DEVELOPMENT OF A NETWORK PLANNING & ANALYSIS TOOL FOR WIRELESS MESH NETWORK

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DEVELOPMENT OF A NETWORK PLANING AND ANALYSIS TOOL FOR WIRELESS MESH NETWORK

By

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CERTIFICATION OF APPROVAL

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Approved by,

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(AP Dr Varun Jeoti - Project supervisor)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NGUYEN NGOC THANH PHUONG

ABSTRACT

A wireless mesh network is a mesh network created through the connection of wireless access points installed within each user's locale. It can easily, effectively and wirelessly connect entire cities using inexpensive, existing technology - IEEE 802.11 standards. Traditional networks rely on a small number of wired access points or wireless hotspots to connect users; but in wireless mesh network, the network connection can be spread out over hundreds of wireless mesh nodes that "talk" to each other to share network connection across a large area. Therefore, wireless mesh network is considered as a new key technology for the future of wireless network. Although it has been developed and applied in reality, wireless mesh network is still an evolving technology with many issues that require further considerations and studies.

The aim of this project, "Development of Wireless Mesh Network Planning and Analysis Tool", is to create a GUI-oriented modeler for wireless mesh network planning and analysis. The main purpose of network planning is to provide a cost-effective solution in term of two objectives which are coverage and capacity. Network planning covers a wide range of issues from coverage (base station or access point) to core network system. It will develop a tool, using Java programming language, which provides functions to help users do planning setting up a desired wireless mesh network and also techniques to analyze the system. With this tool, network planning can be visualized graphically and can give a better understanding of network performance. By taking into account of many aspects, it will help network operator to optimize their WMN deployments in the future.

This is a research-based project which requires extensive study and complex modeling. There's no other similar study under this current scenario.

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ABBREVIATIONS AND NOMENCLATURES

WMN	Wireless Mesh Network
CA	Channel Assignment
MIMO	Multiple inputs Multiple outputs
OFDM	Orthogonal Frequency Division Multiplexing
CDMA	Code Division Multiple Access
IEEE	International Electrical & Electronic Engineer
WLAN	Wireless Local Area Network
CGW	Cluster Gateway
CAP	Cluster Access Point
SNR	Signal-to-noise ratio
SINR	Signal to Interference Noise ratio
FYP	Final Year Project

CHAPTER 1

INTRODUCTION

1.1 Background of Study

This project focuses on designing network with uniform multi-hop mesh cluster topologies and implementing different channel assignment algorithms to find out a better network performance based on capacity of access points and transmission links.

Recently, wireless access has been developing a new technology, which is considered as a key technology for next-generation wireless networking, called wireless mesh networks. With several advantages over other wireless networks in configurations, infrastructure cost, installation and maintenance, WMN can easily, effectively and wirelessly connect entire large areas using inexpensive, existing technology. WMN technology promises cost-effective broadband wireless access solutions especially in places where fixed infrastructures such as DSL or fiber access are limited or expensive. That's the reason why WMN topic inspires many researchers as well as companies to do research and to apply this network in world reality and offer WMN products. Many wireless standards like IEEE 802.11, 802.15, 802.16 are all working on new specifications for WMN as it may bring many facilities and enhancements to wireless access schemes.

Network planning covers a wide range of design issues from access (base station or access point) to core network system (routing, services, databases, …). As in [1], capacity performance of WMN is generally influenced by a wide range of factors including number of radio interfaces per mesh node, co-channel and adjacent channel interferences, routing, network architecture or topology, antenna types and so on. So planning process and design of a mesh network is a complex task because it depends on above factors and their various combinations as well as on type of regions and the main objective of network itself.

1.2 Problem Statement

As stated above, WMN can be seen as an emerging technology which may bring the dream of seamlessly connected world into reality. But in order for WMN to be applied all as it can be, further studies are needed. It's still an evolving technology nowadays. There are still some technical and open research issues, as transmission rate, performance of physical-layer techniques, multiple-antenna systems, advanced features provided by the physical layer ... WMN's performances remain unclear especially when various interdependent optimization approaches are jointly considered under one single deployment. Therefore, a better understanding can only be acquired through a systematic modeling of the network.

This is a research-based project which requires extensive study and complex modeling. There's no other similar study under this current scenario, a graphical network planning modeler with the considerations of directional antennas, different channel assignment techniques. That is a reason why it inspires the author to work on this research with the hope of building a modeler which helps to provide a clearer view about this studied scenario.

1.3 Objective and Scope of Study

1.3.1 Objective

The objective of this project is to provide a better visualization of the performance through a GUI- oriented modeling of a WMN. From analyzing the behavior of WMN, this tool and findings will help network operator to optimize their WMN deployments in the future.

1.3.2 Scope of Study

The scope of study for this project is to build a modeler, as stated in the title, to study on:

- Effects of using directional antenna and configuration
- Effects of applying different clustering techniques, frequency band and capacity requirements
- Effects of different channel assignment techniques

This project as its stated title modeler only involves simulation from software, no hardware involved. Java programming language is used for this project. In order to implement the modeler, the project is divided into three phases. Phase one is to build platform of modeler. Phase two is iteration with development modeler. And phase three is to complete final product. After each phase, its prototype is analyzed and reviewed to prepare for next prototype.

Based on functions and boundary of the project, the final product will be a user-friendly simulation modeler which allows users to set-up network by following the flow of system design, to draw network topologies, apply channel assignment algorithms, calculate channel interference and get capacity of link and node. From there, users can evaluate the network.

1.3.3 Organization of the thesis

The remainder of this thesis is organized as follows: Chapter two discusses about literature review of wireless mesh network and other related theories for this project. Chapter three describes methodology of this project. Results from our simulation-based evaluation are presented in chapter four, followed with discussion part. Chapter five concludes the thesis as well as gives recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

This chapter is organized as follows: the first section is overview of wireless mesh network, which starts with the introduction of Wi-Fi IEEE 802.11 Family, since WMN is implemented based on existing technology – IEEE 802.11. The followed sections are discussions of other theories which are related and used for the project: mesh topology, link budget, SUI pathloss model, channel assignment, antenna configuration. The last section reviews other existing modelers.

2.1 Overview Wireless Mesh Network

2.1.1 Wi-Fi IEEE 802.11 Family

IEEE 802.11 is a set of standards carrying out wireless local area network (WLAN) computer communication in the 2.4, 3.6 and 5 GHz frequency bands. They are implemented by the IEEE LAN/MAN (Local Area Network/ Metropolitan Area Network) standards committee (IEEE 802). [2] The Wi-Fi IEEE 802.11 family is the most popular wireless local area networking technology with various variants can be found such as 802.11a, b, d, e, f, g, h, i and n. The standard specifies an air interface between clients and access point, or between clients. IEEE 802.11 family operates in unlicensed frequency bands.

- 802.11a operates in the 5 GHz frequency band using the OFDM technology and provides a data rate of 54 Mbps.
- 802.11b operates in the 2.4 GHz frequency band using the CDMA technology (Direct Sequence CDMA) and provides a data rate of 11 Mbps
- 802.11g operates in the 2.4 GHz frequency band using the OFDM technology and provides a data rate of 54 Mbps.
- 802.11n uses Multiple Input Multiple Output (MIMO) in addition to the OFDM and is expected to deliver a typical data rate of about 200 Mbps over a wider range

Table 1: Wireless LAN standards [3]

Wireless LAN Standards				
	802.11a	802.11b	802.11g	Bluetooth
Data Rate	54-72	11	54	721 Kbps 56 Kbs
Frequency	5Ghz	2.4Ghz	2.4Ghz	2.4Ghz
Modulation	OFDM	DSSS/CCK	DSSS/PBCC	FHSS
Channels	12/8	11/3	11/3	79 (1Mhz wide)
Bandwidth Available	300	83.5	83.5 (22MHz per channel)	83.5
Power	40-800mW	100mW	100mW	100mW

Table 1 above is to compare between 3 IEEE 802.11 interfaces with different aspects. New technologies using smart antennas and mesh-network with Wi-Fi increase the distance range significantly.

2.1.2 Wireless Mesh Network

Traditional networks rely on a small number of wired access points (APs) or wireless hotspots to connect among users but in WMN, the connection is spread out among hundreds of wireless mesh nodes that "talk" to each other across a large area. [4] It is because WMN are dynamically self-organized and self-configured. Mesh nodes are small radios that function in the same way as a wireless router. There are continuous connections and reconfigurations by "hopping" from node to node until it reaches destination. Nodes use Wi-Fi standards known as 802.11a, b, g to communicate wirelessly with users and with each other, but they will automatically choose the quickest and safest path in a process known as dynamic routing.

Advantages of WMN include [4]:

- Having lesser wires or can be considered as truly wireless. In WMN, only one node needs to be physically wired a Internet. That one wired node will share the connection wirelessly with all other nodes.
- Using fewer wires, means reducing implementation and set-up cost
- Covering larger area of network
- Being based on Wi-Fi standards which have already been using for most wireless networks.
- Being self-configuring, automatically adjust network structure
- Being self-healing, automatically find the fastest and most reliable paths for connection.
- Being easier to install or uninstall network

- Allowing local network to run faster since it doesn't have to travel back central servers.

So, WMN can easily, effectively and wirelessly connect a very large area with inexpensive and existing technology.

2.2 Mesh Topology

According architecture aspects, WMN can be classified into 3 types: [5]

- Infrastructure/backbone WMN: mesh routers form an infrastructure for clients
- Client WMN: provides peer-to-peer networks among client devices. Client nodes constitute the actual network to perform routing and configuration functionalities as well as providing end-user applications to customers
- Hybrid WMN, which consists of both infrastructure mesh and client mesh.

Access point can be simply understood as a bridge, connected on one side to the radio network and on the other side to Ethernet (usually), forwarding packets between the two networks. AP allows dividing the network in cells. Each AP is at the centre of a cell and is given a different channel. Access points are connected by backhaul link.

A cell is the smallest geographical area covered by a base station. Real cell pattern is never in regular shape:

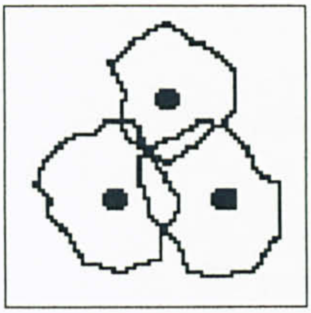


Figure 1: Real cell pattern [6]

For the purpose of designing wireless network, cells are put in regular geometric shapes tessellating a 2D space. Ideal cell pattern is in circle shape:

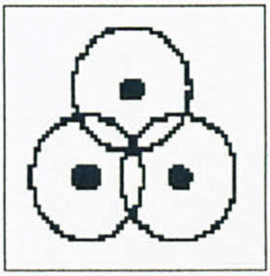


Figure 2: Ideal cell pattern [6]

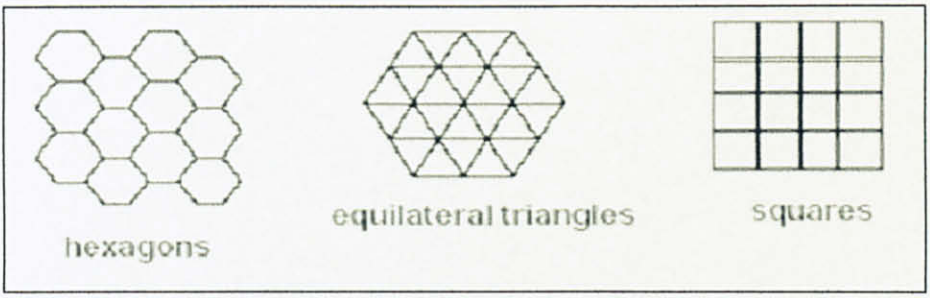


Figure 3: Coverage patterns [6]

The above shapes are regular geometric shapes tessellating a 2D space which cover an entire region without overlap and with equal area. Among those shapes, tessellating hexagon is often used to model cells in wireless systems because it has: ([6])

- good approximation to a circle (useful when antennas radiate uniformly in the x-y directions)
- offer a wide variety of reuse pattern
- simple geometric properties help gain basic understanding and develop useful models

With all of these advantages, hexagon pattern is chosen to be applied network drawing topology.

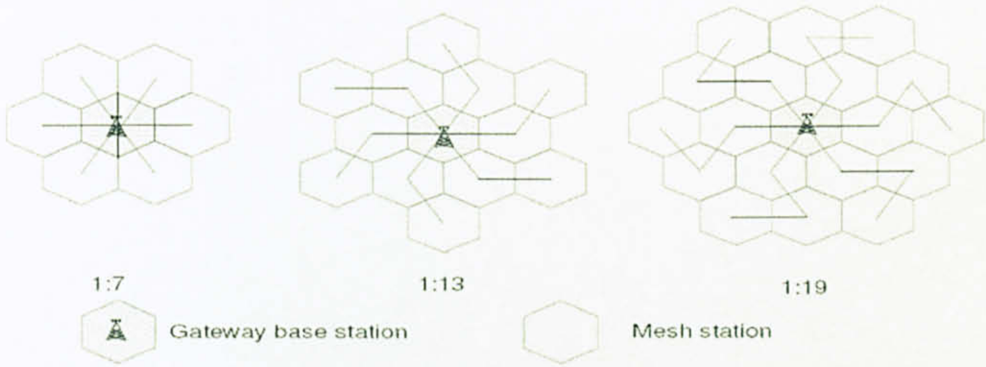


Figure 4: Infrastructure mesh network with different cluster types

Geometry of a hexagonal cell

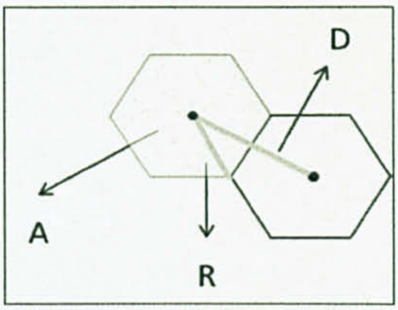


Figure 5: Hexagonal cell

R: radius of hexagon

D: distance between 2 access points

A: coverage area

$$D = 2.R.\cos(\pi / 6) \quad (2.1)$$

$$A = 1.5 * \sqrt{3} * R^2 \quad (2.2)$$

2.3 Link Budget

Link budget is a rough calculation of all known elements of link, accounting all gain & losses from the transmitter, through the medium to the receiver in a telecommunication system, to determine if the signal will have proper strength when it reaches the other end of the link [7]. So link budget can be understood as the maximum path loss which the transmission can accept.

$$LB(dB) = EIRP(dB) - R_{sensitivity}(dB) + G_{rx}(dB) - Total\_Margin(dB) \quad (2.3)$$

Where

$EIRP(dB)$ = equivalent isotropically radiated power, equal to $(P_{tx} + G_{tx})$

$R_{sensitivity}(dB)$ = Receiver sensitivity

$G_{rx}(dB)$ = received antenna gain in dB

$Total\_Margin(dB)$ = total margin in dB including shadow, interference, fading, etc.

Path loss is calculated as shown:

$$Pathloss = -147.6 + 20\log(f_{rf}) + 10\alpha\log(d) + WallLoss \quad (2.4)$$

Where: d is distance (m)

f_{rf} is the operating frequency band (GHz)

α is the propagation coefficient

WallLoss in dBm

Maximum path loss value is link budget value, so if equating two above equations, maximum distance between two access points can be found. And that will be the default distance between two access points for this modeller.

2.4 SUI path loss models

SUI stands for Stanford University Interim. These are channel models which were developed under the Institute of Electrical and Electronic Engineers (IEEE) 802.16 working group [8]. SUI models are extension of the earlier work by AT&T Wireless and Erceg et al. SUI channel models are empirical models with time dispersive characteristics, i.e. multipath delay spread of the channel. It uses three basic terrain types:

- Category A: Hilly/moderate-to-heavy tree density
- Category B: Hilly/light tree density or flat/moderate-to-heavy tree density
- Category C: flat/light tree density

SUI models cover three terrain categories common around the United States and the empirical formulas for the models were obtained based on experiments done in US too. [8]

The median path-loss for the SUI model can be generally written as

$$L = A + 10\gamma \log(d / d_o), \qquad (2.5)$$

for $d > d_o$, where d_o =100m. The term A in the above equation is given by $A = 20\log(4\pi d_o / \lambda)$, where λ is the wavelength in m. The path-loss exponent γ is given by

$$\alpha = a - bh_t + c / h_t \tag{2.6}$$

in which the parameters a, b and c depend on the terrain category and are defined in the table below.

Table 2: SUI model parameters

Model Parameters	Terrain Type A	Terrain Type B	Terrain Type C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

These parameters are obtained at 2GHz frequency and receive antenna height of 2m. In order to use the model for other frequency and receive antenna heights, the following correction terms can be used.

$$L = L + \Delta L_f + \Delta L_h \tag{2.7}$$

where

$$\Delta L_f = 6\log(f / 2000) \tag{2.8}$$

and receive antenna height correction term is given by

$$\Delta L_h = \begin{cases} -10.8\log(h_r / 2), & \text{Categories } A, B \\ -20\log(h_r/2), & \text{Category C} \end{cases} \tag{2.9}$$

where h_r is the receive antenna height.

2.5 Channel Assignment

2.5.1 Objectives

The objective of CA in WMN is to bind each network interface to a radio in such a way that the available bandwidth on each virtual link is proportional to the load it needs to carry.

This is a step-by-step procedure of searching for a frequency channel with adequate bandwidth that can be used without:

- Causing objectionable interference to existing or proposed links
- Receiving objectionable interference from existing or proposed links

2.5.2 Channel Assignment Problem

Channel is a synonym of a specific frequency range on radio, which is used to create a communication link between transmitter and receiver. The aim of CA is to determine which one of all available channels should be assigned to a given 802.11 interface. However, the number of available channels is limited. The bigger the network is, the more interfaces within same interference range are assigned with same channel or partially overlapping channels is. Consequently, the bandwidth available to each interface decreases. Therefore, a good CA algorithm requires effectively balance between the goals of maintaining connectivity and increasing aggregate bandwidth.

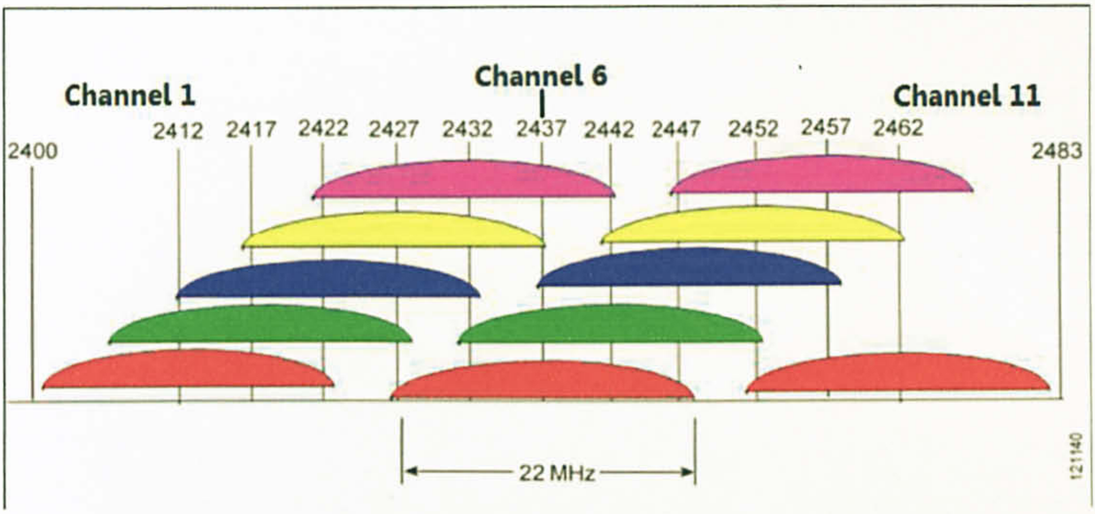


Figure 6: All channels in 802.11g, frequency band 2.4 GHz [9]

Since there is limited number of non-overlapping channels for each band, another way of channel planning is to overlap cells in such a way that each cell would have 3 non-overlapping channels (1, 6, and 11 at the bottom). Figure 6 shows all channels in 802.11g band with different colors represent non-overlapping channels.

2.5.3 Channel Assignment Strategies

2.5.3.1 Types of Channel Assignment Strategies

CA should be carefully planned to avoid degradation caused by channels overlapping interference. CA strategies for coordination-based systems can be classified into three main strategies. [10]

- Fixed channel assignment

- Channels are assigned for designated cells
- Different groups of channels maybe assigned to adjacent cells, but same groups must be assigned to cells separated by a reuse distance to reduce co-channel interference
- It's the easiest one

- Dynamic channel assignment
    - Channels are temporarily assigned to cells in period of time. After that, the channel is returned
    - Any channel that is being used in one cell can only be assign to another cell if distance between 2 cells is larger than reuse distance to reduce co-channel interference
    - Need more transceivers for each base station
    - Worse performance compared to fixed CA in heavy loads case
- Hybrid channel assignment
    - Divide all access points into 2 groups, one for fixed CA, another one for dynamic CA to make use of advantages of both strategies
    - Requires less transceivers than dynamic CA
    - Perform worse than fixed CA in heavy loads case

For this project, according to modeler features, fixed channel assignment strategy is chosen.

2.5.3.2 Literature Review on Channel Assignment Algorithms

Today, there are many channel assignment algorithms are used, each of them has their own advantages and disadvantages. Although there are quite many CA algorithm research works, up till now, there's no optimized CA algorithm. The application of CA algorithm into this project needs further understanding and consideration.

The most straightforward algorithm for doing frequency planning is to simply search through the list of available frequency channels in the appropriate band. Then, at each channel, S/I ratio is calculated at existing as well as new link transmitters. For each considered channel, this calculation must be repeated for any existing link that is a potential interferer.

In [11], the channel assignment problem for mesh network is similar to the list coloring problem, which is constructed that each link receives a color from the list of colors. This list coloring problem is defined a NP-complete (nondeterministic polynomial time) so there is only approximate channel assignment algorithm. The algorithm introduced in this paper is Breadth First Search Channel Assignment (BFS-CA) algorithm, using a breadth first search to assign channels to the mesh radios. Breadth-first search is a graph search algorithm beginning at the root node and explores to all its neighboring nodes, for each of these nodes, they continue explore their unexplored neighbor nodes until it reaches the final goal. So, the algorithm starts from vertices that correspond to links emanating from the gateway then in the process of doing Breadth-first search algorithm, assign to each visited link one channel which has the highest ranked channel that does not conflict with its neighbors. If a non-conflicting channel can't be found, a randomly chosen channel is permanently assigned to the vertex.

The same method is chosen for this project for channel assignment algorithms. Coloring technique is used for this project because it's the best technique for graphical network. There are some other channel assignments introduced in [12]

[13] [14], which aware of interference and take advantage of non-overlapping channel for channel assignment algorithms. Some ideas from these algorithms can be applied for this project with appropriate modifications to be suitable to the modeler.

2.5.4 Channel Interference Effect

According to [15], there are two types of interference:

- Co-channel interference: caused by undesired transmissions carried out on the same frequency channel
- Adjacent channel interference: caused by transmissions on adjacent or partially overlapped channels

Channel interference lower data transfer rates, lower link capacity and node capacity, therefore, lower overall network performance. Furthermore, it causes base stations to broadcast more power at each handset to counter noise. Consequently, it leads to the number of handsets that can be supported simultaneously is reduced. All of the above effects contribute to the greater expenses for operators in network planning.

The paper [15] provides a simple way to quantify the adjacent channel interference and its effect on the throughput performance in IEEE 802.11 WLANs using OFDM or DSSS based on channel distance according to the table below:

Table 3: Attenuation values (in dB) for adjacent channels [15]

c (channel sep.)	1	2	3	4	5
DSSS Theory	0.28	2.19	8.24	25.5	49.87
DSSS Simulation	0.37	1.79	8.03	23.47	53.21
OFDM Theory	**0.55**	**2.46**	**6.6**	**34.97**	**51.87**

OFDM theory is chosen for this project. If two channels are separated more than 5 channels, interference can be avoided.

2.6 Antenna Configuration

Antenna is a transducer designed to transmit or receive electromagnetic waves. There's two types of antenna in term of beam width value, isotropic antenna (omni-directional antenna) and sectorized antenna (directional antenna).

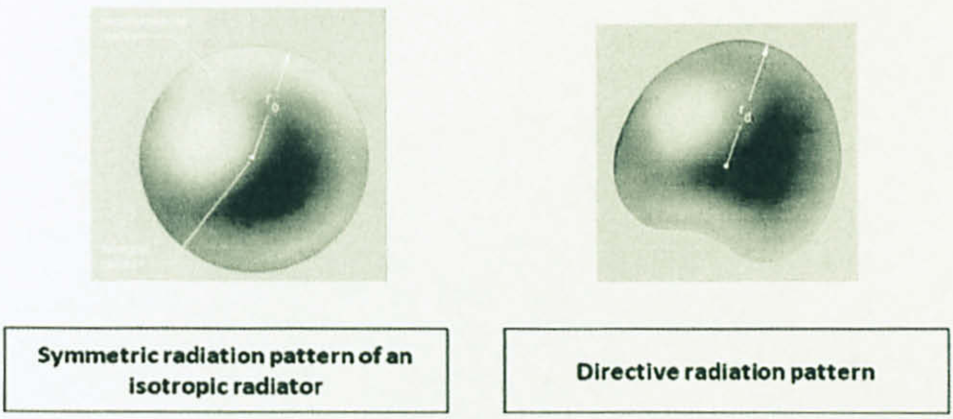


Figure 7: Two types of antenna [16]

The power gain of an antenna is a ratio of the power input to the antenna to the power output from the antenna, often refer to unit dBi. An isotropic antenna radiates equal amount of power in every direction, therefore, it has a linear gain of 1. For directional antenna, it has directivity, the power gain is calculated:

$$G_p = g_d \cdot \eta \tag{2.10}$$

g_d : directive gain

η : radiation efficiency

Directive gain of an antenna is a measure of concentration of the radiated power in a particular direction, in other words, it's a ratio of normalized power in a particular direction to the average normalized power. According to [16], directive gain can be calculated using this table:

Table 4: Computation of directive gain and beam-width for representative aperture-type

Aperture-Type	Beamwidth (From Aperture)	Directive gain (From Aperture)	Directive gain (From Beamwidth)	Antenna Efficiency (Aperture Illumination Efficiency)
Uniformly illuminated circular aperture-hypothetical parabola a 18 dB side-lobe level	$\theta = \frac{58\lambda}{a}$ $\theta = \theta_1 = \theta_2$	$g_d = \frac{15\,a^2}{\lambda^2}$ $g_d = \frac{9.87\,a^2}{\lambda^2}$	$g_d = \frac{52,525}{\theta^2}$ $\theta = \theta_1 = \theta_2$	100%
Uniformly illuminated rectangular aperture or linear array a, b 13 dB side-lobe level	$\theta_1 = \frac{51\lambda}{a}$ $\theta_2 = \frac{51\lambda}{b}$	$g_d = \frac{1.6\,a\,b}{\lambda^2}$	$g_d = \frac{41,253}{\theta_1\theta_2}$	100%
Rectangular horn a) Polarization plane: E-plane a_E 13 dB side-lobe level b) Orthogonal polarization plane: H-plane a_H 26 dB side-lobe level	$\theta_1 = \frac{56\lambda}{a_E}$ $\theta_2 = \frac{67\lambda}{a_H}$	$g_d = \frac{7.5\,a_E\,a_H}{\lambda}$	$g_d = \frac{31,000}{\theta_1\theta_2}$	60%
Nonuniformly illuminated circular aperture (10 dB taper)-normal parabola a 26 dB side-lobe level	$\theta = \frac{72\lambda}{a}$ $\theta = \theta_1 = \theta_2$	$g_d = \frac{5\,a^2}{\lambda^2}$	$g_d = \frac{27,000}{\theta^2}$ $\theta = \theta_1 = \theta_2$	50%
	$a >> \lambda$	$G_d = 10\log_{10}g_d$ dB	$G_d = 10\log_{10}g_d$ dB	

The equation applied to calculate directive gain is the equation in circle, with θ is beam-width of antenna. Antenna beam-width is the angle of an antenna pattern or beam over which the relative power is at or above 50% of the peak power, also known as half-power beam-width.

Radiation efficiency is a measure of those losses internal to the antenna. It's the ratio of the total power radiated by an antenna to the net power accepted by the antenna from a connected transmitter.

Apart from helping to strengthen weak antenna signals, directional antennas also help to reduce interference compared to omni-directional antennas, it also enables antenna transmission to focus only in the desired direction to avoid the interference that weakens them. Recently, smart antenna is one of the most promising technologies nowadays which helps to provide higher network capacity by reducing multipath and channel interference. According to [17], smart antenna employs a set of radiating elements arranged in the form of an array. Signals from these elements are combined to form a movable or switchable beam pattern that follows the desired user. Beside reduction in channel interference, smart antenna has several more benefits, such as range improvement, higher capacity, less transmitted power, compatibility with various multiple access techniques. It's a big challenge to apply smart antenna technology to personal wireless communications since the traffic is denser as well as the time available for a complex computation is limited. However, with powerful, low cost digital processing components and the development of software-based techniques, smart antennas systems have become a practical reality in cellular communications.

2.7 Literature Review of modeler

There is other network simulator doing network planning. Network simulators serve a variety of needs. Compared to the cost and time involved in setting up an entire test bed containing multiple networked computers, routers and data links, network simulators are relatively fast and inexpensive. Networking simulators are useful in allowing designers to test new networking protocols or changes to existing protocols in a controlled and reproducible environment and they also allow engineers to test scenarios that might be particularly difficult or expensive to emulate using real hardware.

[18] NS or the Network Simulator (with current generation NS-2) is a discrete event network simulator. NS is popularly used in the simulation of routing and multicast protocols, among others, and is heavily used in ad-hoc networking

research, however, it doesn't take into account of directional antenna configuration as well as channel assignment techniques.

[19] OMNeT++ is a component-based, modular and open-architecture discrete event network simulator. The most common use of this simulator is the simulation of computer networks, but it is also used for queuing network simulations and other areas as well. OMNeT++ provides an infrastructure for writing network simulations. The models are developed completely independently of OMNeT++, and follow their own release cycles. OMNeT++ is a complicated software which requires time to learn and not user-friendly. The author wants to build a simpler and easier to use modeler which also does networking planning with all the predetermined parameters.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

According to [20], a spiral model is a software development process which was originally proposed by Boehm whereby sequence of activities with backtracking from one activity to another are represented as a spiral process and each loop in the spiral represents a phase of the software process. It combines elements of both design and prototyping-in-stages. The spiral model is intended for large and complicated projects.

This methodology is chosen for this project because it combines features of waterfall method and Prototype model of software development life cycle. Waterfall method provides a step-by-step approach to move from one phase to another phase. Prototype method features, on the other hand, include performing analysis, design and implementation concurrently and repeatedly, outputting prototypes and refining the products thereafter until a final product is produced.

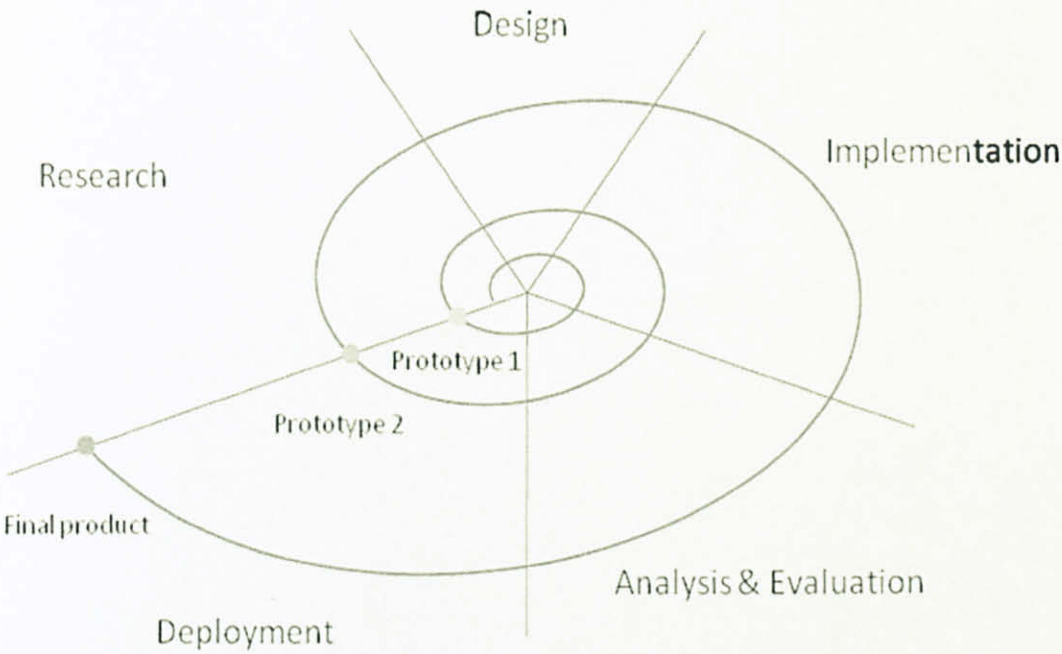


Figure 8: The Spiral model

Each cycle of the diagram represents a full process of software development and it outputs a prototype that will be evaluated and reviewed to prepare work for the next prototype. It then undergoes the loop one more time until the system is completely implemented.

3.1.1 Phase 1: Platform of Modeler

This project is the continuation of the author's internship project which is collaborated with BT Multimedia. At the end of the internship, prototype 1 was implemented. It's a frame of modeler which is able to do the following tasks:

- Draw some cluster techniques (1:1, 1:4, 1:7 with 3 configurations)

- Assign channels (not the main concern for the internship period, one uncompleted channel assignment algorithms which hasn't taken into account of antenna configuration)
- Calculate link capacity
- Calculate node capacity

3.1.2 Phase 2: Iteration with Development Modeler

The continuation of this project in FYP needs more deeply understanding and more concerned aspects to improve the project as well as make it a completed modeler with more features. At the end of FYP I, prototype 2 is implemented. The tasks to be done for FYP I are:

- Build a completed modeler with some friendly-user features to help users can build a network themselves (insert node, link nodes, delete node, show different patterns of cell, map appearance, …)
- Study effect of directional antennas on network performance (antenna gain, effect of directional antenna to interference area)
- Apply different channel assignments to network (complete 2 channel assignment algorithms)

3.1.3 Phase 3: Completed Final Modeler

Final product will be implemented in phase 3, equivalent for FYP II period. The system will be continually developed based on evaluating and analyzing prototype 2 as well as further research study, using simulation results to explain and analyze different network performance (based on link and node capacity) with different cluster techniques, capacity data rate, channel assignment algorithms

3.2 Flow of System Design

Flow chart for system design is as followed:

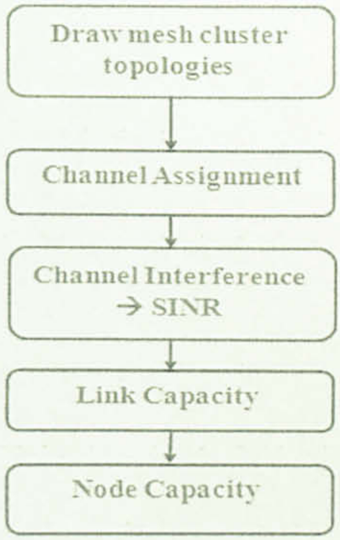


Figure 9: Flow chart for system design

This is the procedure needed to run simulation network planning.

3.2.1 Draw Mesh Cluster Topologies

The number of cells that can form a regular cluster pattern is given by:

$$N = m^2 + n^2 + mn \qquad (3.1)$$

where m and n are integers.

Since one cluster consists of one cluster gateway (CGW) surrounded by cluster access points (CAPs), N can be: 1, 4, 7, 13, ...

- N = 1 → 1:1 (Max 1 hop)

Figure 10: Topology 1:1

- N =4 → 1:4 (1 CGW, 3 hop1 CAP)

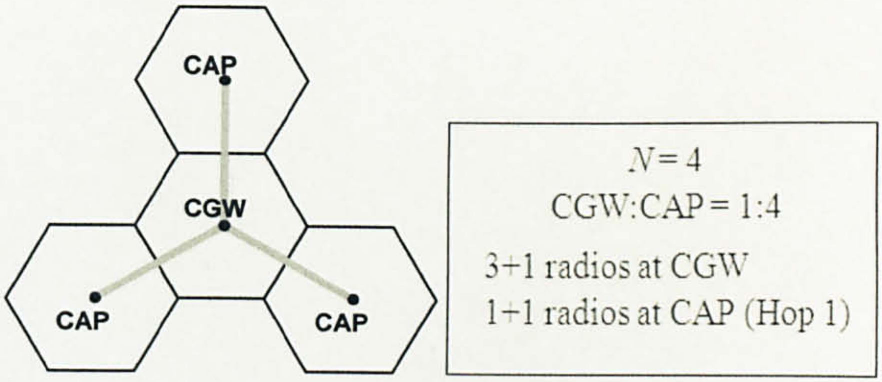
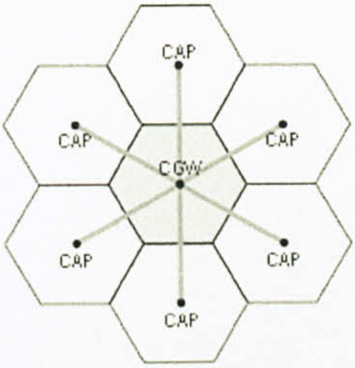


Figure 11: Topology 1:4

- N =7 → 1:7



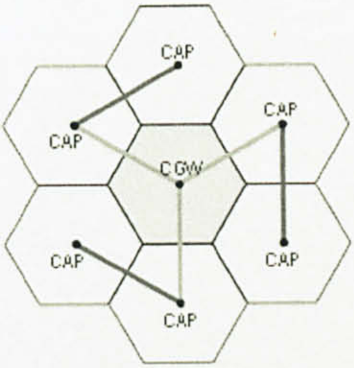
Configuration A

$N=7$

CGW:CAP = 1:7

6+1 radios at CGW

1+1 radios at CAP (Hop 1)



Configuration B

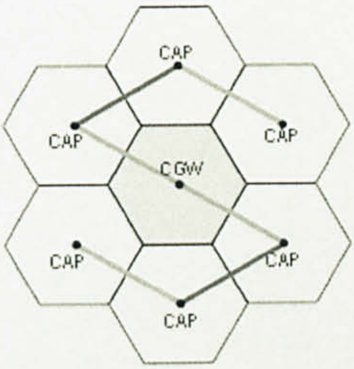
$N=7$

CGW:CAP = 1:7

3+1 radios at CGW

2+1 radios at CAP (Hop 1)

1+1 radios at CAP (Hop 2)



Configuration C

$N=7$

CGW:CAP = 1:7

2+1 radios at CGW

2+1 radios at CAP (Hop 1)

2+1 radios at CAP (Hop 2)

1+1 radios at CAP (Hop 3)

Figure 12: Topology 1:7

- N = 13 → 1:13

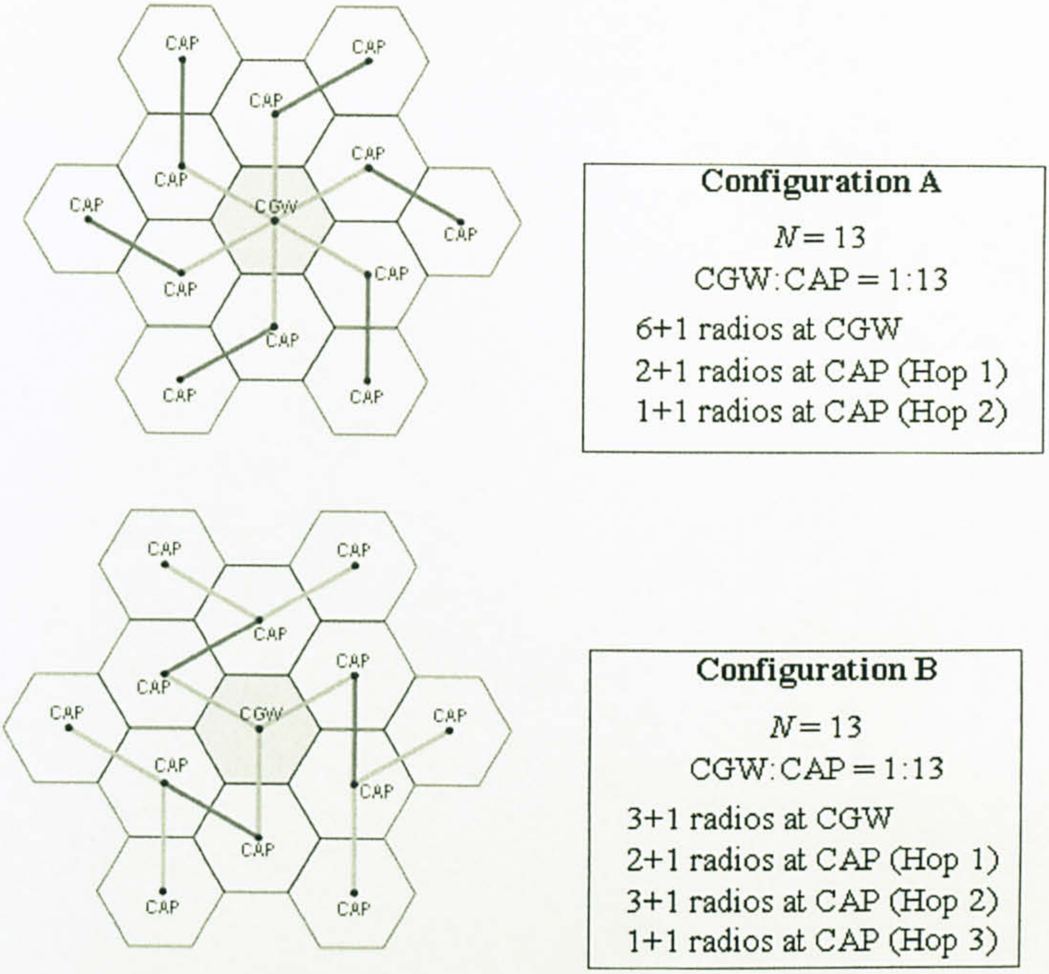


Figure 13: Topology 1:13

Input parameters needed to draw network:

- Choose type of topology
- Choose area size (x-axis & y-axis value), frequency range of network (802.11g with 2.4 GHz or 802.11a with 5Ghz)
- Input parameters for access points and links (set default): power gain of transmitter and receiver, transmitter antenna gain, noise floor, propagation coefficient, data rate, network specifications ...

- Input parameters for antenna configurations: beam-width & radiation efficiency

The following table shows the radio attributes and design parameters of 11g and 11a respectively.

Table 5: General Parameters for 802.11g and 11a Interference Analysis

Parameter	**Unit**	**IEEE802.11g**	**IEEE802.11a**
Area size	Sqkm	100	
Centre Frequency	GHz	2.4	5
EIRP	dBm	20	23
Total Margin (interference, shadow)	dB	10	10
Mesh Node Noise Figure	dB	5	5
Design Data Rate	Mbps	54Mbps	
Receiver antenna Horizontal Beam Width (HBW)	degree	30, 60	30, 60
Radiance efficiency	-	0.9	
Receiver antenna gain	dBi	14, 8	14, 8
Non overlapping channels	-	3	19

3.2.2 Channel Assignment Algorithms

Before assigning channels to links, first step needed is to initialize variable from all links (means to set identity to each link)

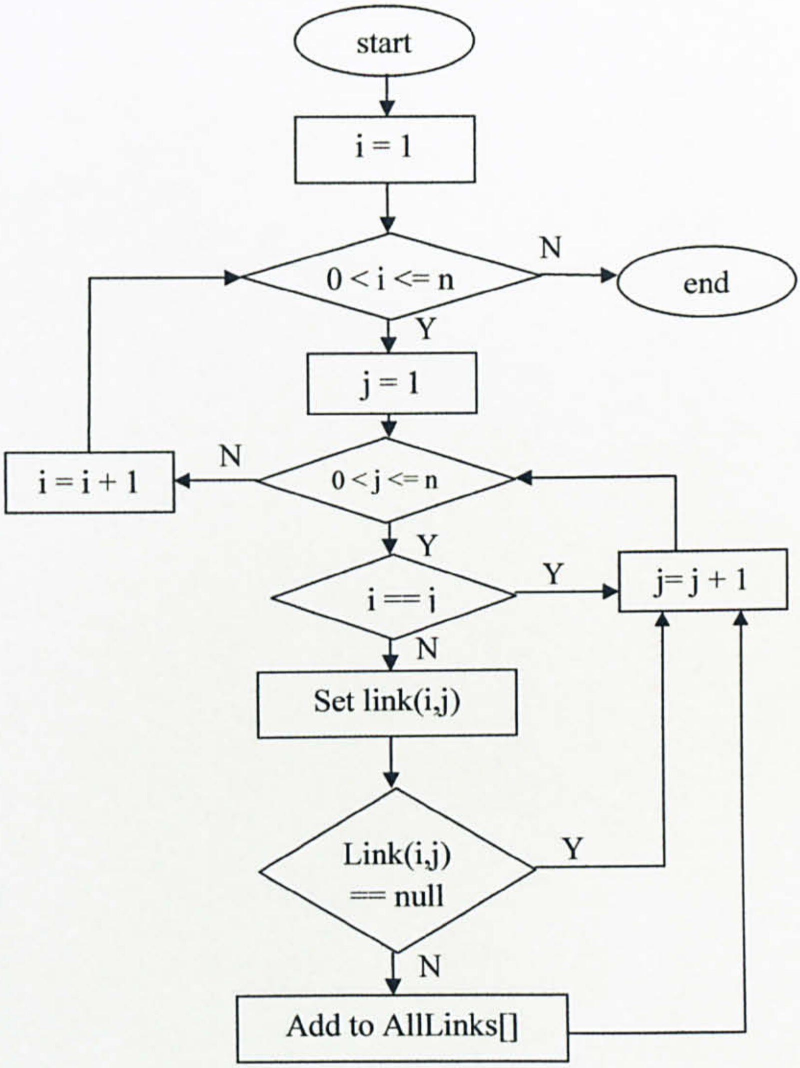


Figure 14: Initialization variables for all links

- n: total number of all nodes in network
- i, j: index variables of node
- array AllLinks: an array which stores all links, initially it's set to be null

1. i=0
2. Loop j from 0 to n. if i=j, increase j+1
3. For each set value (i, j), check from node i to node j. If there's a link (i,j) exists, add to array AllLinks. If not, increase j+1. Loop until j=n
4. Increase i+1, repeat from step 2 again until i=n.

   At the end of the process, all links of network are stored in array AllLinks.

   There are two CA algorithms being used in this modeler.

3.2.2.1 Overlapping Channel Assignment Algorithm

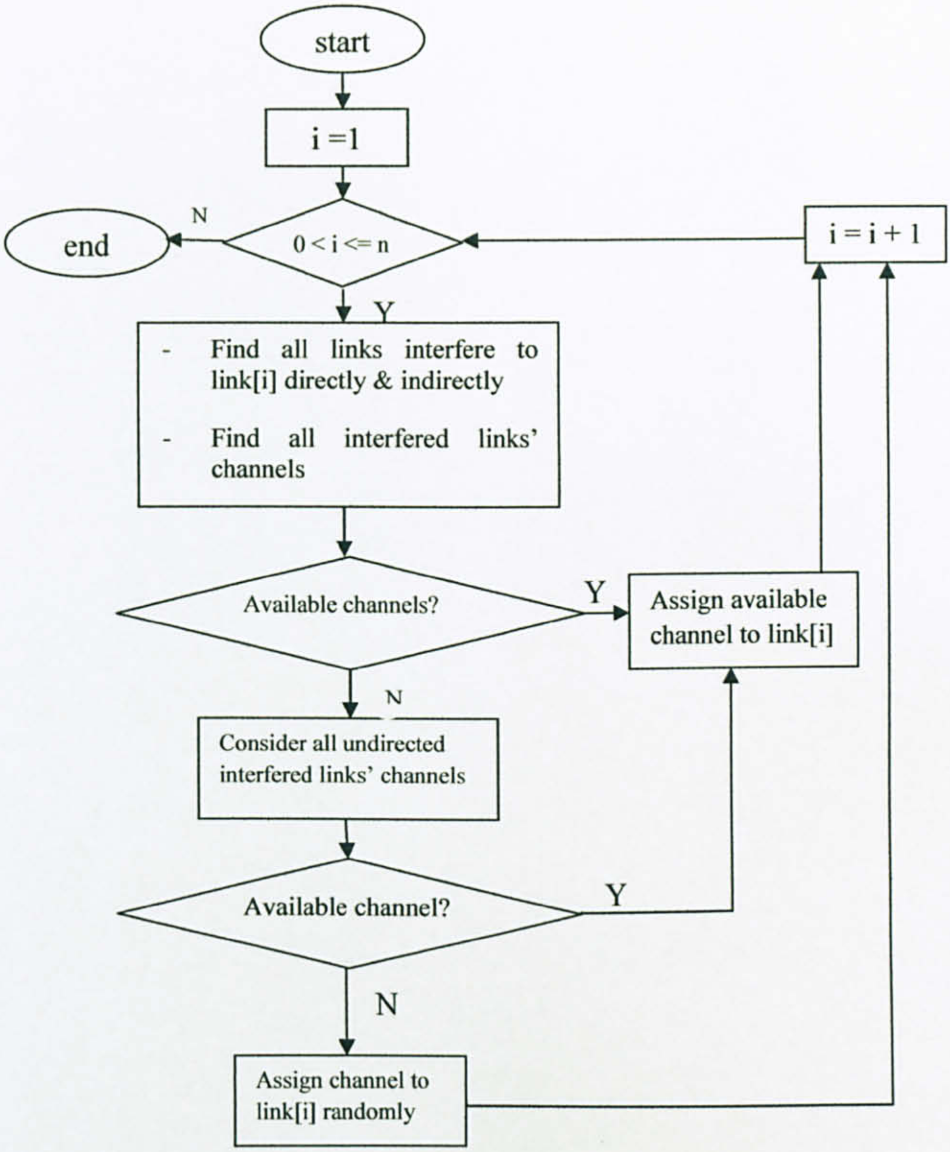


Figure 15: Overlapping Channel Assignment

1. Begin with a cluster at a corner of the deployment area

2. Check channels of all links interfere to the study link directly and indirectly (explain below)

3. If there's still available channel (in total 14 channels for 802.11g and 42 channels for 802.11a), assign that channel to study link (if there are many available channels, choose the smallest index channel)

4. If there's no available channel, check channels of all links interfere to the study link indirectly

5. If there's available channel, assign it to the study link. If it's not, choose channel randomly for the study link

6. Loop until all the links assigned with according channels.

3.2.2.2 Non-overlapping Channel Assignment Algorithm

The second one takes advantage of the fact that there are non-overlapped channels, 3 channels for 802.11g and 19 channels for 802.11a.

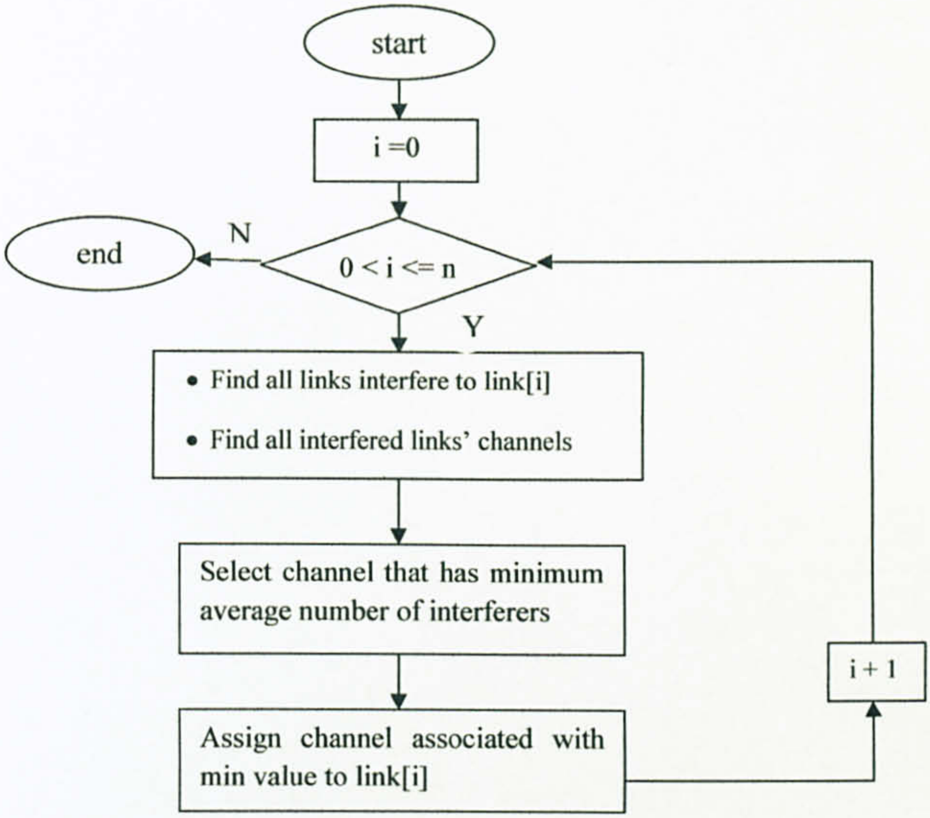


Figure 16: Non-overlapping channel algorithm

1. Begin with a cluster at a corner of the deployment area

2. For each of its link, check the total number of co-channel interferers for both uplink and downlink transmissions across all available non overlapping channels iteratively.

3. From the pool of non overlapping channels {1, 2.. n}, Select channel that has minimum average number of interferes (uplink + downlink). Signals are qualified to be interferers if the degree of arrival <= to horizontal beam width opening angle. A channel with no interferer will be selected immediately.

4. Assign to the study link with the channel has minimum count.

5. Repeat the above for the next cluster.

3.2.3 Channel Interference Consideration

3.2.3.1 Link Interference Conditions

There are 3 conditions for one link interferes to study link

- Link status: ON/OFF. Only a link with status ON can be able to interfere to study link. (If there's a transmission between two nodes, it must be bi-directional link, down link and up link connection. At one time, there's only one direction transmitting, and that link direction is at ON status, the other's OFF. Links' status are assigned randomly)
- Interference area: Check the receiver node's position of study link with interference area of inspecting interfered link: if the receiver node of study link is in interference area, it's able to interfere to study link

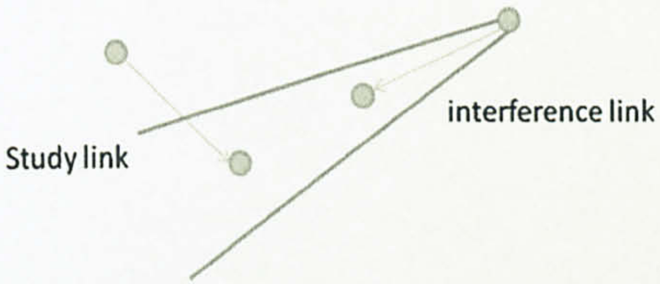


Figure 17: Interference area

- Arriving angle: Check the arriving angle of an inspecting interfered link to a study link

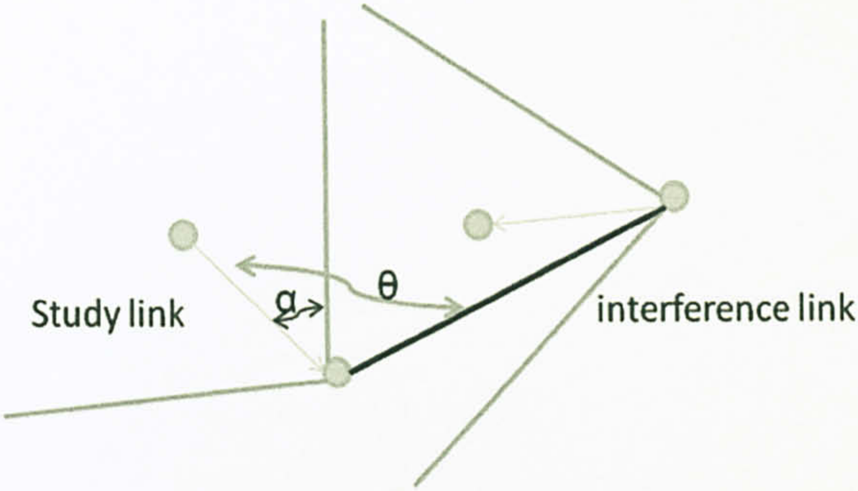


Figure 18: Angle interference

α=beam-width /2

θ= angle (transmitter node of interfered link, receiver node of study link)

Condition: θ =< α

3.2.3.2 Channel Interference Calculation

According to [15] as discussed in literature review part, attenuation value can be calculated based on channel separation. Therefore, interference power can be calculated as below:

Provide: Study link with channel c1, interfered link with channel c2 and signal power S

➔ Channel separation: $|\ c1 - c2\ | = c$

➔ Attenuation: S_A = (c, OFDM technique)

➔ Interference power: $Si\ = S - S_A$

→ $SINR = \frac{S_{study\_link}}{N + \sum S_i}$ (S_{study_link} : signal power of study link, N : noise)

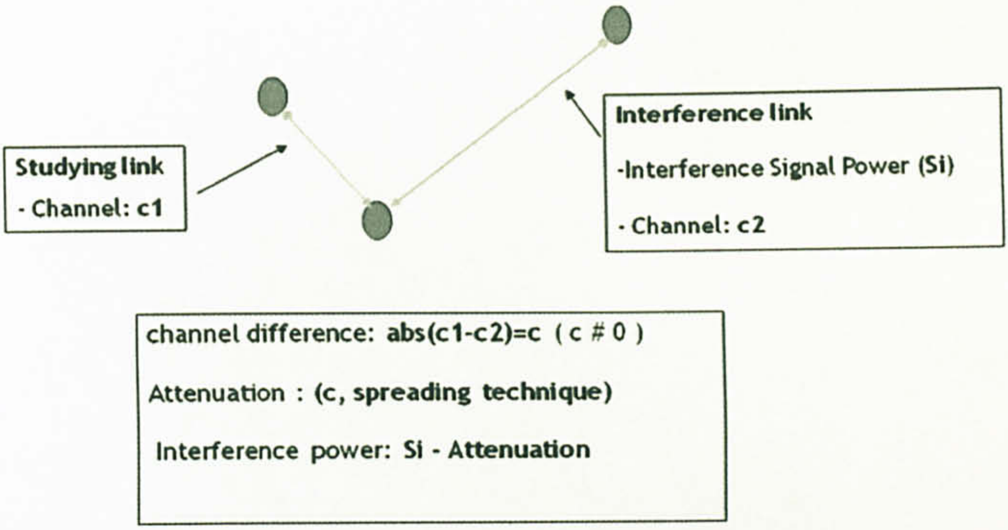


Figure 19: Interference power calculation

3.2.4 Link Capacity Calculation

Capacity of each link is calculated by following those steps:

- Compare SINR value with SNR threshold value
  - $SINR \geq SNR_{threshold}$: achieved data rate equal to desired data rate
  - $SINR < SNR_{threshold}$: find new data rate which satisfies

Table 6: Data rate with expected SNR threshold accordingly

Data Rate (Mbps)	Sensitivity (dBm)	SNR threshold (dBm)
6	-94	5
9	-93	6
12	-91	8
18	-90	9
24	-86	13
36	-83	16
48	-77	22
54	-74	25

This table information, taken from BT's documents, which provides value of SNR threshold for each associated value of data rate. 802.11g & 802.11a were chosen for this project.

- Find total number of co-channel interference links to study link: $N_{co-channel}$

- $LinkCapacity = \dfrac{DateRate}{N_{co-channel}}$

3.2.5 Node Capacity Calculation

Node capacity calculation method was taken from BT's documents, "A method to define access point (raw) capacity/bandwidth in multi-hop network". There are some assumptions needed to be made:

- All nodes are also providing access to clients and acting as router for other nodes simultaneously

- Only consider down links
- Neglect capacity of gateway node
- Completed fairness among all nodes

Procedure is as followed:

1. Formulate all link capacity (link capacity calculation)
2. Divide each link to number of flow sharing the link equally
3. Assign smallest per link flow capacity to all flows
4. Subtract all the used flow bandwidth at each link (fixed branch has no capacity left or no flow in it)
5. Continue divide all leftover bandwidth to unfixed flows, and repeat all the above steps until all flows are fixed

Refer to appendix 1 for an example of node capacity calculation to have a better understanding.

3.3 Evaluation Results

In order to verify the correctness of the results, the modeler was tested firstly with small-scale area size, check simulation results with results obtained from theoretical calculations. The outcomes of all the tests show that the program works correctly.

The practical transmission range in real life is between 80 – 100++ meters. With the determined parameters in table 5, the transmission range obtained from the modeler simulation also around 100 meters, which are not too far off from the real ones. The reason for the range to be high like that is because high antenna gain and maximum EIRP are used.

The propagation model used has been tested to some extent by the creator [8], therefore it can be trusted to use for this modeler. Furthermore, the modeler also used the receiver sensitivities provided by equipment datasheet.

The reason for modeling to be chosen is because it's relatively fast and inexpensive compared to the cost and time involved in setting up an entire test bed containing multiple networked computers, routers and data links. Especially for this study, it's deployed for large-scale (with thousands nodes and large area size) analysis, therefore, usage of modeling is inevitable. This is common practice in industry too.

3.4 Tools/ Equipment

The following are tools suggested to be used in the development of this project.

- Desktop/ Notebook: the work station is needed to develop system prototype. It is recommended to have a high processing machine to simulate modeler efficiently
- Software Java programming language: The reason for choosing this language is because Java is an object-oriented program which has a lot of advantageous functions and is friendly-user. Besides, this project requires a lot of graphical issues which will be most convenient with Java.

3.5 Timeline/ Gantt chart

Time planning was done to ensure the project would be done in right time track. Therefore, Gantt chart has been created to make sure all tasks are completed within the specific time given. It can be referred to appendix 2 to see the time schedule for the whole project for 3 phases.

3.6 Project feasibility

This is a huge and complex system modeler which requires deeply understanding about network planning and also Java language's proficiency. With the lack of knowledge in these involved fields and inexperience in programming, the author has been facing a lot of difficulties. Nevertheless, with serious research study and enthusiasm to learn up new things, also the help and encouragement from UTP supervisor and BT supervisor, it's believed that this project is feasibly completed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

At the moment this report was written, the author has finished final product for this system modeler. The flow activities of the system have been completed, with more aspects of antenna configuration and channel assignment technique.

4.1.1 Developed Modeler Platform

Screenshot of the system:

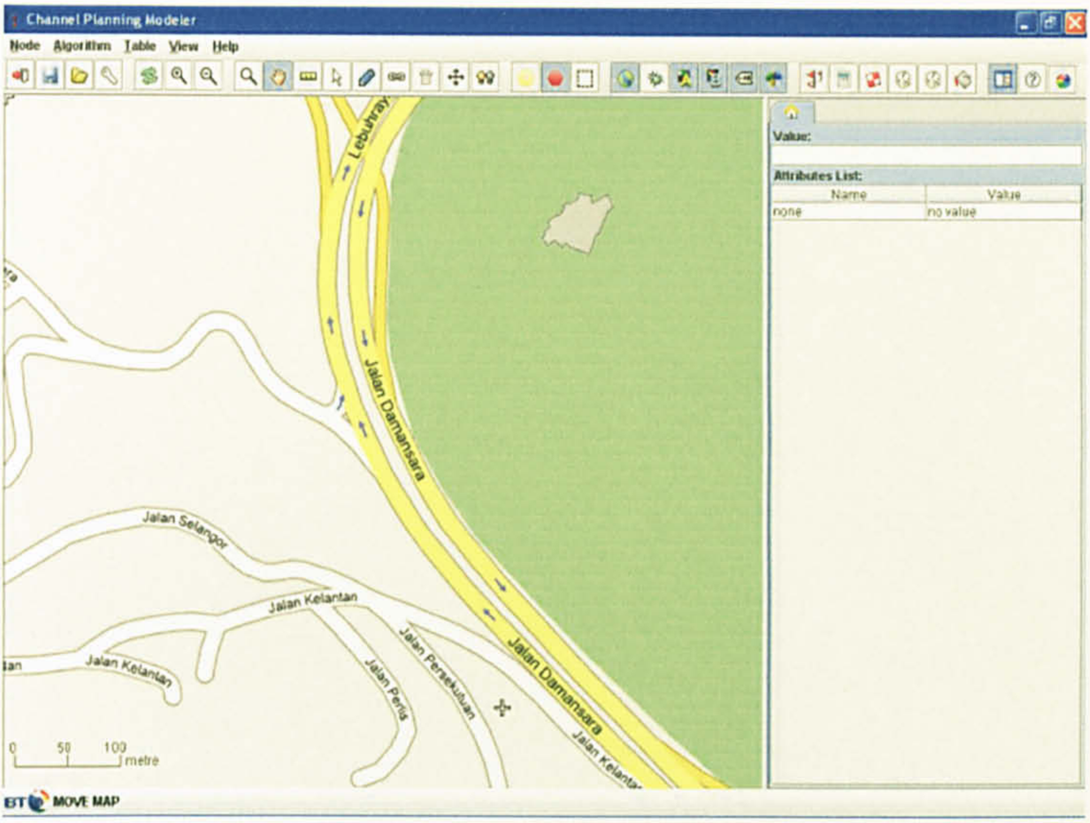
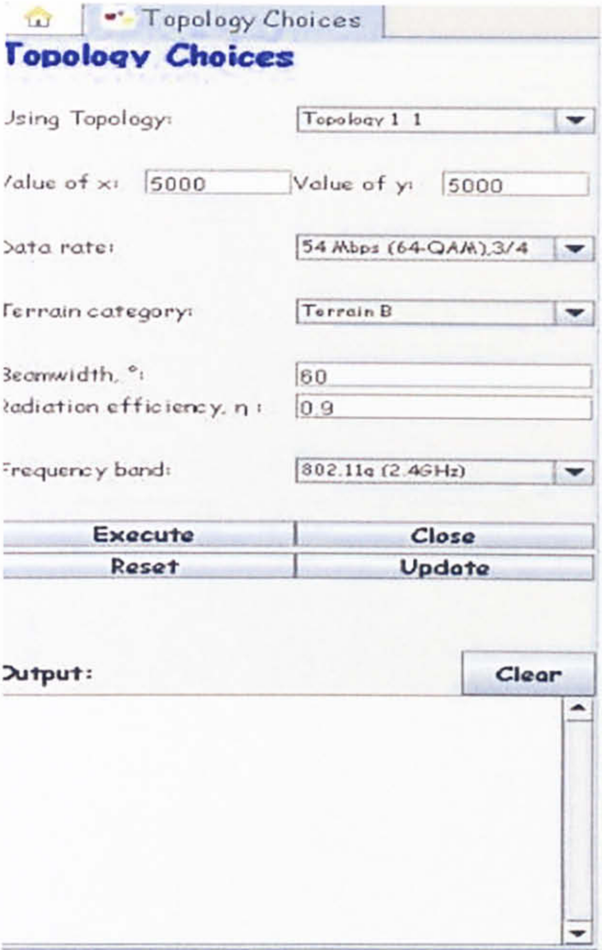


Figure 20: Main page of the system

The main page of the system with menu bar on the top of the modeller and below is the frame to draw network. Side Bar on the right is to perform input as well as output for the network.

With this modeller, users can: draw an AP, draw link between APs, toggle map showing, zoom in/out, refresh...

4.1.2 Mesh Network Topologies



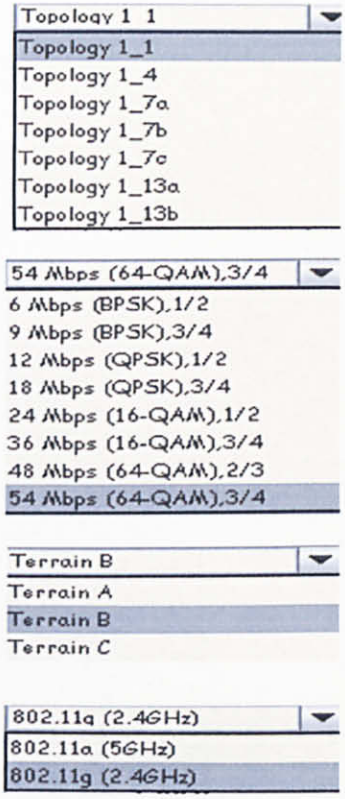


Figure 21: Input drawing network window of the system

The above figure is Topology Choice sidebar which provides input parameters to specify a network for users to draw, topology (7 choices) and data rate (8 choices), area size, propagation coefficient, directional antenna (beam-width & radiation coefficient) configuration and frequency range value.

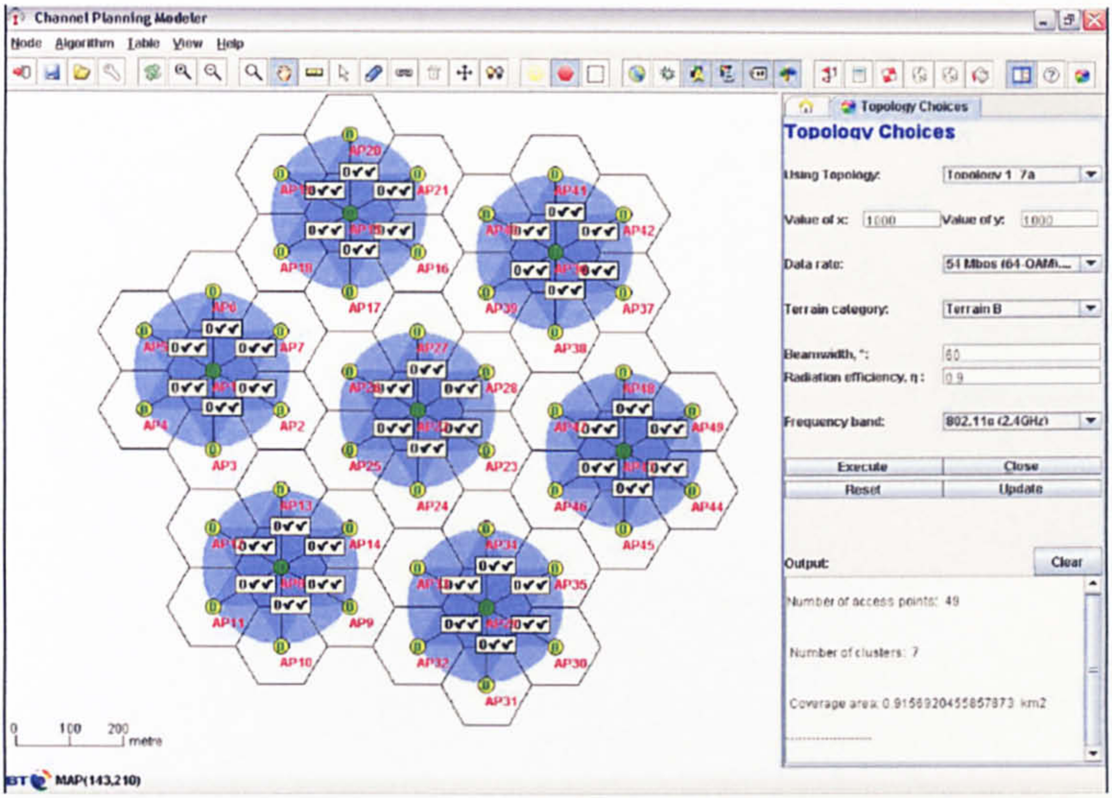


Figure 22: Network topology 1:7a

The above figure is an example of network drawing. This figure draws network with topology 1:7a, area 1km2, terrain B, data rate 54mbps, frequency 2.4 GHz, beamwidth antenna 60, radiation coefficient 0.9. The output box provides information about the number of access points (49), the number of clusters (7), and the real average area size of network (0.92km2 ~ 1km2).

4.1.3 Channel Assignment Strategies

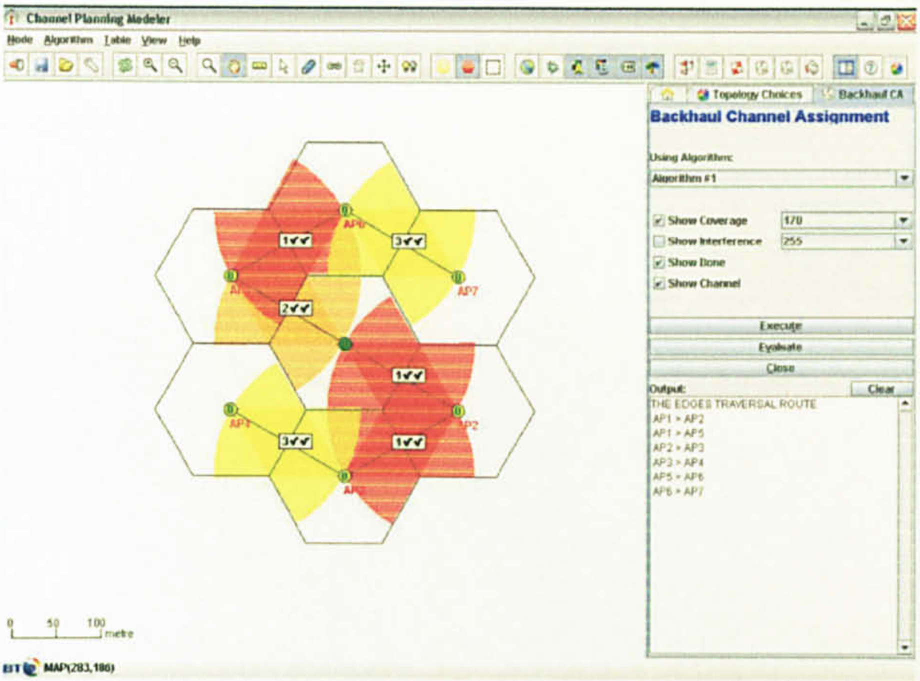


Figure 23: Non-overlapping channel assignment algorithm

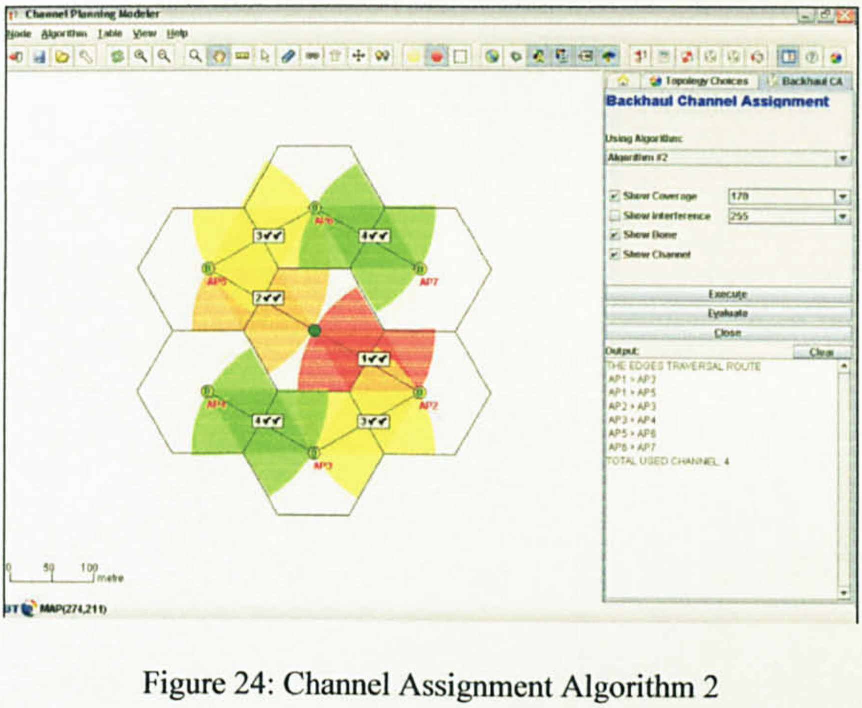


Figure 24: Channel Assignment Algorithm 2

4.1.4 Simulation Results

With this user-friendly modeler, users can design their own network and run simulation to get average link capacity and average node capacity, compared with desired values to evaluate the network. Some examples of simulation can be:

- For 100km2 area, data link 54mbps, beamwidth 60, radiation coefficient 0.9, terrain C

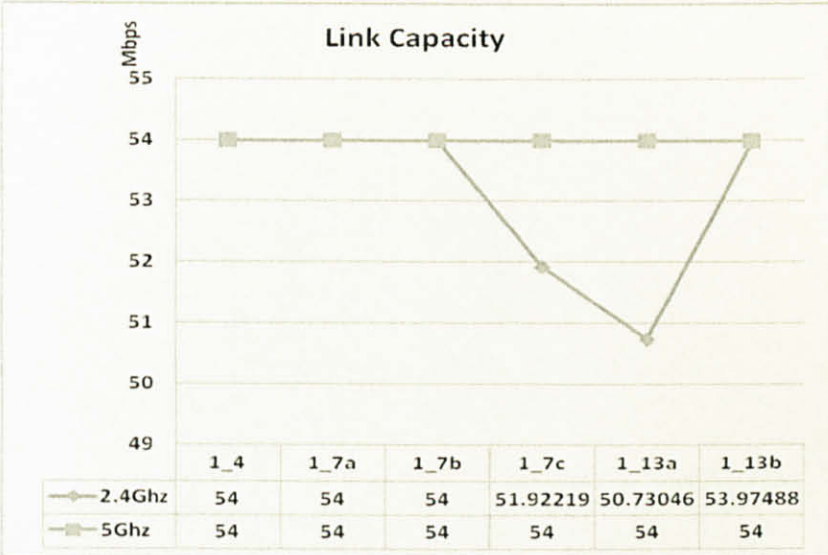
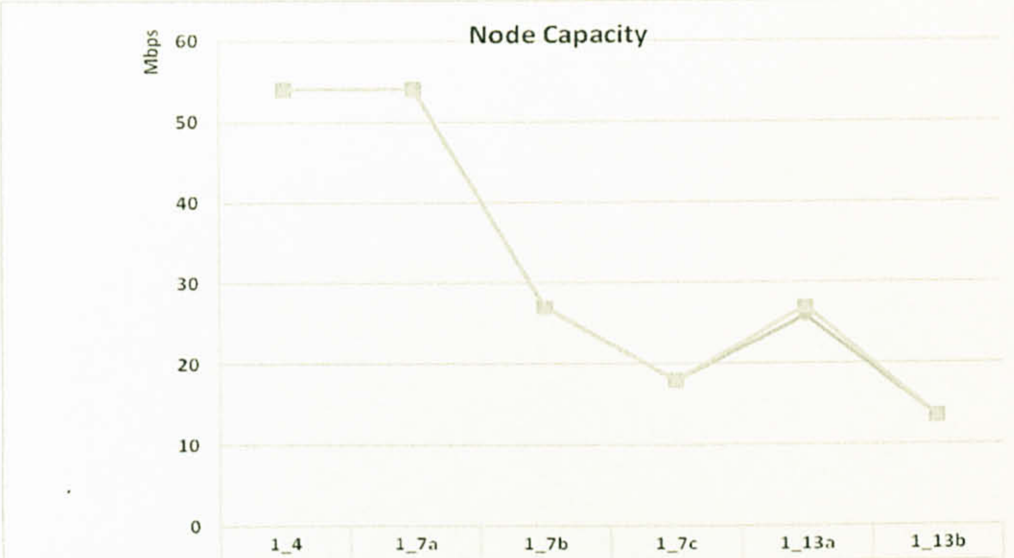


Figure 25: Average link capacity of all topologies for 802.11g and 802.11a

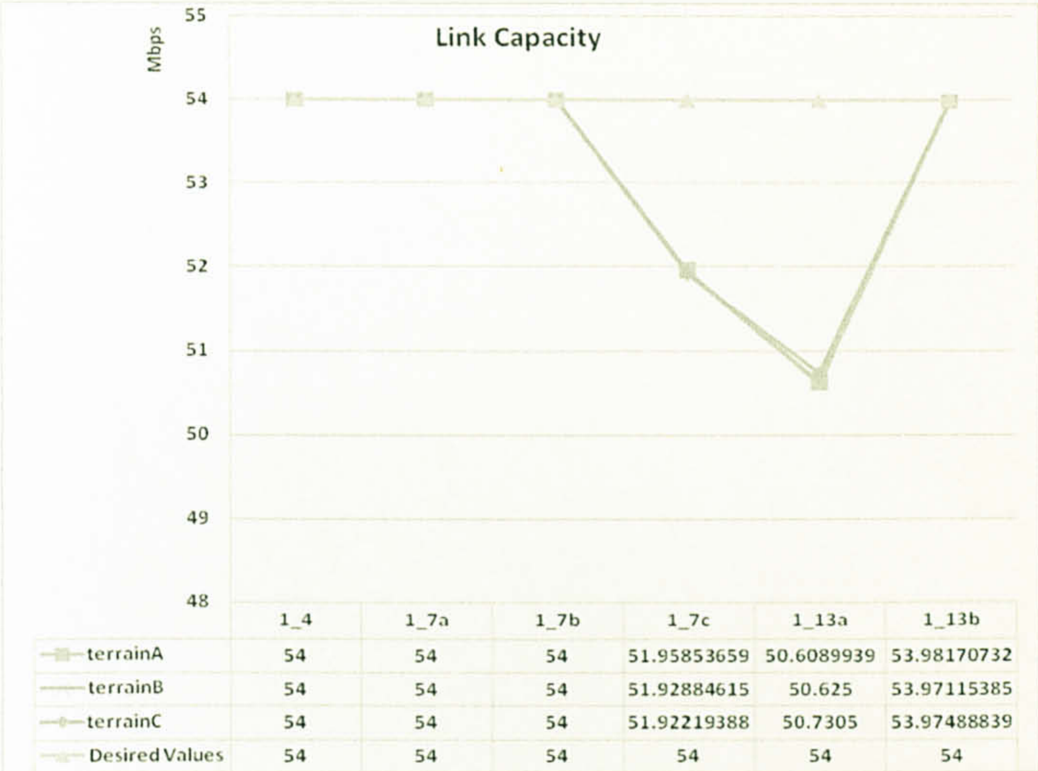


	1_4	1_7a	1_7b	1_7c	1_13a	1_13b
2.4Ghz	54	54	27	17.95408163	25.86495536	13.5
5Ghz	54	54	27	18	27	13.5
Desired Values	54	54	27	18	27	13.5

Figure 26: Average node capacity of all topologies for 802.11g and 802.11a

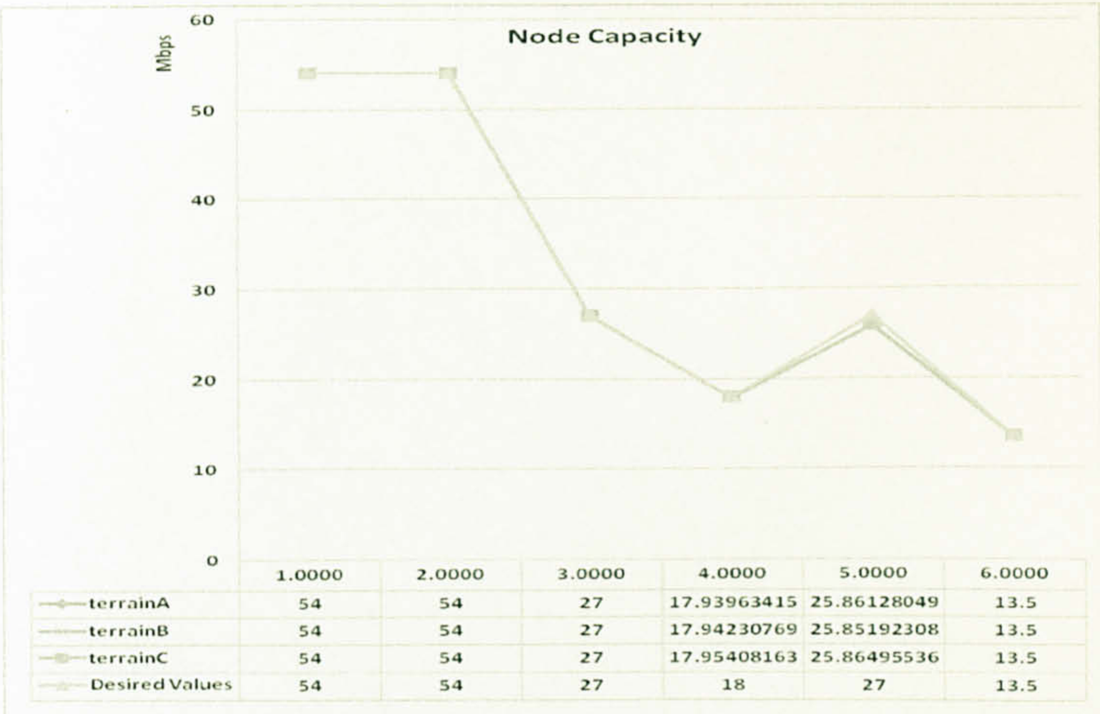
According to average link capacity and node capacity values, 802.11a (5 GHz) provides slightly better performance than 802.11g (2.4 GHz). For both case, 802.11a's average link capacity and average node capacity reach desired values.

- For 100km2 area, data link 54mbps, beamwidth 60, radiation coefficient 0.9, frequency 2.4Ghz



	1_4	1_7a	1_7b	1_7c	1_13a	1_13b
terrainA	54	54	54	51.95853659	50.6089939	53.98170732
terrainB	54	54	54	51.92884615	50.625	53.97115385
terrainC	54	54	54	51.92219388	50.7305	53.97488839
Desired Values	54	54	54	54	54	54

Figure 27: Average link capacity for 802.11g with different terrain types



	1.0000	2.0000	3.0000	4.0000	5.0000	6.0000
terrainA	54	54	27	17.93963415	25.86128049	13.5
terrainB	54	54	27	17.94230769	25.85192308	13.5
terrainC	54	54	27	17.95408163	25.86495536	13.5
Desired Values	54	54	27	18	27	13.5

Figure 28: Average node capacity for 802.11g with different terrain types

From two figures above, which illustrate average link capacity and average node capacity accordingly, there's not much different among different terrain type A, B, C.

- For 4km2 area, data link 54mbps, beamwidth 60, radiation coefficient 0.9, frequency 2.4Ghz, terrain C

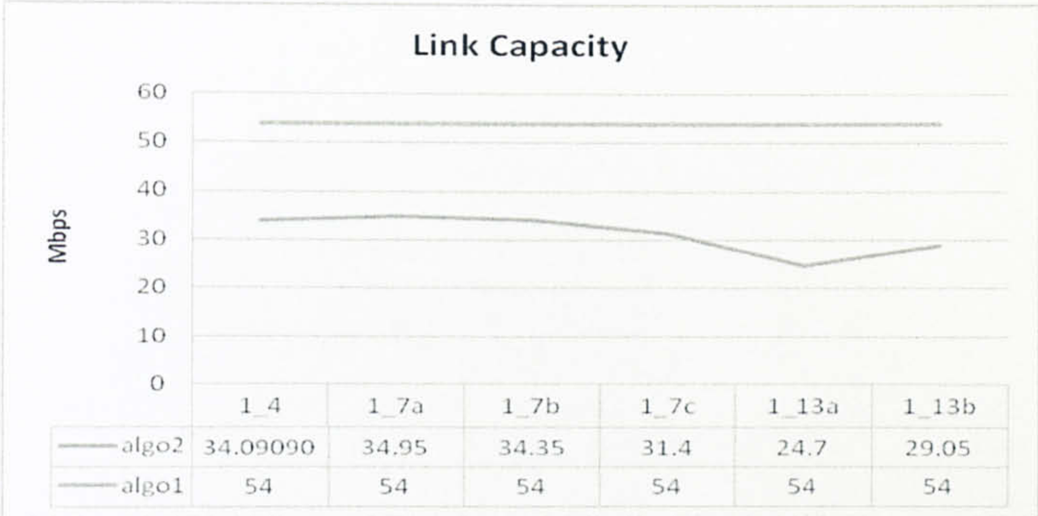


Figure 29: Average link capacity for 802.11g with different channel assignment algorithms

From the figure above, it can be clearly seen that channel assignment algorithm 1 gives much better results than algorithm 2. It's because algorithm 1 takes advantage of non-overlapping channels among all available channels for one frequency band, therefore, it helps to reduce interference due to adjacent channels.

4.2 Discussion

The progress of this project has followed with the schedule. There are some changes for the final product with the application of new propagation model into the modeler which made the author have to work with extra effort in order to not be lagged behind, and reduce some other small modifications which the author wanted to do with the system initially.

The final product of this project as stated above is a user-friendly modeler which helps users with basic background about wireless can set-up network using functions of the modeler (node by node or for large area). Besides that, it also helps you to assign channels to each transmission link in order for them to communicate and from there to study the effect of interference of overlapping channels in the network.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

WMN is considered as a key technology for next-generation wireless networking because it can easily, effectively and wirelessly connect entire large areas using inexpensive, existing technology – IEEE 802.11 standards. Although WMN has been deployed to reality, it's still an evolving technology nowadays, where further study is needed. Its performance remains unclear up till now because various interdependent optimization approaches are jointly considered under one single deployment. That's the reason why this topic inspires many researchers as well as companies to do research to develop WMN techniques and to apply this network in real world with several beneficial products.

The network planning and analysis tool for wireless mesh network has been successfully implemented. It has met all initial objectives, which are to provide a better visualization of the performance through a GUI-based network modeler of a WMN. This is a huge research-based project, involving many aspects and fields, requiring extensive study and proficient coding in order to build a user-friendly simulation modeler which allows users to set-up network, evaluate network performance based on capacity of nodes and transmission links with taking considerations of using directional antenna configuration; applying different clustering techniques, frequency bands and capacity requirements; assigning different channel algorithm techniques.

With all the above features, this modeler is a unique modeler, which does network planning graphically, therefore, it will give a better understanding of network performance.

5.2 Recommendation

During the system process, there are many further ideas beyond this project's objectives which the author can recommend:

- Draw network based on total number of nodes instead of based on area size which can give users to be more flexible in choosing the way to set up a network
- Do access point channel assignment besides link channel assignment and take into account the number of users for each access point coverage area. By that way, the tool would be completed and would be able to go out to the market.

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APPENDICES

Appendix 1: Example of node capacity calculation

This is an example to show how to calculate node capacitiy. The scenario starts with figure 1. Figure 2 shows the first step should be done, formulate all link capacities and the second step which is to divide each link to number of flow sharing the link equally. After that, figure 4 describes step 3 which is to assign smallest flow capacity to all flows. Step 4 is to sum all the used bandwidth at each link, followed by step 5 which is to divide all leftover bandwidth to unfixed flow (the branch which still has leftover bandwidth either in its own or its flows). Step 6-7 loop all the above steps again till all flows are fixed.

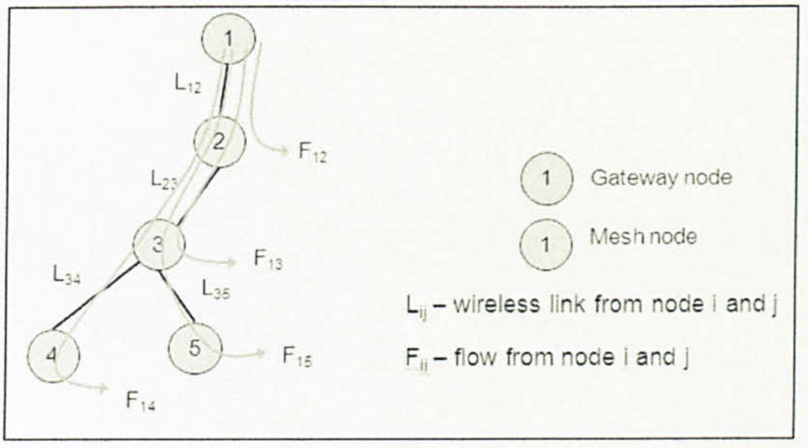

Figure 30: Node capacity calculation scenario

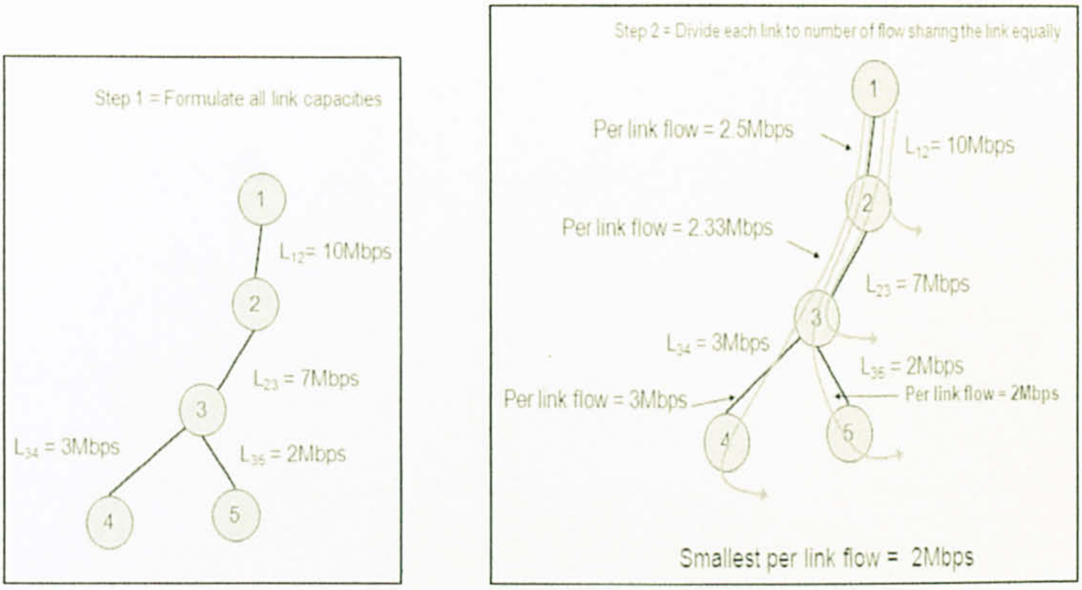

Figure 31: Step 1 & Step 2

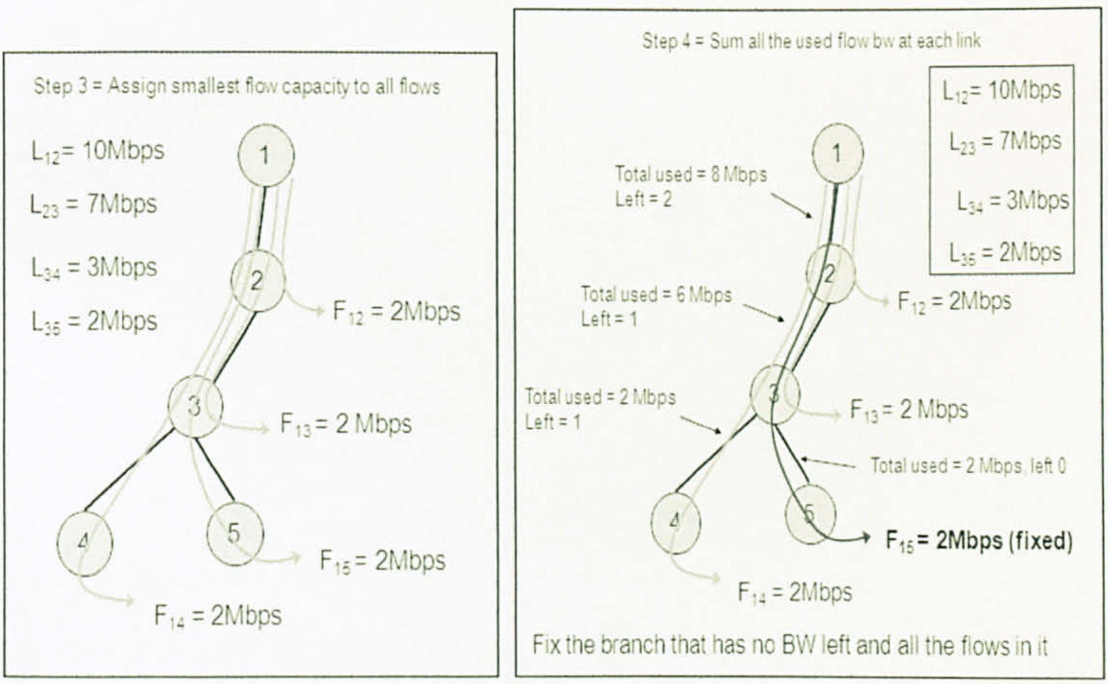

Figure 32: Step 3& Step 4

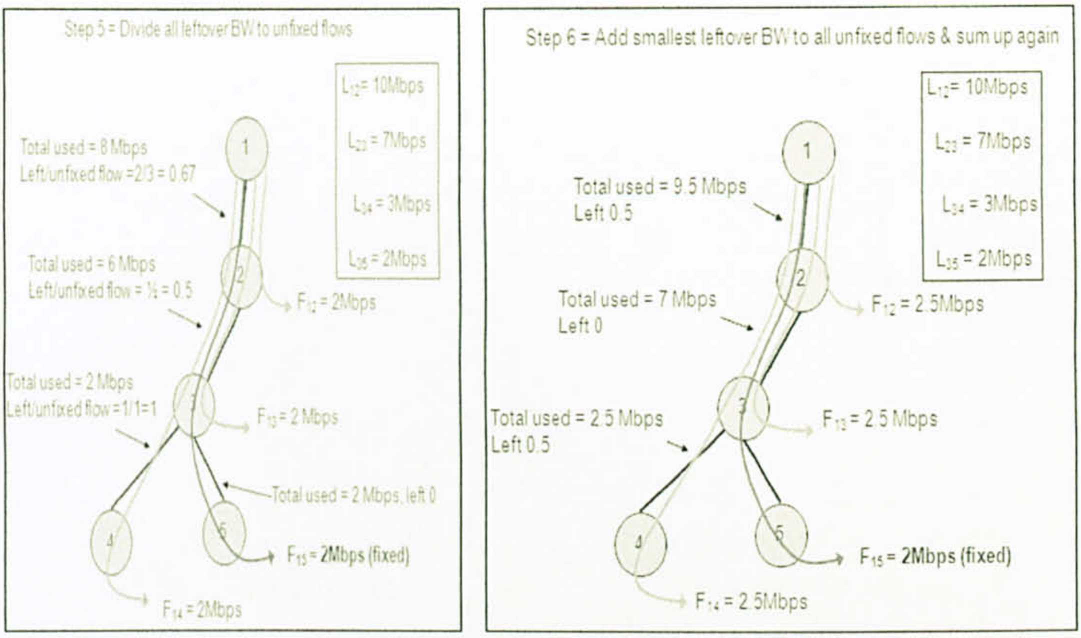

Figure 33: Step 5 & Step 6

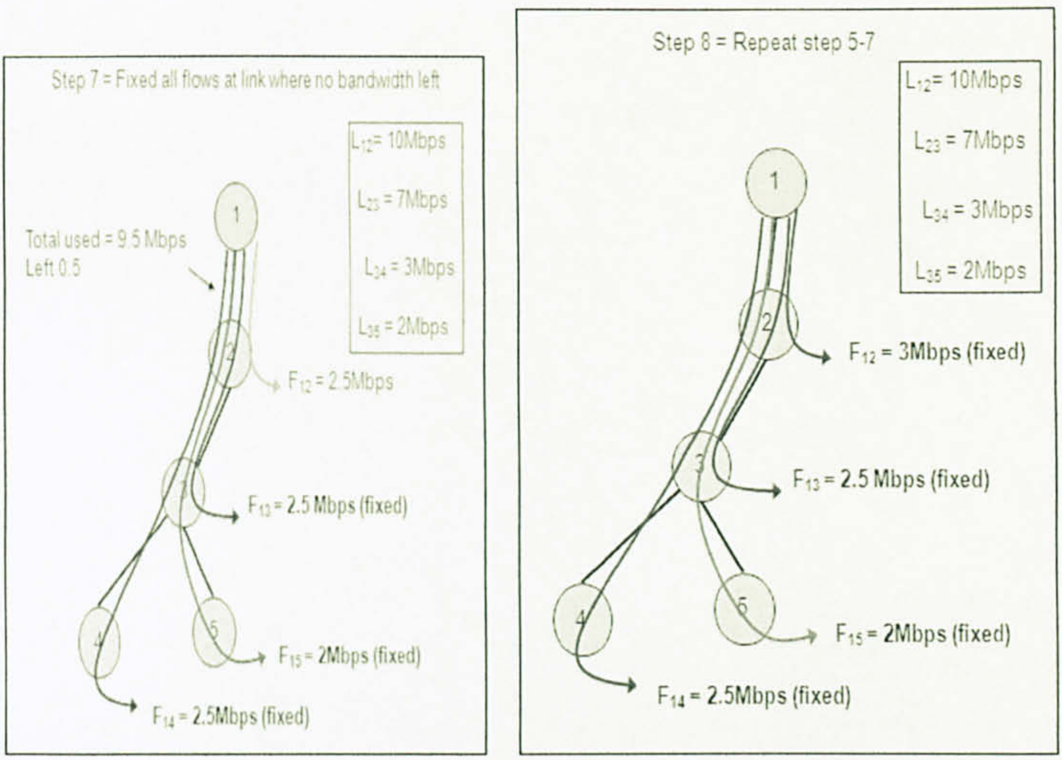

Figure 34: Step 7 & 8

Appendix 2: Gantt chart

Phase 1: Platform of modeler

	Jan 09				Feb 09				March 09				April 09				May 09				June 09			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Study/ Research on wireless mesh network																								
Read and learn to have a general view about Java																								
Build frame modeler for project																								
Draw network topologies																								
Assign channels to each link of network																								
Calculate SINR of each link of network																								
Calculate link capacity																								
Calculate node capacity																								

Phase 2: Iteration with development modeler

	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Submit proposal title of FYP														
Literature review on the project														
Complete modeler for the project														
Prelim report submission														
Draw more topologies														
Study on directional antenna														
Progress report submission														
Study on channel assignment algorithm														
Seminar 1														
Draft report submission														
Interim report submission														
Oral presentation														

Phase 3: Completed final modeler

	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Finish coding for channel assignment														
Obtain results from simulation of modeler														
Study, analyze and explain results														
Prepare and write papers														
Finish writing thesis														