A Novel Energy Efficient Sensor Selection Algorithm for a Multi-Channel Cognitive Radio Network

Maryam Monemian*, Mehdi Mahdavi*, Mohammad Javad Omidi*

Department of Electrical and Computer Engineering

Isfahan University of Technology

Isfahan, Iran, 84156-83111

m.monemian@ec.iut.ac.ir,m_mahdavi@cc.iut.ac.ir,omidi@cc.iut.ac.ir

Abstract—**Cooperative Spectrum Sensing (CSS) improves the reliability of decisions made about the presence of Primary Users in Cognitive Radio Networks (CRN). However, energy consumption for performing CSS by Secondary Users (SU) is not negligible. Consequently, since SUs should perform CSS periodically, they may encounter rapid drain of their battery lifetimes. In this paper, an energy based sensor selection algorithm for multichannel CRNs is proposed to prevent the fast drain of SUs' lifetimes. The simulation results show that the proposed algorithm can considerably improve the lifetime of SUs and network compared to the existing methods.**

Keywords—Energy consumption; Multi-channel cognitive radio network; Battery life; Sensor selection.

I. INTRODUCTION

Cognitive Radio Networks (CRN) have been proposed to solve the problem of spectrum scarcity in wireless networks. In CRNs, Secondary Users (SU) can use the frequency spectrum which belongs to some Primary Users (PU), if they are absent on the frequency spectrum. In order to inhibit harmful interference occurred because of simultaneous transmissions of SUs and PUs, it is necessary for SUs to periodically sense the spectrum to become aware of the presence of PUs [1,2].

The accuracy of spectrum sensing is determined by two parameters. The first one called detection probability is the probability of correctly detecting the presence of PU when it is actually present. The second one named false alarm probability represents the probability of falsely detecting the presence of PU when it is actually absent. Cooperative Spectrum Sensing (CSS) is a well-known method which can improve the accuracy of CSS. In CSS several SUs independently senses the spectrum and jointly detect the presence of PU [3-14].

Although CSS provides valuable benefits in term of improved accuracy of spectrum sensing, it creates some important challenges which should be effectively managed. For instance, the energy amounts consumed by SUs for participation in CSS and the overhead made in Fusion Center (FC) for the combination of sensing results are not negligible.

In order to reduce energy consumption for CSS, some papers have proposed to engage only a number of sensors in CSS [3,12-14]. In [3], a censoring and sleeping method has been proposed to minimize energy consumption in CSS. In the censoring and sleeping method, some sensors sleep during the sensing phase and some of the awake sensors censor their sensing results and avoid from transmission. The authors define a sleeping rate and a censoring rate and determine them in such a way that energy consumption is minimized. In [12], we have proposed an energy-based method for sensor selection to increase the life times of network. First of all, the number of required sensors for CSS is determined based on the desired detection and false alarm probabilities. Such sensors are considered with same detection capabilities. Also, they use the frequency spectrum which belongs to one PU. Then, at the beginning of each frame the required sensors for CSS are chosen from the ones which their current energy values are more than a threshold. Thus, the average number of live sensors is increased in comparison with the existing methods. The energy efficiency of CSS in a multichannel CRN has been discussed in [5]. In [5] some methods have been proposed to select a subset of sensors to sense multiple channels. During a frame, it is possible for a sensor to sense more than one channel in their proposed methods. Moreover, the sensing time considered for sensing a channel by a sensor depends on the value of received SNR from PU and is not same for all sensors. However, since the energy constraints of sensors are not dynamically considered in the methods of [5], the fast battery drain of some sensors may be probable while others experience much more longevities.

In this paper, an energy efficient CSS algorithm for a multichannel CRNs is proposed which considerably increases the life time of network. Moreover, the proposed method which is based on the appropriate selection of sensors for CSS, can fairly engage all sensors with heterogeneous detection capabilities in CSS. Consequently, it prevents from the rapid drain of sensors' battery life times.

The rest of paper is organized as follows. The system model is described in Section II. The proposed algorithm is explained and analyzed in Section III. Performance evaluation and simulation results are presented in Section IV. Section V includes some concluding remarks.

II. SYSTEM MODEL

Consider a cognitive sensor network consisting of N_s sensors. Time is divided to equal frames the duration of which is T. At the beginning of each frame, a number of sensors should perform spectrum sensing in order to become aware of the presence of PUs on the frequency spectrum. A part of each frame considered for sensing is denoted by τ. The frequency spectrum is divided to two parts called A and B. The parts A and B belong to PU1 and PU2, respectively which independently appear on their frequency parts. In other words, one of the frequency parts may be occupied by

978-1-4799-1972-7/15/$31.00 ©2015 IEEE

a PU, while the other part is free during a same time frame. The structure of system model is shown in Fig. 1.

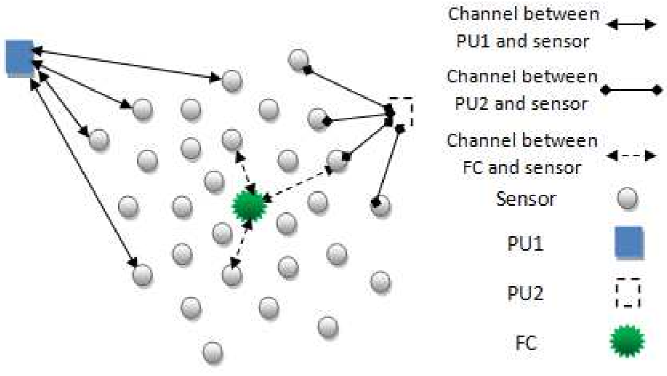

Fig. 1. The structure of system model.

As can be observed in Fig. 1, the sensors are located in different locations from PU1 and PU2. Therefore, they receive different values of SNR from PUs. Moreover, sensors use the same sensing time and sensing thresholds to detect the presence of PUs. Let $p_{i,j}^d$ and $p_{i,j}^f$ denote the detection probability and false alarm probability for i^{th} ($i = 1,\ldots,N_s$) sensor over frequency part j ($j = A,B$), respectively. Since the sensing times are considered to be same for all sensors over two frequency parts, the false alarm probabilities of them are same. Thus, we use p^f to denote the false alarm probability of each sensor.

As explained in the previous section, it is not necessary to engage all the sensors in CSS at the beginning of each frame. Let us denote the number of required sensors for performing CSS on frequency part A and B by m^A and m^B, respectively. The values of m^A and m^B are determined based on the individual detection and false alarm probabilities of sensors and the rule used in FC to combine the sensing results. In order to calculate such parameters we define two sets of sensors denoted by S^A and S^B representing the candidates for sensing the frequency part A and B, respectively. Let $|S^A|$ and $|S^B|$ denote the number of members of S^A and S^B, respectively. We define two threshold probabilities for each set and divide the members of each set to two categories based on their detection probabilities. Let P_{t1}^A (P_{t1}^B) and P_{t2}^A (P_{t2}^B) denote the threshold probabilities related to S^A (S^B). Without loss of generality, we assume that $P_{t2}^A < P_{t1}^A$ ($P_{t2}^B < P_{t1}^B$). The first category of S^A (S^B) denoted by C_1^A (C_1^B) includes the sensors which their detection probabilities are more than P_{t1}^A (P_{t1}^B) and the second category of S^A (S^B) denoted by C_2^A (C_2^B) contains the sensors which their detection probabilities are less than P_{t1}^A (P_{t1}^B) and more than or equal to P_{t2}^A (P_{t2}^B). In fact, we have,

$$C_1^j = \{i | i \in S^j, p_{i,j}^d \geq P_{t1}^j\} \quad j = A,B \tag{1}$$

$$C_2^j = \{i | i \in S^j, P_{t2}^j \leq p_{i,j}^d < P_{t1}^j\} \quad j = A,B \tag{2}$$

Let $E_n^i (n \geq 0, i = 1,\ldots,N_s)$ denote the current energy value of i^{th} sensor at the beginning of n^{th} frame. Let λ_{th} denote the energy threshold based on which sensors receive the priority for performing CSS. In addition, if the current energy value of i^{th} sensor reaches to a minimum threshold denoted by E_{min}, it is considered as a dead sensor. In other words, the i^{th} sensor is considered a live sensor at the beginning of n^{th} frame if $E_n^i \geq E_{min}$ is true. Let Δ_{si} denote the energy amount consumed for listening to the spectrum in the sensing phase and reporting the result to FC by the i^{th} sensor. With respect to the above explanations, E_n^i is related to E_{n-1}^i through the following equation.

$$E_n^i = \begin{cases} E_{n-1}^i \\ E_{n-1}^i - \Delta_{si} \end{cases}, n \geq 0 \tag{3}$$

Equation (3) states that at the beginning of a given frame (e.g. frame n) the energy level of the i^{th} sensor depends only on the energy level of such a sensor at the beginning of the preceding frame (e.g. frame $n-1$). This implies that the stochastic process E_n^i is a Discrete Time Markov Chain (DTMC). $P(E_n^i | E_{n-1}^i)$ can be obtained through the following equation.

$$P(E_n^i = E_{n-1}^i - \Delta_{si} | E_{n-1}^i) = \begin{cases} P_i^A(n), i \in S^A \\ P_i^B(n), i \in S^B \end{cases} \tag{4}$$

$$P(E_n^i = E_{n-1}^i - \Delta_{si} | E_{n-1}^i) = 1 - P(E_n^i = E_{n-1}^i | E_{n-1}^i) \tag{5}$$

Where in (4) $P_i^A(n)$ denotes the probability of participation in CSS at the start of n^{th} frame by the i^{th} sensor that belongs to S^A. Moreover, $P_i^B(n)$ denotes the probability of participation in CSS at the start of n^{th} frame by the i^{th} sensor that belongs to S^B. $P_i^A(n)$and $P_i^B(n)$ are computed after the description of proposed algorithm in section III.

Definition 1: Assume that the energy level of the i^{th} sensor at the start of n^{th} frame is equal to $E_n^i = EI - a\Delta_{si}, 0 \leq a \leq n, n \geq 0$ where EI denotes the initial energy value of each sensor. We define $X_n^i = (a)$ as the state of the i^{th} sensor at the start of n^{th} frame.

Let $T^i(n)$ denote the set of all states at the start of n^{th} frame in which the i^{th} sensor is alive. In fact, we have,

$$T^i(n) = \{ X_n^i = (a) | E - a\Delta_{si} \geq E_{min}, 0 \leq a \leq n, n \geq 0\} \tag{6}$$

Let $N_1(n)$ ($N_2(n)$) denote a subset of C_1^A (C_2^A) including the live sensors at the beginning of n^{th} frame. Also, let $M_1(n)$ ($M_2(n)$) denote a subset of C_1^B (C_2^B) including the live sensors at the beginning of n^{th} frame. The numbers of members of $N_1(n)$ ($N_2(n)$) and $M_1(n)$ ($M_2(n)$) are denoted by $|N_1(n)|$ ($|N_2(n)|$) and $|M_1(n)|$ ($|M_2(n)|$), respectively.

At the beginning of each frame, some sensors should be chosen from S^A and S^B to perform CSS on frequency part A and B, respectively. Let m_1^A (m_1^B) denote the required number of sensors for CSS, if they are chosen from the first category of S^A (S^B). If the OR rule is used in FC for the combination of sensing results, we can write,

$$m_1^j \triangleq \underset{z}{\text{argmin}} \begin{Bmatrix} z | \, 1 - \prod_{i=1}^{z}(1 - p_{i,j}^d) \geq P_{ds}, \\ 1 - \prod_{i=1}^{z}(1 - p^f) \leq P_{fs} \end{Bmatrix}, j = A,B \tag{7}$$

Where in (7) P_{ds} denotes the desired detection probability. Also, P_{fs} denotes the maximum acceptable false alarm probability. Moreover, note that we start with the replacement of the least values of $p_{i,j}^d$ from $C_1^A(C_1^B)$. In addition, the value of m_2^j can be determined via the following equation.

$$m_2^j \triangleq \underset{z}{\text{argmin}}\{z | \, 1 - \prod_{i=1}^{z}(1 - p_{i,j}^d) \geq P_{ds}, 1 - \prod_{i=1}^{z}(1 - p^f) \leq P_{fs}\} \;, j = A,B \tag{8}$$

Where in (8) we start with the replacement of the least values of $p_{i,j}^d$ from $C_2^A(C_2^B)$. With respect to the above explanations, we can write,

$$m^j = \begin{cases} m_1^j, \; if \; sensors \; are \; chosen \; from \; C_1^j \\ m_2^j, \; if \; sensors \; are \; chosen \; from \; C_2^j \end{cases}, \; j = A,B \tag{9}$$

Thus, at the beginning of each frame, m^j sensors are chosen to perform CSS on frequency part j. We define $\rho_i^j(n)$ ($j = A,B$, $i = 1,\ldots,|S^j|$) as a parameter indicating the participation of i^{th} sensor in CSS over j^{th} frequency part. We define $\rho_i^j(n)$ as follows,

$$\rho_i^A(n) = \begin{cases} 0, if \quad i \in S^B \\ 1, if \quad i \in S^A and\ i\ chosen\ for\ CSS \\ 0, if \quad i \in S^A and\ i\ not\ chosen\ for\ CSS \\ 1, if \quad i \in S^A \cap S^B\ and\ i\ chosen\ for\ CSS \\ 0, if \quad i \in S^A \cap S^B\ and\ i\ not\ chosen\ for\ CSS \end{cases} \tag{10}$$

In addition, we have,

$$\rho_i^B(n) = \begin{cases} 0, if \quad i \in S^A \\ 1, if \quad i \in S^B and\ i\ chosen\ for\ CSS \\ 0, if \quad i \in S^B and\ i\ not\ chosen\ for\ CSS \\ 1, if \quad i \in S^A \cap S^B\ and\ i\ chosen\ for\ CSS \\ 0, if \quad i \in S^A \cap S^B\ and\ i\ not\ chosen\ for\ CSS \end{cases} \tag{11}$$

As clear in (10) and (11), if a sensor belongs to S^A and is not a common member of S^A and S^B, it is not chosen for CSS on frequency spectrum B. Also, if a sensor belongs to S^B and is not a common member of S^A and S^B, it is not chosen for CSS on frequency spectrum A.

III. PROPOSED ALGORITHM AND ANALYSIS

A. Preliminaries

In this section we propose a novel algorithm which aims at performing CSS over two separate frequency parts considering energy constraints of sensors.

Let $S_1^A(n)$ denote the set of the first category members of S^A which their energy levels are more than λ_{th} at the beginning of n^{th} frame. The number of members of such a set at the beginning of n^{th} frame is denoted by $|S_1^A(n)|$. In fact, we have,

$$S_1^A(n) = \{i | i \in C_1^A, E_n^i \geq \lambda_{th}, n \geq 0\} \tag{12}$$

Let us denote a subset of the second category members of S^A which their energy levels are more than λ_{th} at the beginning of n^{th} frame by $S_2^A(n)$. The number of members of $S_2^A(n)$ is denoted by $|S_2^A(n)|$. We can write,

$$S_2^A(n) = \{i | i \in C_2^A, E_n^i \geq \lambda_{th}, n \geq 0\} \tag{13}$$

B. Proposed Algorithm

The steps of the proposed algorithm are as follows. At the start of n^{th} frame,

1- If $|S_1^A(n)| \geq m_1^A$, then m_1^A sensors are chosen with equal probabilities from $S_1^A(n)$.

2- If $|S_1^A(n)| < m_1^A$ and $|S_2^A(n)| \geq m_2^A - |S_1^A(n)|$, $m_2^A - |S_1^A(n)|$ sensors are selected with equal probabilities from the $S_2^A(n)$.

3- If $|S_1^A(n)| < m_1^A$ and $|S_2^A(n)| < m_2^A - |S_1^A(n)|$ and $|N_1(n)| \geq m_1^A$, m_1^A sensors are selected with equal probabilities from $N_1(n)$.

4- If $|S_1^A(n)| < m_1^A$ and $|S_2^A(n)| < m_2^A - |S_1^A(n)|$ and $|N_1(n)| < m_1^A$, and $|N_2(n)| \geq m_2^A$- $|N_1(n)|$, m_2^A- $|N_1(n)|$ sensors are chosen with equal probabilities from $N_2(n)$.

5- If $|S_1^A(n)| < m_1^A$ and $|S_2^A(n)| < m_2^A - |S_1^A(n)|$ and $|N_1(n)| < m_1^A$ and $|N_2(n)| < m_2^A$- $|N_1(n)|$, there are not enough sensors for CSS over frequency part A.

After choosing sensors for CSS over frequency part A, we look for appropriate sensors for CSS over frequency part B.

6- If $|S_1^B(n)| - \sum_{j \in S_1^B(n)} \rho_j^A(n) \geq m_1^B$, then m_1^B sensors are selected with equal probabilities from $S_1^B(n)$.

7- If $|S_1^B(n)| - \sum_{j \in S_1^B(n)} \rho_j^A(n) < m_1^B$ and $|S_2^B(n)| - \sum_{j \in S_2^B(n)} \rho_j^A(n) \geq m_2^B - |S_1^B(n)| + \sum_{j \in S_1^B(n)} \rho_j^A(n)$, $m_2^B - |S_1^B(n)| + \sum_{j \in S_1^B(n) \cap S^A} \rho_j^A(n)$ sensors are selected with equal probabilities from $S_2^B(n)$.

8- If $|S_1^B(n)| - \sum_{j \in S_1^B(n)} \rho_j^A(n) < m_1^B$, $|S_2^B(n)| - \sum_{j \in S_2^B(n)} \rho_j^A(n) < m_2^B - |S_1^B(n)| + \sum_{j \in S_1^B(n)} \rho_j^A(n)$, and $|M_1(n)| - \sum_{j \in M_1(n)} \rho_j^A(n) \geq m_1^B$, m_1^B sensors are chosen from $M_1(n)$.

9- If $|S_1^B(n)| - \sum_{j \in S_1^B(n)} \rho_j^A(n) < m_1^B$, $|S_2^B(n)| - \sum_{j \in S_2^B(n)} \rho_j^A(n) < m_2^B - |S_1^B(n)| + \sum_{j \in S_1^B(n)} \rho_j^A(n)$, $|M_1(n)| - \sum_{j \in M_1(n)} \rho_j^A(n) < m_1^B$, and $|M_2(n)| - \sum_{j \in M_2(n)} \rho_j^A(n) \geq m_2^B$- $|M_1(n)| + \sum_{j \in M_1(n)} \rho_j^A(n)$, m_2^B- $|M_1(n)| + \sum_{j \in M_1(n)} \rho_j^A(n)$ sensors are chosen with equal probabilities from $M_2(n)$.

10- If $|S_1^B(n)| - \sum_{j \in S_1^B(n)} \rho_j^A(n) < m_1^B$, $|S_2^B(n)| - \sum_{j \in S_2^B(n)} \rho_j^A(n) < m_2^B - |S_1^B(n)| + \sum_{j \in S_1^B(n)} \rho_j^A(n)$, $|M_1(n)| - \sum_{j \in M_1(n)} \rho_j^A(n) < m_1^B$, and $|M_2(n)| - \sum_{j \in M_2(n)} \rho_j^A(n) < m_2^B - |M_1(n)| + \sum_{j \in M_1(n)} \rho_j^A(n)$, there are not enough sensors for CSS over frequency part B.

The analysis of the proposed algorithm is presented in the following.

C. Algorithm Analysis

In this section, we compute $P_i^A(n)$ and $P_i^B(n)$. We can write,

$$P_i^A(n) = \begin{cases} P_1(n), i \in S_1^A(n) \\ P_2(n), i \in C_1^A - S_1^A(n) \\ P_3(n), i \in S_2^A(n) \\ P_4(n), i \in C_2^A - S_2^A(n) \end{cases} \tag{14}$$

Where $P_1(n)$, $P_2(n)$, $P_3(n)$, and $P_4(n)$ can be found as follows.

$$P_1(n) = \begin{cases} \frac{m_1^A}{|S_1^A(n)|}, if\ U \\ 1, \quad if\ \bar{U} \end{cases} \tag{15}$$

Where in (15) U and $\bar{U}$ denote the conditions of $|S_1^A(n)| \geq m_1^A$ and $|S_1^A(n)| < m_1^A$, respectively. Also, let V and $\bar{V}$ denote the conditions of $|S_2^A(n)| \geq m_2^A - |S_1^A(n)|$ and $|S_2^A(n)| < m_2^A - |S_1^A(n)|$, respectively. Furthermore, let W and $\bar{W}$ denote the conditions of $|N_1(n)| \geq m_1^A$ and $|N_1(n)| < m_1^A$, respectively. In addition, X and $\bar{X}$ denote the conditions of $|N_2(n)| \geq m_2^A - |N_1(n)|$ and $|N_2(n)| < m_2^A - |N_1(n)|$, respectively.

$$P_2(n) = \begin{cases} 0, \quad if\ U \\ 0, \quad if\ \bar{U} \,\&\, V \\ \frac{m_1^A}{|N_1(n)|}, if\ \bar{U} \,\&\, \bar{V} \& \, W \\ 1, \quad if\ \bar{U} \,\&\, \bar{V} \,\&\, \bar{W} \end{cases} \tag{16}$$

$$P_3(n) = \begin{cases} 0, \quad if\ U \\ \frac{m_2^A - |S_1^A(n)|}{|S_2^A(n)|}, if\ \bar{U} \,\&\, V \\ 1, \quad if\ \bar{U} \,\&\, \bar{V} \end{cases} \tag{17}$$

$$P_4(n)=\begin{cases}0, & if\ U\\ 0, & if\ \bar{U}\ \&\ V\\ 0, & if\ \bar{U}\ \&\ \bar{V}\ \&\ W\\ \frac{m_2^A-|N_1(n)|}{|N_2(n)|}, & if\ \bar{U}\ \&\ \bar{V}\ \&\ \bar{W}\ \&\ X\end{cases} \tag{18}$$

Where in (16-18) & is AND operator. Also, for $P_i^B(n)$ we can write.

$$P_i^B(n)=\begin{cases}Q_1(n), i\in S_1^B(n)\\ Q_2(n), i\in C_1^B-S_1^B(n)\\ Q_3(n), i\in S_2^B(n)\\ Q_4(n), i\in C_2^B-S_2^B(n)\end{cases} \tag{19}$$

Where in (19) $Q_1(n)$, $Q_2(n)$, $Q_3(n)$ and $Q_4(n)$ can be found in the following equations. Let C and $\bar{C}$ denote the conditions of $|S_1^B(n)|-\sum_{j\in S_1^B(n)}\rho_j^A(n)\geq m_1^B$ and $|S_1^B(n)|-\sum_{j\in S_1^B(n)}\rho_j^A(n)<m_1^B$, respectively. Also, let D and $\bar{D}$ denote the conditions of $|S_2^B(n)|-\sum_{j\in S_2^B(n)}\rho_j^A(n)\geq m_2^B-|S_1^B(n)|+\sum_{j\in S_1^B(n)}\rho_j^A(n)$ and $|S_2^B(n)|-\sum_{j\in S_2^B(n)}\rho_j^A(n)<m_2^B-|S_1^B(n)|+\sum_{j\in S_1^B(n)}\rho_j^A(n)$, respectively. Furthermore, let E and $\bar{E}$ denote the conditions of $|M_1(n)|-\sum_{j\in M_1(n)}\rho_j^A(n)\geq m_1^B$ and $|M_1(n)|-\sum_{j\in M_1(n)}\rho_j^A(n)<m_1^B$, respectively. Moreover, let F and $\bar{F}$ denote the conditions of $|M_2(n)|-\sum_{j\in M_2(n)}\rho_j^A(n)\geq m_2^B-|M_1(n)|+\sum_{j\in M_1(n)}\rho_j^A(n)$ and $|M_2(n)|-\sum_{j\in M_2(n)}\rho_j^A(n)< m_2^B-|M_1(n)|+\sum_{j\in M_1(n)}\rho_j^A(n)$, respectively. In addition, let Y and $\bar{Y}$ denote the conditions of $\rho_i^A(n)=1$ and $\rho_i^A(n)=0$, respectively.

$$Q_1(n)=\begin{cases}0, & if\ Y\\ \frac{m_1^B}{|S_1^B(n)|-\sum_{j\in S_1^B(n)}\rho_j^A(n)}, & if\ \bar{Y}\&C\\ 1, & if\ \bar{Y}\&\bar{C}\end{cases} \tag{20}$$

$$Q_2(n)=\begin{cases}0, & if\ Y\\ 0, & if\ \bar{Y}\&C\\ 0, & if\ \bar{Y}\&\bar{C}\&D\\ \frac{m_1^B}{|M_1(n)|-\sum_{j\in M_1(n)}\rho_j^A(n)}, & if \bar{Y}\ \&\ \bar{C}\ \&\ \bar{D}\&\ E\end{cases} \tag{21}$$

$$Q_3(n)=\begin{cases}0, & if\ Y\\ 0, & if\ \bar{Y}\ \&\ C\\ \frac{m_2^B-|S_1^B(n)|+\sum_{j\in S_1^B(n)}\rho_j^A(n)}{|S_2^B(n)|-\sum_{j\in S_2^B(n)}\rho_j^A(n)}, & if\ \bar{Y}\ \&\ \bar{C}\&\ D\end{cases} \tag{22}$$

$$Q_4(n)=\begin{cases}0, & if\ Y\\ 0, & if\ \bar{Y}\ \&\ C\\ 0, & if\ \bar{Y}\ \&\ \bar{C}\&\ D\\ 0, & if\ \bar{Y}\ \&\ \bar{C}\&\ \bar{D}\ \&\ E\\ \frac{m_2^B-|M_1(n)|+\sum_{j\in M_2(n)}\rho_j^A(n)}{|M_2(n)|-\sum_{j\in M_2(n)}\rho_j^A(n)}, & if\ \bar{Y}\ \&\ \bar{C}\ \&\ \bar{D}\ \&\ \bar{E}\end{cases} \tag{23}$$

IV. PERFORMANCE EVALUATION

In this section we compare the performance of our proposed algorithm with Energy Efficient (EE) method proposed in [5]. Energy consumption for spectrum sensing in a multichannel cognitive radio network has been considered in [5]. The authors of [5] proposed three methods to minimize the energy consumption in the sensing phase. The EE method which has the best performance among them uses outer linearization to solve the optimization problem. In the EE method, a maximum time is considered for spectrum sensing during which each sensor may sense one or more channels. The time consumed for each sensor to sense a channel depends on the value of received SNR from the corresponding PU. Since sensors experience different values of SNR over a same channel, the required time for sensing a same channel is not same for all sensors. Moreover, each sensor that performs spectrum sensing on one or more channels transmits only one data packet to FC to indicate the presence of PUs. In addition, it is necessary for each channel to be sensed by a minimum number of sensors denoted by δ^{min}. The value of $\delta^{min}$is determined in such a way that the desired detection probability for each channel is satisfied. Table. 1 presents the values of parameters used in the simulations.

Table 1.The values of parameters used for simulation.

Parameter	Value
P_{ds}	0.9
$p_{i,j}^d$ $(j=A,B)$	□[0.48,0.84]
p^f	0.01
Δ_{si}	□[0.7,1.3]

Let $\overline{N(n)}$ denote the average number of live sensors at the start of n^{th} frame. We can write,

$$\overline{N(n)}=\sum_{i=1}^{N_s}\sum_{all\ (a)\in T^i(n)}P(X_n^i=(a)) \tag{24}$$

Let $E_c(n)$ denote the energy amount consumed for CSS in the n^{th} frame. $E_c(n)$ can be obtained via the following equation,

$$E_c(n)=\sum_{i\in S^A}\rho_i^A(n)\Delta_{si}+\sum_{i\in S^B}\rho_i^B(n)\Delta_{si} \tag{25}$$

Let E_{ave} denote the average energy consumption for CSS per frame. If F denotes the maximum lifetime of network, E_{ave} can be obtained through (26).

$$E_{ave}=\frac{\sum_{n=0}^{F}E_c(n)}{F} \tag{26}$$

Fig. 2 presents the average number of live sensors, $\overline{N(n)}$, in our proposed algorithm and EE method. As obvious in Fig. 2, the average number of live sensors in our proposed method is considerably more than EE method. Moreover, the curves obtained for simulation and analysis are close to each other with high approximation.

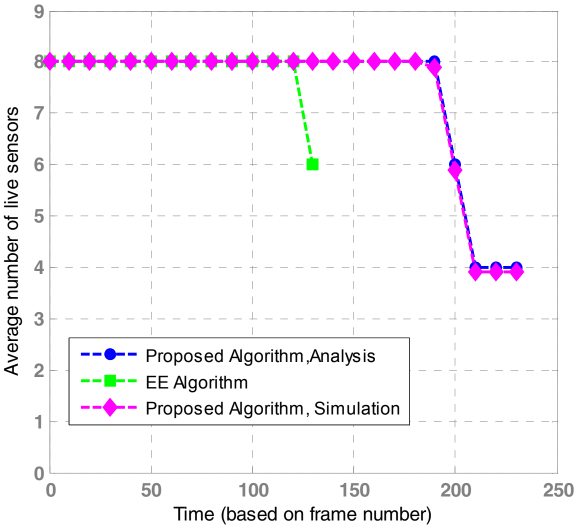

Fig. 2. The average number of live sensors in the proposed algorithm and EE method.

Fig. 3 presents the maximum network lifetime in the proposed algorithm and EE algorithm. By maximum network lifetime, we mean the maximum frame number at the beginning of which it is still possible to sense both of frequency spectrum parts. As can be observed, the maximum network lifetime in the proposed algorithm is considerably more than EE for algorithm.

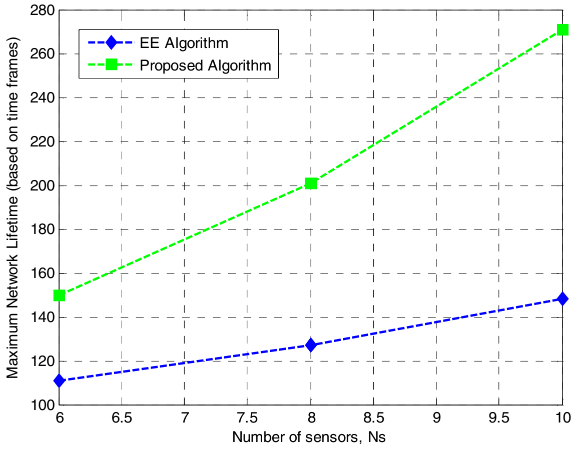

Fig. 3. Maximum network lifetime versus number of sensors in the proposed algorithm and EE algorithm.

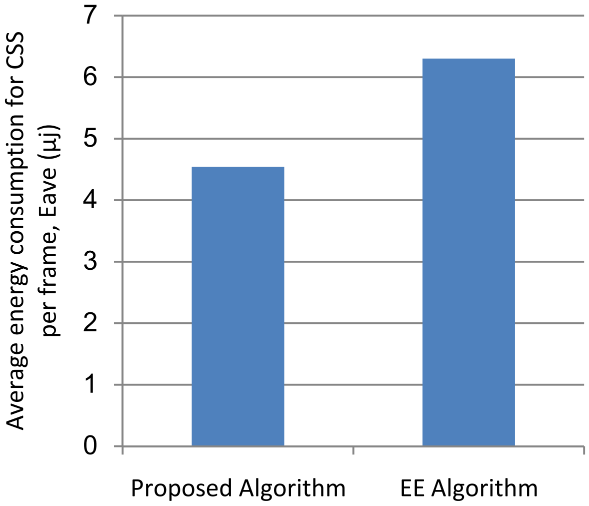

Fig. 4. Average energy consumption for CSS per frame, E_{ave}, in the proposed algorithm and EE algorithm.

Fig. 4 presents the average energy consumption for CSS, E_{ave}, in the proposed algorithm and EE algorithm. As mentioned before, E_{ave} is obtained through (26). It is obvious from Fig. 4 that the average energy consumption for CSS in the proposed algorithm is considerably less than that of EE algorithm.

V. CONCLUSIONS

In this paper, an energy based sensor selection algorithm for a multichannel CRNs has been proposed to improve the lifetimes of SUs. The proposed method selects proper SUs for CSS over each channel from the ones which their current energy levels are more than a pre-defined threshold. Moreover, the proposed method categorizes the SUs candidate for CSS over a channel based on their detection probabilities and for each category finds the minimum required number of sensors for CSS. In this way, the proposed method can appropriately engage the sensors with different detection probabilities in CSS. Furthermore, the simulation results show that the proposed method significantly improves the lifetime of CRN.

REFERENCES

[1] J. Mitola and G. Q. Maguire, Jr., “Cognitive radio: Making software radios more personal,” *IEEE Personal Communication Magazine*, Vol. 6, No. 4, 1999, Pages: 13–18.

[2] A. Ghasemi and E. S. Sousa, “Collaborative spectrum sensing for opportunistic access in fading environments,” in *Proceedings of 1st IEEE International Symposium New Frontiers Dynamic Spectrum Access Networks*, 2005, Pages: 131–136.

[3] S. Maleki, A. Pandharipande, and G. Leus, “Energy-efficient distributed spectrum sensing for cognitive sensor networks,” *IEEE Sensors Journal*, Vol. 11, No. 3, 2011, Pages: 565–573.

[4] Y.-C. Liang, Y. Zeng, E. C. Y. Peh, and A. T. Hoang, “Sensing-throughput tradeoff for cognitive radio networks,” *IEEE Transactions on Wireless Communications*, Vol. 7, No. 4, 2008, Pages: 1326–1337.

[5] S. Eryigit, S. Bayhan, and T. Tugcu, "Energy-efficient multichannel cooperative sensing scheduling with heterogeneous channel conditions for cognitive radio networks", IEEE transactions on vehicular technology, Vol. 62, No. 6, 2013, Pages: 2690-2699.

[6] I. F. Akyildiz, B. F. Lo, and R. Balakrishnan, "Cooperative spectrum sensing in cognitive radio networks: a survey", Elsevier journal on physical communications, Vol. 4, Issue. 1, 2011, Pages: 40-62.

[7] J. Shen, T. Jiang, S. Liu, and Z. Zhang, "Maximum channel throughput via cooperative spectrum sensing in cognitive radio networks", IEEE transactions on wireless communications, Vol. 8, No. 10, 2009, Pages: 5166-5175.

[8] S. Xie, Y. Liu, Y. Zhang, and R. Yu, "A parallel cooperative spectrum sensing in cognitive radio networks", IEEE transactions on vehicular technology, Vol. 59, No. 8, 2010, Pages: 4079-4092.

[9] S. Yarkan, B. U. Toreyin, K. A. Qaraqe, and A. E. Cetin, "An online adaptive cooperative scheme for spectrum sensing based on a second order statistical method", IEEE transactions on vehicular technology, Vol. 61, No. 2, 2012, Pages: 675-686.

[10] S. Chaudhari, J. Lunden, V. Koivunen, and H. V. Poor, "Cooperative sensing with imperfect reporting channels: hard decisions or soft decisions?", IEEE transactions on signal processing, Vol. 60, No. 1, 2012, Pages: 18-28.

[11] K. Umebayashi, J. J. Lehtomäki, T. Yazawa, and Y. Suzuki, "Efficient decision fusion for cooperative spectrum sensing based on OR-rule", IEEE transactions on wireless communications, Vol. 11, No. 7, 2012, Pages: 2585-2595.

[12] A. W. Min, and K. G. Shin, "Joint optimal sensor selection and scheduling in dynamic spectrum access networks", IEEE transactions on mobile computing, Vol. 12, Issue. 8, 2013, Pages: 1532-1545.

[13] M. Monemian, M. Mahdavi, "Sensing user selection based on energy constraints in cognitive radio networks", In proceedings of IEEE Wireless Communications and Networking Conference, WCNC 2014, Istanbul, 2014.

[14] M. Monemian, M. Mahdavi, "Analysis of a new energy-based sensor selection method for cooperative spectrum sensing in cognitive radio networks", IEEE sensors journal, Vol. 14, No. 9, 2014, Pages:3021-3032.