OPTIMIZATION OF THE FIXED CHANNEL MODEL IN CHANNEL ASSIGNMENT PROBLEM USING SIMULATED ANNEALING

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"Saya akui laporan ini adalah hasil kerja saya sendiri kecuali ringkasan dan petikan yang tiap-tiap satunya telah saya jelaskan sumbernya."

Tandatangan : ....

Nama Penulis : NORHANI BT. ROMAN

Tarikh : 14/6/17

"Saya/kami akui bahawa saya telah membaca karya ini pada pandangan saya/kami karya ini adalah memadai dari skop dan kualiti untuk tujuan penganugerahan Ijazah Sarjana Muda Kejuruteraan Elektrik (Kuasa Industri)."

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PREFACE

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ABSTRACT

Recently, mobile communication technology is increasingly sophisticated and users have also increased. Because of it, the channel bandwidth is limited. To increase bandwidth in mobile communications is an expensive operation and it may lead to the wasting of bandwidth. Therefore, frequency reused is one of the techniques in mobile communications to improve utilization of bandwidth. In this study, channel assignment problems for fixed or static assignment of channels is studied and solved by using heuristic technique. An optimal solution is the assignment of channels to cells in network communication with the minimum interference. Simulated annealing (SA) is implemented to solve the channel assignment problem in fixed channel allocation in this study. Annealing is a process in which a solid material will heated to past its melting and then cooled to the frozen state. There have some crucial components of SA which are cooling schedule and neighbourhood structure. The algorithm is written into programming coding to maximize the reuse of the frequency with the minimum interference by using Matlab software. An analytical analysis is carried out to investigate the effects of different parameter values on the cost value that represents the interference level in calls.

ABSTRAK

Baru-baru ini, teknologi komunikasi mudah alih semakin canggih dan pengguna juga telah meningkat. Kerana itu, jalur lebar saluran adalah terhad. Untuk meningkatkan jalur lebar dalam komunikasi mudah alih adalah satu operasi mahal dan ia boleh membawa kepada pembaziran jalur lebar. Oleh itu, kekerapan digunakan semula adalah salah satu teknik dalam komunikasi mudah alih untuk meningkatkan penggunaan jalur lebar. Dalam kajian ini, masalah tugasan saluran untuk tugasan tetap atau statik saluran dikaji dan diselesaikan dengan menggunakan teknik heuristik. Satu penyelesaian yang optimum adalah tugasan saluran kepada sel-sel dalam komunikasi rangkaian dengan gangguan minimum. simulasi penyepuhlindapan (SA) dilaksanakan untuk menyelesaikan tugasan masalah saluran peruntukan saluran tetap dalam kajian ini. Penyepuhlindapan adalah satu proses di mana bahan pepejal akan dipanaskan ke masa lalu lebur dan kemudian disejukkan ke negeri ini beku. Ada mempunyai beberapa komponen penting SA yang penyejukan jadual dan kejiranan struktur. Algoritma yang ditulis ke dalam program pengekodan untuk memaksimumkan penggunaan semula frekuensi dengan gangguan minimum dengan menggunakan perisian Matlab. Analisis dijalankan untuk menyiasat kesan nilai-nilai parameter yang berbeza pada nilai kos yang mewakili tahap campur tangan dalam panggilan.

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SA	-	Simulated Annealing
CAP	-	Channel Assignment Problem
SCA	-	Static Channel Assignment
DCA	-	Dynamic Channel Assignment
HCA	-	Hybrid Channel Assignment
SIR	-	Signal-to-Interference
TS	-	Tabu Search
GA	-	Genetic Algorithm

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, people who communicate using mobile communication devices is increasing due to advances in technology. Mobile communications leads to an increase in the use of mobile phones causing limited radio spectrum. The radio signal is used as a medium of information will provide a communication system known as mobile communication. Therefore, what is important in designing mobile communication system is resource management. Resources are managed effectively is indispensable because the radio frequency spectrum is limited. Bandwidth allocation is limited; therefore, reused frequency or channel is one of the best ways that can improve bandwidth utilization. This is recognized as the channel assignment problem (CAP). Channel assignment was to reduce the overall interference while continuing to meet the demands and requirements of the channel. Furthermore, it is to reduce rejection of calls by passing off to call busy.

From one point to another point communications, which is a radio equipment communicates with another placed somewhere else in the world have a strong limitations. A very strong signal is require due to communicate through far distances. In addition, a different communication channels are use when many people use the communication equipment at the same time. The signal must not have too high a frequency when the long distance communication, otherwise it would be stopped through any obstacle, and this limits the amount of operating bands.

It is classified into two types: static channel assignment (SCA) and dynamic channel assignment (DCA). The combination of the two types yields Hybrid Channel Assignment (HCA). In the geographical area, static channel allocation has been split into several cells. In addition, a number of channels allocated to each cell with different patterns depending on the channel re-use demand and continuing need. Put all frequencies in pool, dynamic channel assignment can provide more flexibility and adaptability of traffic and it provides a channel for a new call [1].

According to interference and traffic constraints in the static channel assignment strategy every cell is permanently a set of nominal channels. Before the system is activate, deciding which channels should be assigned to which cells is needed in the assignment policy. In simplest form, a static channel assignment algorithm will allocate the same number of channels to every cell. Due to that, the set of channel is partitioned into a number of subsets of equal cardinality. For example, consider in the common hexagonal tiling as shown in Figure 1.1. As shown at right of figure, the partitioned three subsets which is numbered 1, 2 and 3 is the set of available channels. Meanwhile at the left of figure, indicate the possible assignment for a reuse distance equal to two.

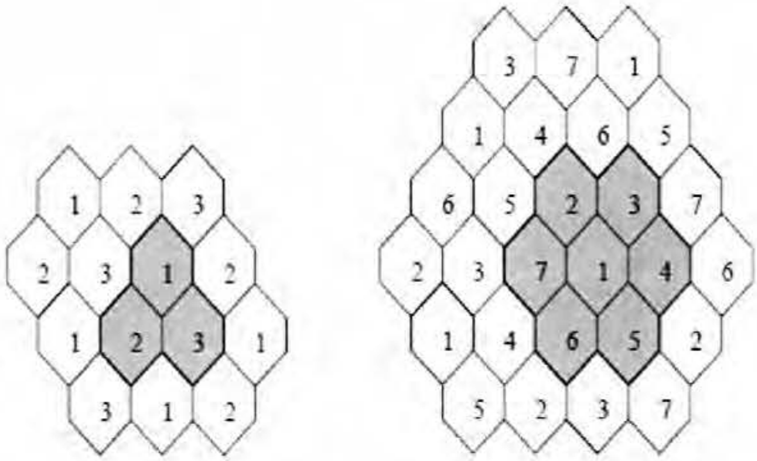

Figure 1.1: Reuse schemes for interference distance[2].

In communication network application, there have two endpoints of the connection where as a fixed antenna and mobile phone. A mobile phones can be pick up at a certain area was cover by each antenna. For a specific region (cell) have cover by each antenna and can assist several network units simultaneously. The frequencies assigned to each antenna must satisfy a number of requirements that depend on the availability, interference levels, technological requirements and size of the area with unacceptable interference[3].

Interference occurs when two users will be sent at a frequency near the radio spectrum. A radio interference susceptible to both external and internal sources when channels are allocated to cells in the communication network. The structure of the building is outside interference happens because the device does not participate in the network, while the channels are spectrally close in frequency domain and receive publications considered geographically close enough internal interference. Therefore, channel allocation is required to receive a call like that the ratio signal-to-interference (SIR) is maintained at an acceptable level. These interference can be classified into three categories with respect to the channel allocation problem are as follows:

- *Co-cell interference*: minimum interference between two channels allocated in the same cell.
- *Co-channel interference*: the same channel cannot be provided in other cells at the same time.
- *Adjacent channel interference:* interference between two adjacent cells allocated to the channel

In this study is aims to apply the approach of heuristic techniques to manage bandwidth allocation of property in the static channel assignments as accessibility is maximized and thus interference between channels is reduced. Channel assignment problem in a static channel complete with simulated annealing algorithm.

1.2 Problem Statement

Nowadays, mobile communication is common throughout the world. People using mobile phone either for calls or messages. Requirements channel are increased from time to time. Therefore, research are needed to provide an efficient channel to minimize disruption to services and maximizing the frequency reuse.

The formulation formed in the static channel assignment (SCA) regarding to the estimate traffic to meet the direct future demand. In a region, there is N is non-overlapping cells and M is the span of channels. While D is the demand vector that specify the channel demand in each of the cell. The minimal separation distance between the channel assigned in cells i and j is presented in compatibility matric C_{ij} which is $N \times N$ a matrix dimensions.

For the diagonal term, $C_{ii} = 5$ represent the co-cell interference constraints where any two channels allocated in cells i must be at least five frequencies apart. $C_{12} = 4$ means the channel assigned in cells one and two must be at least 4 frequencies apart. Furthermore, off-diagonal terms of C_{kj} = 1 known as co-channel and C_{ji} = 2 known as adjacent channel. Meanwhile, C_{ji} = 0 is the same frequencies can be reused. $X_{j,k}$ is set of binary variables are definite as follows:

$$X_{j,k} = \begin{cases} 1, if\ channel\ k\ is\ allocated\ to\ cell\ j \\ 0, otherwise \end{cases}$$

The way to measure penalty cost function by a cost tensor $P_{j,i,m}$ where m = $|k-l|$ which is the distance among channels k and l assigned at cells i and j, respectively. To obtain free-interference the cost decreasing must be far enough apart between two channels. Channel assignment problem in SCA formulated as zero and with the objective function of costs to be reduced. The cost function is shown below [4] and the penalty cost is known as cost value in the project:

$$F(X) = \sum_{j=1}^{N}\sum_{k=1}^{M} X_{j,k} \sum_{i=j}^{N}\sum_{l=k+1}^{M} P_{j,i,m}\ X_{i,l}$$

Formally the cost tensor can be generated from compatibility matrix as below:

$$P_{j,i,m} = \max\{(C_{j,i} - m), 0\},\ \text{for } m = 1, \ldots, M;$$

Cost tensor P is a three-dimensional matrix with diagonal elements are zero, while the first and second dimension is equal to the compatibility matrix [5].

1.3 Objective

There have several objectives as state below:

i. To optimize allocation of channels in mobile network with the minimum interference.

ii. To implement simulated annealing in channel assignment problem.

iii. To investigate the effect of different parameter values on the cost value.

1.4 Scope

In this project, the number of cells, available of channels and call demands are scoped to 21, 51 and 112, respectively. Matlab software is used to code the simulated annealing algorithm for simulation progress.

1.5 Significance of Study

Frequencies that are usable for communication purpose is a limited resource. Equal frequency can be reused in non-adjacent cells caused by mobile phones and base stations are the use of low power transmitters. To maximize the usage of available frequencies or channels need to be reused. Reuse the channels must be assigned in such a many interference between two channels being is minimized. Towards making more effective use of radio resources is accessed by using the frequency reuse.

1.6 Expected Project Outcome

Channel assignment problems have been going on since the demand in mobile phone use increases. Therefore, to solve the fixed channel model of channel assignment problem solution must be all constraints satisfied with the minimum interference. This solution will solve the development of simulation algorithms using MATLAB software.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review on Related Works

Heuristic techniques have used to solve the channel assignment problem. In year 1978, an automated heuristic assignment technique in which channel requirements that proved themselves to be difficult, were solved by Box [1]. Besides that, heuristic techniques are capable to solve complex channel assignment problem, for fixed channel assignment and dynamic channel assignment problem. A heuristic is a one of technique that gives near optimal solutions at reasonable computational cost without being able to guarantee either probability a particular practical solution [1]. Anyway, it is useful in obtaining a satisfied solution for most of the problem where exact solution is unaccusable. Heuristic algorithm can be used to solve an optimization problem. The different methods in heuristic techniques have been suggested, containing local search algorithm, simulated annealing, tabu search, neural networks, genetic algorithm and cultural algorithm.

Simulated annealing is one of the method to solve the channel assignment problem in static channel allocation. Simulated annealing is a single solution based on meta-heuristic. SA is a common method for an approximate solution of an optimization problem that proposed by Kirkpatrick et al. [6]. Simulated annealing is a method can be used if want to maximize or minimize something. Simulated annealing (SA) is a stochastic computational technique established from principles of statistical mechanics to discovered near globally minimum cost solutions to large scale combinatorial optimization problem [7].

2.2 Review of Previous Simulated Annealing

In year 1953, Metropolis's algorithm to match the energy of the system changes the subject to the cooling process; system focused on the final frozen state until certain energy [8]. Annealing is a process in which the solid material is heated up past its melting point and then cooled back into a solid state. After melting the solid material, it is slowly to solid state at any given time melt temperature to reach thermal equilibrium budget. The Metropolis simulation can be used to find solutions for problems that can be implemented with the objective of focusing on the optimal solution [6]. Thus, annealing can be simulated using computer simulation.

A quite time-consuming procedure referred as traditionally simulated annealing which to upkeep must be taken to continue close to equilibrium so as not be fixed in highly local minima[9]. The results of optimality is transferred from finite-time thermodynamic to the context of simulated annealing and through the estimation that constant thermodynamic speed is also the optimal annealing schedule. Therefore, to keep the system near to equilibrium during the complete annealing process by a consequence of their schedule. SA is a random-search technique which is feats an analogy between the way in which a metal cools and freezes into a minimum energy crystalline structure (the annealing process) and the search for a minimum in a more general system[10]. Thus, an analogy of simulated annealing to statistical mechanism is to solve the combinatorial optimization problems.

According to the various method approaches to solving CAP, thus the tabu search (TS) and simulated annealing are presented and compared. Tabu Search meta-heuristics are created to solve hard of large combinatorial optimization problems [7]. TS can be illustrated as a type of neighborhood search with a set of significant and complementary components. In contrast to local search and tabu search, SA does not generate an entire neighborhood but creates it one at random and then evaluates it. With the comparison between two methods approaches are presented which SA is more efficient than the TS. Some small samples test for these methods is shown Figure 2.1. Besides that, SA also have a similar with TS which is allows for non-improving moves.

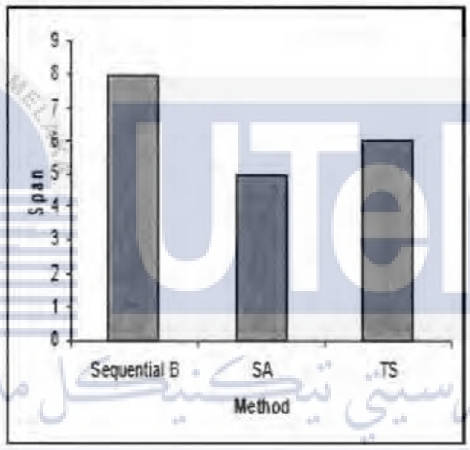

Figure 2.1: Comparison of Algorithm for 15 nodes [7].

The x-axis represent the algorithms used and the number of channels used by each algorithm is represented by y-axis. The simulated annealing and tabu search are tested on two instances having 15 nodes. Besides that, it is also compared to the sequential B algorithm. From the test, it shows that simulated annealing method performs better.

From the various trials conducted by researchers it has been shown that the simulated annealing and genetic algorithm (GA) became two very effective heuristic method for the channel assignment problems [11]. In communication network, to overcome the problem according to the procedures in accordance with the process of evolution by natural selection, known as genetic algorithms [12]. Meanwhile, to solve large scale combinational optimization problem by simulated annealing as an effective algorithm. Thus, to complete the channel assignment problem with new mechanisms and operators of genetic algorithms and simulated annealing recommended. The major idea is to use a traditional approach of genetic algorithm exploring the simultaneously in some areas in the search space and simulated annealing for an enhance search around a few of the selected area at the same time combine as a good mechanism [11]. But then, because of the importance assigned to frequency of radio cells have a certain distance within the frequency domain, this an approach which was considered the solution initialization.

There are plenty of optimization algorithm such as the uphill, genetic algorithms, local search, tabu search, gradient descent and more. But then, to avoid getting caught at local maxima which means the solution that are better than others nearby is strength of simulated annealing algorithms. For annealing simulation, it is known as iteration of improvements scheme (local search) based on the additional parameters: temperature, decrement function and more. And therefore, simulated annealing are an excess of general applicability for an all test conditions and abilities to achieve good quality solutions more consistent. In addition, the major advantages of simulated annealing over other methods are frugality and capability to jump out of local minima [6].

Simulated annealing is a firm and general technique in which can deal with highly nonlinear models, disordered and noisy data and many constraints. It is a method that consider a several practical issues which is the maximum temperature, the scheme for decreasing temperature and the strategy for proposing updates. Since the algorithm does not rely on any restrictive properties of the model, thus it is quite versatile [10]. Besides that, this method can simply be "tuned". Thus, the optimization algorithm can be tuned to improve its performance even though in any reasonably difficult nonlinear or stochastic system. A significant feature of an algorithm is the capability to tune a known algorithm for use in more than one problem.

However, annealing simulation has a weakness that need to be considered. There have a lot of selections are required to turn it into an actual algorithm due to simulated annealing is a metaheuristic [10]. The SA can have a significant effect upon the quality of the outcome at the accurate of the numbers used in execution. Besides that, between the quality of the solutions and the time required to compute them, there must have a perfect interchange. Lastly, when to assign for different classes of constraints and to fine-tune the parameters of the algorithm by fitting work can be rather delicated.

There are other problems can became approached by simulated annealing other than the channel assignment problem. A good examples by approaches simulated annealing is travelling salesman. The algorithm for traveling salesman problem with as much as a few thousand cities used to examine the effect simulation annealing [6]. Apart from that, SA can be applied in partitioning, placement of computers and electronic wiring systems. Furthermore, the SA allowed to be used to complete the hardware / software division

2.3 Summary and Discussion of the Review

This paper contains the review paper of channel assignment for mobile communication. The surveys of several published papers in the channel assignment problem was done to give an overview of various method used to solve CAP. Some of the methods used to solve the problem of channel assignments which are local search, tabu search, simulated annealing, and genetic algorithm. A comparison between several methods to solve the problem of channel assignments indicates that methods are still under research to get the best solution of available frequencies in maximize reused with minimum interference. Furthermore, the advantages focused on simulation annealing; with the available simulated annealing is more simplicity to solve fixed channel model of channel assignment problem.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Development of Topology Simulated Annealing Algorithm

In an optimization problem, the methods used are categorized into exact and approximate methods. When an exact solution is not possible to be obtained, approximate solution would be a good choice as a solution for a problem. In CAP, to maximize the reuse of frequencies with the minimum of interference, approximate method which is heuristic optimization by simulated annealing is used in this project.

Simulated annealing is one of method to maximize or minimize an objective function to finding a good solution to an optimization problem. Simulated annealing is known for the relationship between the type of simulated global optimum thermodynamics and search for optimization problems as shown in Table 3.1. Simulated annealing are a method of descent modified to search the neighbourhood. Their use is moving uphill for the jump out of the local optimum as shown Figure 3.1. The most crucial components for the simulated annealing are cooling schedule and structure the neighbourhood.

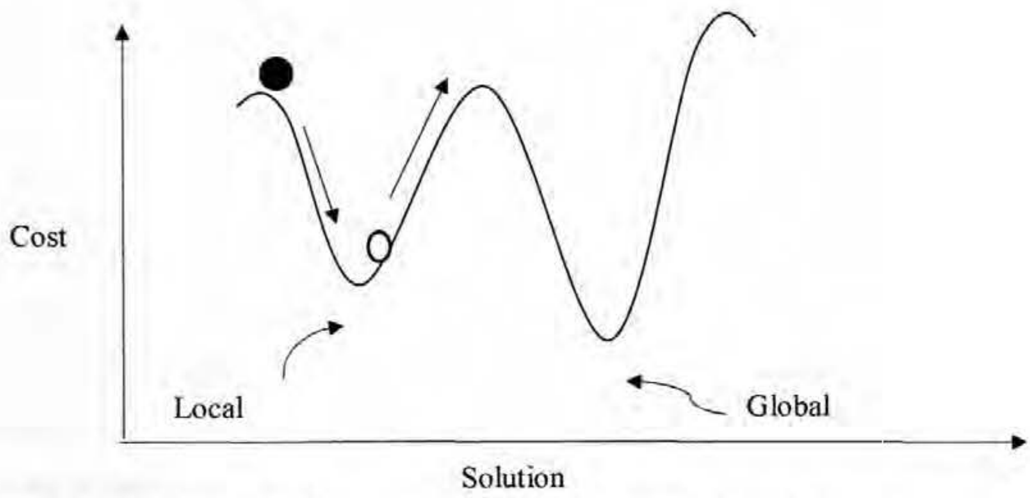

Figure 3.1: Uphill moving of SA to escape from being trapped in local optimum.

Then, in year 1983, simulated annealing was developed to compact with highly nonlinear problems. To find the best solution, an initial solution is generated randomly and the area nearby is being discovered. When neighbour a better solution than the current one, then it will move to the current action; otherwise, the algorithm stays put. The best solution is the global optimum solution. SA randomly enter the right amount into the local optimum to escape early in the process, when the solution close. The main requirements of simulated annealing are initial solution, neighbourhood structure, fitness function (acceptance probability) and cooling strategy.

At each iteration, objective function generates of values for the two solutions are the current solution and a new solution were compared. A small part of the solution rather than increase-acceptable solution is always accepted as it improves the chance of escape local optima in the search for global optimum. But then, the probability of receiving non-improving solutions are dependent on the parameters of temperature, which usually do not increase with each iteration of the algorithm. The temperature decrease as the number of iterations increases (cooling) as shown in Figure 3.3. To close the neighbourhood of configuration, there are some easy option that consists of a single flip and flip-flops -flop. For a single flip, in one channel can be moved in a single cell. Otherwise, flip-flop is replacing one of the channels used by the channel which is not used in the cell.

3.1.1 Initial Solution

In iterative enhancement schemes, which challenge move some existing, suboptimal solution in the direction of a better, lower cost solution. All the values of objective function, taken over all the configuration space of the cost value. In practical, the iterative enhancement algorithms often start with a random initial solution. To catch the good solution, require to move the known solution to improve the solution. In Figure 3.2, is indicate the initial solution is generated for problem D_1. In the real world situation, the co-site constraint can cause more interference. Any numbers of channel assigned to the same cell must have the distance defined in the compatibility matrix. The search efficiency is improved to get an initial solution.

• :Frequency assigned

←→ : co-site constraint

Figure 3.2: Initial solution generation

3.1.2 Neighbourhood Structure

The neighbourhood structure is to allow a thorough search of the room, only small perturbations should be allowed. There consist of flip-flop, compact packaging and wide flip-flop. In the flip-flop is a channel owned by deactivate the cells and a different channel will be active and then select the channel that was assigned to the cell selected randomly; therefore, de-allocate the channels used and provides a channel that is not used. For compact packaging is to provide a mechanism whereby the allocation was bunched up as tightly as possible without preventing local costs. And then, flip-flop in the area which the local minimum is set in through the single steps cannot justify the algorithm to climb out.

3.1.3 Fitness Function

Official proof of simulated annealing convergence to global optimum. There is a Markov chain and stopping criteria. It is clear that the transitional measures taken in order to find a solution to custom a Markov chain. Search transition is well-defined by the structure of the neighborhood that produced by a single iteration or channel for the current situation. Hence, stop criteria is stated that the algorithm ends. It must be set when the algorithm has reached a temperature low enough and there is no significant improvement yet possible, the algorithm ends.

However, after neighboring configuration, a SA was assumed to change its arrangement from cost c_{old} to cost c_{new} with probability[7].

$$\text{Probability} = e^{-((C_{new} - C_{old})/T)}$$

where T is known as Boltzman constant. If c_{new} is smaller than c_{old} then the new configuration has a lower cost the old once and the system always accepts this move. If c_{new} is greater than c_{old} then the new configuration can be accepted with probability $(0 < \text{prob} < 1)$ and therefore, help the system to come out of a local minima.

3.1.4 Cooling Schedule

For a large class of problems, the cooling schedule can be applied in a consistent way. Implementation of different cooling schedule can be obtained a good solution for CAP. For the initial temperature, there is a way to allow the free exchange of approximate solution in the region, but if there is a final solution, it is to be independent of the initial. In the process of simulation heated, t is set to 0 and then the system can be heated quickly up to the desired acceptance ratio is where the ratio of revenue is between 0.7 and 0.9. But then, have various effects when the initial temperature is too high will cause redundant processing overhead. Meanwhile, a higher initial temperature needed to away from local minima. Then, the cooling effect and decrease the temperature should be in a much slower rate in the mid-temperature range for better results. For the final temperature, several iterations were passed without any receipt move at zero temperature.

Table 3.1: The term between thermodynamic simulation and optimization problem.

Thermodynamic Simulation	Optimize Problem
System State	Solution
Molecular Positions	Decision Variables
Energy	Objective Function / Cost
Ground State	Global Optimum
Metastable State	Local Optimum
Rapid quenching	Local Search
Temperature	Control Parameter, T
Careful Annealing	Simulated Annealing

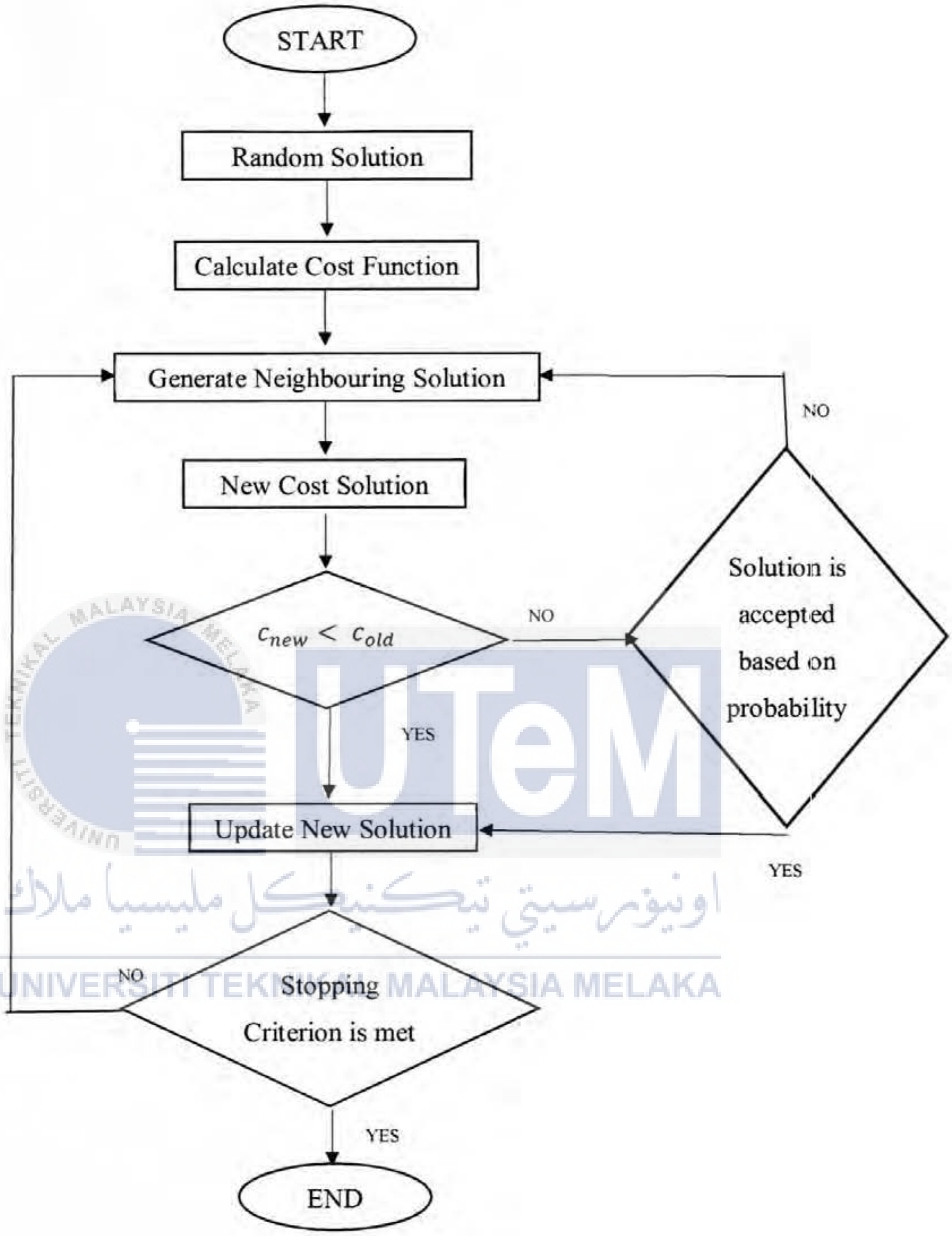

Figure 3.3: Flowchart of Simulated Annealing Methods.

3.2 Development of Coding Algorithm

Algorithm of simulated annealing is coded into Matlab programming to solve the channel assignment problem. The function handle named *CostValue* accepts *input X, N, M, D* which represents binary set number of cells, number of available channels and total demand calls, respectively, and returns output *cost*. Figure 3.4 shows the function handle that computes the cost based on the objective function as shown in Section 1.2.

```
% the objective function to get the value of interference

function cost = CostValue(X,N,M,D)


C=[3 2 0 0;2 3 0 1;0 0 3 2;0 1 2 3];
    sum1=0;
    sum2=0;
    sum3=0;

    for j=1:N  % N is non-overlapping cells
        for k=1:M % M is the span of channels
            sum1=0;
            for i=1:N
                for l=1:M
                    m=abs(k-l);  % m is distance between channels
                    P= max((C(j,i)-m),0);  % P is cost tensor
                    sum1 = sum1 + (P*X(i,l));
                end;
            end
            sum2 = sum2 + (X(j,k)*sum1);
        end
    end
    sum3=sum2-D*C(1,1);
    cost = sum3/2 % the cost value
end
```

Figure 3.4: Function handle for computing the cost value.

As shown in Figure 3.5, initial control parameter, T and the cooling rate are first set at 1000 and 0.95. Control parameter, T is analogous to the temperature in the cooling process. There have three main strategies in setting the initial temperature. First, initial temperature is set high enough to accept all neighbors during initial phase of search. Second, temperature is determined experimentally based on the deviation of the objective function of obtained solutions with several runs. Third, initial temperature to predetermined acceptance rate. Figure 3.5 shows all the initial setting of parameters and the data set used.

```
% this is optimization the channel assignment problem using
% simulated annealing

%setting temperature
T = 100;  % set of initial temperature
Cooling_Rate = 0.95;  % acceptance rate

%the variable of channels and cells are defined
N=4; M=8; D=7;
X=zeros(N,M);
X(1,5)=1;X(2,2)=1;X(3,6)=1;  %channel assigned
X(4,1)=1;X(4,4)=1; X(4,7)=1; X(4,8)=1;  %channel assigned

Best_X=X;
Accepted_X = X;
Accepted_CV = CostValue(X,N,M,D);
index=0;
Best_CV = Accepted_CV;
```

Figure 3.5: Parameters setting and function defining.

Figure 3.6 shows the developed programming coding of simulated annealing for channel assignment problem using Matlab software from the latest accepted solution. If the new generated solution gives a lower cost value than the accepted solution, the new generated will be accepted and replaces the accepted solution. Otherwise, the new generated solution will be accepted with a certain probability under the acceptance probability strategy as shown in Figure 3.7. In generating a new neighbour solution, one randomly chosen call will be assigned with a new channel to form a new binary set. This new binary set will be used to compute for its cost value to check the fitness of solution.

```
% for existing channel assigned at any cell
% there are random assigned and calculate cost function
for iteration = 1:999
    for i = 1:N
        k = randi(M);
        X = Accepted_X;
        for j = k:M
            if (X(i,j)==1)
                rand_1 = j;
                break;
            else
                for j = 1:k
                    if (X(i,j)==1)
                        rand_1 = j;
                        index=1;
                        break;
                    end
                end
                if(index==1)
                     index=0;
                     break
                end
            end
        end
% there are generate neighbouring solution and get new solution
% Choose the new solution has a smaller cost than the old solution
% swap two channels allocation
       for j = 1:999
            k = randi(M);
            if (k ~= rand_1 && X(I,k)==0)
                rand_2 = k;
                break;
            end
       end
       X(I,rand_1) = 0; % channel not assigned
       X(I,rand_2) = 1; % channel unused are assigned
       CV = CostValue(X,N,M,D);
       if (CV < Accepted_CV)
           Accepted_CV = CV;
           Accepted_X = X;
           if (CV < Best_CV)
               Best_CV = CV
               Best_X = X;
           end
       end
      Acceptance Probability Strategy

    T = T*Cooling_Rate;
      if (T < 0.1)
         break;
      end
end
```

Figure 3.6: Programming coding of simulated annealing for channel assignment problem.

In the case where the cost value of a new neighbor is greater than the one from accepted solution, the probability of acceptance for the solution will be computed. The probability follows a Boltzman distribution for these non-improving neighbours. Non-improving solution is accepted with the aim to escape local optima. The acceptance probability of a non-improving solution is higher at a higher temperature. As the iteration runs, the temperature reduces and the iteration stops when the stopping criteria is met. In other words, iteration stops when the temperature drops below a threshold value, which is 0.1 in this project. Finally, the solution with the lowest cost value among all the visited solution is selected as the optimal solution.

```
% solution is accepted based on probability

    if (CV > Accepted_CV)
        Acceptance_Prob = exp(-(CV-Accepted_CV)/T);
        if (Acceptance_Prob > 0.95)
            Accepted_CV = CV;
            Accepted_X = X;
        end
    end
```

Figure 3.7: The acceptance probability strategy

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result and Discussion

Project formulation by Smith and Palaniswami [4] is used to compute the cost penalty value. This formulation is widely known for fixed channel model in channel assignment problem. The result is obtained based on the simulated annealing, annealing applied in the problem formulate by using Matlab.

The data from previous research on the CAP and the SA [5],[13] is used. The two sets of the channel demands are given as follows:

$D_1 = [1, 1, 2, 3]$

$D_2 = [1, 1, 1, 2, 3, 6, 7, 6, 10, 10, 11, 5, 7, 6, 4, 4, 7, 5, 5, 5, 6]$

The simulation algorithm is run using a variety of problem configurations. C_1 is the compatibility matrix for call demand D_1 as shown in Figure 4.1. Meanwhile, Figure 4.2 shows the compatibility matrix, C_1 for call demand D_2. The diagonal term, $C_{ii} = 3$ shows that any two channels assigned in the same cell must be at least four frequencies apart in order to have zero co-site interference. $C_{12} = 2$ means the channel assigned in cells 1 and 2 must be at least three frequencies apart. Furthermore, off-diagonal terms of $C_{ij} = 1$ is known as co-channel constraint and $C_{ij} = 2$ is known as adjacent channel constraint. Meanwhile, $C_{ij} = 0$ indicates the same frequency may be used in the cells i and j at the same time.

$$C_1 = \begin{bmatrix} 3 & 2 & 0 & 0 \\ 2 & 3 & 0 & 1 \\ 0 & 0 & 3 & 2 \\ 0 & 1 & 2 & 3 \end{bmatrix}$$

Figure 4.1: Compatibility matrix for D_1

$$C_2 = \begin{bmatrix}
3 & 2 & 1 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
2 & 3 & 2 & 1 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\
1 & 2 & 3 & 2 & 1 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 2 & 3 & 2 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 2 & 3 & 0 & 0 & 0 & 0 & 1 & 2 & 2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 3 & 2 & 1 & 0 & 0 & 0 & 0 & 2 & 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
2 & 1 & 0 & 0 & 0 & 2 & 3 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 1 & 0 & 0 \\
2 & 2 & 1 & 0 & 0 & 1 & 2 & 3 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 1 & 1 & 0 \\
1 & 2 & 2 & 1 & 0 & 0 & 1 & 2 & 3 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 1 & 1 & 1 \\
0 & 1 & 2 & 2 & 1 & 0 & 0 & 1 & 2 & 3 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 0 & 1 & 1 \\
0 & 0 & 1 & 2 & 2 & 0 & 0 & 0 & 1 & 2 & 3 & 2 & 0 & 0 & 0 & 0 & 1 & 2 & 0 & 0 & 1 \\
0 & 0 & 0 & 2 & 2 & 0 & 0 & 0 & 0 & 1 & 2 & 3 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 2 & 1 & 0 & 0 & 0 & 0 & 0 & 3 & 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 2 & 2 & 1 & 0 & 0 & 0 & 0 & 2 & 3 & 2 & 1 & 0 & 0 & 1 & 0 & 0 \\
1 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 3 & 2 & 1 & 0 & 2 & 1 & 0 \\
1 & 1 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 3 & 2 & 1 & 2 & 2 & 1 \\
0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 3 & 2 & 1 & 2 & 2 \\
0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 0 & 0 & 1 & 2 & 3 & 0 & 1 & 2 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 0 & 3 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 2 & 3 & 2 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 2 & 2 & 1 & 2 & 3
\end{bmatrix}$$

Figure 4.2: Compatibility matrix for D_2

Simulation experiments are earned out to investigate the effect of different parameter values on the cost value. There are two sets of data being used for the simulation work. The size of first set of data is smaller than second set of data. First set of data parameters involves 4 cells, demand calls of 7 from D_1 and compatibility matrix C_1. Cooling rate and number of channels are varies from 0.7 to 0.95 and 6 to 10, respectively. For second set of data, it consists of 21 cells, demand calls of 112 from D_2 and compatibility matrix of C_2. Cooling rate and number of channels are varies from 0.7 to 0.95 and 21 to 51, respectively. Table 4.1 shows the simulation results for the first set of data.

Table 4.1: Simulation results with different cooling rates and number of channels available for $N = 4$ and $D = 7$

Cooling Rate	Best cost value (Best_CV)				
	Number of channels or bandwidth (M)				
	6	7	8	9	10
0.70	5	4	2	1	0
0.75	5	3	2	1	0
0.80	4	3	2	1	0
0.85	4	3	2	1	0
0.90	4	3	2	1	0
0.95	4	3	2	1	0

Based on the given parameters of the first data set, case of 10 channels provides an interference free assignment as shown in Table 4.1. Theoretically, to optimize the channel assignment with the minimum interference, it requires more channels. However, in the real life, the number of channels available is limited compared to the calls demand. Hence, the channels are reused in more than one call to satisfy the call demands. Due to this, interference occurs but be kept at the minimum level.

Simulation results in Table 4.1 is further plotted into a graph as shown in Figure 4.3. The cost values decrease as cooling rates increased from 0.75 to 0.8 and 0.7 to 0.75 for the cases $M = 6$ and $M = 7$, respectively. The cost value remains constant for the rest of cases as the problem size is small significantly. Besides, the cost value is higher when the number of channels is lower. Table 4.2 shows the simulation results of second data set.

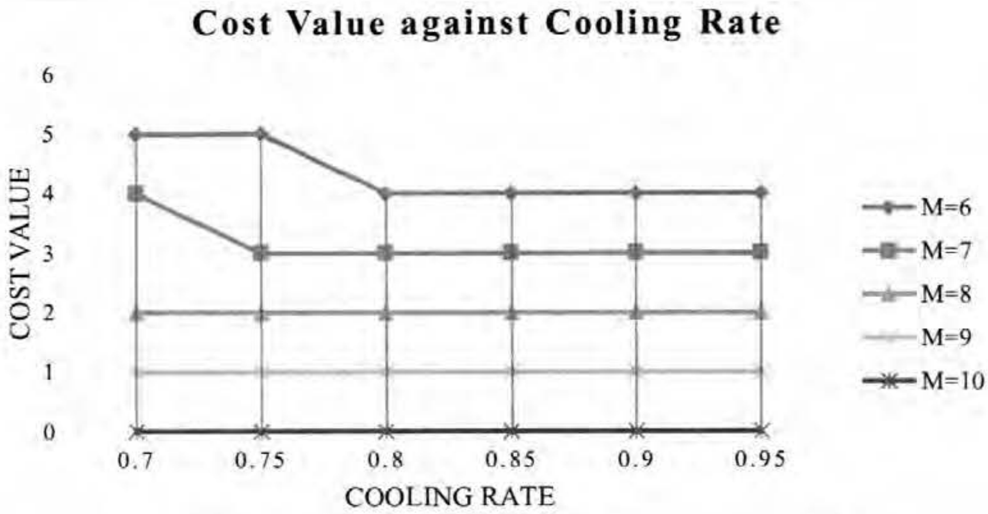

Figure 4.3: Cost value against cooling rate for $D = 7$

Table 4.2: Simulation results with different cooling rates and number of channels available for $N = 21$ and $D = 112$

Cooling Rate	Best cost value (Best_CV)			
	Number of channels or bandwidth (M)			
	21	31	41	51
0.70	337	222	154	124
0.75	325	206	142	116
0.80	324	206	140	113
0.85	321	192	139	106
0.90	316	191	123	96
0.95	316	180	110	74

Based on the given parameters of the second data set, the number of channels are varied in 21, 31, 41 and 51 and the cooling rates are varied in 0.70, 0.75, 0.80, 0.85, 0.90 and 0.95. The result is plotted into a graph as shown in Figure 4.4. Cooling rate of 0.70 has a faster temperature drop in the annealing process compared to the cooling rate of 0.95. The simulation result gives a cost value of 124 and 74, respectively for the case of M = 51. When the number of channels available is reduced to 41, cost value drop from 154 to 110 for cooling rate 0.70 and 0.95, respectively. Next, as the number of channels available is further reduced to 31, the possible solution gives a cost value of 222 for cooling rate 0.70 and the cooling rate of 0.95 gives a lowest cost value than 0.70 cooling rate which is 180.

In overall, cost value decreases from fast cooling rate 0.70 to slow cooling rate 0.95. This is due to the temperature of cooling rate 0.95 drops slowly compared to cooling rate of 0.70. At a higher temperature, the acceptance probability of non-improving solution is higher and this may increase the chance to escape from local minima. Hence, global minima can be found. It is proved that SA is able to find the global optimum by controlling the rate of cooling schedule of the temperature. It is proved that SA can find the global optimum by controlling the rate of cooling schedule of the temperature

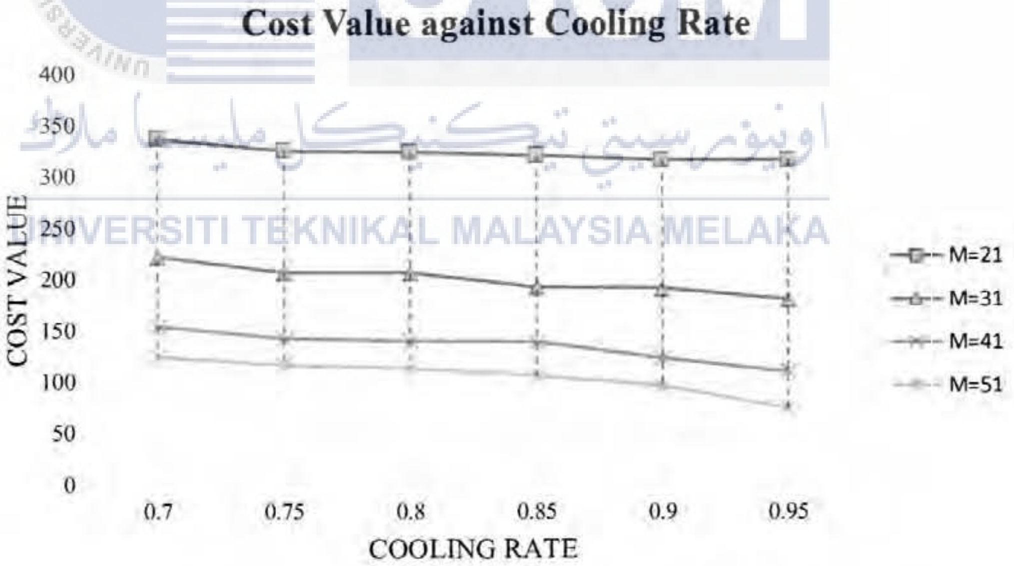

Figure 4.4: Cost value against cooling rate for $D = 112$

Simulation results in Table 4.2 is further plotted into a graph as shown in Figure 4.5 to give a better sight on the effect of channels available to the cost value. Figure 4.5 shows clearly the cost value decreases as the number of available channels increases for all different cases of cooling rate. This is due to the more severe of violation on the minimal frequency separation constraint with lesser number of channels.

Figure 4.5: The cost value against channels available for $D = 112$

As a conclusion, cost value is lower when a higher cooling rate is used. Number of available channels affects the cost value in such a way lower number of channels leads to higher interference in calls due to minima frequency separation constraint.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In light of above, an optimization allocation of channels in mobile network with the minimum interference and an implementation of simulated annealing in channel assignment problem are carried out. An algorithm is developed based on simulated annealing technique by using Matlab software to search for the optimal solution of channel assignment The effect of number of available channels to the cost value according to the different of cooling schedule are investigated. It shows a fast cooling schedule gives a higher cost value. Therefore, to optimize the cost value with the minimum number of channels, a slow cooling rate should be used.

5.2 Recommendation

To improve the solution, simulated annealing may be combined with local search in solving the channel assignment problem. Local search may used to produce the initial solution instead of using a random assignment of channels.

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APPENDIX A

GANTT CHART OF FYP I & FYP II

ACTIVITY	FYP 1														FYP 2													
	DURATION (WEEKS)														DURATION (WEEKS)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Confirmation Title	■	■	■	■	■	■	■																					
Identify and Read Literature		■	■	■	■	■	■	■	■	■	■	■			■	■	■	■	■	■								
Finalise Objective	■																											
Research Strategy and Method		■	■	■																								
Preliminary Result					■	■	■	■																				
Simulation															■	■	■	■	■	■	■	■	■					
Analysis the Result																	■	■	■	■	■	■	■					
Collect Data																	■	■	■	■	■	■	■					
Writing Report for FYP 1									■	■	■	■	■															
Seminar of FYP 1														■														
Writing Report for FYP 2																								■	■	■	■	
Seminar of FYP 2																												■

APPENDIX B

CHANNEL ASSIGNED IN CELLS WITH D = 7 AND M = 6 FOR COOLING RATE 0.70

	1	2	3	4	5	6
1					•	
2		•				
3			•			•
4		•		•	•	

Figure A: The initial channel assigned, X

	1	2	3	4	5	6
1					•	
2		•				
3			•			•
4	•			•	•	

Figure B: The channels assigned as Accepted_X

	1	2	3	4	5	6
1					•	
2		•				
3			•			•
4	•		•		•	

Figure C: The channels assigned as Best_X.

APPENDIX B

CHANNEL ASSIGNED IN CELLS WITH D = 7 AND M = 7 FOR COOLING RATE 0.70

	1	2	3	4	5	6	7
1				•			
2		•					
3		•			•		
4				•	•		•

Figure D: The initial channel assigned, X

	1	2	3	4	5	6	7
1				•			
2		•					
3		•			•		
4	•			•			•

Figure E: The channels assigned as Accepted_X

	1	2	3	4	5	6	7
1				•			
2		•					
3		•				•	
4	•			•			•

Figure F: The channels assigned as Best_X.

APPENDIX B

CHANNEL ASSIGNED IN CELLS WITH D = 7 AND M = 8 FOR COOLING RATE 0.70

	1	2	3	4	5	6	7	8
1								•
2				•				
3	•			•				
4		•				•		•

Figure G: The initial channel assigned, X

	1	2	3	4	5	6	7	8
1								•
2				•				
3	•			•				
4			•			•		•

Figure H: The channels assigned as Accepted_X

	1	2	3	4	5	6	7	8
1								•
2				•				
3	•			•				
4			•			•		•

Figure I: The channels assigned as Best_X.

APPENDIX B

CHANNEL ASSIGNED IN CELLS WITH D = 7 AND M = 9 FOR COOLING RATE 0.70

	1	2	3	4	5	6	7	8	9
1								•	
2		•							
3	•				•				
4		•	•				•		

Figure J: The initial channel assigned, X

	1	2	3	4	5	6	7	8	9
1								•	
2		•							
3	•				•				
4			•				•		•

Figure K: The channels assigned as Accepted_X

	1	2	3	4	5	6	7	8	9
1								•	
2		•							
3	•				•				
4			•				•		•

Figure L: The channels assigned as Best_X.

APPENDIX B

CHANNEL ASSIGNED IN CELLS WITH D = 7 AND M = 10 FOR COOLING RATE 0.70

	1	2	3	4	5	6	7	8	9	10
1					•					
2							•			
3				•				•		
4						•			•	•

Figure M: The initial channel assigned, X

	1	2	3	4	5	6	7	8	9	10
1					•					
2							•			
3				•				•		
4	•					•				•

Figure N: The channels assigned as Accepted_X

	1	2	3	4	5	6	7	8	9	10
1					•					
2							•			
3				•				•		
4	•					•				•

Figure O: The channels assigned as Best_X.

APPENDIX C

VARIETY OF PROBLEM CONFIGURATION FOR D = 7

Table 1: Configuration of the different of cooling rate with M = 6

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	3.7161e-12	5
25	0.75	0.0753	4.6961e-05	5
31	0.80	0.0990	9.6293e-08	4
43	0.85	0.0923	9.9452e-09	4
66	0.90	0.0955	5.2672e-13	4
135	0.95	0.0983	1.6465e-17	4

APPENDIX C

Table 2: Configuration of the different of cooling rate with M = 7

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	5.7560e-16	4
25	0.75	0.0753	4.6961e-05	3
31	0.80	0.0990	3.1031e-04	3
43	0.85	0.0923	9.9726e-05	3
66	0.90	0.0955	5.2671e-13	3
135	0.95	0.0983	2.5847e-13	3

APPENDIX C

Table 3: Configuration of the different of cooling rate with M = 8

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	1.5489e-04	2
25	0.75	0.0753	4.6961e-05	2
31	0.80	0.0990	3.1031e-04	2
43	0.85	0.0923	9.9452e-09	2
66	0.90	0.0955	8.0760e-05	2
135	0.95	0.0983	6.3700e-05	2

APPENDIX C

Table 4: Configuration of the different of cooling rate with M = 9

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	3.7161e-12	1
25	0.75	0.0753	1.0356e-13	1
31	0.80	0.0990	2.9881e-11	1
43	0.85	0.0923	9.9452e-09	1
66	0.90	0.0955	6.5221e-09	1
135	0.95	0.0983	2.5847e-13	1

APPENDIX C

Table 5: Configuration of the different of cooling rate with M = 10

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	3.7161e-12	0
25	0.75	0.0753	1.0356e-13	0
31	0.80	0.0990	3.1031e04	0
43	0.85	0.0923	9.8908e-17	0
66	0.90	0.0955	6.5221e-09	0
135	0.95	0.0983	6.3700e-05	0

APPENDIX D

VARIETY OF PROBLEM CONFIGURATION FOR D = 112

Table 6: Configuration of the different of cooling rate with M = 11

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	1.5489e-04	720
25	0.75	0.0753	2.2053e-09	712
31	0.80	0.0990	2.9881e-11	710
43	0.85	0.0923	9.9452e-09	709
66	0.90	0.0955	3.4343e-21	706
135	0.95	0.0983	1.0488e-21	704

APPENDIX D

Table 7: Configuration of the different of cooling rate with M = 21

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	1.3810e-23	337
25	0.75	0.0753	2.2053e-09	325
31	0.80	0.0990	9.6293e-08	324
43	0.85	0.0923	9.9180e-13	321
66	0.90	0.0955	8.0760e-05	316
135	0.95	0.0983	1.6465e-17	316

APPENDIX D

Table 8: Configuration of the different of cooling rate with M = 31

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	1.5489e-04	222
25	0.75	0.0753	2.2053e-09	206
31	0.80	0.0990	3.1031e-04	206
43	0.85	0.0923	9.9452e-09	192
66	0.90	0.0955	3.4353e-21	191
135	0.95	0.0983	2.7108e-34	180

APPENDIX D

Table 9: Configuration of the different of cooling rate with M = 41

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	2.3992e-08	154
25	0.75	0.0753	2.2053e-09	142
31	0.80	0.0990	9.6293e-08	140
43	0.85	0.0923	9.9180e-13	139
66	0.90	0.0955	6.5221e-09	123
135	0.95	0.0983	6.3700e-05	110

APPENDIX D

Table 10: Configuration of the different of cooling rate with M = 51

Iteration	Cooling Rate	Temperature	Acceptance Probability	Best cost value (Best_CV)
20	0.70	0.0798	0.0124	124
25	0.75	0.0753	2.2053e-09	116
31	0.80	0.0990	3.1031e-04	113
43	0.85	0.0923	9.9180e-13	106
66	0.90	0.0955	5.2672e-13	96
135	0.95	0.0983	4.0577e-09	74

APPENDIX E

CHANNEL ASSIGNMENT WITH M = 11 AND D =112

Cell No.	Number of Channels	Assigned Channels
1	1	1
2	1	5
3	1	7
4	2	5, 10
5	3	2, 8, 10
6	6	1, 2, 4, 5, 8, 10
7	7	1,3,5,6,7,8,10
8	6	2, 3, 5, 6, 9, 10,
9	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
10	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
11	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
12	5	2, 4, 6, 8, 10
13	7	1, 3, 4, 5, 7, 9, 11
14	6	2, 4, 5, 7, 9, 11
15	4	2, 6, 8, 10
16	4	4, 6, 8, 11
17	7	1, 3, 4, 6, 8, 9, 11
18	5	1, 3, 5, 7, 9
19	5	2, 4, 6, 8, 10
20	5	3, 4, 6, 7, 11
21	6	3, 4, 5, 7, 9, 11

APPENDIX E

CHANNEL ASSIGNMENT WITH M = 21 AND D =112

Cell No.	Number of Channels	Assigned Channels
1	1	1
2	1	5
3	1	7
4	2	5, 18
5	3	12, 18, 21
6	6	3, 7, 9, 13 17, 19
7	7	1,5,11,15,17,20,21
8	6	3, 8, 11, 14, 16, 19
9	10	1, 4, 8, 10, 12, 14, 16, 18, 20, 21
10	10	2, 4, 6, 9, 11, 13, 15, 17, 18, 20
11	11	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21
12	5	4, 10, 14, 16, 20
13	7	2, 5, 8, 12, 16, 18, 21
14	6	4, 6, 10, 13, 15, 17
15	4	2, 12, 16, 21
16	4	7, 11, 15, 18
17	7	2, 7, 11, 14, 16, 19, 21
18	5	4, 8, 10, 11, 14
19	5	6, 9, 16, 17, 20
20	5	3, 7, 12, 18, 21
21	6	1, 4, 9, 14, 16, 20

APPENDIX E

CHANNEL ASSIGNMENT WITH M = 31 AND D =112

Cell No.	Number of Channels	Assigned Channels
1	1	1
2	1	5
3	1	7
4	2	5, 18
5	3	12, 18, 31
6	6	3, 7, 9, 13 17, 29
7	7	1,5,11,15,17,25,31
8	6	3, 8, 11, 14, 16, 29
9	10	1, 4, 8, 10, 12, 14, 16, 18, 24, 31
10	10	2, 4, 6, 9, 11, 13, 15, 27, 28, 30
11	11	1, 3, 5, 7, 9, 11, 13, 15, 17, 29, 31
12	5	4, 10, 14, 26, 30
13	7	2, 5, 8, 12, 16, 28, 31
14	6	4, 6, 10, 13, 15, 17
15	4	2, 12, 26, 31
16	4	7, 11, 15, 18
17	7	2, 7, 11, 14, 16, 19, 21
18	5	4, 8, 10, 11, 14
19	5	6, 9, 16, 27, 30
20	5	3, 7, 12, 18, 23
21	6	1, 4, 9, 14, 16, 30

APPENDIX E

CHANNEL ASSIGNMENT WITH M = 41 AND D =112

Cell No.	Number of Channels	Assigned Channels
1	1	1
2	1	5
3	1	7
4	2	5, 18
5	3	12, 38, 41
6	6	3, 7, 29, 33, 37, 41
7	7	1, 5, 11, 25, 27, 30, 41
8	6	3, 8, 11, 24, 36, 39
9	10	1, 4, 8, 10, 12, 24, 26, 38, 40, 41
10	10	2, 4, 6, 9, 11, 13, 15, 17, 18, 20
11	11	1, 3, 5, 7, 9, 11, 13, 15, 27, 39, 41
12	5	4, 10, 24, 36, 40
13	7	2, 5, 8, 12, 26, 28, 31
14	6	4, 6, 10, 13, 25, 37
15	4	2, 12, 16, 21
16	4	7, 11, 25, 38
17	7	2, 7, 11, 14, 26, 39, 41
18	5	4, 8, 20, 31, 34
19	5	6, 9, 16, 27, 40
20	5	3, 7, 12, 18, 21
21	6	1, 4, 9, 14, 36, 30

APPENDIX E

CHANNEL ASSIGNMENT WITH M = 51 AND D =112

Cell No.	Number of Channels	Assigned Channels
1	1	1
2	1	5
3	1	7
4	2	15, 28
5	3	12, 18, 31
6	6	13, 17, 29, 33, 37, 49
7	7	1, 5, 21, 25, 37, 40, 51
8	6	3, 8, 11, 24, 36, 49
9	10	1, 4, 8, 10, 32, 34, 46, 48, 50, 51
10	10	2, 4, 6, 9, 21, 33, 45, 47, 48, 50
11	11	1, 3, 5, 7, 9, 21, 23, 35, 37, 49, 51
12	5	4, 10, 14, 16, 20
13	7	2, 5, 8, 12, 16, 38, 41
14	6	4, 6, 10, 13, 35, 47
15	4	2, 12, 16, 21
16	4	7, 11, 35, 38
17	7	2, 7, 11, 24, 26, 39, 41
18	5	4, 8, 10, 11, 14
19	5	6, 9, 26, 37, 40
20	5	3, 7, 12, 18, 21
21	6	1, 4, 9, 34, 46, 50