested under AWGN and Rayleigh multipath fading channels. All results in this section include the amount of energy consumption of CU in sensing and transmission stages. To evaluate the performance of the proposed method, it is compared with traditional sensing method which senses all spectrum samples (i.e k=1) and with CC4C [12] and TSEEOB-CSS [13] methods that are based on two stages. The simulation parameters used are shown in Table 1. The multipath fading used is "ITU indoor channel model" as shown in Table 2 [16].

Table 1. Simulation Parameters

Parameter Name	Value
Bit rate	2 Mbps
Number of channels (m)	10
Modulation type	QPSK (PU signal)
Probability of false alarm	10^{-3}
Sensing ratio k	16%
Total number of samples in the spectrum N	1000
Samples per symbol	100
Distance (d)	10 m

Table 2. Multipath Fading Properties Of ITU Indoor Channel Model

Tap	Relative delay (ns)	Average power (dB)	Doppler spectrum
1	0	0	flat
2	50	-3.0	flat
3	110	-10.0	flat
4	170	-18.0	flat
5	290	-26.0	flat
6	310	-32.0	flat

A. Non–Cooperative Scenario

Figs.3 and 4 show the proposed method performance curves of energy consumption of CU versus E_b/N_o in AWGN and Rayleigh multipath fading channels respectively as compared with the traditional method. In Fig. 3 it can be seen that energy consumption decreases as E_b/N_0 increases since less number of sensing samples is required by CU in sensing process to detect the PU signal when E_b/N_o is high. Also it is noted that the proposed method achieves an improvement in energy consumption when compared with the traditional method. For example at E_b/N_0 equals 0 dB, energy consumption decreases by 73% using the proposed method.

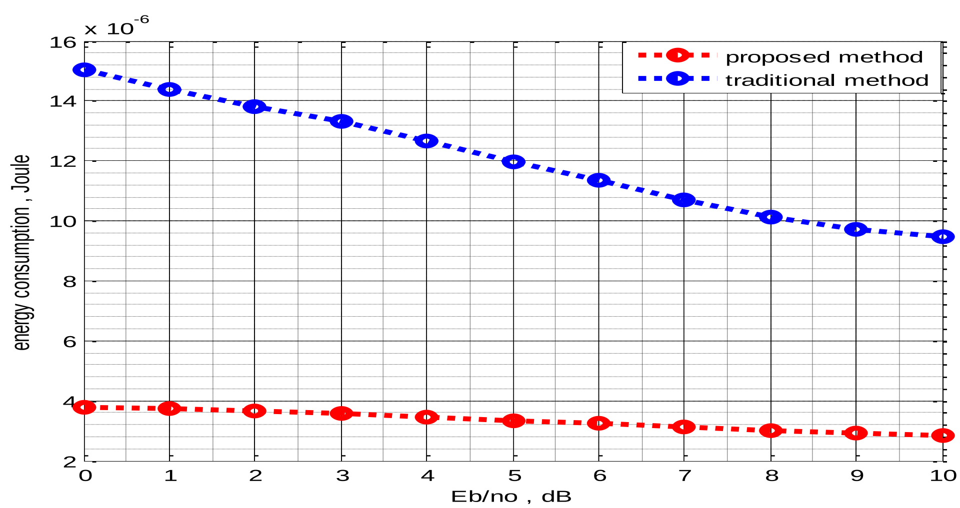

Fig 3. Energy consumption versus E_b/N_o in AWGN channel.

Fig.4 shows the same performance in Fig.3 but with more energy consumption due to the fading effect. Figs.5 and 6 show the performance curves of probability of detection versus E_b/N_o in AWGN and Rayleigh multipath fading channels respectively. It can be seen that in Fig.5 that the detection performance increases as E_b/N_o increases and the proposed method outperforms the traditional method. The improvement in detection probability introduced by the proposed method become more significant in the small values in E_b/N_o. For example for E_b/N_o equals 3 dB, P_d is increased from 0.42 in traditional method to 0.65 in the proposed method. Fig.6 shows that the same performance as in Fig.5 but with slight degradation in detection performance due to the effect of fading. This improvement in detection performance of the proposed method is referred to the use of fine sensing stage which senses the channel with sensing ratio 100% increasing the accuracy in detection.

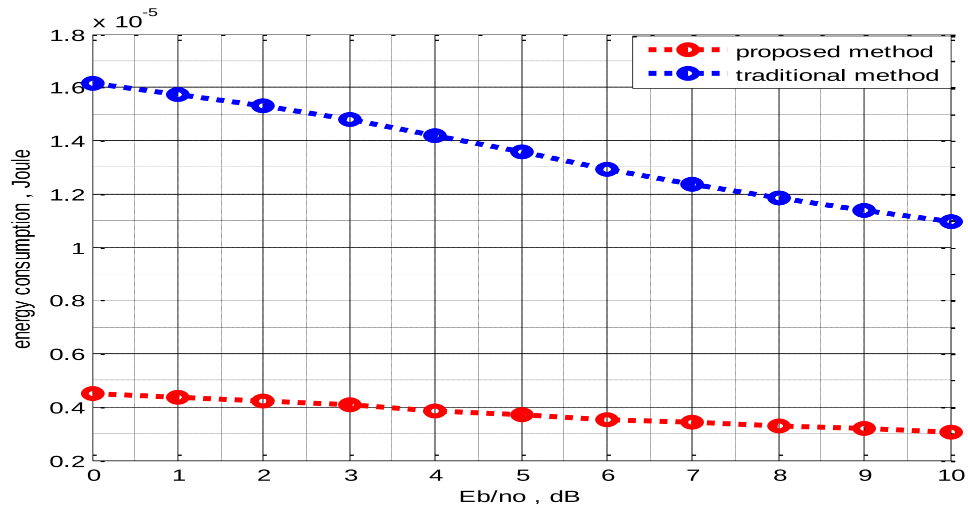

Fig 4. Energy consumption versus E_b/N_o in Rayleigh multipath fading channel.

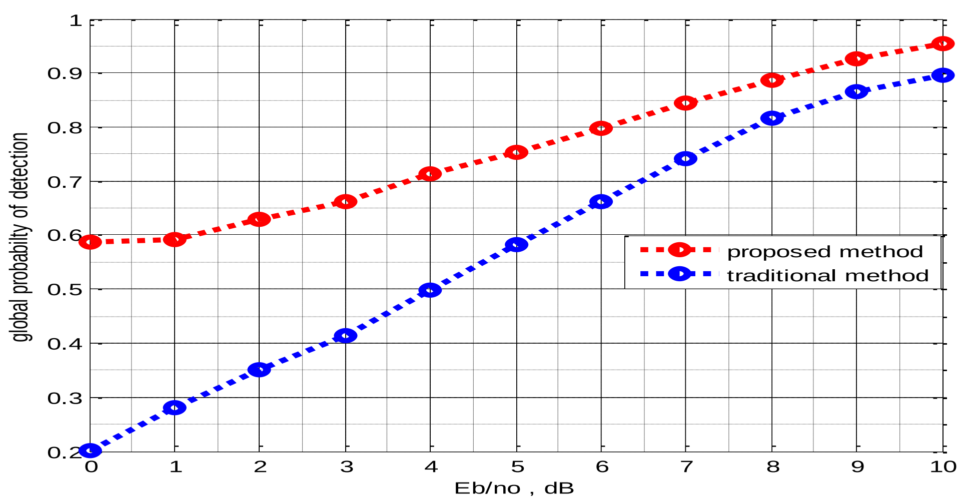

Fig 5. P_d versus E_b/N_o in AWGN channel.

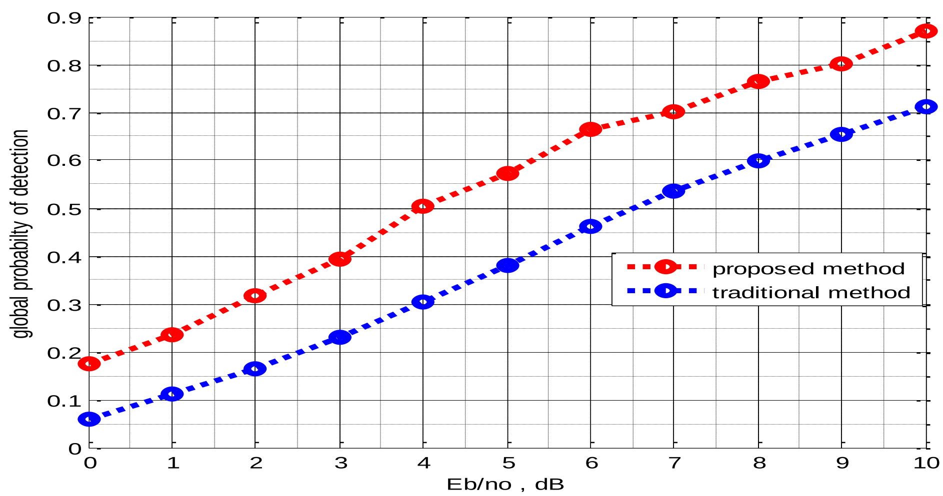

Fig 6. P_d versus E_b/N_o in Rayleigh multipath fading channel.

B. Cooperative Scenario

In the cooperative scenario, 5 CUs, and the OR rule in the FC for the final decision are used. Figs.7 and 8 show the performance curves of energy consumption and Q_d versus E_b/N_o respectively. The scenarios considered assume that only 3 CUs out of 5 CUs are suffering from multipath fading. As depicted by Fig.7, the average energy consumption per sensor is increased as E_b/N_o is increased. When we compare this figure with non-cooperative scenario given in Fig.4, we can see that the reduction in energy consumption is increased in both traditional and proposed methods. For example, when E_b/N_o equals 0 dB, energy consumption reduces by 72% using the proposed method. The reason behind this improvement is that the CUs will share the statistics about PU existence which will increase the overall detection probability as shown in Fig.8. Also in Fig.8 it can be seen that the proposed method have more improvement in detection performance than traditional method. This is because of the use of two stages of detection process which increase detection probability, especially in fine sensing.

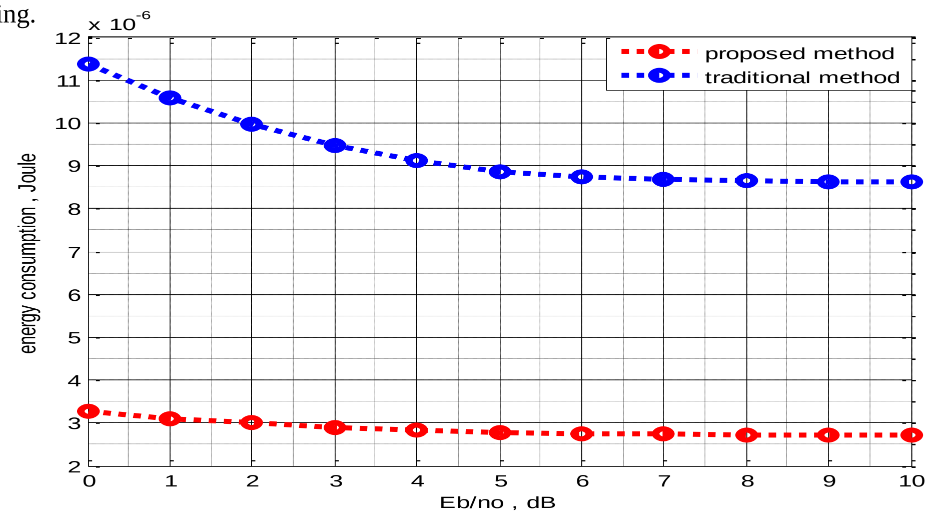

Fig. 7. Energy consumption versus E_b/N_o using 5 CUs.

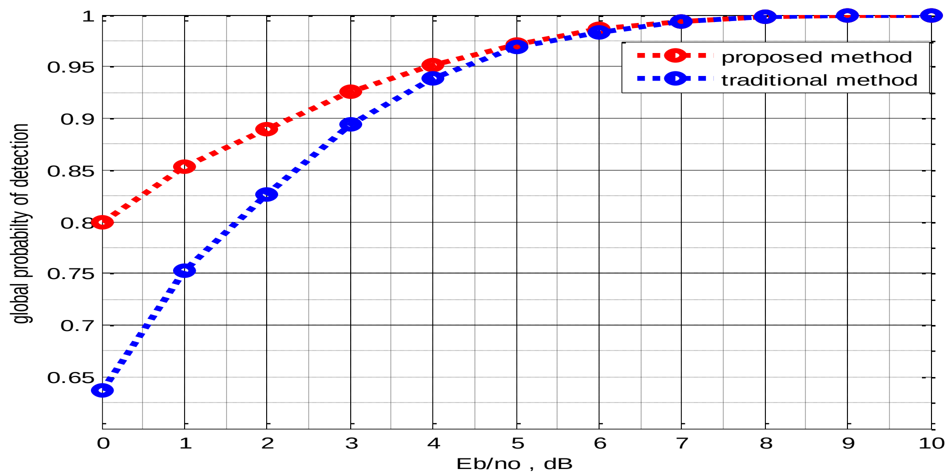

Fig.8. Q_D versus E_b/N_o using 5 CUs

Fig. 9 shows the performance curves of energy consumption versus E_b/N_o of the proposed method in comparison with TSSEE-CSS, CC4C, and traditional methods. In this result we used 5 CUs with the same simulation parameters in Table 1. It can be seen from the figure that the proposed method significantly improve the energy especially at low values of E_b/N_o . For example when E_b/N_o equals 0 dB, the energy consumption of the proposed method is reduced by 72%, 57%, and 54% as compared with traditional method, TSEEOB-CSS, and CC4C methods respectively.

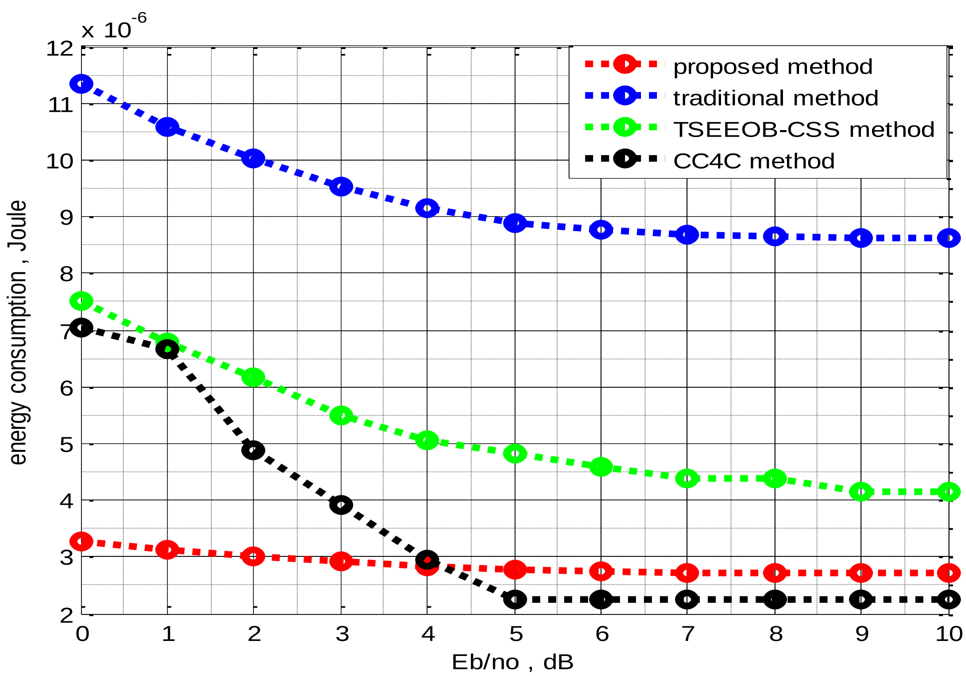

Fig. 9. Average energy consumption per sensor versus E_b/N_o using 5 CUs.

The reason behind this improvement can be discussed as follows: in TSEEOB-CSS method, the fine sensing stage is not used upon testing the spectrum channels all the time except when the accumulated energy does not cross the higher threshold or drop below the lower threshold which reduces the detection performance. In CC4C method, sequential sensing scheme is used in the coarse sensing stage which costs more energy at low E_b/N_o values because it continues to apply sensing process using more and more samples until it can produce a local decision and stops sensing process. So, the reasons mentioned above makes these two methods cost high energy consumption at low value of E_b/N_o. Conversely, the main reason of improvement in energy consumption in the proposed method is the use of less number of samples in coarse stage and the two stage sensing is used always for the channel with the highest accumulated energy after passing the threshold check which gives significant improvement in energy consumption due to improved detection performance.

5 CONCLUSIONS

In this paper we proposed an efficient method to improve energy consumption in CR networks. In simulation results are presented in forms of comparisons with traditional method in two scenario: cooperative and non-cooperative, and with TSEEOB-CSS and CC4C methods. The results have showed the significant improvement in energy consumption introduced by the proposed method. The main reason behind this improvement is that the proposed method combine both reduction in energy consumption by reducing number of sensed samples and the increase in probability of detection. The improvement in energy consumption is referred to the fixed length coarse sensing stage by using small number of samples while the increase the detection performance is referred to the use of fine sensing stage. The impact of the proposed scheme become more clear at low signal to noise ratio values.

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