Faculty of Electrical Engineering

OPTIMIZATION OF MINIMUM SPAN FREQUENCY ASSIGNMENT IN MOBILE COMMUNICATION

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Bachelor of Electrical Engineering (Industrial Power)

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DECLARATION

I hereby, declared this report entitled "Optimization of Minimum Span Frequency Assignment in Mobile Communication" is the result of my own research except as cited in references.

Signature : ………………………………………

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Date : 25 MAY 2017

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and qualify for the award of the degree of Bachelor of Electrical Engineering (Industrial Power).

Signature : ....

Name of Supervisor : ....

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ABSTRACT

Recent years, the use of mobile communication has been steadily increases. An important process in mobile communication is the assignment of frequency spectrum called channel to each of the caller and receiver pair in order to communicate. This headed to some problems faced by mobile communication such as how to distribute the large number of users efficiently with the limited capital of radio frequency spectrum. Zero interference between channels assigned may contributed to a high quality call service between users. Hence, in mobile communication one of the ways to solve the problem is dividing a geographical area into a number of cells in order to reuse the limited frequencies with the aim of supporting more users and also to minimize interference. Hence, a local search method is proposed in this project to solve the channel assignment problem with the minimum span of frequency and zero interference between the channels assigned. The proposed local search algorithm will be coded into programming language by using Matlab software for the exhaustive search. The expected solution is the channel assignment that fulfills all call constraints with the minimum span of frequency and zero interference.

ABSTRAK

Tahun kebelakangan ini, penggunaan komunikasi mudah alih telah semakin meningkat. Satu proses yang penting dalam komunikasi mudah alih adalah tugasan spektrum frekuensi dipanggil saluran kepada setiap pemanggil dan penerima pasangan untuk berkomunikasi. Ini menuju ke beberapa masalah yang dihadapi oleh komunikasi mudah alih seperti bagaimana untuk mengagihkan bilangan besar pengguna cekap dengan modal yang terhad frekuensi radio spektrum. Tanpa gangguan antara saluran yang ditugaskan boleh menyumbang kepada perkhidmatan panggilan berkualiti tinggi di antara pengguna. Oleh itu, dalam komunikasi mudah alih salah satu cara untuk menyelesaikan masalah ini membahagikan kawasan geografi kepada beberapa sel untuk menggunakan semula frekuensi terhad dengan tujuan untuk menyokong lebih ramai pengguna dan juga untuk mengurangkan gangguan. Oleh itu, satu kaedah carian tempatan adalah dicadangkan dalam projek ini untuk menyelesaikan masalah tugasan saluran dengan span minimum kekerapan dan gangguan sifar antara saluran yang diberikan. Algoritma carian tempatan yang dicadangkan akan dikodkan ke dalam bahasa pengaturcaraan dengan menggunakan perisian Matlab untuk carian menyeluruh. Penyelesaian jangkaan adalah tugasan saluran yang memenuhi semua kekangan panggilan dengan tempoh minimum kekerapan dan gangguan sifar .

DEDICATION

Dedicated to

my beloved father, Lim Kean Boon

my appreciated sibling, Lim Seik Lee, Lim Seik Hua and Lim Selk Qi

my special friend Soong Chee Ching for giving me moral support, cooperation, encouragement and also understanding.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In a cellular communication system, the geographical area is logically divided into small region called cells. Each cell has a cell site or a base station. A given transmission capacity can be classified into a set of non-interfering radio channels for the communication purpose. All channels can be used at the same time at different cells, provided these frequencies are sufficiently separated in difference, so that there is no interference between them.

Recently, as mobile phones become distinctly universal, there is a constantly developing requirement in mobile communication and their popularity guaranteed its high development rate. In any case, the frequency spectrum that can be used for communication purpose limited. Therefore, of the efficient utilization of channel frequencies turns into more and more important. The allocated spectrum has been separated into a number of channels depends on service requirement. Optimal assignment of frequency channels is an approach to solve the problem on limited usable frequencies and thus gives inspiration for the research on channels assignment problem (CAP). The purpose of CAP is to allocate of channels to every base station in such a way that the radio spectra is efficiently used and the interference among calls is avoided.

There are three constraints of the channel assignment that must be fulfilled due to the wireless interference between frequency spectrums. The cells assigned with the same channel are known as co-channel cells. Co-channel interference occurs when the signals at the same frequencies reach the receiver from the co-channel cells. Thus, certain pairs of radio cells cannot use the same channel simultaneously. Signals with nearby frequencies from adjacent cells cause the adjacent channel interference. Hence, certain pair of cells cannot use an adjacent frequency at the same time. The channels allocated in the same cell are known as co-site channels. The distance between any co-site channels must have a minimal separation of frequency between each other.

The channel allocation schemes can be divided into two types which are fixed channel allocation (FCA), where the channels are assigned to every cell permanently, and dynamic channel allocation (DCA), where all vacant channels are accessible for every cell. Insert FCA strategy in DCA strategies, firstly all channels are put in a central pool. When there have call requests, they are assigned to the new calls dynamically. When the call is done, they will be assigned back to the central pool. To avoid the interference, the selection of the most appropriate channel for any call is straightforward if it is only depend on current allocation and current traffic.

1.2 Problem statement

This project aims to minimize the span frequency assignment in mobile communication. From the past experience, the demand for channels or the number of calls in cell i is recorded and denoted by m_i. Based on this demand information, frequency or channel is assigned without violating the frequency separation constraint. Span frequency refers to the difference between the values of the maximum and the minimum frequencies assigned. To maximize the usage of limited channels, frequencies are reused in such a way the assignment gives zero interference.

The minimum span frequency assignment consists of the following five components [1]:

1. The number of cells in the system is represented by *N*.
2. The number of channel required in cell i is represented by m_i for $i = 1, \dots, N$
3. The frequency separation demand between a call in cell i and a call in cell j is represented by c_{ij} for $i, j = 1, \dots, N$.

4. The frequency allocated to the kth call in the ith cell is represented by f_{ik} for $= 1, \dots, N$, $k = 1, \dots, m_i$. All frequency has been represented by a positive integer.
5. The set of frequency-separation requirement is represented with the compatibility matrix C, where $|f_{ik} - f_{jl}| \geq c_{ij}$ for all $i, j, k, l (i \neq j), (k \neq l)$.

The compatibility matrix C, has been used to make sure interference does not occur by giving enough frequency separation distance among channels.

The linear programming of the problem is presented as follows:

Minimize

$$\left(\max_{i,k} f_{ik} \right)$$

subject to

$$|f_{ik} - f_{jl}| \geq c_{ij} \quad , \quad i, j = 1, \dots, N \text{ , } k, l = 1, \dots, m_i$$

This problem can be represented in a connected graph where a call is represents by each node of the graph, and while the identical calls cannot use the similar frequency, an edge has been connected from two vertices. The minimum demand frequency separate distance between the two calls at its endpoints is represented with an edge. Frequency f_{ik} is the frequency allocated to the kth call in the ith cell.

The channel assignment problem is similar to allocating positive integers that represent frequencies to the vertices of the graph by satisfying the following two criteria:

1. The absolute difference value of the integers allocated to these nodes is greater than or equivalent to the edge value if they are joined by an edge.
2. The maximum number of allocated integer is as low as possible.

1.3 Objective

1. To propose local search algorithm to minimize the span frequency assignment in mobile communication.
2. To develop coding algorithm for the proposed local search method.
3. To investigate the effect of different call demand distributions and co-site constraints on the minimum span of frequency.

1.4 Scope

This project scoped at minimum span frequency assignment in mobile communication under the fixed channel allocation scheme. Interference is not allowed but channels may be reused as long as the minimal frequency separation constraint is fulfilled. The coding algorithms of the proposed local search will be developed using Matlab software. For the result analysis, the call demand distribution used are uniform and random demand distributions, the number of cells is scoped to 5 and the co-site constraint is limited to 6 units.

1.5 Significant of study

Recent years the evolution of mobile telecommunication raised the expansion of cellular users significantly. The number of vacant frequencies needed in mobile communication is much lower than the popularity of mobile usage increasing rate. Channels are assigned in such a way overall interference is zero, channel demand requirements are met and the span frequency assigned is being minimized. Zero interference may contribute to high quality calls. In overall, an optimal assignment of channels may increase the efficiency of mobile communication.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter related works of the Channel Assignment Problem (CAP) are presented. In order to enhance the work of mobile calls and relevant services in mobile wireless system, different strategies and models have been created. The performance aspects are contributed by different factors for example, network traffic, bandwidth, computing devices and the wireless signals between the mobile equipment and close to base stations of cellular radio network.

2.2 Channel Assignment Model

Different channel assignments strategies are generally studied with the aim of maximize the frequency reuse. Basically, the channel assignment can be divided into two categories which are Fixed Channel Assignment (FCA) and Dynamic Channel Assignment (DCA).

2.2.1 Fixed Channel Assignment (FCA)

In Fixed Channel Assignment (FCA) strategy, a fixed number of channels are assigned to every cell. Communication is successfully made only when unused channel of the specific cell is assigned to it. The call will be rejected or subscriber has to hold on when all the channels are occupied. The worst case is some calls are unable to be assigned with any channel and this is the main issue of FCA schemes.

2.2.2 Dynamic Channel Assignment (DCA)

In dynamic channel assignment strategy, temporarily assigned channels are used in the cells during the period of the call. Allocation of channels to cells is not permanently allocated. Every time a call attempt is made from a cell the corresponding Base Station (BS) demands a channel from Mobile Switching Center (MSC). Next, channels are allocated to the demanding the BS by MSC. The channels are returned to central pool when the call is end. The channel can reassigned at the same time to another cell in the system with the condition of separation between the two cells must bigger than the required minimum separation in order to avoid co-channel interference. In comparison with the FCA, DCA has less probability of cutting off and even expanded the trunking capacity of the system as all of the channels are accessible to every cell. However, this category of assignment scheme brings in excessive load on switching center at large traffic status.

2.2.3 Comparison of FCA and DCA

In general, FCA strategy is more suitable to mainly high uniform traffic load while DCA strategy perform under low traffic density in case of non-constant traffic load. Therefore, there is an exchange-off between aspect of services, the performance complication of the channel assigned algorithms and spectrum has been using efficiency. In the FCA schemes, channels are preassigned to cells, so there might be occurrences of blocked calls when there is fluctuation in traffic despite the fact that, there are accessible channels in adjacent cells. The beginning of the requests for services between the cells is an irregular process. Hence, the various channels also have been assigned random to the serve calls while using the dynamic assignment. Consequently, that cells have been found which have obtained the same channel for use are, on average, separated a greater separation apart than the minimum reuse distance.

Thus, dynamic assignment schemes are not always successful in reusing the channels the greatest possible number of times.

Besides, in FCA schemes in order to elude interference a particular channel assigned to a cell must be separated with the required minimum separation. The assignment of the channels is performed in a way that the channels maximum reusability is always accomplished. Thus, the FCA scheme give a better performance sensitive to spatial changes and time in the offered traffic. Therefore, it gives rise to almost stable performance in each cell [2]. Moreover the quality of service within an interference group of cells relies on the average loading within that group, not on its dimension distribution. In addition, for the FCA, the service deviation, a measure of the grade of service fluctuations from one cell to another, is particularly intensified by time and spatial traffic changes.

Typically, for similar cut-off rate, DCA has lower constrained call and end rate than FCA. If co-channel interference does not exist, the similar channel can be allocated to the new cell in DCA. A call need to be handed off to another channel during every handoff due to the same channel is not accessible in adjacent cells according to FCA strategy. Use of DCA in such a system may implement better because of the way that DCA adjust to flexibility in the system. It has been appeared in FCA that it does not give the best result when the cells are small [3].

In the FCA scheme, the assignment control is made independently in every cell by selecting an empty channel among those allocated to that cell in advance. Then, in DCA, knowledge of occupied channels in the relevant cell and also the other cells is required. Thus, DCA needs huge knowledge of the state of the whole system and needs high-speed processing and signaling, otherwise there would be a long call set-up delay. In fact, a lot of the processing time is required by the physical implementation of DCA to establish optimal allocations.

2.3 Related work

Recently, many researches of Channel Assignment Problem (CAP) have been carried out by using graph-theoretic method, heuristic approaches, and different optimization methods. The algorithms can be divided into two categories which are non-iterative algorithms and iterative algorithms. Calls ordering, cell ordering or heuristic frequency assignment techniques are used by most of non-iterative algorithms. Examples of iterative procedures are neural-network algorithms, genetic algorithms [4-5], simulated annealing, other approaches and local search methods. A brief introduction of these iterative procedures will be presented in the following sections.

2.3.1 Neural-network algorithms

A Neural-network algorithm utilizes energy function which consists of the objective function and also an individual term for every of the requirement of the problem. Hence, an appropriate energy function is defined as crucial for utilizing neural network. Furthermore, for purpose of minimization, the terms of the energy function will challenge with themselves. Accordingly, an exchange-off between the objective and constraints might be needed in much of the cases. The Hopfield neural network is used to solve the CAP [6]. Some algorithms using neural network are proposed to solve the problem [6-12]. A multistage self-sorting out channel assignment algorithm depends on the Transiently Chaotic Neural Network (TCNN) for the channel assignment problem had been proposed [12]. In [11], the CAP have been solved by Discrete Competitive Hopfield Neural-Network (DCHNN). The purpose is to reduce the overall interference in the all cellular system. The problem constraint is constantly satisfied by DCHNN. Therefore it guarantees the possibility of the solutions for the CAP. Besides, the DCHNN allows temporarily increasing in energy to avoid from local minima by establishing stochastic dynamics [13].

An inalienable obstacle of the neural-network algorithms is they will probably converge to local optima, and consequently optimal results cannot generally be ensured.

Hence, the neural-network algorithms are regularly perform well on unreal limited test problem [14].

2.3.2 Genetic algorithms

Genetic Algorithm (GA) is a search algorithm depend on the mechanics of regular selection [15]. From this system, a *g*-bit binary string acts as an individual with *h* fixed element in this formula. The smallest distance between continuous elements is described by d_{min}. This formula is representing the solution in such a way that a one is followed by (d_{min}-1) zeroes is encoded as a new “one”, represented as $\tilde{1}$ [4,16]. For instance, an individual with g=10 and h=3 can de encoded as below:

$$\frac{Original}{1000100100} \rightarrow \frac{Encoded}{\tilde{1} \;\; 0 \;\; \tilde{1} \;\; \tilde{1}} \tag{2.1}$$

The channel assignment problem’s cost function can be reduced to

$$C(F) = \sum_{i=1}^{n} \sum_{g=1}^{m} \left(\sum_{\substack{j=1 \\ j \neq i \\ c_{ij}>0}}^{n} \sum_{\substack{h=g-(c_{ii}-1) \\ h \neq g \\ 1 \leq h \leq m}}^{g+(c_{ii}-1)} f_{ih} \right) f_{ig} \tag{2.2}$$

The channel assignment problem’s cost function can be further reduced by abusing the symmetry of the compatibility matrix *C*. Therefore, the final cost function is denoted by

$$C(F) = \sum_{i=1}^{n-1} \sum_{\substack{j=i+1 \\ c_{ij}>0}}^{n} \left(\sum_{g=1}^{c_{ij}-1} \sum_{h=1}^{g-1} f_{jh} f_{ig} + \sum_{g=c_{ij}}^{m} \sum_{h=g-c_{ij}+1}^{g-1} f_{jh} f_{ig} + \frac{1}{2} \sum_{g=1}^{m} f_{jh} f_{ig} \right) \tag{2.3}$$

In genetic algorithm strategy, *F* represents the solution space, a $N \times M$ matrix is considered as a chromosome in the community. This implies that if a community contains chromosome, there will be *F* of solution matrices, where each matrix represents a chromosome in the community. The randomly generated *F* solution matrices can be used to solve the problem for the channel assignment. The parameter that have to control expresses the number of chromosomes in a population is the population size to acquire an optimized solution [17].

All channel assignment in the network, *F* solution matrix is called by strings of 1 and 0, and in this manner there is no coding issue [18]. The ability of every chromosome should be assessed, after arbitrarily producing a population of chromosomes. Hence, the final cost function is used to evaluate the ability values of the entire *F* solution matrices in the population. The smaller the cost function value, the more suit the chromosome.

Produce a new population by utilizing genetic algorithm operators, such as selection, crossover and mutation is the following step in the genetic algorithm. The strategy of selection can be appliance by many different techniques. The value measure h of an individual is $h=b$, which is the number of cut off calls after FEA, can be utilized to figure out which individuals should be selected. The strategy is used in which the probability P_i of an individual L_i to be chosen is proportional to the quality value $h(L_i)$ [19].

$$P_i = \frac{h(L_i)}{\sum_{j=1}^{z} h(L_i)} \tag{2.4}$$

The process of selection includes of choosing 2 parent chromosomes from a population based on their ability value. For example, individual with great ability will have higher chances to be selected. After the process of selecting 2 parent chromosomes, the 2 part chromosomes will be encoded. Next, the selected parent chromosomes or *F* solution matrix will go through the process of crossover with a probability of crossover and mutation. Optimized solution can be obtained by controlling the parameter of mutation and crossover probability. Hence, the new posterity of the parent chromosomes is put in the new population after crossover and mutation. For parents chromosome with no crossover or mutation will be put into the new population as well. Repeat processes of the selected crossover and mutation until the current population has the equal parameter as the old population is developed. Next to this step, the entire new rows in the *F* solution matrix or chromosome are utilized to keep all genetic algorithms to run as long as an optimized solution is yet to be discovered.

2.3.3 Simulated Annealing

In simulated annealing, there is a need to define the analogous distinct cost function *C*, neighborhood structure *N* and configuration space *S* in order to formulate CAP as a discrete optimization problem.

A. Configuration space *S*

Consider a mobile wireless system of *n* cells, every cell is able to carry with any *m* channels that are accessible for entire network. Value of *m* is given either by the available radio spectrum or can be assessed by utilizing graph theoretic methods to compute lower bounds for it [20,21]. The condition of the channel assignment has been represented by one wish in a structure. In this way, characteristic decision is provided by a binary matrix (S_{ij}) of the dimension $m \times n$ with the interpretation of the solution access:

$$S_{ij} = \begin{cases} 0, & \text{if channel } i \text{ is not used at radio cell } j. \\ 1, & \text{if channel } i \text{ is used at radio cell } j. \end{cases} \quad (2.5)$$

B. Cost Function

The interference is to be avoided and the capacity to serve the normal traffic demand, $traf_j$, in cell j is the basic requirement for a mobile radio network. A common preferred the cost function [22] is

$$C(S) = \frac{1}{2}A \sum_{\substack{(i,j),(i',j'),(i,j)\neq(i',j') \\ |i-i'| \leq c_{jj'}}} S_{ij}S_{i'j'} + \frac{1}{2}B \sum_{j}\left(\sum_{i} S_{ij} - traf_j\right)^2 \quad (2.6)$$

If two interfering cell j and j' are allocated with two channels i and i' with the interference bandwidth of C_{jj}, and the first point will becomes positive. While the second point penalizes traffic violations for example if the number of channel instantly occupied at cell j it will becomes positive. Hence, if all requirement r are satisfied then the $C(S)$ will reache its minimum at zero.

C. Neighborhood Structure

Choices for the neighborhood of a configuration S are produced by performing the following transitions:

- A single flip, which is just switching on or off one channel i in one cell j.
- A flip flop, which is replacing one used channel i_1 at cell j with one unused i_2.

A generation probability which proposes new configuration equally in $N(S)$ is used. Obviously design the flip-flop to preserve the number of channels used at each base station. Subsequently, the configuration space has to be restricted to the channel assignments with the required channel number and the traffic term in the cost function renders itself superfluous. This shows the very close interchange between the different elements of simulated annealing.

2.3.4 Other Approaches

The authors solve the problem by using a hyper-heuristic method depends on the immense deluge algorithm [23]. However, a different method is used where the showed algorithms to figure the CAP in a case where the coverage is separated into different sizes of circular cells [24,25]. A meta-heuristic with two stages, which is named *Greedy Randomized Adaptive Search Procedure* (GRASP) is proposed in [26] to solve the CAP. A set of starting solutions is constructed in the first stage. The neighborhood of constructed solution is carried out by local search in the second stage. A typical local search method is known as Frequency Exhaustive Assignment (FEA) which allocates calls to the least available frequency, while achieving the interference constraints. Optimal solution that achieves all benchmark occurrences considered is proposed by a hybrid GRASP-FEA in [27]. In [28], the authors solved the CAP by using the GRASP method, and both utilizing a graph coloring model.

In [29], the CAP as a hexagonal cellular system and violating the symmetry of the system were considered by the authors, a few of channel assignment system for a case constant demand on each node has been proposed. As demonstrated by these schemes, assign the channels are allocated to the nodes in a highly consistent and systematic way. Therefore, operation of GA utilizing these plans led to close-optimal assignment in a little number of iteration. A research introduced the non-constant requests on hexagonal cellular system, a clever idea of *critical block*, a fraternity whose minimum bandwidth demand is maximum with all other such clique for working out the CAP [30]. The non-constant requirements on the critical block followed by apportioned (by a linear integer programming formulation) into constant request of few littler sub-systems which gives an exquisite method of allocating frequency to critical block utilizing the system is proposed [29]. This apportioning followed by drawn-out for allocating frequency to the remaining system.

In [31], an algorithm is exhibited which is pertinent to the regular non-hexagonal network too. In this method, the first issue is changed to an identical smaller issue demanding smaller pursuit space. Then the smaller issue has been determined by using proper estimate algorithm rapidly. At last, the solution for the first issue have been acquired from the arrangement of the exchanged problem by using an altered Forced Assignment with Rearrangement (FAR) operation described in [32]. Furthermore, as a final-product of this method, there are some vacant or excess channels in some cell, as a rule. The particular excess channels may effectively use to address the transients request changes will emerge in actuality situation.

2.3.5 Local Search Methods

A local search method is the earliest strategies proposed to adapt to the computational obstinacy of NP-hard combinatorial advancement issues. Given a minimization issue with objective function f and feasible place R, a standard local search algorithms accomplice with every point $x_p \in R$ and neighborhood $N(x_p) \in R$. A present solution point $x_p \in R$ is given, the set $N(x_p)$ is finding for a point x_{p+1} with $f(x_{p+1}) < f(x_p)$. If the sort of point exists, it will become the new solution point, and the method is iterated. In any other case, x_p is remaining as a neighborhood best inside $N(x_p)$. To begin the technique, a set of feasible solution points is produce and every of them are the locally stepped forward inside its neighborhood.

In this project, iterative produces will be applied to solve channel assignment problem under fixed channel assignment scheme. The details of work will be presented in next chapter.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter presents the flow of the research. The methodology of this research includes the principal of the method that will be carried out to complete the research. Coding algorithms are developed based on the proposed local search method.

3.1 An overview of methodology

A flow chart that summarizes an overall flow of this research work is shown in Figure 3.1. This research is started with the literature review. Literature review is an investigation of previous research on the similar channel assignment problem. Next, a local search algorithm is proposed and coding algorithms are developed using Matlab software. There are 3 stages involved in developing the proposed local search algorithm. Firstly in stage 1, matrix E, which is the minimal separation of frequency between the calls, is formed. Next in stage 2, the range of infeasible solution is identified and finally in stage 3, the channels are assigned in the range of feasible solution. The minimum span frequency is obtained from the channel assignment. The proposed algorithm is refined and improved until the satisfactory simulation result is obtained. After that, result comparison and discussion are carried out before the full report writing.

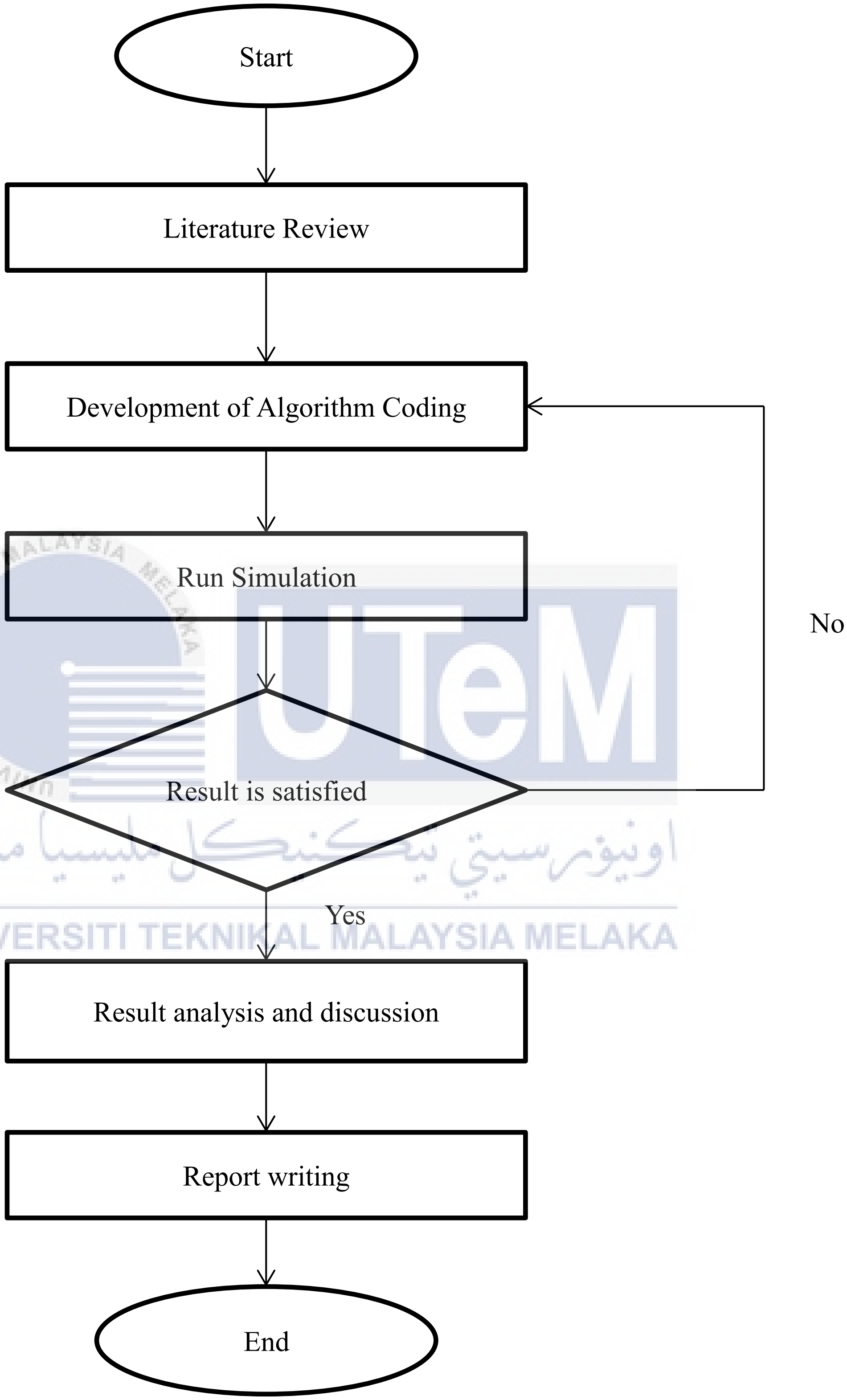

Figure 3.1: Flow chart of the project

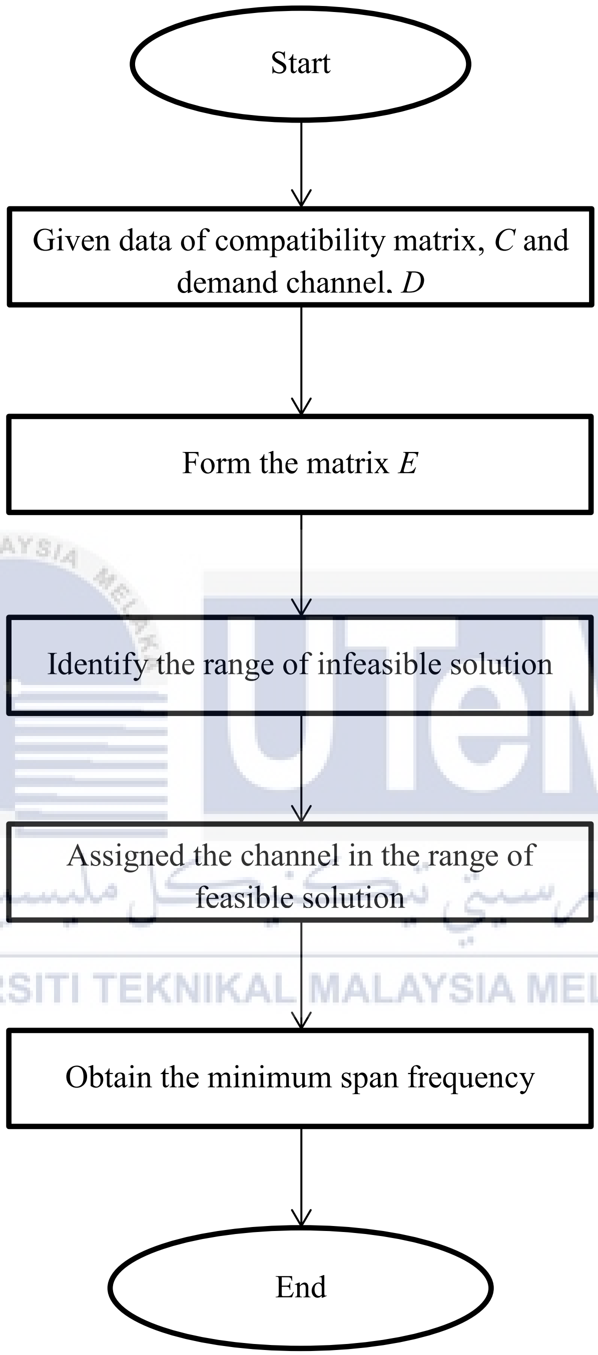

Figure 3.2: Flow chart of proposed local search method

3.2 Development of proposed local search method

From the problem statement, given a number of cells, *N*, separation matrix C and demand of channels, *D*, where $D = [m_1, m_2, \ldots, m_N]^T$ and $M = \sum m_i$ for $i = 1, \ldots, N$. The frequency span assigned to all calls in N cells is being minimized.

An illustrative example is given as follows:

Given number of cells, *N*=5, separation matrix $C = \begin{pmatrix} 6 & 5 & 1 & 0 & 0 \\ 5 & 6 & 4 & 2 & 0 \\ 1 & 4 & 6 & 3 & 1 \\ 0 & 2 & 3 & 6 & 2 \\ 0 & 0 & 1 & 2 & 6 \end{pmatrix}$ and the demand of channels or number of calls in each of the cells, $D = \begin{pmatrix} 2 \\ 1 \\ 2 \\ 3 \\ 2 \end{pmatrix}$. The call list that needs to be assigned with channels and the radio channels which are assigned to serve a call in each cell are shown in Table 3.1. This problem is then represented by a connected graph as shown in Figure 3.3.

Table 3.1: Call list and radio channel at each cell

	Call list	Radio channel, f_{ik}
Cell 1	$Call_{11}$, $Call_{12}$ $(i = 1, \quad 1 \leq k \leq 2)$	f_{11}, f_{12}
Cell 2	$Call_{21}$ $(i = 2, \quad k = 1)$	f_{21}
Cell 3	$Call_{31}$, $Call_{32}$ $(i = 3, \quad 1 \leq k \leq 2)$	f_{31} , f_{32}
Cell 4	$Call_{41}$, $Call_{42}$, $Call_{43}$ $(i = 4, \quad 1 \leq k \leq 3)$	f_{41} , f_{42} , f_{43}
Cell 5	$Call_{51}$, $Call_{52}$ $(i = 1, \quad 1 \leq k \leq 2)$	f_{51} , f_{52}

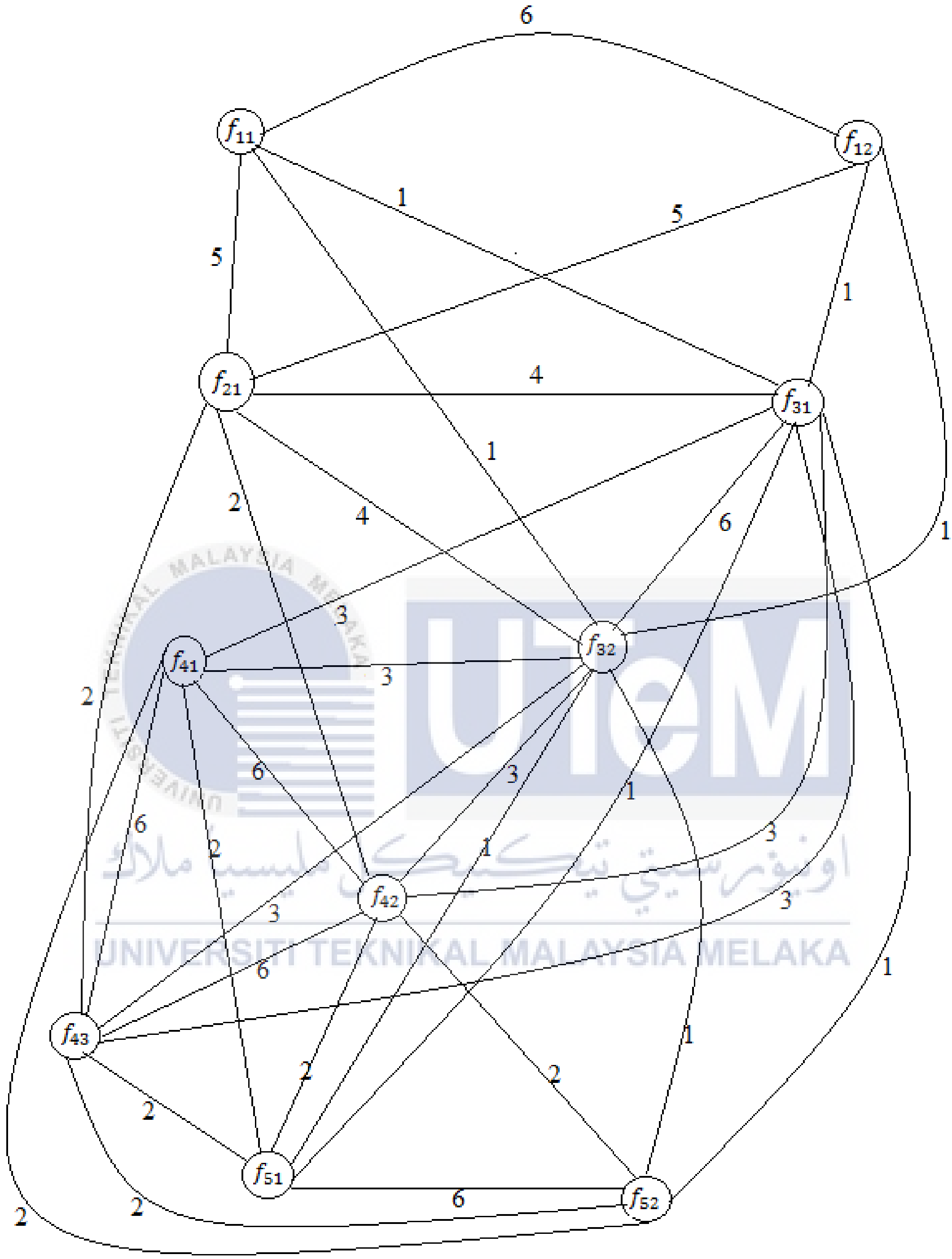

Figure 3.3: A graphical representation of minimum span frequency assignment problem

From the Figure 3.3, nodes f_{11} and f_{21} are connected since the minimum frequency separation between cells 1 and 2 is non-zero ($C_{12} = 5$). In addition, the frequency assigned to f_{11} and f_{21} must have a minimum difference of 5 units. Nodes f_{11} and f_{41} is not connected because the minimum frequency separation between cells 1 and 4 is zero ($C_{14} = 0$). In other words, f_{11} and f_{41} may be assigned the same frequency.

3.2.1 Stage 1: Form the matrix E

In this project, a new local search algorithm will be developed to solve the minimum span frequency problem. The calls are assigned in order starting from the first cell to the last cell. The minimal separation of frequency between the calls is then transformed from C_{ij} for $i, j = 1,2, \dots, N$ into matrix E_{ij} for $i, j = 1,2, \dots, M$ given by matrix E, where the entries E_{ij} represent the minimal separation frequency between the calls i and j. For example, the minimum frequency separation between call 1 and call 2 is equal to 6.

$$E = \begin{bmatrix} 0 & 6 & 5 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 6 & 0 & 5 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 5 & 5 & 0 & 4 & 4 & 2 & 2 & 2 & 0 & 0 \\ 1 & 1 & 4 & 0 & 6 & 3 & 3 & 3 & 1 & 1 \\ 1 & 1 & 4 & 6 & 0 & 3 & 3 & 3 & 1 & 1 \\ 0 & 0 & 2 & 3 & 3 & 0 & 6 & 6 & 2 & 2 \\ 0 & 0 & 2 & 3 & 3 & 6 & 0 & 6 & 2 & 2 \\ 0 & 0 & 2 & 3 & 3 & 6 & 6 & 0 & 2 & 2 \\ 0 & 0 & 0 & 1 & 1 & 2 & 2 & 2 & 0 & 6 \\ 0 & 0 & 0 & 1 & 1 & 2 & 2 & 2 & 6 & 0 \end{bmatrix}$$

Table 3.2: Call list and radio channel at each cell after transformation

	Call list	Radio channel, f_{ik}
Cell 1	$Call_{11} = Call_1$ $Call_{12} = Call_2$	$f_{11} = f_1$ $f_{12} = f_2$
Cell 2	$Call_{21} = Call_3$	$f_{21} = f_3$
Cell 3	$Call_{31} = Call_4$ $Call_{32} = Call_5$	$f_{31} = f_4$ $f_{32} = f_5$
Cell 4	$Call_{41} = Call_6$ $Call_{42} = Call_7$ $Call_{43} = Call_8$	$f_{41} = f_6$ $f_{42} = f_7$ $f_{43} = f_8$
Cell 5	$Call_{51} = Call_9$ $Call_{52} = Call_{10}$	$f_{51} = f_9$ $f_{52} = f_{10}$

3.2.2 Stage 2: Identify the range of infeasible solution

With the formation of matrix *E*, the set of frequency channel separation constraint, *C* is transformed into matrix *E*, where the difference between frequencies f_i and f_j must be greater than the entries, E_{ij} as follow:

$$|f_i - f_j| \geq E_{ij} \quad , \qquad i, j = 1, \ldots, M$$

and f_i represents the channel assigned to ith call in the list.

To find f_i, firstly, the initial channel is assigned to the first call in the first cell, which is $f_j = f_1 = 1$. Then the values of all $f_j \pm E_{ij}$, where f_j is all calls that have been assigned with channel and have a nonzero minimal separation with *i*th call, are calculated. The range of $f_j \pm E_{ij}$ is the range for infeasible solutions since the f_i within the range of $(f_j - E_{ij}) < x < (f_j + E_{ij})$ violates the minimal separation constraint. Hence, f_i must be assigned a channel which is outside the range of x. Finally, the lowest available channel outside the range of x is assigned to f_i.

For example, f_1, f_2 and f_3 are assigned with channel 1, 7 and 12, respectively. Then, three ranges need to be computed to assign f_4 as shown by solid lines in Figure 3.4:

1. The frequency different between call 1 and call 4 must be greater than 1 which is $|f_4 - f_1| \geq 1$. As the frequency allocated to the call 1 is equal to 1 ($f_1 = 1$), hence the f_4 cannot be in the range of $0 < f_4 < 2$.
2. The frequency different between call 2 and call 4 must be greater than 1 which is $|f_4 - f_2| \geq 1$. As the frequency allocated to the call 1 is equal to 1 ($f_2 = 7$), hence the f_4 cannot be in the range of $6 < f_4 < 8$.
3. The frequency different between call 3 and call 4 must be greater than 4 which is $|f_4 - f_1| \geq 4$. As the frequency allocated to the call 1 is equal to 1 ($f_3 = 12$), hence the f_4 cannot be in the range of $8 < f_4 < 16$.

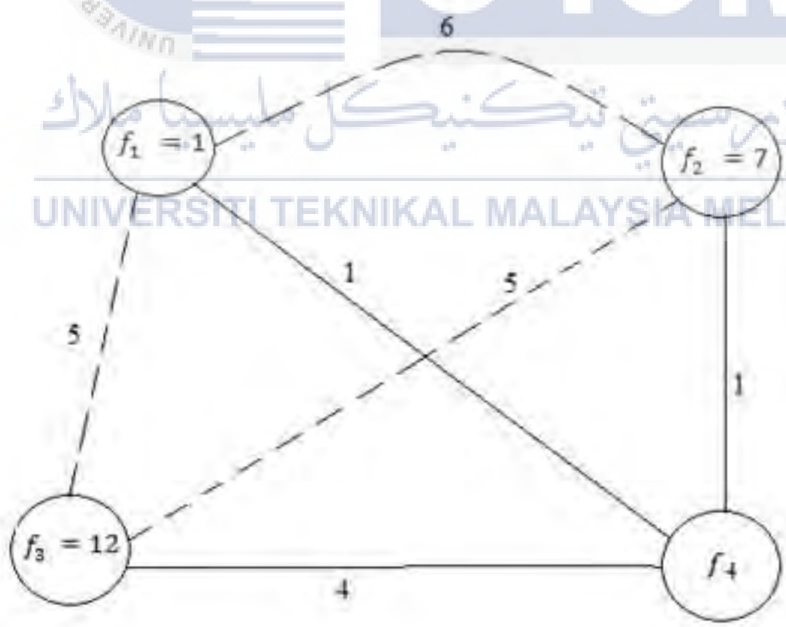

Figure 3.4: A graphical representation of minimum span frequency assignment for $\boldsymbol{f_4}$

3.2.3 Stage 3: Assigned the channel in the range of feasible solution

The 3 ranges obtained in section 3.2.2 are drawn as shown in Figure 3.5. From these 3 ranges of infeasible solutions, the f_4 will be set as 2 since channel number 2 is the lowest feasible available channel that is not in the ranges of $0 < f_1 < 2$, $6 < f_2 < 8$ and $8 < f_3 < 16$ as shown in Figure 3.5.

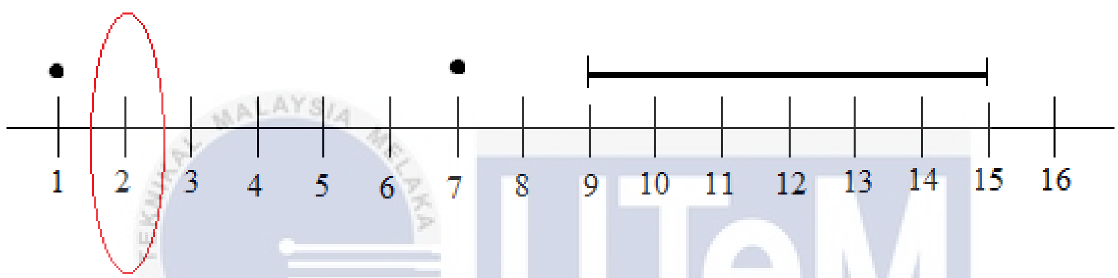

Figure 3.5: A graphical representation of the frequency allocated to the *k*th call in the *i*th cell as low as possible

The rest of the calls are assigned with channels using the same procedure and finally, minimum span is obtained from the maximum number of channel used. Next, the result and analysis will be presented in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter presents and discusses the analysis of simulation data after the simulation run by using Matlab software. All the hypothesis and statements given were supported by the previous similar research with further justification and consideration after careful observation.

4.1 Development of Coding Algorithm

To solve the minimum frequency span problem, the problem formulation is presented in Section 1.3. A local search algorithm is developed to assign channel in such a way the frequency span is being minimized. In developing the algorithm, a matrix E is created to show the minimal frequency separation between every single call as mentioned in Section 3.2. Coding algorithms are developed based on the proposed local search method that includes the 3 stages as shown in Figure 4.1 and Figure 4.3. Figure 4.1 shows the stage 1 coding algorithms that forms the matrix E, the minimal separation of frequency between the calls as shown in Figure 4.2. The data input used in this section are number of cells, N=5, separation matrix $C = \begin{pmatrix} 6 & 5 & 1 & 0 & 0 \\ 5 & 6 & 4 & 2 & 0 \\ 1 & 4 & 6 & 3 & 1 \\ 0 & 2 & 3 & 6 & 2 \\ 0 & 0 & 1 & 2 & 6 \end{pmatrix}$ and the demand of channels or number of calls in each of the cells, $D = \begin{pmatrix} 2 \\ 1 \\ 2 \\ 3 \\ 2 \end{pmatrix}$. The output of stage 1 is the minimal separation of frequency between ith and jth calls where , $j = 1, 2, \dots, M$, as shown in Figure 4.2.

```
C=[6 5 1 0 0 ; 5 6 4 2 0 ; 1 4 6 3 1 ; 0 2 3 6 2 ; 0 0 1 2 6]; %non interference constraint
N=5; %the number of cell
M=[2 1 2 3 2]; %demand number of channel
a=0; % an initialization

    for i=1:N  % create a for loop that add the number 1-N
        for j=1:M(i) % create a for loop that add the number 1-M(i)
            a=a+1, b=0; % movement to the next row for matrix E
            for k=1:N % create a for loop that add the number 1-N
                for l=1:M(k) %create a for loop that add the number 1-M(k)
                    b=b+1; % movement to the next column for matrix E
                    if (k==i && l==j) % to evaluate the matrix E by the terms and condition
                        E(a,b)=0;
                    else
                        E(a,b)=C(i,k); % if the condition is not satisfy
                    end
                end
            end
        end
    end
```

Figure 4.1: Stage 1 coding algorithm

```
E =

     0     6     5     1     1     0     0     0     0     0
     6     0     5     1     1     0     0     0     0     0
     5     5     0     4     4     2     2     2     0     0
     1     1     4     0     6     3     3     3     1     1
     1     1     4     6     0     3     3     3     1     1
     0     0     2     3     3     0     6     6     2     2
     0     0     2     3     3     6     0     6     2     2
     0     0     2     3     3     6     6     0     2     2
     0     0     0     1     1     2     2     2     0     6
     0     0     0     1     1     2     2     2     6     0
```

Figure 4.2: The minimal separation of frequency between the calls

```
P=100; % an initialization
f(1)=1;
for i=1:a %create a for loop that add the number 1-a
    A=ones(1,P);
    for j=1:i % create a for loop that add the number 1-i
        if(E(i,j)>0)
            e=f(j)-E(i,j)
            for k=1:E(i,j)*2-1
                e=e+1;
                if (e>0) %Identify the range of infeasible solution
                    A(e)=0;
                end
            end
        end
    end
    for l=1:P
        if (A(l)==1) %Assign the channel in the range of feasible solution
            f(i)=l;
            break;
        end
    end
end

k=0;M_S=0;
for i=1:N
    for j=1:M(i)
        k=k+1; % movement to the next call in the same cell
        F(i,j)=f(k) %Display the result
        if (F(i,j)>M_S) %Obtain the minimum span frequency
            M_S=F(i,j);
        end
    end
end
```


Figure 4.3: Stage 2 and Stage 3 coding algorithms

Figure 4.3 is shows the coding algorithms of identifying the range of infeasible solution and the assignment of channels in the range of feasible solution. Finally, the minimum span frequency is produced as shown in Figure 4.4.

```
F =

     1     7     0
    12     0     0
     2     8     0
     5    14    20
     1     7     0
```

Figure 4.4: The minimum span frequency

$$f_{11} = 1$$
$$f_{12} = 7$$
$$f_{21} = 12$$
$$f_{31} = 2$$
$$f_{32} = 8$$
$$f_{41} = 5$$
$$f_{42} = 14$$
$$f_{43} = 20$$
$$f_{51} = 1$$
$$f_{52} = 7$$

This obtained result is tabulated into a table as shown in Figure 4.5.

Channel Number

Cell Number	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		■						■													
2													■								
3			■						■												
4						■									■						■
5		■						■													

Figure 4.5: Interference free assignment for 5-cell and 10-channel system

There are 3 call demands in cell 4 where channels 5, 14 and 20 are assigned respectively to these 3 calls. Cell 2 has only 1 call demand and channel 12 is assigned. Cells 1, 3 and 5 have 2 call demands, respectively. Hence, channels 2 and 8 are assigned in cell 3 and channels 1 and 7 are assigned in cell 1 and cell 5, respectively. The minimum frequency separation constraint is fulfilled. For example, $C_{44} = 6$ restricts the minimum difference of frequencies assigned in cell 4 is 6. Hence, the difference between any of the assigned channels to the calls in cell 4 is all at least 6. From this example, channels 1 and 7 are reused at cells 1 and 5, and the minimum span frequency is 20.

4.2 Analysis on the factors affecting the minimum span of channel assignment

Two factors are being tested through the simulation experiments to investigate the effect of the factors on the minimum span frequency assignment. The first factor is distribution of call demands in cells.

Two demand distributions are being tested, which are uniform demand distribution and random demand distribution. The uniform demand distribution is defined as each of the cells has the same number of call demands and the random demand distribution is defined as each of the cells has a random number of call demands. For example, the uniform demand are [1 1 1 1 1], [2 2 2 2 2], [3 3 3 3 3], [4 4 4 4 4] and [5 5 5 5 5] in which the total number of calls equally to 5, 10, 15, 20 and 25 respectively. Meanwhile, the random demand used are [1 1 3 0 0], [2 1 2 4 1], [2 3 7 2 1], [4 1 3 8 4] and [8 7 4 1 5] where the number of calls equally to 5, 10, 15, 20 and 25 respectively.

The second factor is the co-site constraint in the compatibility matrix, C. The channels allocated in the same cell are known as co-site channels. Three cases of co-site constraints which are 4, 5 and 6 units are being tested. The results combination based on these two factors are tabulated as shown in Table 4.1.

Table 4.1: The minimum span frequency with different demand distributions and co-site constraints

Number of calls	Minimum span of frequency					
	Uniform demand			Random demand		
	Co-site constraint 6	Co-site constraint 5	Co-site constraint 4	Co-site constraint 6	Co-site constraint 5	Co-site constraint 4
5	8	5	4	16	13	10
10	18	15	12	26	18	14
15	30	25	20	52	43	26
20	42	35	28	50	38	30
25	54	45	36	84	70	56

From table 4.1, the results of the minimum span frequency form different demand distributions and co-site constraints are further plotted as shown in Figure 4.6. Figure 4.6 shows the uniform demand distribution gives a lower minimum span frequency than the random demand distribution. For random demand, the number of channels needed is larger than that of in uniform demand.

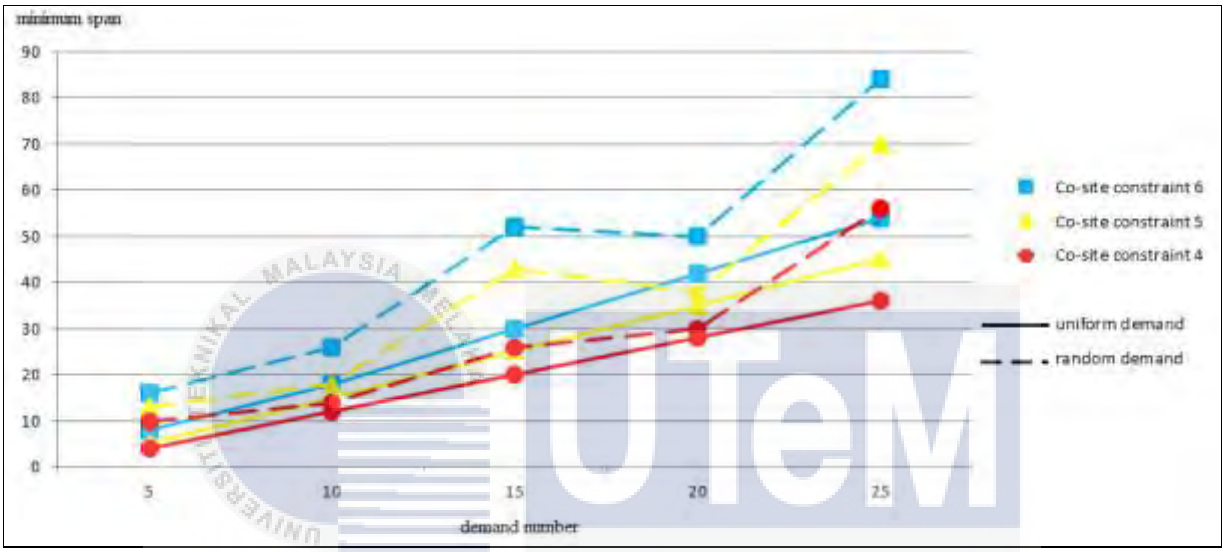

Figure 4.6: Minimum span frequency versus number of demands with different demand distributions and co-site constraints

The frequencies are distributed evenly among uniform demand; while in random demand, the frequencies are distributed randomly. For instance, the number of call demands in random mode for 10 calls is [2 1 2 4 1]; while in uniform demand the call demand is [2 2 2 2 2]. Figures 4.7 and 4.8 show the final allocation of 10 channels for random and uniform distribution, respectively.

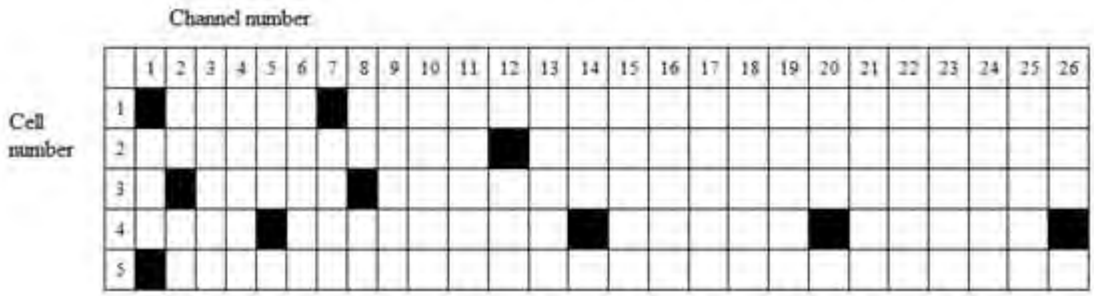

Figure 4.7: Interference free assignment for random demand of 10 calls

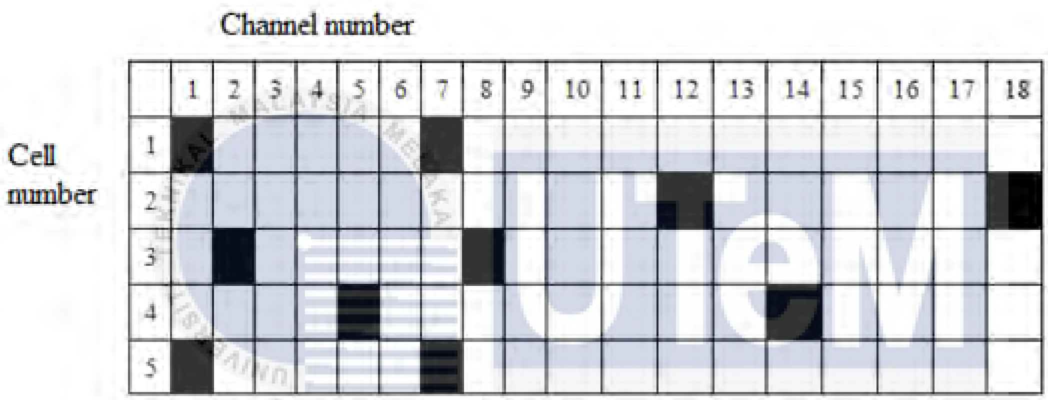

Figure 4.8: Interference free assignment for uniform demand of 10 calls

From this example; the random demand case has 4 call demands in cell 4. When more call demands appear in the same cell, the minimum span of frequency will be larger due to the frequency separation constraint between each of the 4 calls. While for uniform demand it has only 2 call demands in all cells. Hence, the minimum span of frequency will be smaller.

For the second factor which is co-site constraint, it is found that minimum span of frequency increases proportional to the site of co-site constraint. For example, Figures 4.9 and 4.10 show the allocation of channels with uniform demand of 2 for co-site constraint of 4 and 6, respectively. Co-site constraint gives a minimal separation between channels assigned in a cell. In other words, the separation of frequency in Figure 4.9 is 4 compared to 6 in Figure 4.10. Hence, the larger is the co-site constraint value, the larger is the minimum span of frequency.

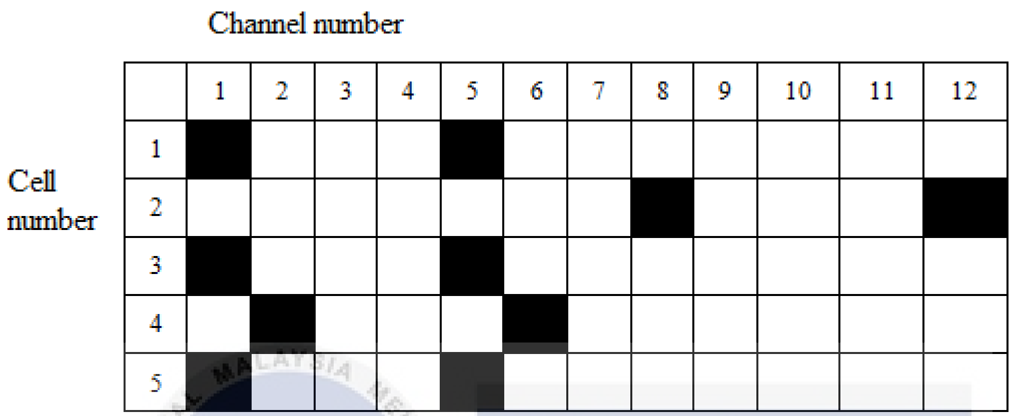

Figure 4.9: Interference free assignment for co-site constraint of 4 with uniform demand of 2

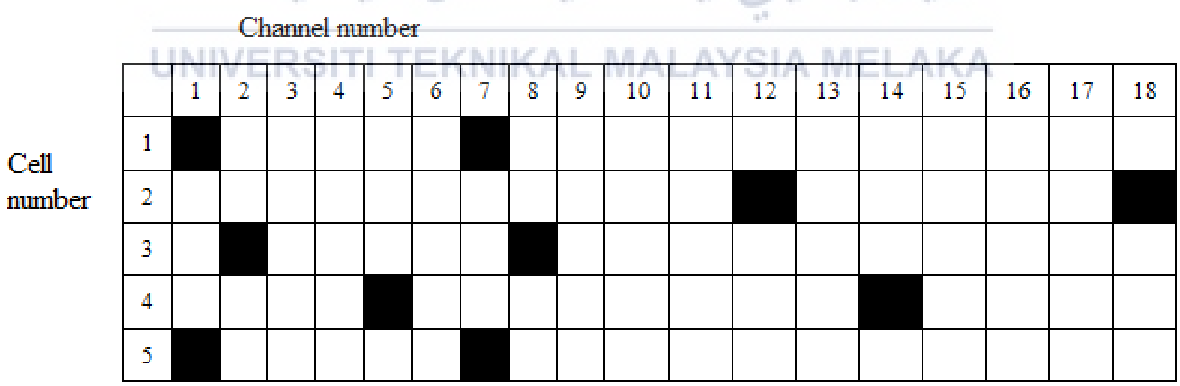

Figure 4.10: Interference free assignment for co-site constraint of 6 with uniform demand of 2

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In recent years, the channel assignment problem has received tremendous attention due to the rapidly growing interest in the area of wireless communication. The channel assignment problem is one of the real world problems within the telecommunications industry. The number of available channels is fixed but demand is increasing due to additional mobile subscribers.

A study on the channel assignment problem has been done in this paper. In each of the sections, detailed techniques and idea used to optimize the minimum span frequency assignment in mobile communication are discussed. This research aims to avoid any of the interferences in mobile communication

This project presents the developed local search algorithms for minimum span frequency assignment and the results are analyzed based on two factors, random and uniform demand distribution, and different co-site constraint values.

As a conclusion, uniform demand distribution gives a lower value of minimum span of frequency. In addition, a higher co-site constraints leads to a higher span of frequency. This means the cell with more call requests should be separated into a number of cells in order to reduce the span of frequency. This suggestion is supported by simulation of the local search with uniform demand and smaller co-site constraint done by using MATLAB software.

5.2 Recommendation

There are several recommendations are suggested to further improve this research outcome. Among all are as follows:

1. The channel borrowing may be proposed. The cell may borrow the channels from neighbors after assigning a set of intact nominal channels to all cell, afford that the borrowed channel avoid interference with channels which are in use in other cells.
2. The hybrid channel assignment schemes with heuristic method which combines the Fixed Channel Assignment (FCA) and Dynamic Channel Assignment (DCA) technique may be developed to optimize the channel assignment problem.
3. Some constant thresholds (named as stop thresholds and re-start) are proposed to use, contrary to the recognition ratio to re-initialize the search at typical intervals to modify the simple local search method.
4. The channel assignment may start from any other calls, instead of the first call in the first cell.

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APPENDICES

Appendix A: Gantt charts of project for FPY 1

		Duration (weeks)													
no	activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Finalize FYP title and supervisor														
2	Gather important information based on title														
3	Briefing & online register title for PSM 1														
4	Research on project background														
5	Research on literature review														
6	Research on methodology of project														
7	Write report PSM 1														
8	Submission report PSM 1														
9	Presentation PSM 1														

Appendix B: Gantt charts of project for FPY 2

		Duration (weeks)													
no	activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Research on literature review														
2	Simulation of problem formulation														
3	Analysis of simulation														
4	Findings and conclusion														
5	Write report PSM 2														
6	Submission report PSM 2														
7	Presentation PSM 2														