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Channel Allocation for a Single Cell Cognitive Radio Network Using Genetic Algorithm

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***Abstract*—We have considered a cognitive radio network in which there is a single cell and a Base Station (BS) within that cell. Our objective is to maximize the channel allocation of the active subscribers within that network. Genetic Algorithm (GA) has been used to solve the allocation problem. Power control has not been considered here. Our approach channel allocation using GA (CAGA) yields better result with respect to percentage of customer premise equipment (CPEs) covered than previously reported Dynamic Interference Graph (DIGA) allocation and Minimum Incremental power allocation method (MIPA).**

Keywords- Genetic Algorithm, channel allocation, Customer premise equipment.

I. INTRODUCTION

As reported by the FCC, with recent rapid increases of wireless devices there is a radio spectrum scarcity [3]. To solve this problem, unlicensed spectrum users are allowed to use the idle licensed spectrum, and interference to the licensed users caused due to the transmission of unlicensed users should not exceed acceptable limit. This is termed as *dynamic spectrum access,* and cognitive radio techniques are used to implement it [1]. Cognitive radio (CR) is an autonomous unit in a communication environment that senses the environment and changes its operating parameters to achieve the requirements [4]. Wireless networks operate over contiguous bands [5]. But, cognitive radio network (CRN) works over a set of non-contiguous frequency bands. In CRN cognitive users must operate with low transmission power, so that Primary users (PU's) communication remains uninterrupted [6]. So, there are many challenges in designing CRN. In [7], a power control technique was proposed to maximize the total capacity of a CRN while each cognitive user may contract or expand its bandwidth. Two important design criteria for CRN are to maximize spectrum utilization and minimize interference to the licensed users [1]. Different channel assignment techniques have been proposed in the recent past. In [8], component based channel assignment technique has been proposed, and this approach has several advantages over other strategies. The main disadvantage of flow based channel assignment strategy in CR network is that all the secondary nodes within a flow must not access the same channels. Existing strategies mostly follow link-based approaches [9]. In this paper, we implement a channel assignment scheme, following [1] by using Genetic Algorithm instead of mixed integer linear programming (MILP). We compare our scheme channel assignment using GA (CAGA) with the previously reported schemes like dynamic interference graph allocation (DIGA) and minimum incremental power allocation (MIPA). Here, power management is not considered. Only channel allocation problem in a single cell cognitive radio network with a single base station (BS) is considered. We consider here that in a cognitive radio network, each customer premise equipment (CPE) is either active or idle [1]. For a single cell network there is a single BS, a number of primary users (PU) and CPEs. Our objective is to Maximize the number of active CPEs, subject to the constraints that: 1. the amount of interference caused by secondary users' transmissions to each PU must not exceed a threshold value, and 2.signal to interference plus noise ratio (SINR) for each active CPE should exceed a threshold [1]. For small spaces, classical exhaustive methods are usually sufficient; for larger spaces artificial intelligence techniques such as GA is used [2]. GA has been quite successful optimization technique that can solve different optimization problems like scheduling, cognitive modeling, transportation problem, traveling salesman problem etc [2]. The first approach to CR control uses GA [10]. In this problem, we vary the activation probability depending on the number of PUs in the network and, by varying the probability the channel assignment can be changed. Our work results in higher number of CPEs covered than other schemes like DIGA and MIPA.

The rest of the paper is organized as follows. In section II, construction of objective function for channel allocation is discussed. In section III, we have introduced the solution of the problem by using GA. In section IV, experiments and

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results are discussed. Section V depicts the relative merits of this scheme over reported results. We conclude the paper in section VI.

II. CONSTRUCTION OF OBJECTIVE FUNCTION FOR CHANNEL ALLOCATION

In [1] ,if A be an N X K channel assignment matrix where A(i,c)= a_i^c *= 1,if channel c is assigned to CPE i 0,otherwise. We can formulate the optimization problem of maximizing the number of CPEs served as in the form:*

$$\arg\max \sum_{c=1}^{K}\sum_{i=1}^{N} a_i^c$$

Subject to the conditions that 1. Each CPE requires at most one channel .2. Each BS can serve at most one CPE on each channel. 3. For unassigned channels BS does not emit power. 4. For each PU, the tolerable interference should not exceed predefined threshold value. 5. SINR value for each CPE should exceed threshold. The conditions are as follows:

$$\sum_{c=1}^{K} a_i^c \le 1 \quad (2)$$

$$\sum_{i\in\sigma b} a_i^c \le 1 \quad (3)$$

$$\sum_{i=1}^{N} p_i^c G_{pi}^c \le \xi \quad (4)$$

$$\gamma_i^c >= \check{Y} \quad (5)$$

Where, $\gamma_i^c = G_{ii} P_i^c / (N_0 + I_i^c + \sum^{N}_{j=1,j!=i} G_{ij}{}^c P_j^c)$ is the SINR experienced by each CPE. Where, N_0 = noise power spectrum density of each CPE. I_i^c is the total interference caused by all primary transmissions on channel c. $G_{ij}{}^c$ = channel power gain from the BS serving CPE j to CPE I in channel c. P_j^c = Transmit power from BS serving CPE j toward CPE j on channel c. $\check{Y}$ = SINR threshold value. ξ = threshold value for interference to PU. σ b is the set of all CPEs that are associated with BS b. We have first multiplied λ1 with the condition in equation (2). When $\sum \mathbf{a_i^c} \le 1$, then $(1-\sum \mathbf{a_i^c})$ is always positive or zero. So, we have multiplied the term $(1-\sum \mathbf{a_i^c})$ with λ_1 and add it with the objective function z. For the condition in (3), if this condition violates then $(1-\sum \mathbf{a_i^c})$ is negative, so we have similarly get the third term as the second term. Similarly, $\sum P_i^c G_{pi}^c$ is less than ξ. So, when this condition is satisfied it will maximize z. We get the fifth term in similar way. So, the resultant constrained optimization problem is

$$z=\max \sum\sum a_i^c + \boldsymbol{\lambda}_1(1-\sum a_i^c) + \lambda_2(1-\sum \mathbf{a_i^c}) + \boldsymbol{\lambda}_3(\xi - \sum P_i^c G_{pi}^c) + \lambda_4(\gamma_i^c - \check{Y}) .$$

Where, $\boldsymbol{\lambda}_1$, λ_2, $\boldsymbol{\lambda}_3$ and λ_4 are the Lagrange's coefficients. The method of Lagrange multipliers provides a strategy for finding maximum, minimum of a function. λ may be either added or subtracted**.** If (x,y) is maximum for the original constrained problem , then there exists a **λ** such that (x,y, **λ**) is a stationary point for the Lagrange function . λ_1, λ_2, λ_4 ranges from 0 to +30, $\boldsymbol{\lambda}_3$ ranges from -30 to 0.

III. SOLVING THE ALLOCATION PROBLEM BY GA

Algorithm of GA :

STEP 1: initialize (population)
Fitness value=fitness function (objective function)
STEP 2: Loop (until max generation)
STEP 3: Construct roulette wheel for selection.
For i=1 to no_chromosome
Find cumulative probabilities q_i.
If (q_i > random number)
Select i[th] chromosome.
Endif
Endfor
STEP 4: single point crossover
STEP 5: Mutation
STEP 6: Decode (chromosome) and
Fitness value=fitness function (objective function)
STEP 7: End of Loop
STEP 8: END

System Parameters for GA

Initial Population size POPSIZE=30
Probability of Crossover=0.25
Probability of Mutation=0.078
Number of Generations=30

We use classical binary GA. We would talk about individuals (or genotypes, structures) in a population; quite often these individuals are called also strings or chromosomes. The structure of a chromosome in our system is as follows:

gene[100]
gaintopu[no_pu]
powertoCPE[no_cpe]
gaintocpe[no_cpe]
fitness
rfitness
cfitness
survivor
lower
upper
ac_prob
Lambda1
Lambda2
Lambda3
Lambda4

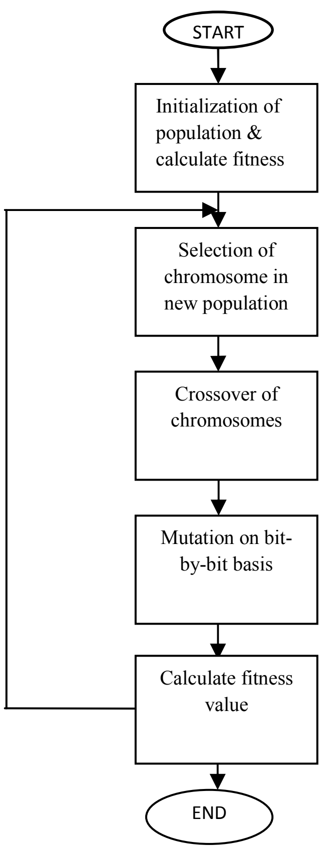

Fig. 1. Flowchart for GA

Where, gene[100] contains 1/0 depending on the allocation of channels. Here, number of CPEs are=10, Number of channels are=10. When a channel is allocated to a CPE then the corresponding bit is 1 otherwise it is 0.

$$A(i,j)=\begin{pmatrix} 1&0&0&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0&0&0\\ 0&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&1&0&0&0&0&0\\ 0&0&0&0&0&1&0&0&0&0\\ 0&0&0&0&0&0&1&0&0&0\\ 0&0&0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&0&0&1 \end{pmatrix}$$

Gene[100] stores this allocation matrix in a row major form. The term ac_prob denotes the *activation probability*. *Activation probability* is the probability by which CPE may be active. Basically, each CPE may be active or idle. When a CPE is active it requires data transmission. Depending on the number of primary users we have varied the activation probability. When number of primary user is higher then activation probability is lower and vice versa. Figure 2 shows the variation of average fitness with the variation of λ. We have varied the values of λ in the range between -30 to +30. We have seen that when all λ's values are in the range 0 to 30, then fitness value is negative. As this is a maximization function we can't accept it. When all λ's values are in the range 0 to -30, we get fitness value as 32858.427512. But, when all λ's are positive, only λ_3 is negative then we get highest fit ness value. So, we have generated it randomly as λ_1 =0 to 30, λ_2 =0 to 30, λ_3 =0 to -30 and λ_4 =0 to 30. In figure 2, some points coincide, so we get only four points a, b, c, d. Table 1 depicts the variation of λ's with the fitness values.

TABLE I. VARIATION OF λ

λ_1	λ_2	λ_3	λ_4	Avg.Fitness
[-30,0]	[-30,0]	[-30,0]	[-30,0]	32858.427512
[0, 30]	[0,30]	[0,30]	[0,30]	-31751.213454
[0,30]	[0,30]	[-30,0]	[0, 30]	35002.300472

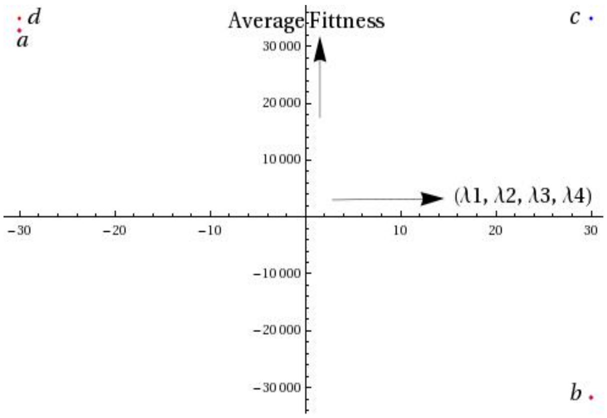

Fig. 2. Average Fitness vs. variation of λ

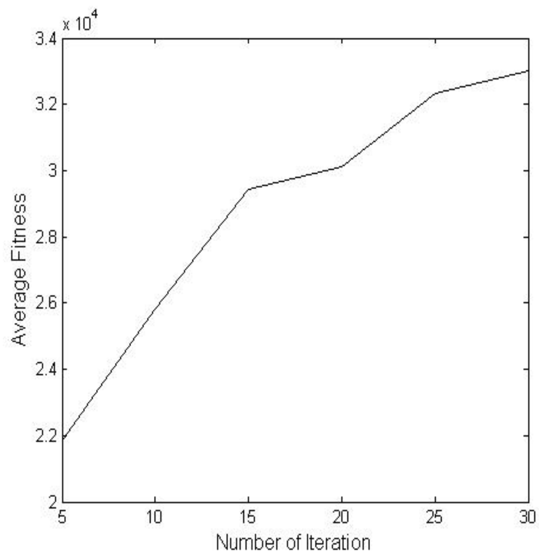

Fig. 3. Average Fitness vs Number of Iteration

Figure 3 shows the variation of average fitness with number of iteration. As the number of iterations increase from 5 to 30, the average fitness increases from 21850.239256 to 33010.289352

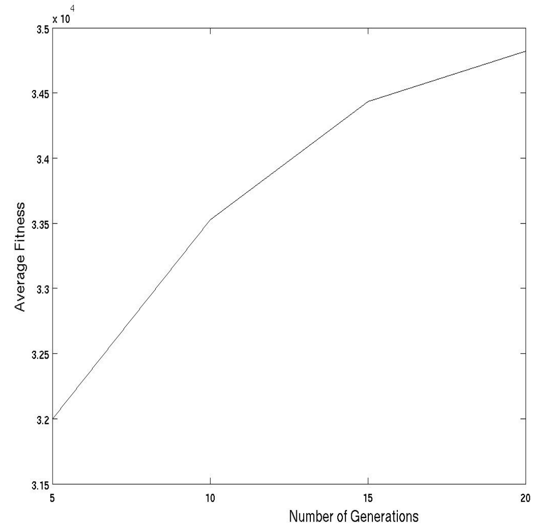

Fig. 4. Average Fitness vs Number of Generation

In figure 4, the variation of average fitness with the number of generations is shown. In our program we have taken 30 generations. Then by varying the generations from 5 to 30 , we get the results. With the progress of generations the average fitness increases.

System Architecture

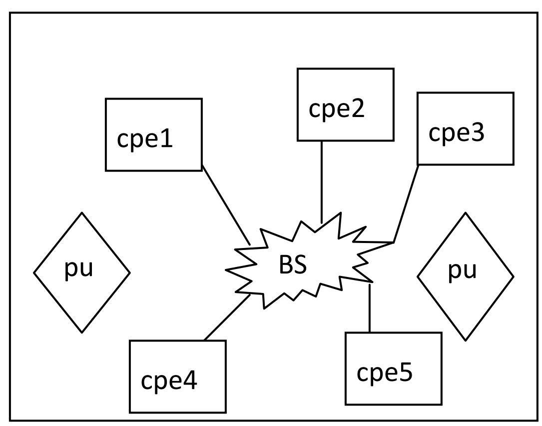

Fig. 5. Network Architecture

We consider a network scenario in which there are 10 channels in the spectrum. Figure 5 shows the network architecture. These channels are licensed to the licensed users or PU in the network. We vary the number of primary users from 5 to 25. In the same location there is a cognitive radio network which consists of exactly one cell. There is a single BS inside that cell and that BS serves 10 CPEs within that cell. By opportunistic channel access strategy, the CPEs make use of these 10 channels. Here, the channel usage pattern of the primary users is fixed and for that reason secondary users or cognitive users or CPEs access the channels without interference with the primary users. Figure 6 shows the variation of probability of mutation and probability of crossover with the percentage of CPEs covered. When probability of mutation (p_m) changes from 0.050 to 0.078, percentage of CPEs covered changes from 0% to 50%. We have assumed that when there is a violation of the constraint that each CPE should get exactly one channel, then percentage of CPEs covered is zero. But when probability of cross over (p_c) varies from .05 to 0.25, the percentage of CPEs covered remains constant(50%). Thus, we have selected p_m =0.078 and p_c =0.025.

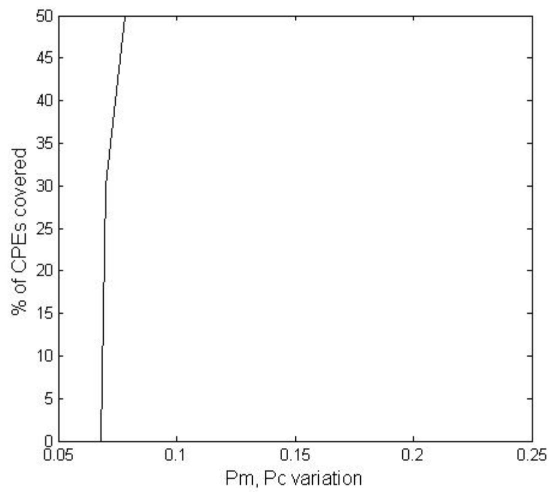

Fig. 6. % of CPEs covered with variation of pm

IV. EXPERIMENTS AND RESULTS

We consider a service area where there is a single cell and a single BS. Within this cell there are CPEs and primary users (PU). We vary PUs from 5 to 22 and as a result the activation probability (ac_prob) varies from 0.51 to 0.15.

Simulation Parameters and constants
Number of BS=1
Number of CPE=10
Number of Channel=10
Number of PU= changes from 5 to 22
Noise power spectrum density (N_0)= -100 dBm
Required SINR for each CPE (Ў) =15 dB.
Maximum tolerable interference for PU=-110 dBm

We assume that the channel usage pattern of Primary users' is fixed and when there is idle channel, then cognitive users use that.

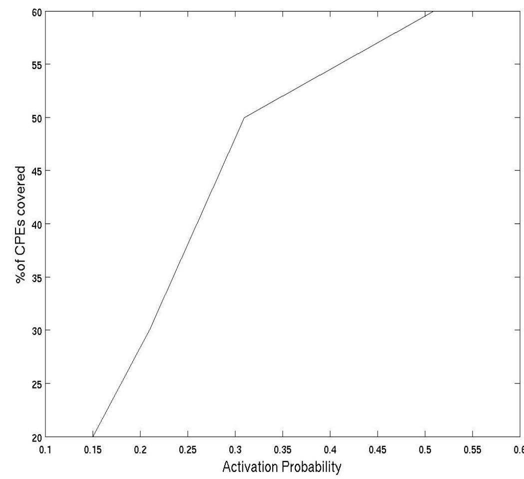

Fig. 7. % of CPEs covered with activation probability

Figure 7 shows the changes of % of CPEs covered with the changes of activation probability. We vary the activation probability from 0.15 to 0.51. As we increase the activation probability, the percentage of CPEs covered also increases. When probability of activation for each CPE increases from 0.15 to 0.51, the percentage of CPEs covered increases from 20% to 60%. It is seen from the graph that when activation probability changes from 0.31 to 0.51, then there is a slope change in the graph. This point is called saturation point (POS). POS means point of saturation. This point indicates that at that point, increase of the activation probability does not increase the percentage of CPEs covered in the same ratio as because of the limitations of number of primary users and availability of channels. Figure 8 shows the changes of percentage of CPEs covered with the changes of number of primary users. As we increase the number of primary users then the availability of channels decreases and as a result the percentage of CPEs covered also decreases. We change the number of primary users from 5 to 22 and observe that percentage of CPEs covered decreases from 60% to 20%.

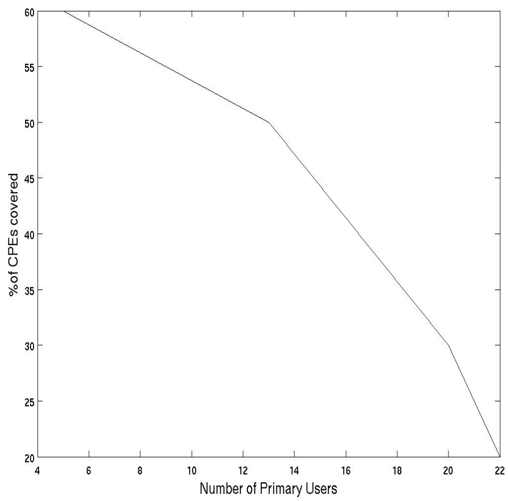

Fig. 8. % of CPEs covered with Primary users

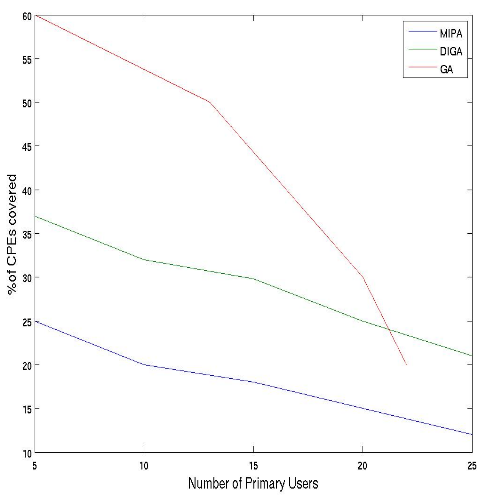

Fig. 9. Comparison showing changes of % of CPEs covered with number of primary users for DIGA,MIPA and GA

Figure9 shows the comparative study of percentage of CPEs covered with number of primary users for DIGA, MIPA and GA. It is seen from the graph that GA gives better coverage of CPEs than DIGA and MIPA. When number of primary users is 5, MIPA covers 25% of CPEs and DIGA covers 37%.GA gives 60% coverage of CPEs. But, the rate of fall of coverage is higher in case of GA than the other two schemes DIGA and MIPA. The slope of the curve for the graph of GA falls rapidly due to the changes of activation probability.

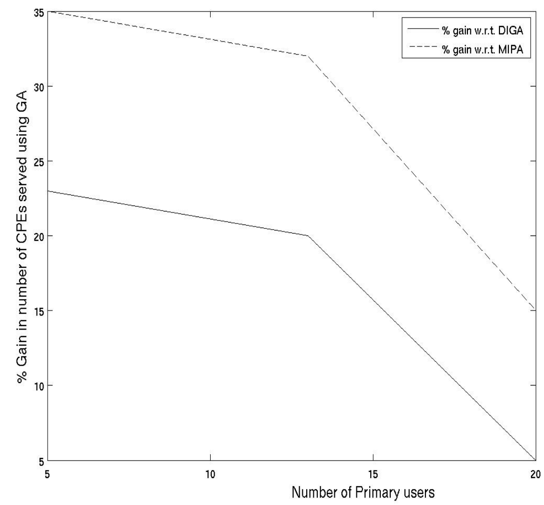

Fig. 10. % gain in number of CPEs served w.r.t .number of primary users

We change this probability with the changes of number of primary users. Figure 10 depicts the percentage gain in number of CPEs served w.r.t. DIGA and MIPA with number of primary users when GA is used. It shows that when number of PU is 5, percentage gain w.r.t. DIGA is 23 but percentage gain w.r.t. MIPA is 35. Then we increase the number of PU s and observe the variation.

V. RELATIVE MERIT OF THE SCHEME OVER THE REPORTED RESULT

In DIGA, mentioned in [1], the interference between pair of links between CPEs is considered. Two CPEs are connected by a link, if both of them cannot be supported on a single channel. Degree of each CPE is considered and the CPE with minimum degree has been assigned a channel. Degree of a CPE i is the number of CPEs that cannot be assigned a particular channel when that channel is assigned to CPE i. In [11], kulkerni et al. proposes MIPA. This scheme is same as DIGA, but degree calculation of each CPE is different. Our scheme (CAGA) produces better result than DIGA and MIPA. No consideration for power management is done here. Only channel allocation problem is considered. In our scheme each CPE is active depending on the number of primary users in the system. This activation probability decreases with the increase of number of primary users. Our scheme produces an elegant solution for this channel allocation problem by varying the number of primary users. As GA has very good performance in solving multi objective optimization problem by finding best chromosomes that has highest fitness value in each and every generation. We use it to solve this problem. We see that our solution depends on the mutation probability but it has no effect on the change of crossover probability.

VI. CONCLUSIONS

In this paper we consider a single cell cognitive radio network. There are CPEs which opportunistically use the number of available channels without any interference with the primary users. Our objective is to maximize the allocation of channels between these CPEs. We form a constrained optimization problem and solve that problem using GA. Our result gives higher coverage of CPEs than the previous schemes. Further, our work can be extended by considering the power management in this channel allocation concept.

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