Energy-efficient Cooperative Sensing Schedule for Heterogenous Users in Cognitive Radio Networks

Xin Huang, Xinxin Feng, Hang Qiu, Xinbing Wang
Department of Electronic Engineering
Shanghai Jiao Tong University, China
Email:{h-x, fxx1116, sunny_boy, xwang8}@sjtu.edu.cn

***Abstract*—In this paper, we study the Cooperative Sensing Scheduling (CSS) problem for Cognitive Radio Network (CRN), from the perspective of balance between sensing performance and energy consumption. We place this problem in a practical scenario where both the primary users (PUs) and the secondary users (SUs) are heterogeneous: PU channels are different in terms of channel admission control, idle probability and channel capacity; SUs differs in sensing performance and sensing energy consumption. We formulate the CSS problem as a programming problem, whose optimal solution is proved to exist but takes considerable time and energy to reach. We then propose two heuristic algorithms, i.e., *Centralized Algorithm* and *Multi-oligarch Algorithm*, to obtain sub-optimal solutions. A *Revised Initialization* algorithm is also presented to improve the performance of these two algorithms. Simulation results show that the two algorithms achieve sub-optimal solutions with efficiency and effectiveness.**

I. INTRODUCTION

Past decades have witnessed dramatic development in wireless services, and increasingly huge demand for the scarce spectrum resources. However, ample evidence [1] shows that most of the licensed spectrum is under-utilized due to the fixed channel allocation strategies now under operation. To resolve the conflict between spectrum under-utilization and the increasing demand for spectrum, the concept of Cognitive Radio Network (CRN) has been proposed [2]. In CRN, secondary users (SUs) can sense the channels of primary users (PUs) and operates on the channel whose PU is absent. Thus channel sensing is one of the urging tasks in CRN. [3] studies the sensing-throughput tradeoff for sensing in CRN and provides useful tools to analyze SU's sensing performance. In [4], a collaborative spectrum sensing (CSS) strategy proposed helps to improve SUs' sensing performance as a coalition. In [5], the authors model CSS as a cooperative game. Moreover, the authors of [7] proceed to seek an optimality in CSS with heterogeneous users. However, these works mentioned above focus more on the expected channel resource as the revenue of cooperative sensing, rather than energy friendly CSS strategies.

In CSS, spectrum sensing process is power intensive[6]. Although more SUs devoting to sense a channel bring more expected channel resource opportunity, however, with the number of sensing SUs increases, the energy spent on sensing will be higher. The energy-efficient CSS issus is consider in [8], which takes into account both expected channel resource discovered by CSS and SUs' energy consumption. In this paper, the authors propose a two-step approach to achieve an optimal solution .

However, the problem is solved in the assumption of homogeneous SUs in terms of sensing energy consumption, sensing detection probability and false alarm probability. But this is not always the case in a practical scenario. SUs' sensing performance varies with many factors. For example, the degradation of the PU signal due to path loss, or different constructions of SU devices may also affect each SU's performance and power consumption during sensing. In this paper, we consider a more practical scenario where both the PUs and SUs are heterogeneous. The objective of this paper is to find a proper CSS to achieve a tradeoff between energy consumption and the expected channel opportunity in a CRN with heterogeneous PUs and SUs.

The rest of this paper is organized as follows. System model is given in section II. Then the problem is reinterpreted and analyzed in section III. In section IV, two heuristic algorithms, together with an improved initialization method, are proposed to obtain sub-optimal solutions. Simulation results in section V illustrate and validate the effectiveness and efficiency of our algorithm. Finally, conclusion is given in section VI.

II. SYSTEM MODEL

Consider a cognitive network consisting of N PUs and M SUs. There is also a Base Station (BS) which is responsible to collect channel sensing information from SUs, and to assign Channel Sensing Schedule (CSS). Each SU, denoted as $\mathscr{M} = \{1, 2, ..., m, ..., M\}$ respectively, is capable to sense each of the N primary channels, denoted as $\mathscr{N} = \{1, 2, ..., n, ..., N\}$ respectively. The users are heterogenous: PUs are different in the channel admission control, idle probability and channel capacity; SUs differs in terms of sensing performance and sensing energy consumption.

A. Sensing Performance

First we consider the relationship between sensing performance of the cooperative SUs and the expected channel opportunities. We assume that decision fusion based cooperative spectrum sensing is adopted in this CRN. In this paper, we also assume that the SUs are equipped with single radio interface, so for each time slot, a SU is only allowed to sense or access one primary channel at most. Let $s(n)$ denotes the status of the primary channel n and

$$s(n) = 0 \text{ when primary channel } n \text{ is idle,}$$

$s(n) = 1$ when primary channel n is busy.

Let $D(m,n)$ denotes SU m 's decision when it is chosen to sense channel n using energy detection based spectrum sensing [3]. In this paper, we assume that the CRN works in a slotted frame structure and the sensing duration is fixed in each frame. But for each SU, its sensing performance varies with different primary channels. Let $P_f(m,n)$ denotes SU m's false alarm probability when it senses primary channel n , $P_d(m,n)$ denotes the SU m's detection probability when it senses primary channel n, i.e.

$$P_d(m,n) = P(D(m,n) = 1|s(n) = 1), \quad (1)$$

$$P_f(m,n) = P(D(m,n) = 1|s(n) = 0). \quad (2)$$

BS collects sensing report indicating "busy" or "idle" from all SUs and combines the collected results using "OR" rule. Suppose channel n is sensed by a set of SUs, denoted as $\mathscr{P}_n = \{m_{i_1}, m_{i_2}, ..., m_{i_k}\}$, where k is the number of SUs assigned to sense this primary channel, and $m_{i_k} \in \mathscr{P}_n$ is one of the SUs assigned to sense PU n. Then the false alarm probability for primary channel n is expressed as

$$P_f(n, \mathscr{P}_n) = 1 - \prod_{m \in \mathscr{P}_n} [1 - P_f(m,n)], \quad (3)$$

and the detection probability for primary channel n is

$$P_d(n, \mathscr{P}_n) = 1 - \prod_{m \in \mathscr{P}_n} [1 - P_d(m,n)]. \quad (4)$$

Assume that all the SUs should stay quiet if the final result comes as "busy". Then for the set of SUs $\mathscr{P}_n$ devoting to sense channel n, the expected channel opportunity is

$$\begin{aligned} R(n, \mathscr{P}_n) &= C(n)P_0(n)[1 - P_f(n, \mathscr{P}_n)] \\ &= \alpha(n)[1 - P_f(n, \mathscr{P}_n)], \end{aligned} \quad (5)$$

where $C(n)$ is the channel n's capacity, $P_0(n)$ channel n's idle probability, and $\alpha(n)$ a constant for a given channel n. .

To protect the quality of service for PUs, the admission control requires the detection probability of each channel in the CRN should be larger than some required thresholds. Denote λ_n as channel n's detection probability requirement. For a set of SUs devoting to sense channel n, if their sensing performance together fails to meet PU n's requirement for detection probability, the SUs would refuse to cooperate, because they would not be admitted by primary channel n even though they consumes energy to sense. In this case, their expected channel opportunity should be zero. Therefore, the expected channel opportunity of $\mathscr{P}_n$ should be rewritten as

$$R(n, \mathscr{P}_n) = \begin{cases} \alpha(n)[1 - P_f(n, \mathscr{P}_n)] & \text{if } P_d(n, \mathscr{P}_n) \geq \lambda_n \\ 0 & \text{otherwise} \end{cases}. \quad (6)$$

B. Energy Consumption

Then we consider the energy consumption for channel sensing. Let $\phi_s(m,n) > 0$ denotes the energy consumption for SU m to sense primary channel n. For each SU, it may take different level of energy consumption to sense different primary channels, i.e. $\phi_s(m,n_1) \neq \phi_s(m,n_2)(n_1 \neq n_2)$. Then for the set of SUs $\mathscr{P}_n$ devoting to sense channel n , the total energy consumption is

$$E(n, \mathscr{P}_n) = \sum_{m \in \mathscr{P}_n} \phi_s(m,n). \quad (7)$$

C. Utility Function

The objective of this paper is to find a proper CSS to keep a balance between expected channel opportunity and energy consumption. Therefore, the utility of $\mathscr{P}_n$ can be given by

$$\begin{aligned} U(n, \mathscr{P}_n) &= \frac{R(n, \mathscr{P}_n)}{E(n, \mathscr{P}_n)} \\ &= \frac{\alpha(n)[1 - P_f(n, \mathscr{P}_n)]}{\sum_{m \in \mathscr{P}_n} \phi_s(m,n)}. \end{aligned} \quad (8)$$

Then we have the utility function for a certain CSS

$$U(\mathscr{P}) = \sum_{n=1}^{N} U(n, \mathscr{P}_n), \quad (9)$$

where $\mathscr{P} = \{\mathscr{P}_1, \mathscr{P}_2, ..., \mathscr{P}_N\}$ denotes CSS.

Then the CSS problem can be formulated as follows

$$\begin{aligned} \max \quad & U(\mathscr{P}) = \sum_{n=1}^{N} U(n, \mathscr{P}_n), \\ s.t. \quad & \mathscr{P}_i \cap \mathscr{P}_j = \Phi, \quad (i \neq j) \quad and \quad i, j \in \mathscr{N}. \end{aligned} \quad (10)$$

III. PROBLEM ANALYSIS

Because each SU is allowed to sense one primary channel in a single time slot, SU is faced with $N + 1$ choices: it may sense one of the N primary channels, or it may stay idle and not participate in the cooperative sensing. The BS is responsible to decide each SU's choice to achieve a reasonable balance between energy consumption and expected channel opportunity. For a given CRN where PUs' channel capacity, idle probability, together with each SU's sensing performance and sensing energy consumption are fixed, if each SU's choice is also determined, so is the energy-opportunity utility. Thus in a CRN, the combination of all SUs' choices is one of the solutions to CSS problem.

A. Problem Reshape

Denote $\mathscr{C} = \{c_0, c_1, ..., c_n, ..., c_N\}$ as each SU's choice set, where c_0 indicating SU stays idle in sensing and c_n SU senses primary channel n. And BS decides a certain SU m's choice d_m should be which element in $\mathscr{C}$, i.e. $d_m \in \mathscr{C}$. The choice combination set of all SUs is $\mathscr{S} = \{d_1, ..., d_M\}$, which also serves as the solution of CSS. Therefore the problem of equation (10) can be rewritten as

$$\begin{aligned} \max \quad & U(\mathscr{S}) = \sum_{n=1}^{N} U(n, \mathscr{P}_n), \\ s.t. \quad & \mathscr{S} = \{d_1, ..., d_m, ..., d_M\}, \\ & d_m \in \mathscr{C} = \{c_0, c_1, ..., c_N\}, \forall m \in \mathscr{M}, \\ & \mathscr{P}_n = \bigcup \{m_i | d_{m_i} = c_n, m_i \in \mathscr{M}\}. \end{aligned} \quad (11)$$

Note that, as defined in the previous section, $\mathscr{P}_n$ indicates the set of SUs who choose to sense primary channel n.

B. The Existence of Optimal Solution

Property 1 : In a CRN with N PUs and M SUs, the number of solutions is limited and enumerable.

Proof: As a direct interpretation of equation (11), the number of solutions is the number of SUs' choice combinations, which equals M^{N+1}. Thus the number of solutions is limited and enumerable.

Property 2 : The utility is bounded both below and above.

Proof: As shown in equations (6), $0 \leq C(n) < \infty$, $0 \leq P_0(n) \leq 1$ and $0 \leq [1 - P_f(n, \mathscr{P}_n)] \leq 1$, so the expected channel resource is bounded above, i.e. $\exists B < \infty$, $0 \leq R(n, \mathscr{P}_n) < B$.

Further more, as shown in equations (7), as $0 < \phi_s(m, n) < \infty$, so $0 < E(m, n) < \infty$.

Thus, for each solution $\mathscr{S}$, $0 \leq U(\mathscr{S}) < \infty$

Property 3 : The CSS problem of equation (11) has optimal solution(s).

Proof: As the utility is bounded both below and above and the solution set is enumerable, we have the optimal solution(s) for such CSS problem as equation (11). We may enumerate all the possible SUs' choice combinations to find out the CSS with the maximum utility.

IV. HEURISTIC APPROACH FOR CSS

Although the solution set is enumerable and we may find out the optimal solution(s) by exhaustive method. However, this means that we have to find out the M^{N+1} solutions and calculate the utility for each of them, which consumes considerable time and energy. Here we propose two heuristic algorithms to solve this problem. As shown in the simulation section, they are time efficient to reach satisfactory suboptimal solutions.

A. Centralized Algorithm

We construct a coalition formation algorithm based on centralized coordinator and it is divided into two phases: information collection, and cooperative sensing scheduling. In *Centralized Game Algorithm*, BS acts as the CSS coordinator. In information collection phrase, it is responsible to collect channel status from PUs and sensing reports from SUs. In cooperative sensing scheduling, BS first assigns each SUs a random choice from choice set $\mathscr{C}$, thus a solution $\mathscr{S}_{ini}$ is initialized. Then it adjusts each SU's choice from its current choice $d_m (m \in \mathscr{M})$ to other possible ones $d'_m \in \mathscr{C} \backslash d_m (m \in \mathscr{M})$, forming other solutions $\mathscr{T} = \{\mathscr{S}_1, ..., \mathscr{S}_{MN}\}$. Then BS chooses the solution $\mathscr{S}_{max} \in \mathscr{T}$ which best improves the utility compared to the current solutions $\mathscr{S}_{cur}$, and replaces the current solution with $\mathscr{S}_{max}$. In this way, an iteration happens until the solution is not changed after another round of iteration, i.e., $\mathscr{S}_{max} = \mathscr{S}_{cur}$.

It is possible that in a certain solution $\mathscr{S}_{cur}$, some of the coalitions fail to meet the corresponding PU's detection probability requirement and their utility are set to zero. Even worse, no matter which SU is added into this coalition, some of them still fail the admission requirement, so there will be no improvement in utility. To encourage the SUs to actively participate in sensing, when there is no adjustment with positive improvement to utility, BS would add one of the idle SUs to a certain sensing coalition, as long as such change would not decrease the utility.

The end of iteration means that no matter adjust which one of the SUs, the utility will not be improved or no SUs can join in sensing coalition without decreasing the utility.

In the *Centralized Algorithm*, each adjustment ensures the non-negative improvement to the utility, and eventually reach an optimal or suboptimal solution, depending on the initialization situation. This algorithm is promised to converge as there is always at least an optimal solution as discussed in the previous section.

B. Revised Initialization

In the *Centralized Algorithm*, the initialized solution is random and to a large degree determines the optimality of the result. To deal with this problem, we also propose a way to improve the initialization for a better result.

In the initialization process, BS ignores PUs' detection probability constraints and, for each SU, calculates the utility when there is only this SU to sense one of the primary channels, with other SUs idle. Then this SU will be assigned to sense the PU with the maximum utility, i.e.

$$\begin{aligned} q &= \arg\max_n \frac{\alpha(n)[1 - P_f(m, n)]}{\phi_s(m, n)} \\ d_m &= c_q, \forall m \in \mathscr{M} \end{aligned} \qquad (12)$$

The revised initialization process helps to get a better suboptimal solution, which will be discussed in the simulation section.

Algorithm 1 summarizes the proposed *Centralized Algorithm* together with the *Centralized Algorithm with Revised Initialization*.

C. Multi-oligarch Algorithm

In the *Centralized Algorithm*, one BS acts as the CSS coordinator and has ultimate power of CSS assignment. It can change each SU's choice to any other one in choice set $\mathscr{C}$. We now consider a *Multi-oligarch Algorithm* in which several BSs work on behalf of the PUs, and one BS represents one PU in CSS. Each BS is endowed of the power to kick out some of the SUs who are intended to sense the primary channel it represents or to offer this opportunity to the idle SUs. In other words, BSs choose the SUs without robbing SUs from other BSs. Same as *Centralized Algorithm*, the standard for all BSs' choices is to maximize the global utility, so each BSs need global information. In this game, BSs may act as a information collectors and distributors to other BSs, but no longer holds the ultimate assignment power.

Multi-oligarch Algorithm is divided into two phases: information collection and distribution, and cooperative sensing

Algorithm 1 Centralized Algorithm

```
Require:
    PUs' parameters: $N$, $P_0(n)$, $C(n)$ ;
    SUs' parameters: $M$, $P_f(m,n)$, $P_d(m,n)$, $\phi_s(m,n)$ ;
Initialization:
if Random Initialization then
    for all $m \in \mathscr{M}$ do
        $d_m \leftarrow random\{c_0, c_1, ..., c_N\}$;
    end for
end if
if Revised Initialization then
    for all $m \in \mathscr{M}$ do
        $q \leftarrow \arg\max_n \frac{\alpha(n)[1-P_f(m,n)]}{\phi_s(m,n)}$; $d_m \leftarrow c_q$;
    end for
end if
$\mathscr{S}_{cur} \leftarrow \mathscr{S}_{ini}$; $Utility \leftarrow U(\mathscr{S}_{cur})$; $Improve \leftarrow 0$;
Iteration:
while $\mathscr{S}_{cur} \neq \mathscr{S}_{bef}$ do
    $\mathscr{S}_{bef} \leftarrow \mathscr{S}_{cur}$
    Find the adjust $d_m \leftarrow c_n$ with maximum improvement to Utility
    $Improve = U(\mathscr{S}_{cur} \setminus d_m \cup \{d_m | d_m = c_n\}) - Utility$
    if $Improve > 0$ or ($Improve = 0$ and $n^* \neq 0$) then
        $d_m \leftarrow c_n$,$d_m \in \mathscr{S}_{cur}$ ;
        $Utility \leftarrow Utility + Improve$;
    end if
end while
Output:
    CSS $\mathscr{S}_{cur}$;
```

Algorithm 2 Multi-oligarch Algorithm

```
Require:
    Same as Require part in Algorithm 1.
Initialization:
    Same as Initialization part in Algorithm 1.
Iteration:
while $\mathscr{S}_{cur} \neq \mathscr{S}_{bef}$ do
    $\mathscr{S}_{bef} \leftarrow \mathscr{S}_{cur}$;
    $\mathscr{O} \leftarrow [n_{i_1}, ..., n_{i_k}, ..., n_{i_N}]$ = random order of $\mathscr{N}$;
    for $k = 0$; $k \leq N$; $k \leftarrow k+1$ do
        $n \leftarrow n_{i_k} \in \mathscr{O}$ ;
        Find the adjust $d_m \leftarrow c_{n^*} = \begin{cases} c_0 & \text{if } d_m = c_n \\ c_n & \text{if } d_m = c_0 \\ d_m & \text{otherwise} \end{cases}$
        with maximum improvement to utility
        $Improve = U(\mathscr{S}_{cur} \setminus d_m \cup \{d_m | d_m = c_{n^*}\}) - Utility$
        if $Improve > 0$ or ($Improve = 0$ and $n^* \neq 0$) then
            $d_m \leftarrow c_n$,$d_m \in \mathscr{S}_{cur}$ ;
            $Utility \leftarrow Utility + Improve$;
        end if
    end for
end while
Output:
    CSS $\mathscr{S}_{cur}$;
```

scheduling. In information collection phrase, BSs collect channel status from PUs and sensing reports from SUs, and distributes them to other BSs. In cooperative sensing scheduling, BSs work one by one, in a random order, to adjust one SU's choice. However, each BS is only allowed to kick out one of the SUs intended to sense the corresponding primary channel, or to offer this opportunity to other idle SUs. In a round of iteration, each one of the BSs, in a random order, is able to adjust the CSS. In this way, an iteration happens until the CSS remains the same after another round of iteration, which means for all the BSs, no matter how they adjust any one of the SUs within their assignment power, the utility will not be improved or no SUs can join in sensing coalition without decreasing the utility.

Note that the *Revised Initialization* method still works in *Multi-oligarch Algorithm.*

Algorithm 2 summarizes the proposed *Multi-oligarch Algorithm* together with the *Multi-oligarch Algorithm with Revised Initialization.*

V. SIMULATION RESULTS AND ANALYSIS

In simulation, we assume that the difference of distance between PUs and different SUs is the major reason to cause SUs' sensing performance differs with various PUs, although in other specific situations, SUs' sensing performance can also be determined by other factors.

For simulations, we consider a CRN with 2 PUs and 13 SUs. PU_1 and PU_2 are located at (25, 25) and (75, 75) respectively, and the SUs are located randomly on a square centering on (50, 50) with side length D = 100m.

Denote ϵ as the detection threshold, σ_u^2 the variance of white gaussian noise with zero mean, γ the received signal-to-noise ratio (SNR) of PU's signal measured at SU, τ sensing duration and f_s SU's sensing sampling rate, then each SU m's sensing performance for primary channel n is given by [3]

$$\begin{aligned} P_d(m,n) &= Q((\frac{\epsilon}{\sigma_u^2} - \gamma - 1)\sqrt{\frac{\tau f_S}{2\gamma+1}}), \\ P_f(m,n) &= Q((\frac{\epsilon}{\sigma_u^2} - 1)\sqrt{\tau f_S}), \end{aligned} \tag{13}$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp(-\frac{t^2}{2}) dt \tag{14}$$

is the complementary distribution function of the standard Gaussian. And SNR γ is given by $\gamma = \frac{\sigma_s^2}{d^2 \sigma_u^2}$, where d denotes the distance between SU and PU and σ_s^2 the transmission power of PU.

For each primary channels, we set the the transmission power of PU_1 as $\sigma_s^2(PU_1) = 10mW$ and that for PU_2 $\sigma_s^2(PU_2) = 20mW$, the idle probability of PU1 $P_0(PU_1) = 0.5$ and that for PU_2 $P_0(PU_2) = 0.8$, the capacity of Primary

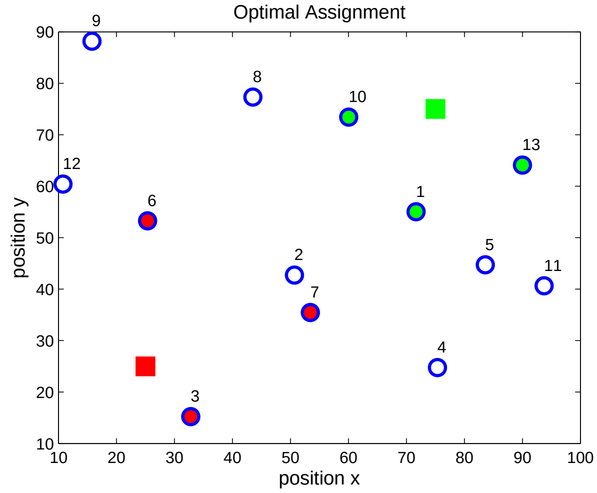

Fig. 1. Topology

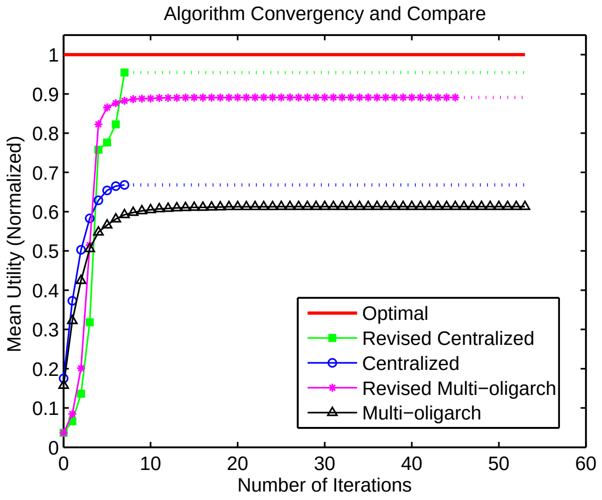

Fig. 2. Simulation Results

channel 1 $C(PU_1) = 100$ and channel 2 $C(PU_2) = 200$, the power of gaussian white noise $\sigma_u^2 = 5.5mW$, and the detection probability constraint is $\lambda_1 = 0.9$ and $\lambda_2 = 0.95$ for PU_1 and PU_2 respectively. For each SU, we set the sensing energy consumption $\phi_s(m, n)$ is a random number distributed uniformly in (5,10) mW, detection threshold $\epsilon = \sigma_s^2/2 + \sigma_u^2$, sensing duration $\tau = 0.005sec$, sensing sampling rate $f_s = 1MHz$.

Figure 1 shows the topology of the CRN in simulation and the optimal CSS. The red and green squares represent PU_1 and PU_2 respectively, and the blue-edged circles are SUs. The solid circles painted red represents the members of sensing coalition assigned to sense PU_1 and those painted green PU_2. Intuitively in this simulation case, the SUs chosen to sense are normally assigned to the nearest PU, although sensing power and PUs' channel condition would affect the results as well.

In figure 2 we show the average utility in each round of iteration of 500 times of simulations. Note that for those iteration rounds after convergency, we assume that the utility remains the same as the converged utility, i.e., the maximum utility in the same simulation. Also, as the the initialization and iteration part of *Centralized Algorithm with Revised Initialization* is fixed, the simulation result of this algorithm is one time of simulation. The dotted line after each curve represents the converged iteration rounds in all of these simulations, thus the point at which the simulation curve shifts to dotted line represents the maximum iteration number of rounds to reach convergency in all of the simulation for each algorithm.

As shown in figure 2, all these algorithm achieved more than 60% of the optimal utility on average. In terms of effectiveness, *Centralized Algorithm* performances better than *Multi-oligarch Algorithm* as the ultimate BS has more flexibility to adjust CSS. Also, we find out that the revised initialization process helps to achieve a better converged utility: in *Centralized Algorithm*, simulation with *Revised Initialization* achieves 27.8% more of the optimal utility than that with *Random Initialization*; in *Multi-oligarch Algorithm*, simulation with *Revised Initialization* achieves 25.7% more of the optimal utility than that with *Random Initialization*.

In terms of efficiency, we find out that it takes both 7 iteration rounds at most for *Centralized Algorithm with/without Revised Initialization* to converge. Although with *Revised Initialization*, *Multi-oligarch Algorithm* performs slightly better with maximum iteration number of 35, however, *Multi-oligarch Algorithm without Revised Initialization* needs more than 50 times of iteration rounds at the worst case to achieve convergency.

VI. CONCLUSION

In this paper, we study the CSS problem in CRN under a practical scenario where both PUs and SUs are heterogenous. Both the sensing performance and energy consumption are taken into account in our system model. We formulate the energy-efficient CSS problem as a non-linear programming problem, whose optimal solution exist but is difficult to achieve. Two heuristic algorithms, i.e., *Centralized Algorithm* and *Multi-oligarch Algorithm*, are proposed to obtain sub-optimal solutions. Besides, a *Revised Initialization* algorithm is also introduced to improve the performance of these two algorithm. In *Centralized Algorithm*, a BS holds the ultimate CSS assignment power while in *Multi-oligarch Algorithm*, negotiations among BSs determine CSS. Simulation results shows that *Centralized Algorithm* is more efficient and effective than *Multi-oligarch Algorithm*, in that BSs needs time to negotiate with each other in the latter algorithm, and negotiation among BSs is less flexible than CSS by an ultimate BS. Besides, *Revised Initialization* helps both algorithms to achieve better results in terms of efficiency and effectiveness.

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