Multi Objective Optimization of Expense and Revenue in a Cognitive Radio Network Using NSGA-II

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Abstract. In this paper we consider an auction framework of cognitive radio network comprises of primary and secondary users (SU). The spectrum is divided into channels using frequency division multiple access (FDMA). Primary users have license to use the channels. When the channels are idle, primary users lease the vacant spectrum for monetary gain. Cognitive users or SUs bid for the channels. The purchaser who provides highest bid value is selected by primary user. Our objective is to maximize the revenue earned by primary users and to minimize the expense given by the secondary users. The problem is bi-objective and both the objectives are conflicting. Using Non dominated sorting genetic algorithm II; we solve both the objectives of primary and secondary users. The algorithm solves the problem well and find optimize values of both expense and revenue.

1 Introduction

In the last few decades there is an exponential growth of wireless devices. Now, the key focus of wireless service providers is to increase the efficiency of use of available spectrum (band). The recent trend of explorations is on the cognitive use of radio spectrum which is popularly known in literature as cognitive radio. In the CR context, there are two types of users namely licensed users (primary users) and unlicensed users (also known as cognitive users or secondary users). In this context of CR, by leasing the channels to secondary users, primary users will get incentives in the form of rebate which can be considered as revenue for primary users and this revenue of primary users is directly correlated to the expenses incurred by secondary users for the usage of licensed bands allocated to primary users. So, the allocation problem is here to strike a balance between revenue of primary users and expenses of secondary users. Considering primary users and secondary users are selfish entities. The above mentioned objective of the allocation problem is conflicting in nature. In this paper we focused on formulating the problem as an optimization problem and solve it by using NSGA-II.

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To the best of our knowledge and as revealed by our literature survey that till date there is no effort made by researchers to view this allocation problem as a conflicting multi objective problem to solve it. However, here we present some of the works related to this domain. In [1] authors propose rules for secondary users to use idle spectrum band but have to ensure that interference is within the threshold limit. In [2], secondary user's spectrum access pattern is followed and a suitable spectrum sharing scheme is proposed. Auction strategy brings a good approach of spectrum sharing, if we consider the economic aspect [3],[4].

Among the various evolutionary algorithms, the NSGA II and SPEA2 are the most popular algorithms. Non dominated sorting Genetic Algorithm (NSGA-II) is a particular evolutionary algorithm that has been used for multi objective optimization.

The rest of the paper is organized as follows. In section 2, construction of objective function for channel allocation is discussed. In section 3, we have introduced the solution of the problem by using NSGA-II. In section 4, experiments and results are discussed. We conclude the paper in section 5.

2 System Model

In this paper we consider multi cell cognitive radio network in which there are multiple primary and secondary users. Numbers of channels for each cell is equal to M. When the channels are vacant, primary users apply marketing strategy for auctioning the channels. Secondary users provide bids for channels. The auctioneer selects the purchaser who provides highest bid value.. The main objective is to make both purchaser and the seller benefitted.

Let, rev be an N X K channel assignment matrix where rev (PU,ch)= rev_{PU}^{ch} = r, if PU earns revenue r for channel ch. 0,if that channel is not assigned to PU. We can formulate the optimization problem of maximizing the revenue earned by all primary users in the system. The optimization problem is of the form:

$$arg\ max \sum_{PU=1}^{N} \sum_{ch=1}^{K} rev_{PU}^{ch} \tag{1}$$

Subject to the conditions that 1. Each primary user requires at most one channel .2. Each channel cannot be used by more than one primary user. The conditions are as follows:

$$c_{\min} \leq \sum_{ch=1}^{K} rev_{PU}^{ch} < c_{\max} \tag{2}$$

$$c_{\min} \leq \sum_{PU=1}^{N} rev_{PU}^{ch} < c_{\max} \tag{3}$$

Here, $c_{\min}$ is equal to the minimum revenue of a channel that a primary user earns and $c_{\max}$ is the maximum revenue of a channel earned by primary user.

The resultant constrained optimization problem is Max z1=

$$\sum_{PU=1}^{N}\sum_{ch=1}^{K} rev_{PU}^{ch} + \lambda_1(\mathrm{c}_{\max} - \sum_{ch=1}^{K} rev_{PU}^{ch}) + \lambda_2(\mathbf{c}_{\max} - \sum_{PU=1}^{N} rev_{PU}^{ch}) \quad (4)$$

$\lambda 1$, λ_2 are Lagrange coefficients. Whose values vary from +30 to -30.Equation (4) is our first objective function. Now, if expense be an M X K channel assignment matrix where expense (SU,ch)= expense_{SU}^{ch} = e, if SU has expense value e for purchasing channel ch. 0, if that SU will not purchase the channel ch. We can formulate the optimization problem of minimizing the expense provided by all secondary users in the system. The optimization problem is of the form:

$$\arg\min \sum_{SU=1}^{M}\sum_{ch=1}^{K} \exp ense_{SU}^{ch} \quad (5)$$

Subject to the condition that total amount of bid provided by a single secondary user should not exceed a threshold value (b_{max})

$$0 \leq \sum_{ch=1}^{K} \exp ense_{SU}^{ch} \leq b_{\max} \quad (6)$$

The resultant constrained optimization problem is Min z2=

$$\sum_{SU=1}^{M}\sum_{ch=1}^{K} \exp ense_{SU}^{ch} - \lambda_3(b_{\max} - \sum_{ch=1}^{K} \exp ense_{SU}^{ch}) \quad (7)$$

Where, $\lambda 3$ is Lagrange coefficient. Equation (7) depicts our second objective function.

3 Solving the Problem Using NSGA-II

We firstly describe NSGA-II and then outline the pseudo code for the proposed system.

3.1 Non Dominated Sorting Genetic Algorithm

A Pareto optimal solution set is to be determined for solving multi objective optimization problem [5]. Deb et. al. proposed an evolutionary algorithm which is well known as non dominated sorting GA-II (NSGA-II). NSGA-II is very simple and it has better spread of solutions and better convergence near the Pareto optimal front.

Pseudo code

Input: Initial Revenue matrix and expense matrix. **Output**: Optimum value of revenue and expense for all users and for all channels.

Begin

Set: rev_i^c ←real number, $expense_j^c$ ←real number ,$demand_c$ ← real number ;

Repeat

Call NSGA-II (rev_i^c, $expense_j^c$, $demand_c$, mutprob, crprob, Gener, MAXGENER);
Move-to (rev_i^c, $expense_j^c$);
Until Gener<=MAXGener
End.
Procedure NSGA-II (rev_i^c, $expense_j^c$, $demand_c$, mutprob, crprob, Gener, MAXGENER)
Begin
Initialize a random parent population of size N;
Sort initial population based on the non-domination.
For
K< MAXGENER do
Begin
Create child population (Q_t) using following three
operations: 1) Binary tournament selection, 2)
recombination, and 3) mutation;
Combine parent and child population to form
merged population i.e. $R_t = P_t \cup Q_t$
Construct all non dominated Front sets
($F_1, F_2, \ldots\ldots$);
Set: $P_{t+1} = \emptyset$; i=0
Repeat
$P_{t+1} = P_{t+1} \cup F_i$;
i=i+1;
Until $|P_{t+1}|+|F_i| \leq N$
End.
Calculate crowding distance in F_i ;
Based on the crowding distance sort F_i in descending order;
$P_{t+1} = P_{t+1} \cup$ First ($N-|P_{t+1}|$) elements of F_i ;
End.
End For
End.
Update
1. $Expense_j^c$
2. $Demand_c$ using equation (7)
3. rev_i^c
Return
End

4 Result and Discussion

The revenue and expense matrices are initialized randomly. After the convergence of NSGA-II, the best chromosome is obtained from the Pareto front. To select the best chromosome in the Pareto front we propose a metric. This metric is the ratio of normalized value of revenue and normalized value of expense. Let, $f1_i$ (.) and $f2_i$ (.)

are the measures of revenue and expense for i^{th} chromosome and $f1_i^*(.)$ and $f2_i^*(.)$ are the normalized values of revenue and expense. The normalized values can be defined as

$$f1_i^*(.) = \frac{f1_i}{\sum_{i=1}^{n} f1_i} \quad \text{and} \quad f2_i^*(.) = \frac{f2_i}{\sum_{i=1}^{n} f2_i}$$

The above equation is repeated for all chromosomes in the Pareto front. Next the ratio of normalized value of revenue and normalized value of expense is calculated for all chromosomes in the Pareto front. This new measure is defined as

$$P_i^*(.) = \frac{f1_i^*}{f2_i^*} \text{..........(8)}$$

The effective chromosome $chrom_j$ for j=1 to popsize, is the one which has largest $P_j^*(.)$ value. Figure 1 shows the variation of objective functions with iteration. We vary the number of iteration from 50 to 200.We observe that the first objective function f1 increases as iteration increases and the second objective function f2 decreases as iteration increases. It is seen from the graph that at point z, f1 and f2 intersect each other. At this point f1=f2. At this point revenue earned by primary users=expense paid by secondary users. This point z is termed as ‘zero point’. Pareto optimal fronts in the spectrum auction problem are shown in Fig.2 for different generations. The effective solutions on each Pareto front have been marked in figure 2 . The effective solutions indicate the chromosome with maximum normalized ratio of revenue and expense value as expressed in equation (8).

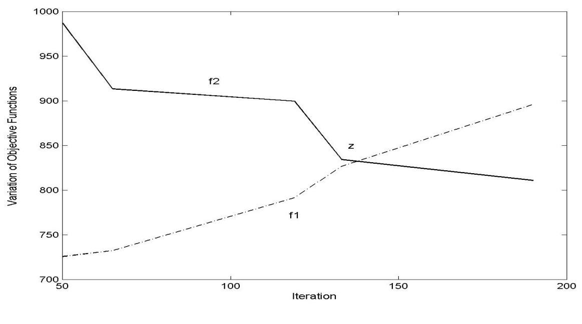

Fig. 1. Variation of objective Functions with Iteration

Table 1. Comparison of our present and previous work

Method Used	Revenue Earned
Simple Greedy Method	887.28
Our Approach using NSGA-II	896.1892

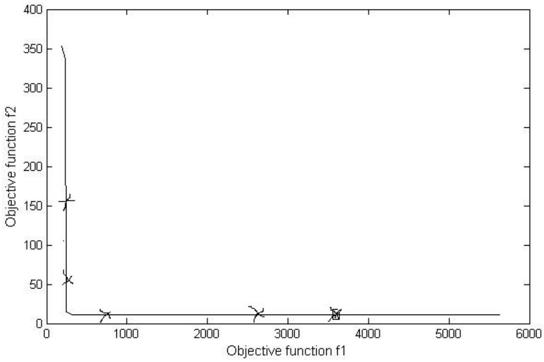

Fig. 2. Non Dominated Solutions for generation up to 75

5 Conclusions

In this paper, we consider a cognitive radio network where primary users perform auction to sell the vacant spectrum to the secondary users. Our objectives are to maximize the revenue earned by primary users and minimize the expense paid by secondary users. We use NSGA-II to optimize the problem. The results are compared with previously used Simple Greedy Method and our approach provides better results.

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