H.N. Abdullah
Information and Communication Engineering Department, College of Information Engineering, Al-Nahrain University, Baghdad, Iraq.
dr.h.abdullah@ieee.org

H.S. Abed
Information and Communication Engineering Department, College of Information Engineering, Al-Nahrain University, Baghdad, Iraq.
hs_eng1992@yahoo.com

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Low Energy Consumption for Cooperative and Non-cooperative Cognitive Radio

Abstract- *Recently the subject of energy-efficient is very important in cognitive radio (CR), especially during spectrum sensing, since the large energy consumption (EC) cost, produces a restriction in their implementation especially in devices with limited power, i.e battery. In these design, energy detector consumes a significant part of energy during spectrum sensing to detect the activity of the primary user (PU). In this paper, we investigated a method for improving EC in two scenarios: non-cooperative and cooperative. The idea behind the improvement is based on sensing the spectrum with low-density samples. The optimization concept for reducing EC through controlling the number of frequency samples to be sensed is illustrated as well as the probability of detection in both scenarios. To evaluate the proposed method a comparison is made between the proposed method and censoring method. The performance of energy detection system is evaluated in AWGN and Rayleigh fading channels. The simulation results show that in non-cooperative scenario at E_b/N_o equal 10 dB, and for sensing ratio equal 50%, EC decreases by 50% and 46% with sma loss in of detection probability of 5% in AWGN channel and 12% in Rayleigh channel. In cooperative scenario, the results show that as the number of cognitive users (CU) increased the average EC per user decreased with an improvement in probability of detection. In case of sensing ratio 50%, the EC is decreased by 43.6% as compared with censoring method.*

Keywords- *Cognitive radio, Cooperative sensing, Energy consumption, Non-cooperative sensing, Spectrum sensing.*

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1. Introduction

With the rapid growth of wireless technology, lack of spectrum resources has become the bottleneck of its development [1]. CR is generally defined as a wireless technology that adjust its operating parameters (e.g. carrier frequency, power, bandwidth, modulation and coding) according to the knowledge of its medium. CRs allow unlicensed user which called secondary users (SUs) to access and use the spectrum bands at a time that is unused by licensed primary users (PUs). The temporary empty channels are called as spectrum holes [2]. High-energy consumption is considered a main challenge in CR networks where the nodes have limited energy source. The CR networks composed of multi stages. In sensing stage, the CR senses the activity of PU by using one of the sensing techniques. In transmission stage, the CR sends the local sensing decisions from different cooperative users (CU) to a special terminal called fusion center (FC). The final stage is the decision stage where the FC makes the final decision to the secondary user about the presence of PU. Two scenarios of spectrum sensing are used in CR networks, these are: non-cooperative and cooperative. In non-cooperative scenario single CR are used to sense the activity of PU, while in cooperative scenario multiple CRs are used to sense the spectrum. When the CR network is shadowed or in severe multipath fading, it cannot detect the presence of the PU. Then, primary transmission undergoes a harmful interference, since channel access is allowed while PU is still in operation, so cooperative scenario are used to address this issue [3]. In this work, the reduction of EC is achieved at the sensing stage with both non-cooperative and cooperative scenarios and energy detection technique is used.

Many works aimed to reduce EC through sensing stage are available in the literature. A method called sequential sensing to decrease the average number of CUs needed to provide sensing decision is described in [4-7]. In [8], many thresholds are used to reduce the time sensing. Depending on certain probability of false alarm P_f and probability of detection P_d these thresholds are determined. This method is called truncated sequential sensing technique. In [9-10], an improvement in EC can be done by using the less number of SUs with predefined thresholds that keep the detection accuracy in acceptable level. In [9], the optimization problem of energy efficiency is formed by decreasing the number of CUs that make sensing as much as possible with saving the accepted limits of probability of detection and false-alarm. In [10], a mathematical formula is derived for reduction the

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

number of SUs that can satisfy the required values of probabilities of detection and false alarm. In [11-12], a clustering mechanism are used for CUs where they are divided into non-disjoint groups. When sensing is, initiated only single group will make sensing while the other groups remain in a save, power mode taking into account the constraints of detection probability. In [13], censoring method is explained, in this approach, an energy detector is used by each CU to calculate the accumulated energy over N the total sensing samples. When the accumulated energy of the monitoring samples is calculated, a censoring policy is applied at each radio in a way that if the accumulated energy is between the lower and upper threshold no decision is forward to the FC, but if the accumulated energy below the lower threshold or above the upper threshold a decision 0 or 1 is forward to the FC. In [14], an improvement of EC is done but only in non-cooperative scenario. In [15], the EC is improved by employed spectrum sensing through two stages: coarse-fine sensing.

In this research, amount of energy saving gained when to the reduction of sensed spectrum samples number is performed and the corresponding deterioration in detection probability of the energy detector are computed and evaluated in both non-cooperative and cooperative CR networks.

2. Energy Detection Based Spectrum Sensing

Energy detection is a simple technique for sensing the spectrum, and is one of the most commonly used spectrum sensing schemes. The CR senses the spectrum band and when it does not detect a PU activity, it starts transmission of data to its receiver. At SU receiver, the received samples are [3]:

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

Where $X_p(n)$ is the PU signal with P_p transmitted power, θ is the indicator of presence and absence of primary user as described by equation, (2). The transmission channel between PU and SU has h_{ps} amplitude gain and $W(n)$ an additive White Gaussian Noise (AWGN). During the sensing window t, the energy of the total sensed samples N would produce a decision metric DMED defined by [3]:

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

According to the value of DMED, two hypothesises can occur. If the PU is present, it is referred to as hypothesis H_1, while the case of PU absent is referred to as hypothesis H_0. These are described mathematically as:

$$\theta = \begin{cases} 0 & for \quad H_0\ hypothesis \\ 1 & for \quad H_1\ hypothesis \end{cases}$$
(3)

The probability of detection and the probability of false alarm are computed by comparing the accumulated energy DMED with a pre-defined threshold, λ as in the following equations [3]:

$$P_f = P_r(DEMD > \lambda \mid H_0)$$
(4)

$$P_d = P_r(DEMD > \lambda \mid H_1)$$
(5)

3. The Proposed Energy Saving Scheme

Improvement of Energy consumption of CR during spectrum sensing can be done by minimizing the number of samples included in the sensing process. This minimization will decrease the rate of calculations that implemented by energy detection sensing technique before making a sensing decision. This algorithm can be useful if the energy detection is maintained without affecting the sensing performance criteria of the CR network too much. The sensing performance criteria is mean that maximize of detection probability and minimize of false alarm probability [16]. Figure 1 shows the flowchart to explain the procedures of designed spectrum sensing method. Figure 2 shows the way followed for choosing the sensed samples when the sensing ratios (SR) are 50 %, 33 %, and 25 % respectively. The SR is the amount of spectrum samples included in the sensing process to the total spectrum samples used normally. In this figure, the sensed samples selected are highlighted by black color. When the SR is 50%, the sensing includes only the odd (or even) indexed samples. When the SR is 33%, the sensing is performed by taking one sample and leaving the next two samples. Finally, when the SR is 25%, the sensing is performed by taking two samples and leaving the next two samples. The concept is the same for other SR values.

To compute the energy consumed by the cognitive user C_j, we write it in terms of the energy consumed by the j-th radio in sensing per sample C_{sj} and transmission per bit C_{tj} [13]:

$$C_j = NC_{sj} + (1 - \rho_i)C_{tj}$$
(6)

Where ρ_j is the average rate of censoring. Considering the calculations only in sensing stage, equation (6) becomes:

$$C_j = \mathrm{N}C_{sj}$$
(7)

As mentioned in [13] and [17], the energy consumed by the j-th radio in sensing per sample is fixed and it is depending on the energy consumption of the sensing stage and the sampling rate. When the detection probability decreases, the energy consumed by the j-th radio in sensing per sample increases because the energy detection technique will result wrong hypothesis and this lead to repeat the spectrum sensing process. Therefore, C_{sj} can be formulated as follows [18]:

$$C_{sj} = C_{sa} + C_{sa}(1 - P_d)$$

(8)

Where C_{sa} is energy consumption per sample when detection probability equals one. Hence, equation (7) will be:

$$C_j = kN(C_{sa} + C_{sa}(1 - P_d))$$

(9)

Where k is the SR. We can see that when P_d =1 equation (9) becomes $C_j = NC_{sa}$. To make a valid numeric comparison for evaluating the impact of partial sensing, we will consider that sensor used by secondary user uses IEEE 802.15.4/ZigBee radio. For each decision, the EC consists of two parts: the energy consumed in sensing the channel and the EC in signal processing including signal shaping, modulation, etc. According to [19], the number of samples per sensing period of 1µs was chosen to be 5. Given that the power consumption of typical circuit of ZigBee is about 40 mW [19], the energy consumed for sensing under these assumptions is approximately 40 nJ. Hence, we can draw that the 40 nJ/5 =8nJ which equal the EC over one sample. So, C_{sa} =8 nJ, will be applied in our simulations.

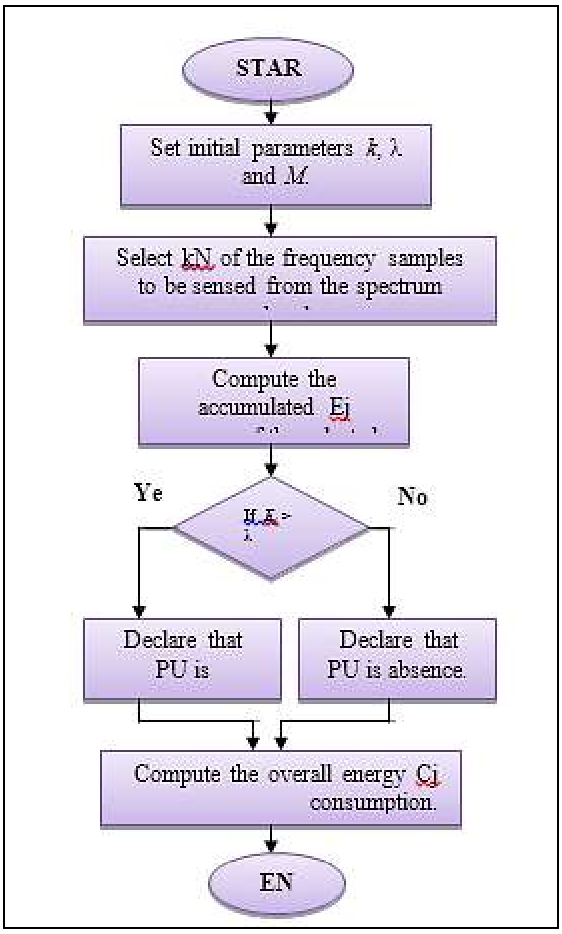

Figure 1: Flowchart of design spectrum sensing with the proposed scheme

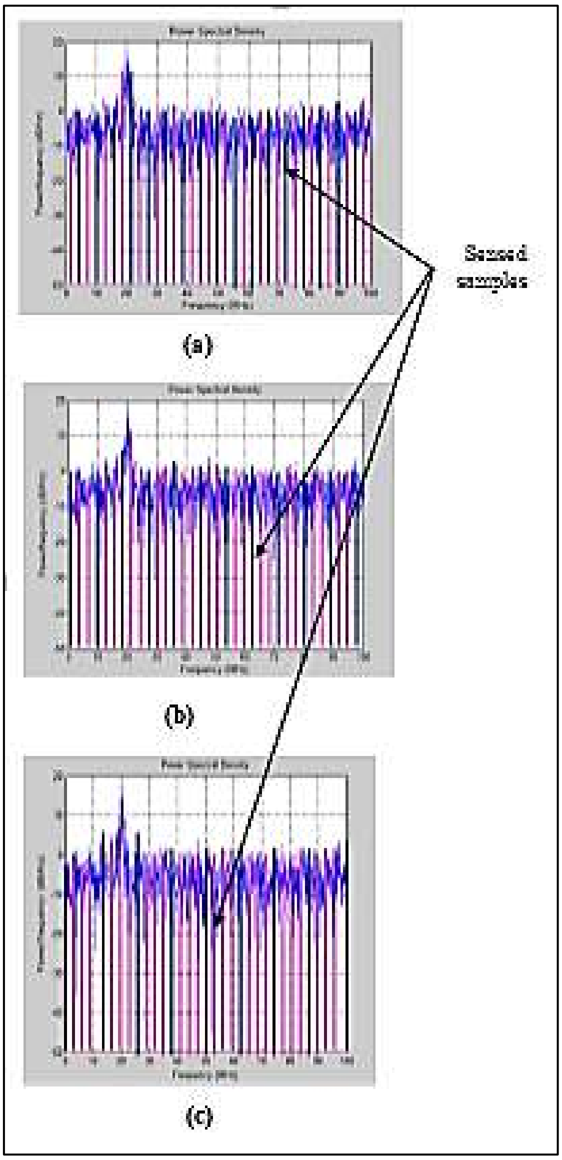

Figure 2: Spectrum sensing with different SR. (a) 50%, (b) 33%, (c) 25%

4. Simulation Results

This section shows the simulation results of energy consumption in energy detection technique and its evaluation criteria in non-cooperative and cooperative CR when we control the reduction in the number of sensed sample are presented in this section. To evaluate the proposed method, the comparison is made between different cases of SR with the traditional method (100% SR) and compare the case of (50% SR) with the censoring method [13]. The simulation parameters used are listed in Table 1 [18]. The system behavior is checked under Rayleigh multipath fading for “ITU indoor channel (ch.) model (A)” as given in Table 2 [20].

Table 1: Simulation Parameters

Parameter Name	Value
Carrier frequency	20 MHz
Modulation type	QPSK (PU signal)
Bit rate	2 Mbps
false alarm probabilty	10^{-3}
Band of spectrum sensing	(0–100) MHz
frequency Sampling	200 MHz
Number of Bits / symbol	2
Number of Samples / symbol	100

Table 2: ITU Indoor multipath fading channel properties (A)

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

Figures 3 and 4 explain the energy consumption performance and P_d in CU versus E_b/N_o in additive Wight gaussian noise (AWGN) channel with number of sensed samples as a parameter, respectively. In Figure 2, it can be noted that the reduction of energy consumption when E_b/N_o increases since not a high amount of sensing samples is demined to discover the PU, signal presence when E_b/N_o is high. For example, at E_b/N_o equals 8 dB, the energy consumption decreased by 60%, 55% and 45% when SR equals 25%, 33% and 50% respectively. Figure 4 shows that an improvement in performance detection when E_b/N_o is increased, and P_d increases as the number of sensed samples increases. Numerically speaking, at E_b/N_o equals 10 dB, P_d is decreased from 1 when the SR is 100% to 0.5 , 0.75 and 0.96 for SR values 25% , 33% and 50% respectively. It can be seen that when P_d is 0.75 and 0.5 the number of times that the sensing process is repeated is increased by 25% and 50% respectively (as concluded analytical expression is proved in equation (8)).

Figure 5 shows the comparison between proposed methods in case of SR 50% with censoring method in [13]. It can be seen that a significant improvement in EC is introduced by the proposed method since less number of sense samples are used with a good probability of detection. For example, when E_b/N_o equals 10 dB, the EC of the proposed method reduces by 43.6 %, but for low value of Eb/N_o equals 0 dB censoring method consumes slightly less EC than proposed method. The reason behind this degradation at 0 dB is that the value of accumulated energy at this value of E_b/N_o is between the upper and lower threshold and in this case no decision is send to the FC and EC in the transmission stage is saved.

Figures 6 and 7 explain the EC performance and P_d vs. E_b/N_o in Rayleigh fading ch., respectively. Figure 6, shows the same behavior as Figure 3 (AWGN channel). For example, at E_b/N_o equals 10 dB, the EC is decrease by 62%, 57% and 46% when we reduces the SR to 25%, 33% and 50% respectively. However, if we make a comparison between Figure 3 and Figure 6 we seen that the EC is increased in Figure 6. Numerically speaking at E_b/N_o equals 10 dB, the EC in Figure 6 in Rayleigh ch. is raised by 1%, 3% and 4% for SR equal 25%, 33% and 50% respectively, as compared to Figure 3 in AWGN ch.

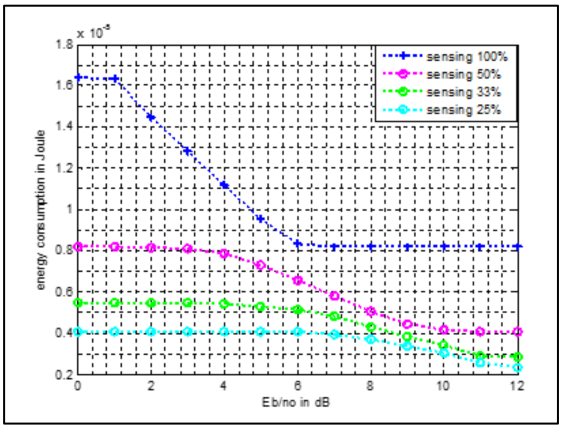

Figure 3: E_b/N_o versus energy consumption in AWGN channel

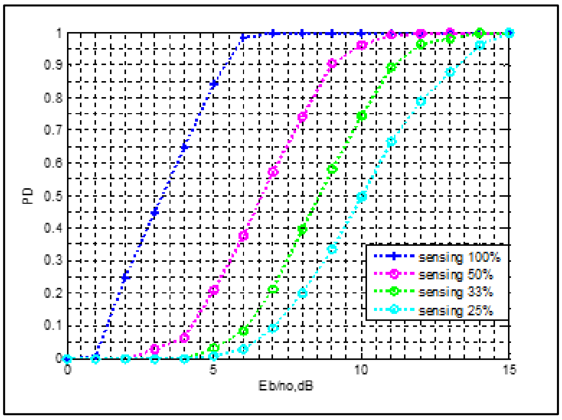

Figure 4: P_d versus Eb/N_o in AWGN channel

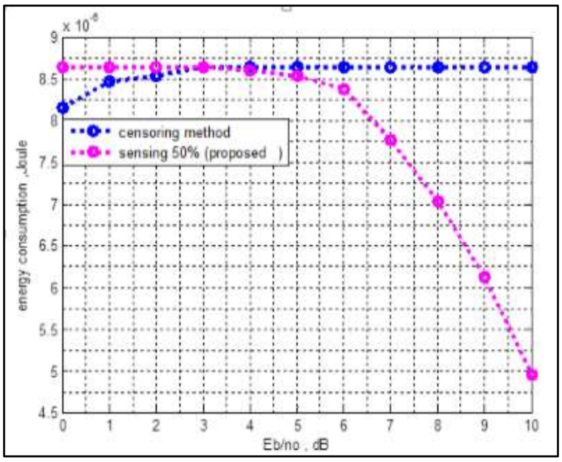

Figure 5: Compression between proposed method and censoring method in AWGN

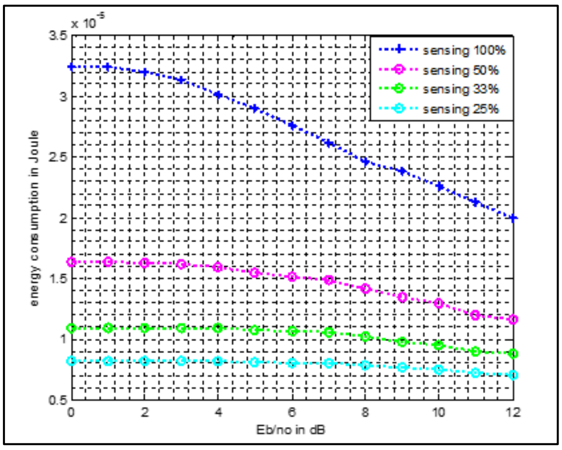

Figure 6: E_b/N_o versus energy consumption in Rayleigh multipath fading channel

It can be note that in Rayleigh ch. , despite we gain energy saving when decreasing the SR (25%, 33%, and 50%) as compared with 100%, but a significant lost in P_d will produce as shown in Figure 7. In this figure it can be seen that the high P_d values (more than 0.9) could not be reached unless E_b/N_o is raised to about 20 dB because the imact of Rayleigh fading ch. For example, when E_b/N_o is 10 dB, in Rayleigh ch P_d is reduced from 0.67 in 100% SR to 0.15, 0.25 and 0.35 for SR values 25%, 33% and 50% respectively, and the figure shows that EC is remain fixed even if E_b/N_o is riased for SR values 33% and 25%, this is according to the effect of high degradation in P_d values.

B. Cooperative Senario

This section explain the curves of EC performance and P_d vs E_b/N_o with SR and number of SUs as parameters. various number of SUs are selected to take the values: 1, 2, 4, and 6. The scenarios of multipath fading are considered as follows: in single SU scenario, the SU suffers from multipath fading, in two SUs scenario, only one SU suffers from multipath fading, in four and six SUs only two SUs suffers from multipath fading. Figures 8 and 9 explain the performance curves of average EC per sensor vs E_b/N_o with SR of 100% and 50% respectively. Figure 8 shows the decreasing in average EC per sensor as E_b/N_o increases, and this reduction become large when the number of SUs increased since they will share the statistics about PU activity, which will increase the overall probability of detection. Numerically speaking at E_b/N_o equals 6 dB, and as compare with single SU the average EC per sensor reduces to 33%, 42%, and 43 % when the number of CUs is: 2, 4, and 6 respectively. It can be seen that the significant improvement in the average EC per sensor is produced when we change from single SU to 2 and 4 SUs. However, larger increase in number of CU will not result larger improvement especially when E_b/N_0 values are high, because of the fact that P_d will already have high values and the increase in number of SUs will increase a very small fractions to P_d value. It can be noted that Figure 9 shows the same performance to that obtained in Figure 8 but with more improvement in EC, since SR is reduced by 50%. When we make a comparison with Figure 6 (for SR 100%), and at E_b/N_o equals 6 dB, the EC is decreased by 38%, 40%, and 45% when the number of SUs is increased to 2, 4, and 6 respectively.

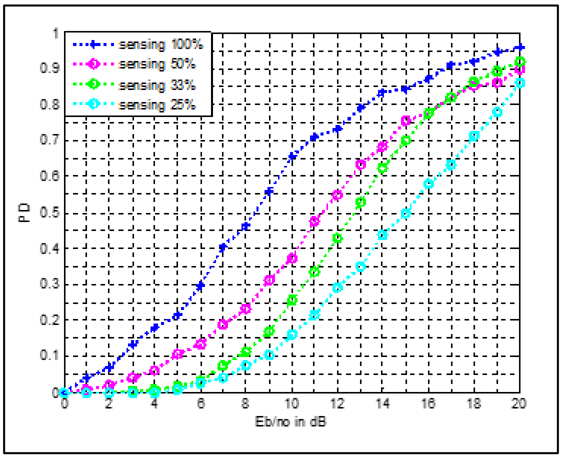

Figure 7: P_d versus Eb/N_o in Rayleigh multipath fading channel

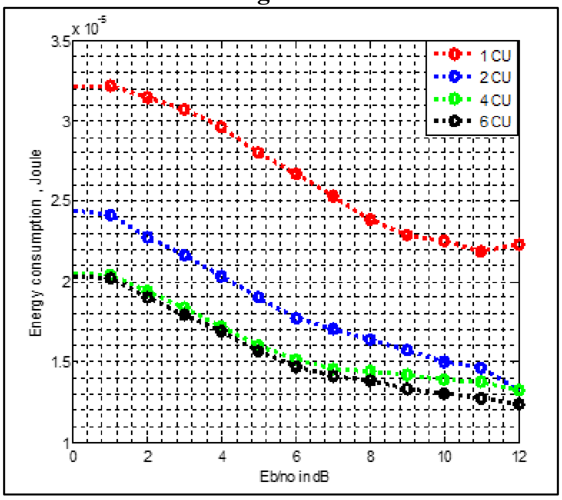

Figure 8: E_b/N_o versus energy consumption in cooperative scenario, sensing ratio=100%

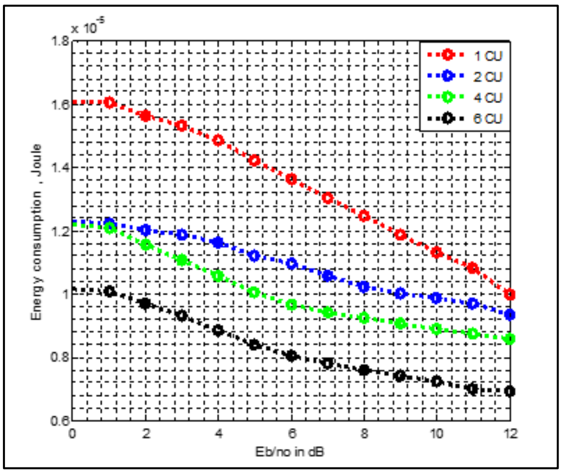

Figure 9: E_b/N_o versus energy consumption in Cooperative scenario, sensing ratio=50%

Figures 10 and 11 explain the performance curves of the average probability of detection P_d vs E_b/N_o when SR are 100%, and 50% respectively. Figure 10 shows the curve for P_d in single and 4 SUs when SR 100%. It can be noted a significant improvement in performance detection is produced in 4 Sus case as compared with single SU case. Numerically speaking, at E_b/N_o equals 10 dB, Pd value is increased from 0.75 in single SU to 0.87 in 4 SUs. In Figure 11 the same analysis shown in Figure 10 is also valid here, i.e. when the sensed samples is decreased, this lead to reduce in probability of detection in single SU, but in 4 SUs the reduction in P_d is very small. For example, when E_b/N_o is 10 dB and when comparing with Fig.10 (100% SR), P_d is reduced hugely from 0.75 to 0.6 in single SU , while in 4 SU P_d is reduced slightly from 0.87 to 0.83.

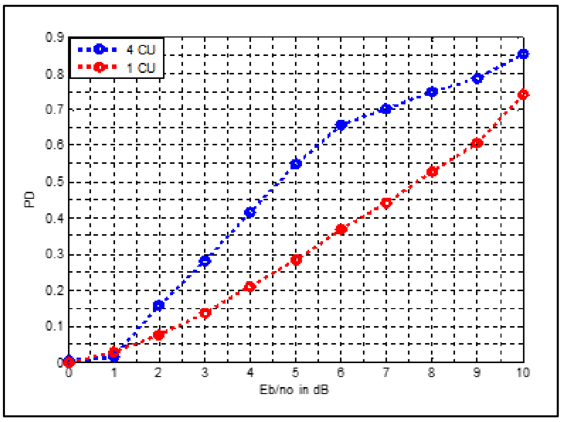

Figure 10: P_d versus Eb/N_o in Cooperative scenario sensing ratio 100%

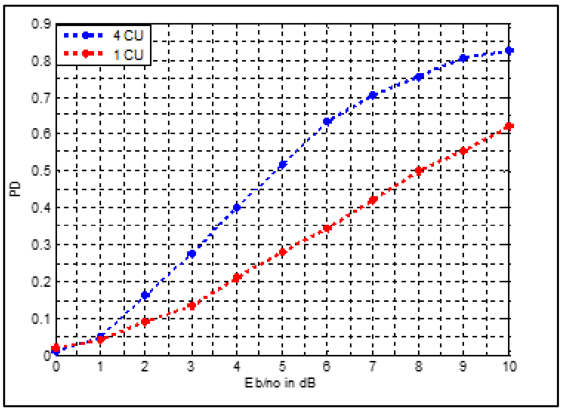

Figure 11: P_d versus Eb/N_o in Cooperative scenario sensing ratio 50%

5. Conclusion

This research have discussed the way to make an improvement in EC of spectrum sensing in CR networks by using an efficient method, based on energy detector technique with two scenarios: non-cooperative and cooperative scenario. The improvement of EC using an efficient method is done by decreasing the number of spectrum sensing samples and then evaluate the effects of this improvement on receiver operating metrics. Based on the results obtained, we conclude that in non-cooperative scenario, the use of partial sensing can reduce the EC by more than 40% at the high values of E_b/N_o with acceptance degradation value in probability of detection. The bounds of SR values that can achieve this optimization process starts from half the number of the total number of samples in the spectrum sensing method. In cooperative scenario, the conclusion can be drawn is that the average EC per user is decreased and probability of detection is improved when the number of SU is raised up to a certain limit after which no further improvements are obtained. The best performance that give energy saving with high probability of detection can be produced when the number of cognitive user CUs is 4 with 50% of SR.

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Author(s) biography

Hikmat. N. Abdullah was born in Baghdad, Iraq in 1974. He obtained his B.Sc. in Electrical Engineering in 1995, M.Sc. in Communication Engineering in 1998 at University of Al-Mustansiryah, Iraq and Ph.D. in Communication Engineering in 2004 at University of Technology, Iraq. From 1998 to 2015 he worked as lecturer/associate professor in the Electrical Engineering Department, at AlMustansiryah University, Iraq. Since the beginning of 2015 he works as a associate professor/ full professor in college of Information Engineering at Al-Nahrain University, Iraq. From 2011–2013 he got a research award from International Institute of Education (IIE/USA) at Bonn-Rhein-Sieg university of applied sciences, Germany. He is a senior member of IEEE association since 2014. He is interested in subject of wireless communication systems and cognitive radio networks.

Hadeel. S. Abed was born in Baghdad, 1992. She obtained her B.Sc. in Information and Communication Engineering Department in AL-Khawarizmi college of Engineering in 2014 at University of Baghdad, Iraq and M.Sc. in Network Engineering and Internet Technologies in 2017 at University of AlNahrain, Baghdad, Iraq. Since 2017, she works as part time lecturer in communication laboratory of Information and Communication Engineering Department in AL-Khawarizmi college of Engineering, University of Baghdad. She is interested in the subject of cognitive radio networks.