

Optimizing Channel Allocation in Wireless Communication Using Single-Swap Mutation Based Heuristic

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Abstract—This paper presents a simple heuristic method, combined with a single-swap mutation, for minimizing the use of available channels in wireless communication networks. The task is to allocate carriers or channels to satisfy all demands in each cell for a particular network, subject to a number of constraints. The proposed method is to get the least number of channels without violating the constraint set. We test the proposed methodology on benchmark problems and manage to produce good quality solutions within a few seconds. Some of the results are very close to optimality, making this method suitable for generating initial solutions for population based approaches, such as genetic algorithm and artificial immune systems, to search for even better quality solutions.

Keywords - heuristic; channel allocation; wireless communication; simple mutation; optimization;

I. INTRODUCTION

The use of mobile communication applications has increased tremendously over the last decade. Nowadays people are less interested with applications or equipment that require them to stay at a certain location for a long period. Therefore, wireless and mobile applications are increasingly attractive and gaining popularity worldwide.

The need for suitable and effective platforms to provide wireless and mobile communication has become increasingly important. Telecommunication companies that provide these services are continuously trying to improve their infrastructures in order to satisfy ever increasing usage as well as to provide improved user experience. Therefore, good and efficient allocation of communication channels is very important in fulfilling the needs of all parties.

In mobile communications, the area covered by the network is depicted to be divided into a number of hexagonal shape cells [1]. Each cell has a base station or transmitter at its centre which transmits radio channels to the covered geographical area. This base station must handle all mobile communication activities inside the covered area by allocating communication channels. These activities are accomplished from the mobile hosts to the base station through the allocated

channels. Therefore, satisfying the demands of channels from each cell is a crucial task that must be performed effectively and efficiently to make sure all mobile hosts obtain the necessary channels in order to perform their activities, without any interference from other users' calls as well as avoid the occurrence of information delay.

Channel allocation is the task of assigning available channels to the mobile users while at the same time performing either one of the following tasks [2]:

- 1) Minimize the number of channels used subject to several constraints in order to avoid the occurrence of interferences between calls
- 2) If interferences are imminent, minimize its severity.

In this paper, we will only focus on the first task which is to allocate channels to satisfy demands without violating any constraints or to produce interference-free allocation.

II. CHANNELS ALLOCATION PROBLEM IN WIRELESS COMMUNICATION NETWORKS

The channel allocation task is an NP-hard problem. It cannot be solved in a polynomial time (unless $P=NP$), which means that, except for small instances, it is likely that approximation methods will probably be required to produce possible solutions. This problem must meet several constraints in order to avoid interference. Interference in mobile communication may occur across cells as well as within a cell. The basic channel allocation problem model consists of the following components [3]:

- 1) N : the number of cells in a network
- 2) d_i , $1 \leq i \leq N$: number of channel required for cell i , where the total demands $D = \sum_{i=1}^N d_i$
- 3) $|N| \times |N|$ compatibility matrix C_{ij} , $1 \leq i, j \leq N$:
 - a. minimum reuse distance between cell i and cell j if $i \neq j$ for co-channel constraint.

- b. minimum channel distance between cell i and cell j if $i \neq j$ for adjacent channel constraint.
- c. minimum separation distance if $i = j$ for co-site constraint.

The main objective is to find the minimum number of channels used to satisfy all demands, at the same time avoiding any violation of constraints which could result in interference. The objective function can be defined as

$$\text{Min } \sum f_{ik}, i \geq 1, 1 \leq k \leq N,$$

with f_i is a channel allocated to cell k and represented by a positive integer normally in ascending order (1, 2, 3, 4 N).

Each channel in a mobile communication network can accommodate a call. When a channel is allocated to a user in a particular cell, users in the same cell are not permitted from acquiring the same channel at the same time. However, it can be re-used in other cells subject to minimum reuse distance [3]. This can be represented as

$$|f_i - f_j| \geq C_{ij},$$

where f_i and f_j are channels assigned to cell i and j respectively. The value of C_{ij} refers to the element for column i and row j , or vice versa, in compatibility matrix C . It determines the minimum distance which other users in different cells must have in order to use the same channel. For example, consider the 21-cell network as shown in Figure 1. Channel 3, f_3 is allocated to cell 7 and the minimum reuse distance for the network is 2, therefore f_3 can only be reallocated simultaneously in cells which have distance value at least 2 units from cell 7 such as cell 3, 4, 5, 10, 11, 12, 17, 18, 20 and 21. It cannot be assigned to cells 1, 2, 6, 8, 9, 13, 14, 15, 16 and 19 because of the constraint.

The quality of the channel allocation is determined by looking at the electromagnetic compatibility constraints. The objective is accomplished if all of the constraints are minimized. The electromagnetic compatibility constraints are represented in a matrix form called a compatibility matrix, C [6]. For example, if we have 21 cells network as shown in Figure 1, then we will have a matrix with 21 rows and 21 columns, $C_{21 \times 21}$. This matrix represents the three constraints used in the channel allocation task which are co-channel, adjacent channel and co-site constraints. The diagonal elements in the matrix represent the co-site constraint and non-diagonal elements represent the co-channel and adjacent channel constraints.

A. An Example

An example of a simple channel allocation problem is shown in Figure 2. The network consists of 4 cells. Compatibility matrix C_i represents the three constraints that must be respected in order to prevent any interference. For the non-diagonal elements, only values of 0 and 1 can be used. It indicates that this compatibility matrix represents a pure co-channel problem without the presence of adjacent channel constraints. The value of 3 for the diagonal elements is the example of co-site constraint. Each cell is indicated as having the minimum separation distance between

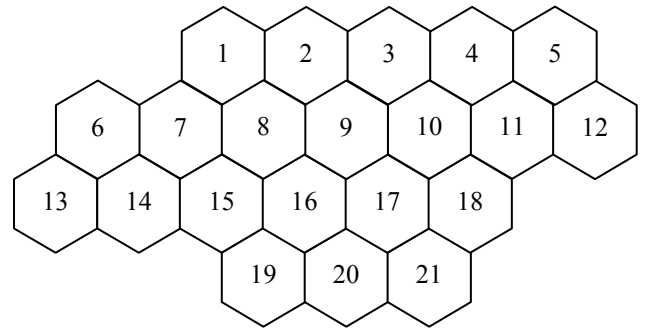


Figure 1. The 21-cell wireless system

channels as 3. For example C_{33} , let say channel 2, f_2 is allocated to cell 3, the next acceptable channel can be allocated this cell is channel $6, f_6$.

For all non-diagonal elements in the matrix, a 0 value means those 2 cells are not bound to co-channel and adjacent channel constraints. Therefore, the same and adjacent channels are admissible in both cells. This can be observed between cells 1 and 3, as well as cells 3 and 4 as C_{13} and C_{34} are both 0. Element $C_{24} = 1$ indicates the presence of co-channel constraint for cell 2 and cell 4. It means that no same channel should be allocated to both cells simultaneously.

The demand vector for each cell is shown in matrix D_i . Cell 1 and cell 3 need two channels meanwhile cells 2 and 4 only require 1 channel to satisfy its demand. The order of cells to be assigned with channels will determine the span of this task as well as the objective function, which will be optimized in order to get the least number of channels assigned without violating any of those two aforementioned constraints.

An example of a valid solution for the problem as shown in Figure 2 is presented in Table 1. Cell ordering of 3, 2, 1, 4 is constructed randomly. It means cell 3 is the first cell to be assigned with channels. Since the demand for the cell is two, two channels should be allocated. Channel 1, f_1 is first assigned. As the value for the diagonal element in C_{33} is three, which represents the co-site constraint, which is also the minimum separation distance of channels in the cell, the next valid channel for cell 3 is channel 4, f_4 . Cell 2 has a co-channel constraint condition with all cells in the network, i.e. cells 1, 3 and 4. But it needs to consider only cell 3's assignment because it is the only cell that has been assigned with channels. Therefore, cell 2 cannot re-use the same channels as assigned to cell 3.

The next available channel is channel 2, f_2 . For the third cell in the order (cell 1), two channels are required. As can be

TABLE 1 EXAMPLE OF A VALID SOLUTION FOR THE PROBLEM IN FIGURE 2

Cell	Channels	
3	f_1	f_4
2	f_2	-
1	f_1	f_4
4	f_3	-

$$C_I = \begin{pmatrix} 3 & 1 & 0 & 1 \\ 1 & 3 & 1 & 1 \\ 0 & 1 & 3 & 0 \\ 1 & 1 & 0 & 3 \end{pmatrix} \quad D_I = \begin{pmatrix} 2 \\ 1 \\ 2 \\ 1 \end{pmatrix}$$

Figure 2. A four-cell channel allocation problem

observed from the compatibility matrix, cell 1 poses a co-channel constraint condition with cells 2 and 4. Therefore, no co-channel constraint with cell 3 is present, hence reusing the same channels as assigned in cell 3 is admissible. As a result, channels 1 and 4 are allocated to cell 1. At the same time, it satisfies the co-site constraint for cell 1, because at least 3 units of channels are required to separate the valid channels allocated to cell 1. The last cell in the order is cell 4, and the presence of co-channel constraints with cells 1 and 2 is observed. Therefore, no same channel is allowed to be reassigned to cell 4 as allocated to cells 1 and 2. As a result, channel 3, f_3 is allocated. The total number of channels used for the overall assignment of this problem is 4, and it is the optimal solution as proven using equation proposed in [3].

B. Previous Work

Since the emergence of mobile communication in the late 70's, researchers have been trying to find efficient ways of dealing with resources required in wireless communication networks. Poor assignments of radio channels will result in increased cost of operation and restricting the service that can be offered to users. In this study, benchmark problems and instances are based on 21-cell networks as presented in [3] and [7].

The use of simple-yet-efficient heuristics was introduced by Chakraborty in [3]. He created a pool of possible solutions using his proposed method. The pool consists of every result produced by the heuristics regardless of their quality. The best solution from the pool was then chosen as the final solution. His method of selection has managed to produce optimal or near-optimal solution for most of the instances tested.

Simulated annealing is one of the methodologies that is widely used in solving optimization problems. It was utilized on channel assignment problem by Anton, Kunz and Ruber [8]. However, the results produced were not up to their expectation as it was relatively computationally expensive, with the solutions not close to optimality. Consequently, they introduced a hybrid algorithm of simulated annealing and the concept of a neighbourhood structure. They were able to utilize fewer frequencies for 14-cell networks with clusters of 7 cells for co-channel constraint.

Simple heuristic method with exhaustive strategy was proposed by Sivarajan and McEliece in [7]. Frequencies were assigned one by one with respect to the constraints until all demands were satisfied. This study focused on the implementation of the proposed approach on 21-cell network with cluster sizes of 12 and 7 cells for the co-channel constraint. It managed to find the optimal solutions presented by Gamst [9] for most of the problems tested.

Many researchers have utilized genetic algorithm (GA) for the channel assignment problem [10]-[12]. Smith managed to escape local optima, which would affect the final solution, by applying an enhancement technique on the genetic operator [10]. Chakraborty and Chakraborty suggested the application of novel genetic mutation operator in their GA version to produce good quality solutions [11]. The use of a hybrid-GA algorithm in performing channel allocation was successful utilized by Fu, Bourgeois, Fan and Pan [12]. The methodology consists of three steps which begins with the determination of lower bound. The assignment of channels to satisfy each demand then performed using a greedy algorithm before being further improved by a GA. From 13 instances tested, their method managed to find 11 optimal solutions.

The use of hyper-heuristics on channel assignment problem was first introduced by Mohamad and Kendall [6] in 2003. Unlike most algorithms, instead of directly dealing with possible solutions, their method deals with a number of low level heuristics. The objective is to find the best ordering of heuristics to be applied to various instances in getting a good channel assignment. This method manages to find good quality solutions in short computational time.

III. THE ALGORITHM

The idea is to introduce a simple yet efficient heuristic for the purpose of getting a good channel assignment that satisfies all constraints in a fast computation time.

Firstly, a set of available channels was created for the purpose of easy access during the channel allocation process. Then, the order of cells which will determine the arrangement of which cell to be assigned with channels first was created. The strategy here is to generate the first order of cells based on demands from each cell. Then the next order will be produced based on the previous order using a single swap mutation technique. This approach is repeated for every iteration until the stopping criterion is met. The detailed mutation algorithm is as follows :

- 1) For the first iteration, the order of cells is constructed based on the value of demand for each cell. The cells are arranged in descending order. It means the first cell will have the highest demand.
- 2) For the second iteration, select two positions from the first order randomly, and their values are swapped. This new order will be used for channel assignment task for that iteration.
- 3) For the next iteration, the same process is repeated, meaning for iteration i , the order of the previous iteration, $i-1$ will be used to generate the new order.

The assignment of channels starts with the first order. Let's say we have the order of 3, 2, 1, 4 as discussed in Section II, the assignment of cell 3 will be executed first. Since it is the first cell, only co-site constraint will be considered. For the next cell's assignment which is cell 2, it needs to consider other constraints which are co-channel and adjacent channel constraints. Therefore, the assignment of previously allocated-with-channels cells must be taken into consideration in order to

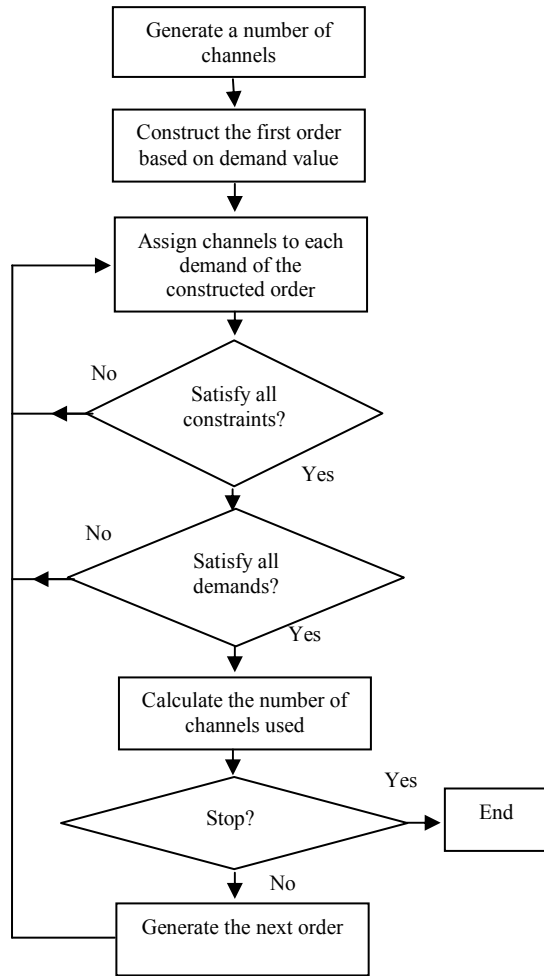


Figure 3. Flowchart of the algorithm

avoid constraint violations. The same rule applies for the next cells' allocation until all cells in that order are completed.

The same process is repeated for the new order until termination criteria is met, which is when the optimal solution is found, or a specific number of iterations has been carried out, whichever is met first. The complete algorithm for the proposed heuristic is shown in Figure 3.

IV. EXPERIMENT AND RESULTS

Six problems with two demand vectors for 21-cell wireless network were chosen to be tested using the proposed method. These problems are combined with different co-site constraint values of 5, 7 and 9. The two demand vectors are as follow:

$$D_1 = 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20$$

$$D_2 = 16, 50, 16, 16, 16, 30, 36, 104, 154, 56, 26, 30, 62, 30, 72, 114, 56, 16, 20, 26, 16$$

TABLE 2. RESULTS

Prob.	Demand Vector	Co-site Const.	Lower Bound	Our Result	Comp. Time	Results from [13]
1	1	5	178	197	0.250	198
2	2	5	766	766	0.188	856
3	1	7	134	140	0.157	-
4	2	7	1072	1072	0.094	-
5	1	9	172	178	0.157	-
6	2	9	1378	1378	0.219	-

The demands were arranged in cell order, meaning the first element is the demand for cell 1, the second element is for cell 2 and so on until the last element which is for cell 21. D_1 has the same pattern for every cell with 20 requests of channels each and the total requirement for the network is 420 channels. For D_2 , different ranges of channel requests can be observed from as low as 16 demands and with 154 channels request as the highest demand from cell 9. The total demand for D_2 is 962 channels.

The results of the proposed heuristic in solving the channel allocation task are presented in Table 2. Comparison with the results discussed in [13] and the lower bound are also shown for comparison purposes.

The proposed heuristic manages to achieve the optimal solutions for all problems utilizing D_2 in less than two seconds. However, due to the complexity of D_1 which requests the same number of channels for each cell, our approach is not able to reach the optimal solution for all problem instances. Nonetheless, it is not far from the desired outcomes. In fact our method produces better results compared to Steve, Derek and Valenzuela's work in [13] for the first two problems.

V. CONCLUSION AND FUTURE WORKS

Considering our study is still in the early stages and the method used is quite simple, the results obtained look promising. Combination with other techniques is one of the possibilities that can be look into in order to improve the results. We hope to extend this study with the introduction of larger and more complex problem instances, so that we can test the effectiveness of the proposed methodology.

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