A FAST CONSTRUCTIVE ALGORITHM FOR FIXED CHANNEL ASSIGNMENT PROBLEM

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ABSTRACT

With limited frequency spectrum and an increasing demand for mobile communication services, the problem of channel assignment becomes increasingly important. It has been shown that this problem is equivalent to the graph-coloring problem, which is an NP-hard problem [1]. In this work, a fast constructive algorithm is introduced to solve the problem. The objective of the algorithm is to obtain a conflict free channel assignment to cells which satisfies traffic demand requirements. The algorithm was tested on several benchmark problems, and conflict free results were obtained within one second. Moreover, the quality of solution obtained was always same or better than the other reported techniques.

1. INTRODUCTION

In recent years, there has been tremendous increase in the demand for cellular phones. This has enhanced the need for efficient use of frequency channels. This includes reuse of channels in different sites in such a way that there will be no conflict with Electromagnetic Compatibility Constraints (EMC), while fulfilling the traffic demand.

Generally there are three types of EMC constraints, namely 1) the co-channel constraint (CCC), where same channel cannot be assigned to certain pairs of radio cells simultaneously, 2) the adjacent channel constraint (ACC), where adjacent channels in the frequency domain cannot be assigned to adjacent cells simultaneously, and, 3) the co-site constraint (CSC), where channels in the same cells must be separated by certain distance in the frequency domain [2]. All these constraints can be combined in what is known as the compatibility matrix. In addition, the user demand is normally expressed with the help of a demand vector.

The channel assignment problem can be classified into two sub-categories i.e., 1) Fixed Channel Assignment (FCA), where channels are permanently allocated to each cell, and, 2) Dynamic Channel Assignment (DCA), where all channels, that are available for every cell, are allocated dynamically upon request. In normal situations DCA performs better than FCA, but under heavy load condition FCA outperforms DCA [3]. Since today mobile communication systems suffer from heavy loads, hence FCA was chosen for this research.

It has been shown that fixed channel assignment problem is equivalent to the graph-coloring problem [1], which is an NP-hard problem. Thus it is not possible to find an optimum solution by traditional numerical techniques (such as brute force algorithm). In [4], the author used Neural Networks to solve this problem. In [5], simulated annealing was used to cope with the NP-hard nature of the problem. In [6, 7, 8], genetic algorithm was used to solve this problem. All these techniques [9] suffer from heavy computation time since these are iterative in nature. In this work, a time efficient constructive algorithm is presented, which fulfills all EMCs and traffic demand requirements.

2. PROBLEM FORMULATION

The cellular radio network to be considered consists of n arbitrary cells. Without loss of generality, it is assumed that channels are evenly spaced in radio frequency spectrum. Using an appropriate mapping, channels can be represented by consecutive positive integers.

The frequency $f_m = f_l + \Delta f \cdot m$ can be mapped to integer m where f_l is the lowest frequency in the available radio frequency spectrum and Δf is the frequency spacing between two channels.

Using this mapping, the EMC constraints can be described by $n \times n$ symmetric matrix called compatibility matrix C, where:

1. each diagonal element c_{ii} represents the CSC, i.e., the minimum separation distance in frequency between any two channels at cell i,

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2. each non-diagonal element c_{ij} represents the minimum separation distance in frequency between any two frequencies assigned to cell i and cell j.

In the compatibility matrix, CCC is represented by $c_{ij} = 1$, ACC is represented by $c_{ij} = 2$, and cells that are free to use the same channel simultaneously are represented by $c_{ij} = 0$. In all cases $c_{ii} \geq 1$.

By analyzing the traffic at each cell, the traffic demand requirement can be obtained. This can be represented by an $n - element$ demand vector denoted as D. In this vector D, each element d_i represents the number of channels to be assigned to cell i.

An example of compatibility matrix C_1 and demand vector D_1 is shown below:

$$C_1 = \begin{pmatrix} 5 & 4 & 0 & 0 \\ 4 & 5 & 0 & 1 \\ 0 & 0 & 5 & 2 \\ 0 & 1 & 2 & 5 \end{pmatrix}$$

$$D_1^t = \begin{pmatrix} 1 & 1 & 1 & 3 \end{pmatrix}$$

Now the problem can be represented as: Given the compatibility matrix, demand matrix and number of available channels, it is required to assign these channels to the cells such that the demand will be achieved and the EMC constraints will be fulfilled, by using minimum possible frequency channels.

3. PROPOSED CONSTRUCTIVE ALGORITHM

The proposed Algorithm is shown in Figure 1. Below we discuss each step of the algorithm in detail.

Initial solution

If the number of cells in the problem is n, then the solution representation consists of n vectors. Each vector V_i represents one cell; the size of vector V_i is the channel demand d_i for the corresponding cell. The members of the vector V_i represent the mapped integer values of the frequency channels allotted to the corresponding cell.

Since this solution representation always fulfills the demand requirements. hence we can get rid of the extra computation to satisfy the demand requirements as in many previous works [2, 6, 7].

The initial solution is created randomly, only taking care of the number of minimum available channels (given), which can provide the solution with no conflict. Suppose that the number of minimum available channels is M, then members of V_i consists of integers from 0 to $M - 1$.

An example of solution representation for the problem, with $M = 11$ given in Section 2 is:

$$\begin{array}{lr} V_1^t & (0) \\ V_2^t & (5) \\ V_3^t & (7) \\ V_4^t & (2 \quad 4 \quad 10) \end{array}$$

It is clear from this example that this solution representation always fulfills the demand requirements.

```
Algorithm  Channel_Assignment(D_i, C_i)
Begin
  Create Initial Solution.

  Sort the cells with respect to demand.

  Do.

    Allocate frequencies to the top cell in the
    sorted list, with respect to the partial cost.

    Remove the cell from the list.

  While   the list is not empty.
End
```

Figure 1: Fast Constructive Algorithm for FCA.

Sorting

The next step in the algorithm is sorting of cells with respect to their respective demands. The cell with the highest demand value are put at the top of the sorted list and the cell with the lowest demand value are put at the bottom of the sorted list. Sorting is an important step in the algorithm as it decides to which cell channels are allocated first. The cells with higher demand values must have precedence over the cells with lower demand values.

Channel Allocation

After the sorting, the cell at the top of sorted list is picked and channels are allocated to it with certain strategy, that is as follows.

For each vector V_i, start with the channel 0 as the first member of V_i. Now, allocate channels with the increment of c_{ii} (CSC) to avoid any co-site conflict. Calculate the partial cost of this allocation. Now add 1 to all the members of V_i and compute the partial cost due to this allocation. Continue this while the last member of $V_i < M$. Among all these allocations, pick the one that gives the least partial cost (normally =

0). If there are more than one optimal allocations then pick the last allocation.

After allocation, delete the cell from the sorted list, and then pick the next cell at the top of the list. This process is continued until the list is empty, indicating that the final solution has been achieved.

Partial Cost

Partial cost means the cost due to those cells only to which channels have been allocated.

Since allocation has been done in such a way that there is no possibility of CSC, there is no need to include CSC in the partial cost calculation. Partial cost of a cell x is calculated in terms of number of conflicts between the cell x and other cells to which channels have been already allocated, as in Equation 1.

$$Pcost(x) = \sum_{y=1, y \neq x}^{N} \sum_{i=1}^{M_x} \sum_{j=1}^{M_y} \Psi(x_i, y_j) \cdot \Phi(y) \quad (1)$$

Where

x... is the cell whose partial cost is to be calculated.
N ... is the number of cells in the problem.
M_x ... Demand of cell x.
M_y ... Demand of cell y.

$$\Phi(y) = \begin{cases} 0 & : \; if\ cell\ y\ is\ in\ the\ sorted\ list \\ 1 & : \; otherwise\ (channels\ already\ allocated) \end{cases}$$

$$\Psi(x_i, y_j) = \begin{cases} 0 & : \; if\ |x_i - y_j| \geq c_{xy} \\ 1 & : \; otherwise\ (there\ is\ a\ conflict) \end{cases}$$

4. SIMULATION RESULTS AND COMPARISON

Simulation experiments were conducted on 21-node network for which the compatibility matrix C_3 is given in [7]. Two different demand vectors D_3 and D_4 were also used from [7]. Algorithm was also tested for the compatibility matrix and demand vector C_1 and D_1 of Section 2.

The lower bounds on number of available channels are $7 \times (45-1)+1 = 309$ for (C_3, D_3) case, $7 \times (77-1)+1 = 533$ for (C_3, D_4) case and $5 \times (3-1)+1 = 11$ for (C_1, D_1).

For all cases the conflict free assignment is obtained within a fraction of a second on P-III machines. When compared with the results presented in [7], where authors have used genetic algorithm, it was observed that the quality of solution achieved by our proposed algorithm is better with considerably less execution time for the same test cases. In [7], completely conflict-free allocation was not obtained, whereas the proposed algorithm was able to achieve it. Due to limited space, conflict-free allocations only for (C_1, D_1) and (C_3, D_3) are shown below.

Channel Allocation for C_1, D_1

Cells	Channels
1.	5
2.	9
3.	8
4.	0,5,10

Channel Allocation for C_3, D_3

Cells	Channels
1.	274,281,288,295,302
2.	239,246,253,260,267
3.	204,211,218,225,232
4.	254,261,268,275,282,289,296,303
5.	228,235,242,249,256,263,270,277,284,291,298,305
6.	137,144,151,158,165,172,179,186,193,200,207,214,221,228,235,242,249,256,263,270,277,284,291,298,305
7.	104,111,118,125,132,139,146,153,160,167,174,181,188,195,202,209,216,223,230,237,244,251,258,265,272,279,286,293,300,307
8.	135,142,149,156,163,170,177,184,191,198,205,212,219,226,233,240,247,254,261,268,275,282,289,296,303
9.	102,109,116,123,130,137,144,151,158,165,172,179,186,193,200,207,214,221,228,235,242,249,256,263,270,277,284,291,298,305
10.	33,40,47,54,61,68,75,82,89,96,103,110,117,124,131,138,145,152,159,166,173,180,187,194,201,208,215,222,229,236,243,250,257,264,271,278,285,292,299,306
11.	34,41,48,55,62,69,76,83,90,97,104,111,118,125,132,139,146,153,160,167,174,181,188,195,202,209,216,223,230,237,244,251,258,265,272,279,286,293,300,307

12. 0,7,14,21,28,35,42,49,56,63,70,77,84,91,98,105,112, 119,126,133,140,147,154,161,168,175,182,189,196, 203,210,217,224,231,238,245,252,259,266,273,280, 287,294,301,308

13. 170,177,184,191,198,205,212,219,226,233,240,247, 254,261,268,275,282,289,296,303

14. 103,110,117,124,131,138,145,152,159,166,173,180, 187,194,201,208,215,222,229,236,243,250,257,264, 271,278,285,292,299,306

15. 136,143,151,157,164,171,178,185,192,199,206,213, 220,227,234,241,248,255,262,269,276,283,290,297, 304

16. 203,210,217,224,231,238,245,252,259,266,273,280, 287,294,301

17. 98,105,112,119,126,133,140,147,154,161,168,175, 182,189,196

18. 101,108,115,122,129,136,143,150,157,164,171,178, 185,192,199,206,213,220,227,234,241,248,255,262, 269,276,283,290,297,304

19. 169,176,183,190,197,204,211,218,225,232,239,246, 253,260,267,274,281,288,295,302

20. 174,181,188,195,202,209,216,223,230,237,244,251, 258,265,272,279,286,293,300,307

21. 135,142,149,156,163,170,177,184,191,198,205,212, 219,226,233,240,254,261,268,275,282,289,296,303

5. CONCLUSION AND DISCUSSION

In this paper a fast constructive algorithm for fixed channel assignment in mobile radio networks was proposed. The algorithm was tested on different benchmark problems and conflict free allocation that also satisfies the demand requirement was obtained in each case. The quality of solution achieved was always the same or better than those of obtained by using reported iterative techniques. As compared to iterative algorithms like genetic algorithm [2, 6, 7, 8] and simulated annealing [5], the proposed algorithm exhibits approximately negligible execution time, as all the results were obtained within one second. Moreover, less computation is required due to efficient solution representation (there is no computation for demand constraint). Also, due to the proposed allocation strategy, there is no computation for CSC. The idea of partial cost also minimizes the computation as conflicts for only one cell under consideration are to be calculated at a time.

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