Evaluation of Mesh Points Placement Schemes for Rural Wireless Mesh Network (RWMN) Deployment

by

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DECLARATION

I declare that this research study on Evaluation of Mesh Points Placement Schemes for Rural Wireless Mesh Network Deployment is my work. This work has never been presented for the award of any degree at any University. All the information used has been duly acknowledged in text and in the references. A portion of this work was published and presented at IST-Africa 2011 in Botswana.

________________________ ________________________Signature

Date

DEDICATION

To

My Family

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Abstract

Internet connectivity in most rural African areas has been viewed as a major challenge due to lack of reliable power, scarcity of network expertise, expensive installation of network equipment and the high cost of providing Internet connectivity. However, with the rapid development of wireless technologies, Wireless Mesh Network (WMN) has emerged as a promising networking infrastructure, bridging the digital divide between town and countryside. This is because of low cost, easy deployment and increased high speed of WMN internet connectivity. Despite the aforementioned features, WMN deployments still suffer from a challenge of achieving optimum network performance which is affected by a number of factors. One of these factors is choosing optimal positions for Mesh Points' (MP's) placement in a geographical environment.

MP's placement problems have been thoroughly investigated in the WMN field and different research works propose MP's placement schemes that can be used to solve the placement problem. Deploying a WMN requires taking into account limitations and topology of the terrain. However, none of the existing MP's placement schemes have been evaluated and compared using rural settlement patterns in order to judge their suitability of solving MP's placement problem in such environments.

The purpose of this study was to compare the existing MP's placement schemes and to recommend the best scheme(s) to be used during rural WMN deployment. This can be viewed as a twofold objective, the first one involves evaluating Mesh Access Points (MAP's) placement schemes and the second one involves evaluating Mesh Portal Points (MPP's) placement schemes in the rural settlement patterns. Four MAP's placement schemes were evaluated namely; Hill Climbing, Virtual Force Based (VFPlace), Time-efficient Local Search and Random placement schemes and, on the other hand, Four MPP's placement schemes were evaluated namely Incremental Clustering, Multi-hop Traffic-flow Weight (MTW), Grid Based and Random MPPs placement schemes. Simulation was done in NS2, and four rural settlement patterns were considered, Nucleated, Dispersed, Linear and Isolated rural settlement patterns. The experimental evaluation revealed that Hill Climbing is better fitted to solving a placement problem in nucleated and dispersed settlement patterns. VFPlace could be applied as a first choice for placement in linear settlement patterns while Time-efficient Local Search is better for deployment in isolated settlement patterns. As an improvement from the existing works of MAP's placement schemes, this study not only focuses on optimizing coverage and connectivity among the MAPs, but also focuses on the other factors like network throughput, packet deliver ratio and end-to-end delay.

To complete the deployment problem, the recommended placement schemes were used as bases for MPP's placement. The study revealed that MTW is best fit for placement in linear and nucleated settlement patterns, Grid is best for dispersed settlement patterns while incremental clustering is best for isolated settlement patterns. The performance of MPP's placement schemes was evaluated by measuring and comparing the packet delivery ratio, throughput and end-to-end delay in the network. Random selection of MP's led to poor network performance in all scenarios. Deploying single MPP improves network performance only in a small instance. However, the increase in the number of MAP's results in a bottleneck on the MPP, hence the findings of this study recommends more than one MPP should be deployed when there are too many MAP's in the network. In all scenarios a good placement scheme should be adaptive to the number of MAP's and MPPs.

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LIST OF ACRONYMS AND ABBREVIATIONS

WMN	Wireless Mesh Network
RWMN	Rural Wireless Mesh Network
MP’s	Mesh Points
MAP’s	Mesh Access Points
MPP’s	Mesh Portal Points
VFPlace	Virtual Force Based
MTW	Multi-hop Traffic-flow Weight
NS2	Network Simulating Tool
STA	Station
AP	Access Point
QoS	Quality of Service
SA	Simulated Annealing
GA	Genetic Algorithm
DCTST	Degree-Constrained Terminal Steiner Tree
CPU	Central Processing Unit
RAM	Random Access Memory
TSP	Tree Set Partitioning
DW-GDTSP	Degree and Weight based Greedy Dominating Tree Set Partitioning
BFS	Breadth-First Search
TDMA	Time Division Multiple Access
MC’s	Mesh Clients
OF	Objective Function
BWMN	Backbone Wireless Mesh Network
fPrIM	Fixed Protocol Interference Model
MAC	Media Access Control
OTcl	Object Oriented Extension of Tool Command Language
DSDV	Destination-Sequenced Distance-Vector
CBR	Constant Bit Rate
TCL	Tool Command Language
FTP	File Transfer Protocol
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
PDR	packet delivery ratio
VoIP	Voice over Internet Protocol

CHAPTER ONE

Introduction

1.1 Preamble

Wireless Mesh Networks (WMNs) has emerged as a promising technology to meet the challenges in future generation wireless networks by providing internet connectivity to applications such as broadband home networking, community neighborhood networks, and enterprise networking (Akylidiz *et al*, 2005). A WMN is dynamically self-organized and self-configured with Mesh Points (MP's) relaying messages on behalf of other nodes in the network automatically establishing and maintaining mesh connectivity among themselves hence increasing the available bandwidth and communication range. These desirable features bring many advantages to WMNs such as low up-front cost, reduced network deployment complexity, easy network maintenance, robustness, and reliable service coverage (Naeem and Loo, 2009).

Figure 1.1 illustrates a typical backbone of a WMN which is made up of four types of network nodes (according to 802.11s standard) namely Station (STA), Mesh Point (MP), Mesh Access Point (MAP) and Mesh Portal Point (MPP). STA is a client or mobile user device that does not participate in route discovery. A MP is a device that helps in providing mesh services and may be a dedicated infrastructure device or a regular user device that is capable of fully participating in the operation of a mesh network.

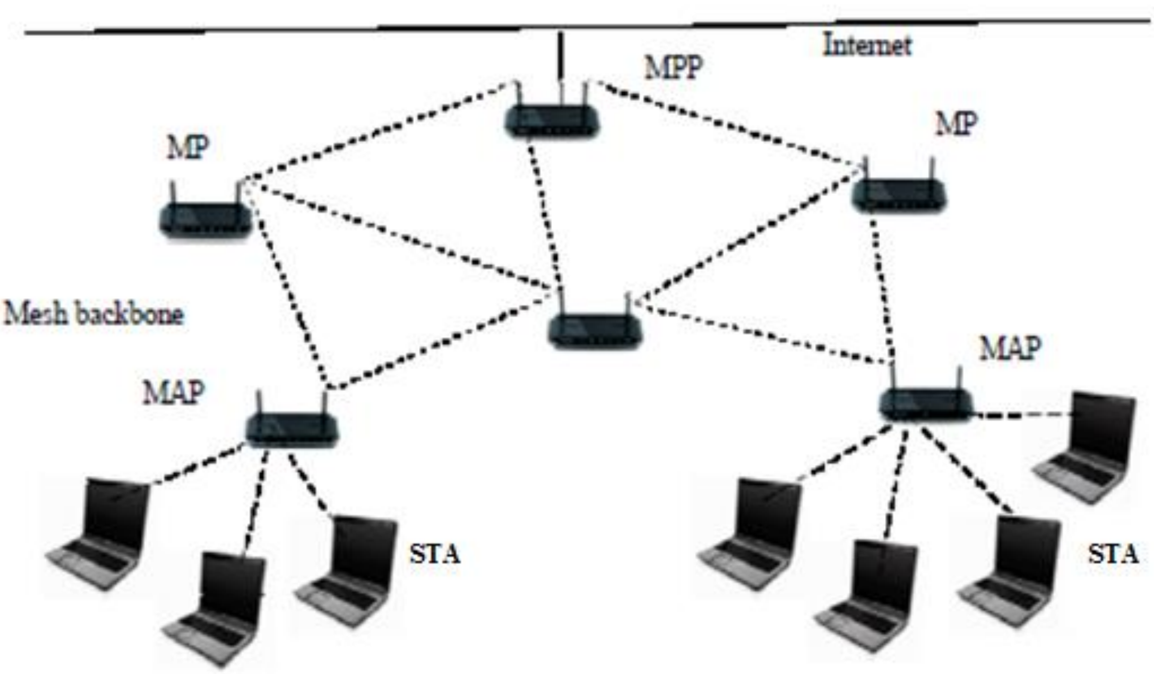

Figure 1.1 A Backbone WMN Infrastructure (Prasina *et al*, 2012)

A MAP is a special MP that is attached to an Access Point (AP) and helps to provide mesh services for a STA. The MPP is a special MP that acts as a bridge or a gateway to a wired network. When deploying the WMNs placement of MP's is an important design issue because the performance of WMNs depends on the topology of the mesh backbone which in turn depends on the location of MP's (Xhafa *et al,* 2009).

The main design issues in the deployment of the WMN's are providing good coverage area (the terrain area that has good connectivity to client nodes) and connectivity (multi-hop path between MP's). The network performance is largely affected by the placement of MP's, thus placement sites should be properly chosen in order to obtain better coverage and connectivity (Antony *et al*, 2007). Most traffic is forwarded toward the Internet via the MPP. Even if maximum coverage can be obtained by MAP's, bottlenecks can still occur causing congestion in the MPP, if the locations are not properly selected (Jun and QiangQiang, 2009). An effective MAP selection scheme would also be able to obtain maximum coverage and connectivity while maintaining the Quality of Service (QoS) requirements. Many cities and wireless companies have already deployed WMN around the world (Li and Wang, 2008). Inadequate Internet access is widening the digital divide between town and countryside, degrading both social communication and business advancements in rural areas (Ishmael *et al*, 2008); WMN's could provide an excellent framework for delivering broadband services to rural areas. Community WMN's in rural areas are starting to emerge and some examples of these networks are: The Wray WMN (Ishmael et al, 2008), Peebles valley WMN (Johnson and Roux, 2008), Aravind WMN (Surana *et al*, 2008), AirJaldi WMN (Surana *et al*, 2008), Link net WMN (Johnson et. al. 2008), Village Net (Dutta *et al*, 2007) and many more.

Rural WMNs are characterized by a fixed, outdoor topology and very long-distance links between the nodes. Deploying a WMN requires taking into account specific restrictions and characteristics of the real geographic area. For this reason one needs to explore different topologies for placing MP's (Xhafa *et al*, 2009). The nature of the terrain dictates where MP's could be placed. This dissertation explores the problem of MP's placement for deployment in rural areas by looking at different settlement patterns that exist in rural areas.
A settlement is a place where people live; early settlements were developed within the rural environment and were influenced mainly by physical factors e.g. landforms (local rocks, hills, and rivers), local weather, soil and vegetation (Dilley *et al*, 2006). Examples of rural settlements are isolated houses or farms, hamlets, villages and small towns. There are number of different types of rural settlement patterns namely, Isolated Settlement, Dispersed Settlement, Nucleated Settlement and Linear Settlement. (Dilley *et al*, 2006). Isolated settlements are individual farmhouses found in some rural areas; the harsher the environment the further apart these tend to be.

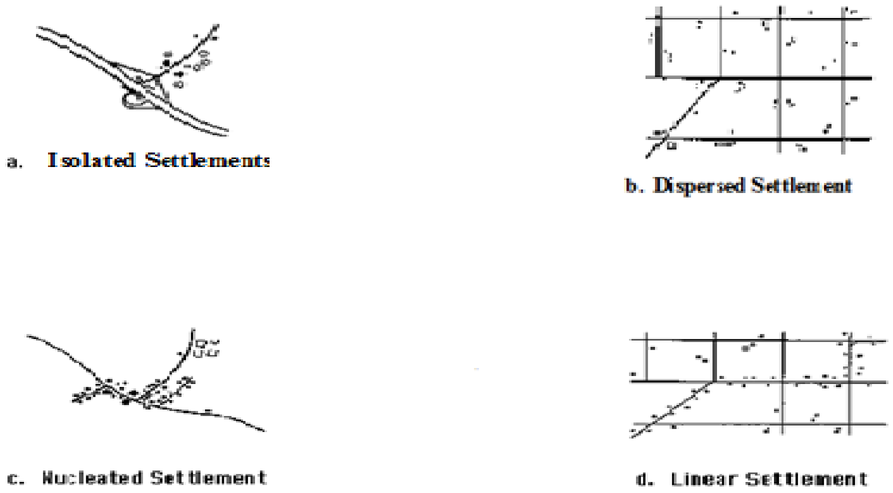

Figure 1.2 Rural settlement patterns (http://ludwig.missouri.edu/2840/rural/sprawl.html)

Dispersed settlements are formed when small clusters of individual settlements are found spread across the landscape. In a typical dispersed settlement, there are a number of separate farmsteads scattered throughout the area. Nucleated settlements are grouping of buildings toward the centre might be because of certain resource. Linear Settlements refers to the type of settlement which is elongated along a line of communication floor of a valley. This study investigates the effectiveness of the existing MAP's and MPP's placement algorithms in different rural settlement patterns.

Regular placement of MP's provide better performance compared to a random placement because the number of MP's used can be reduced drastically if they are placed in regular pattern rather than placing them randomly. But, in real deployment scenario, placing the MP's in a regular grid form is not feasible. This is because MP's are typically installed on existing infrastructure e.g. buildings, streetlight, houses etc. the other reason is that the clients distribution may not be uniform in the given deployment area (Robinson and Knightly, 2007). MP's placement schemes have been proposed but however they have not been evaluated using rural settlement patterns.

1.2 Statement of the Problem

MAP's and MPP's placement problems have been long investigated in the optimization field, placement schemes were proposed to select optimal candidate position for deploying MP's such that network performance will be improved. MP's placement schemes aim to optimize network coverage and connectivity while maintaining quality of service requirements in the network. These MP placement schemes have been evaluated considering different distribution of mesh clients some which are Random, Uniform, Normal, Exponential and Weibull distribution.

The good performance and operability of a WMN largely depends on the terrain and the selection of MP's position. To the best of our knowledge none of these works have evaluated their effectiveness using rural settlements patterns, therefore it is not clear which scheme is more appropriate to be used in the Rural WMN (RWMN) deployment. These placement schemes have not been evaluated and compared in an efficient manner; therefore, there is a need for evaluation of MP placement schemes using rural settlement patterns in order to test their suitability in solving placement problem. The research findings of this work is hoped to improve the future RWMN deployment. This work seeks to answer two research questions:

1.2.1 How are mesh points placement schemes classified in literature?

1.2.2 Which MP placement scheme(s) can be used in rural settlement patterns during RWMN deployment?

1.3 Rationale of the Study

Providing connectivity to under-serviced rural areas comes with a unique set of challenges such as the high cost of installing equipment, lack of reliable power, skill shortages and the high cost of providing Internet connectivity, which is mostly satellite based. Deploying a WMN in rural areas provide access solutions for low cost internet connectivity.

A major challenge when deploying a WMN is choosing candidate locations for MAP's and MPP nodes because poor placement of MP's will result in a WMN with undesirable performance. Lack of planning on how to locate MP's implies that network performance cannot be guaranteed because MP placement schemes contribute in achieving desirable properties of WMN; it is this vision that inspires us to conduct a study on evaluation of MP placement schemes in WMN's.

To the best of our knowledge there is no research reported on evaluating mesh points placement schemes for RWMN deployment hence with the increasing number of RWMN deployment, finding the best MAP's and MPP placement schemes will contribute in improving the network performance for future RWMN deployments.

1.4 Research Goal and Objectives

1.4.1 Goal

The purpose of this study is to evaluate the existing MP placement schemes and to recommend the best scheme(s) to be used during RWMN deployment.

1.4.2 Objectives

1.4.2.1 To investigate the way MAP's and MPP's placement schemes have been classified in the literature.

1.4.2.2 To simulate MAP’s placement algorithms in rural settlement patterns.

1.4.2.3 To evaluate and recommend the best MAP(s) placement scheme(s) to be used during RWMN deployment.

1.4.2.4 To simulate MPP’s placement algorithms in rural settlement patterns.

1.4.2.5 To evaluate and recommend the best MPP’s placement scheme(s) to be used during RWMN deployment.

1.5 Research Methodology

Two research methods will be used in order to fulfill the research goal of this study. The first method is to perform a case study which will help to investigate the way MAP’s and MPP’s placement schemes address the placement problem. The second research method will be to evaluate the reviewed placement schemes using simulations.

1.5.1 Primary Research Method

A case study is going to be conducted in order to investigate the way MAP’s and MPP’s placement problem has been solved in the literature. The case study will involve developing a classification framework that will help to analyze, categorize and determine which MP placement could be selected for simulation to suit the purpose of this study. A case study will be used because the main aim of this work is to recommend MAP’s and MPP placement schemes that can be used for RWMN deployment. In order to validate that the scheme can indeed work for RWMN, it has to be evaluated in rural settlement patterns that exist. Hence a preliminary research was conducted and the settlement patterns that exist in most African rural areas were identified, namely; isolated, dispersed, nucleated and linear rural settlement patterns. The performance of the selected MP placement schemes will be simulated and fair recommendations will be made. This method answers the first question and helps to fulfill the first research objective.

1.5.2 Secondary Research Method

The secondary research method that is going to be used is simulation, which will involve evaluating placement schemes in Isolated, Dispersed, Nucleated and Linear Rural Settlement Patterns. Using the primary research method MAP's and MPP's placement schemes will be categorized into groups determined by the techniques each scheme uses to solve the placement problem. Only one placement scheme will be selected to represent each group during the simulation. The result of the recommended MAP placement scheme will be used as a basis for selecting the MPP's positions using the selected MPP's placement schemes. After simulation, placement schemes will be evaluated and compared. The best placement scheme(s) in an Isolated, Dispersed, Nucleated and Linear rural settlement pattern will be recommended for adoption in future RWMN deployment. This research method helps to answer the second research question and fulfills the second, third, fourth and the fifth research objectives.

1.6 Organization of the Dissertation

The rest of the dissertation is set out as stated:

Chapter Two presents a Literature Review based on a classification framework for analyzing, categorizing and selecting MPs placement schemes. Chapter Three presents a detailed description of the selected MPs placement schemes using pseudo-codes and flowcharts.

In Chapter four the simulation environment, experimental setup, analysis and recommendations of the MAP placement schemes is being presented. Chapter Five presents the analysis and recommendation of MPP placement schemes for each settlement pattern.

Chapter Six presents limitations and future works of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

MAP's and MPP's placement are two crucial problems that need to be carefully addressed to achieve the optimal performance and operability of a Wireless Mesh Network (WMN). There is much research conducted in literature tackling the problem of MAP's and MPP placement. The existing literature has not been classified in any consistent manner, while new approaches are continuously being employed. In order to fully utilize all the knowledge from the literature, a classification framework was developed, which helped to analyse, categorise and select MAP and MPP's placement schemes for simulation.

MAP's were categorized into three groups, namely: movement based, measure and place, relay based, placement schemes while MPP placement schemes were categorized into three groups namely: greedy based, clustering based and weighted based. All the research works falling into these groups has gone into the optimization of MP's placement for deployment. However, to the best of our knowledge, none of these studies used rural settlement patterns to evaluate the efficiency of the placement schemes. One MP placement scheme was selected from each group for simulation and evaluation in rural settlement patterns in order to find the best scheme(s) suited to RWMN deployment. In section 2.2, the classification framework for analyzing MAP's placement scheme is developed and used, while section 2.3 presents MPP's classification framework and analysis of placement schemes. Section 2.4 provides the summary of the chapter and includes the resultant findings of this chapter.

2.2. Classification Framework for Analyzing MAP's Placement Schemes

In order to critically analyze the work done by different scholars in this field we have developed a classification framework for MAP's placement schemes presented in Table 2.1 showing the purpose or functionality of each feature contributing into placement problem.

Table 2.1 Classification Framework for MAP's Placement Schemes

Features	Functionality
Types of Mesh Clients	Determines the nature of mesh clients whether they are of mobile or of stationary.
Distribution of Mesh Clients	Determines the client distribution used whether it is uniform or non-uniform, normal, exponential and weibull, etc.
Objective to optimize	Help to identify the aim and the contribution of the scheme. For MAP we consider looking at factors like coverage, connectivity, cost, traffic constraints.
Approach	Determines the method or the technique used to place MAP and how this method work (where are MP's located and how).
Evaluation	Involve determining the performance factors like metrics, environment, tools, number of mesh clients, number of MAP's, number of MPP's used.

2.2.1 MAPs Placement Schemes Category

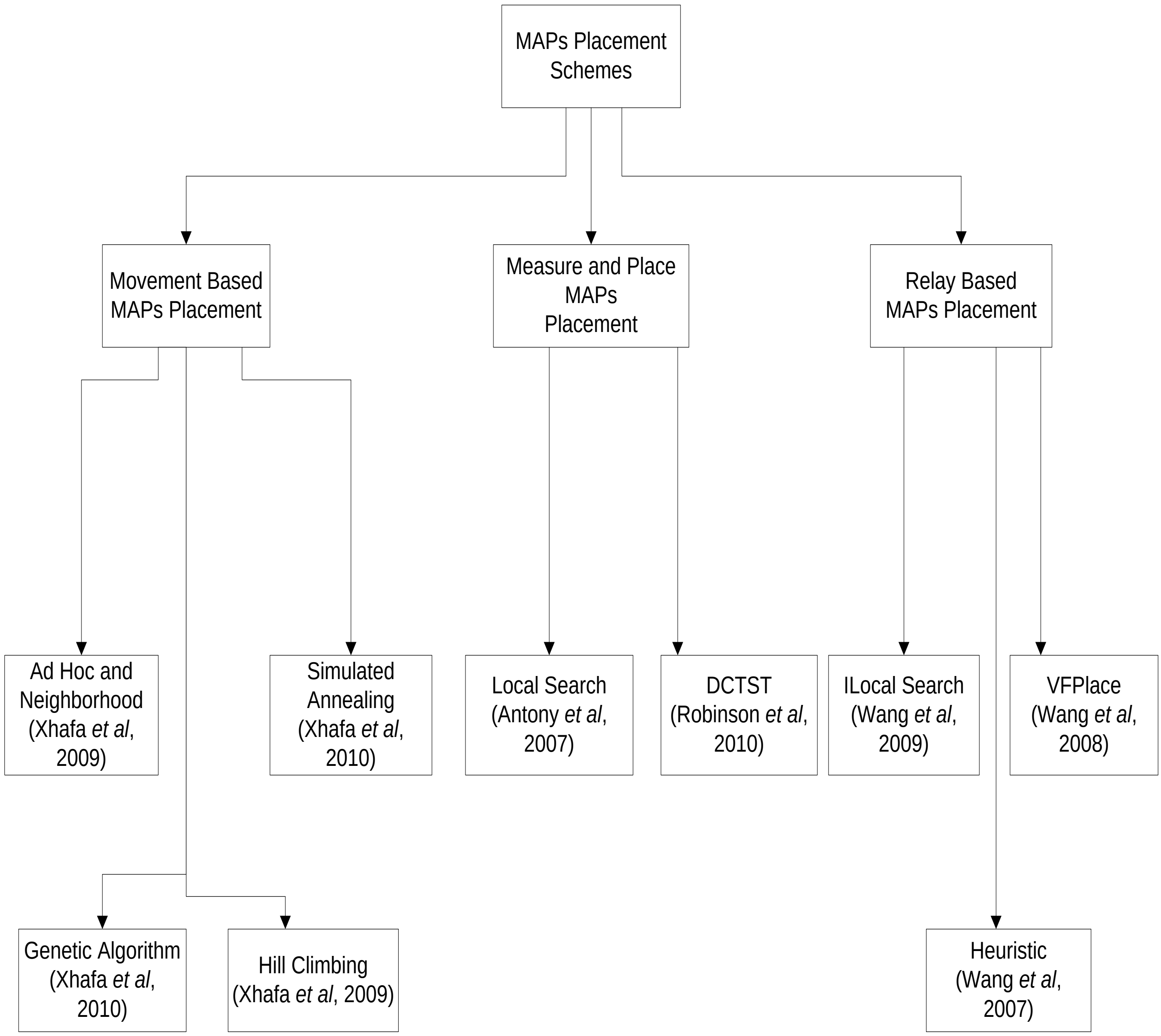

Figure 2.1 Classification Diagram of MAP's Placement Schemes

Figure 2.1 represents the Classification Diagram showing explicitly the groups of MAP's placement schemes. Using the developed classification framework the literature was studied and categorized into three groups namely: Movement Based, Measure and Place, and Relay Based MAP's placement.

2.2.1.1 Movement Based MAP's placement

This group evaluates the effectiveness of random, radius and swap local movements in terms of obtaining maximum coverage and connectivity. Random local movement involves choosing a location of MAP's randomly in a deployment area. Radius local movement chooses the MAP of the largest radio coverage and places it at the center where the mesh clients are largely populated. Swap local movement consist of exchanging a MAP of the lowest radio coverage in the most densely populated region of mesh clients with a MAP of the largest radio coverage in the less densely populated region.

The movement based MAP's placement group consists of the ad hoc and neighborhood schemes, hill climbing scheme, simulated annealing scheme and genetic placement scheme. Placement schemes under this group were not evaluated under rural settlement patterns and the client distribution considered was uniform, normal, exponential, and weibull. Typically for deployment in rural areas, a certain distribution should be best fitted for a particular settlement pattern. The performance of a network is highly dependent on the distribution of clients.

A. Ad hoc and Neighborhoods Search Based Schemes (Xhafa *et al,* 2009)

Ad hoc and Neighborhoods search based placement explored MAP's placement problem by mainly focusing on the following different placement topologies:

1. Diagonal placement: MAP's are concentrated along the diagonal of the grid area.
2. Random placement: MAP's nodes are placed uniformly at random in the grid area.
3. Cross placement: MAP's are placed along both diagonals of the grid area.
4. Corner placement: MAP's are placed in the corners of the grid area.
5. ColLeft placement: MAP's are placed at the left side of the grid area.
6. Near placement: MAP's are concentrated in the central zone of the grid area.

Table 2.2 Characteristics of the Ad hoc and Neighborhoods Schemes (Xhafa *et al*, 2009)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	stationary
Distribution of Mesh Clients	Uniform, normal, exponential and weibull
Purpose	To deploy MAPs such that maximum coverage and connectivity is obtained in a network.
Approach	Diagonal, random, cross, corners, colLeft, near, hotspot and swap local movements for MAP's placement.
Evaluation	64 MAP's in a 128×128 grid area for covering 192 clients.

7. HotSpot placement: places the most powerful MAP's in the most dense zone of the grid area and places the second most powerful MAP's in the second densest zone until all MAP's are placed.

Neighborhood Search Methods was introduced to enhance the performance of Ad hoc and Neighborhoods. The two types of local movements that were proposed are:

1. Random local movement: randomly place MAP's in a deployment area.
2. Swap local movement: exchange the placement of two MAP's, the worst MAP with smallest radio coverage in a most dense area is exchanged with the best MAP with largest radio coverage of the least dense area.

Table 2-2 briefly explains characteristics of Ad hoc and Neighborhood search-based schemes. In this work the Ad hoc and Neighborhoods did not vary the number of MAP's and this might not reflect the accurate trend of the performance of the scheme compared to when the number of MAP's is varied. The reason behind such argument is because the performance of the network changes as the number of deployed MAP's increase. Based on the performance evaluation performed by the Ad hoc and Neighborhoods, it is not easy to judge on the suitability of the scheme for rural areas.

B. Hill Climbing Scheme (Xhafa *et al*, 2009)

Table 2-3 gives a summary of the Hill climbing scheme which aims to maximize the size of the giant component and to maximize user coverage. The study evaluated the performance of four local movements namely: random, swap, radius and a combination local movement in terms of MAP placement. A noticeable improvement of this work from the above previously discussed scheme, is the addition of the radius and combination local movement. Radius local movement selects the MAP of the largest radio coverage and places it in the densest area in terms of the number of mesh clients in the grid area. A combination local movement is a composite of the swap, radius and random local movements. The experimental study presented in this work showed that the performance of the four local movements depends on the distribution of mesh client nodes.

The main challenge with the Hill Climbing scheme is that sometime it can end up in local optima; however, this could be escaped by:

1. Getting back to the previous state and explore different direction,
2. Jumping to the new solution far away from current solution,
3. Simultaneously exploring various search directions in a solution space

Table 2.3 Characteristics of the Hill Climbing Scheme (Xhafa *et al*, 2009)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	stationary
Distribution of Mesh Clients	Uniform, normal, exponential and weibull
Purpose	Finds a location assignment for the MAP's that maximizes the network connectivity and client coverage.
Approach	Explore random, radius, swap and combination local movements in terms of mesh node placement.
Evaluation	16 MAPs for 48 clients on a 64x64 grid area, 32MAPs for 92 clients on 128 x 128 grid area and 64 for 192 clients. 15 independent runs were carried out for the same instance.

Despite these mentioned limitations Hill climbing works well for hard combinatorial optimization problems. Deployment in a rural area needs strategic placement because of the clients' distribution diversity. It is not certain if the client distribution that the Hill climbing considered will guarantee the same network behavior as client distribution in nucleated, isolated, dispersed and linear settlement patterns. According to the analyses, there is a need for the valuation of local movements on rural settlement patterns. Hill Climbing is the best scheme to represent the movement based MAP's placement group because, despite of its drawbacks, it copes in practice with hard combinatorial optimization problems without involving complicated costly methods like the simulated and genetic methods.

C. Simulated Annealing Placement Scheme (Xhafa *et al,* 2010)

Table 2.4 Characteristics of Simulated Annealing Placement Scheme (Xhafa *et al*, 2010)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	stationary
Distribution of Mesh Clients	Uniform, normal, exponential and weibull
Purpose	Finds a location assignment for the MAP's that maximizes the network connectivity (size of the giant component) and client coverage.
Approach	Explore different types of local movements, namely, random, radius, swap and combination in terms of the maximization of coverage and connectivity.
Evaluation	Randomly generated instances of three different grid area sizes (32x32, 64x64, and 128x128) were used. 16 MAP's were placed to cover 48 mesh clients for grid size 32x32. 32 MAP's were placed in the 64x64 grid area to cover 96 clients and temperature was set to 2. 64 MAP's were placed in a 128x128 grid area to cover 192 clients and temperature was set to 2. 15 independent runs were made in all the mentioned instances.

A Simulated Annealing (SA) placement scheme is a scheme proposed for placement of MAP's mainly focusing in obtaining maximum coverage and connectivity within the network. SA was mainly designed to solve global optimization problems, i.e., finding a good approximation to the global optimum of a function in a large search space.

In contrast to simple local search methods such as Hill climbing, SA accepts neighbouring solutions, which could be worse than the current solution, in an attempt to escape from the local optima. SA produced better slow results and the most striking challenge is choosing and tuning parameters like initial temperature and equilibrium detection.

Table 2-4 represents a summary of the Simulated Annealing Scheme. The swap movement in the simulated annealing was found to be too computationally expensive, hence it is not advisable to use expensive search methods for deployment in rural areas, rather use low cost search methods.

D. Genetic Algorithm (Xhafa *et al,* 2010)

Genetic Algorithm (GA) selects the optimal candidate positions for placing MPP's. The main features of GA's are:

1. Population of Individuals: use a population of individuals giving the search a larger scope and chances to find better solutions.
2. Fitness: involves the determination of an appropriate adaptive function or objective function.
3. Convergence: when the genetic method reaches optimal solutions.
4. Crossover operators: when GA transmits best genetic features of parents to offspring during many generations of the evolution process.
5. Mutation operators: provide a component of randomness in the neighborhood of the individuals of the population.
6. Escape from local optima: avoids getting stacked from local optima by escaping during the search space.

However the main disadvantage of the Genetic Algorithm is that it is computationally expensive because of the usage of genetic operators, requiring larger numbers of iterations to reach high quality solutions. Even though the GA scheme obtains optimal solution it cannot be considered as a representative for movement-based schemes because WMN deployment in rural areas will require low cost infrastructure.

Table 2.5 Characteristics of a Genetic Algorithm (Xhafa *et al*, 2010)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	stationary
Distribution of Mesh Clients	Uniform, normal, exponential and weibull distribution
Purpose	To find location assignment for MP's that maximizes the network connectivity (size of a giant component) and client coverage.
Approach	Explore the solution space by means of a population of individuals which are evaluated, selected, crossed and mutated to reproduce new individuals of better quality.
Evaluation	For 32x32 grid area size cross over probability = 0.8, population size = 26, intermediate population size = 12, mutate probability. 16 MAP were placed to cover 48 clients. For 64x64 grid area size cross over probability = 0.75, population size = 36, intermediate population size = 17, mutate probability =0.25. 32 MAP's were placed to cover 96 clients. For 128x128 grid area size cross over probability = 0.8, population size = 49, intermediate population size = 24, mutate probability =0.20. 64 MAPs were placed to cover 192 clients.15 independent runs were performed

Most schemes in the movement-based placement group evaluated the effectiveness of the local movements in different distributions namely uniform, normal, exponential and weibull and it was concluded that each schemes optimize MAP's placement and network performance altogether. However, since Hill Climbing is selected as representative sample for this group, authors observed that Hill Climbing tends to cope well in practice with hard combinatorial problems and works well for practical purposes.

2.2.1.2 Measure and Place MAP's placement

This group measures signal strength in each grid in a deployment area which varies and decays exponentially as a function of distance. The main objective is to strategically find the best locations for placing MAP's such that maximum coverage and connectivity is obtained. This section discus two placement schemes belonging to Measure and Place placement, namely: Time-efficient local search, and Degree-constrained terminal Steiner tree scheme.

A. Time-efficient Local Search Scheme (Antony *et al*, 2007)

Local Search finds the optimal location for MAP's given the possible locations for the MAP's in the deployment area, number of users and signal strength of all MAP's in each grid. MAP's are randomly added one by one to the network until the number of MAP's to be placed is reached. In each iteration, the scheme selects one MAP from the remaining MAP's available, which gives largest objective function together with already selected MAP's.

Table 2-6 gives a summary of the Time-efficient Local Search Scheme, the number of MAP's required not only depends on the number of candidate locations, but also the locations where the MAP's can be placed. The Time-efficient local search algorithm finds near optimal solution for small size networks.

In a Rural WMN (RWMN) there are long distances in between the MAP's and the signal strength or quality degrade as a function of distance and this means that if there is a long link between two MAP's the signal strength will be weak due to physical and signal disturbances in the transmission media. The Time-efficient local search placement scheme considered only uniform client distribution and should be evaluated in all the rural settlement patterns. The reason behind the performance evaluation is to investigate the fitness of the placement scheme since performance uniform client distribution cannot be assumed to be equivalent with the performance for the client in rural settlement patterns.

Table 2.6 Characteristics of Time-efficient Local Search Scheme (Antony *et al*, 2007)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	Stationary
Distribution of Mesh Clients	Uniform
Purpose	To find the best possible locations for MAP's so that the network has good coverage and good connectivity.
Approach	A client device connects to MAP's if the average signal strength received from MAP's is above a threshold value. To find the coverage and connectivity of the network the terrain is divided into cells of equal size adding MAP's one by one till the number of MAP's is reached.
Evaluation	Deployment area of size 1000m × 1000m was partitioned into grid sizes of 10m × 10m.

B. Degree-Constrained Terminal Steiner Tree Scheme (Robinson *et al,* 2010)

Table 2-7 gives a summary of the Degree-Constrained Terminal Steiner Tree Scheme (DCTST). The DCTST scheme selects MAP's (i.e. Steiner Points) to build a tree which spans all selected MAP's (connectivity) with the constraints of bounded vertex degree (capacity) and the requirement that all target client locations are connected as leafs of the tree (coverage), thereby jointly satisfying mesh network constraints. This work also incorporates non-uniform propagation by specifying the estimated signal quality per link and also uses method Minimize-Nodes to minimize the number of deployed MAP's.

In the placement evaluation Minimize-Nodes scheme was compared with a geometric covering scheme in a non-uniform propagation setting based on measured propagation data deployed in GoogleWiFi mesh network. Even though the fitness of the DCTST was evaluated and compared with the GoogleWiFi network the settings and factors affecting the

Table 2.7 Degree-Constrained Terminal Steiner Tree Scheme (Robinson *et al*, 2010)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	Stationary
Distribution of Mesh Clients	Non-uniform
Purpose	To find the placement of MAP's that will jointly satisfy client coverage, mesh connectivity and mesh capacity constraints.
Approach	Physical-layer estimation techniques are used to specify the potential links for input connectivity.
Evaluation	GoogleWiFi network in Mountain View 7.25 km2 urban city-block topology was used, 5 meter spacing between MAP's location, MAP's locations density was 200 locations per km. 168 nodes considered.

experiments cannot be predicted or assumed to be the same as the one for RWMN deployment. The reason behind this argument is because the DCTST measured signal strength from the estimated propagation at any given potential MAP location in the city. This serve as a proof that the DCTST was only evaluated for urban WMN and this raise the need for evaluating the effectiveness of the DCTST in the rural settlement pattern. Time-efficient Local Search Scheme is selected as representative of this category due to the fact that it also consider shadowing propagation which is the amount of variation to path loss and this technique makes it the prediction of the received signal strength essentially probabilistic.

2.2.1.3 Relay Based MAP's placement

This group aims to optimize MAP placement such that maximum coverage and connectivity is achieved by taking into account the traffic distribution with pre-decided MPP position. The Relay Based MAP placement group consists of Heuristic placement; Virtual Force based (VFPlace) placement and Incremental placement schemes.

A. Heuristic Placement Scheme (Wang *et al,* 2007)

The Heuristic placement scheme is proposed for minimizing the number of deployed MAPs and to cater for traffic demand.

Table 2.8 Characteristics of a Heuristic Placement Scheme (Wang *et al*, 2007)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	Stationary
Distribution of Mesh Clients	Non-uniform traffic demand distribution whereby the candidate positions for MAPs are pre-decided.
Purpose	To find the minimal configuration of MAP's so as to satisfy network coverage, connectivity and internet traffic demand.
Approach	Analytical model is used for both MP's placement, the focus is getting minimal MAP's placement in the local network with one MPP. Validate traffic demand, place MPP's then place MAP's.
Evaluation	Initial candidate positions are randomly generated evaluation through simulation, parameters used are number of MAP's, traffic density, time, network size, 10 independent runs were made, scheme was implemented using C++ and simulated using Matlab.

The objective is satisfied by following three steps:

1. Validating the traffic demand in the network by ensuring that the MAP's placement is only done if the overall network traffic demand is less than the MPP's throughput capacity; if not so the current network area must be split into two or more network local domains with multiple MPP's.
2. Placement of MPP at the candidate node which has the shortest Euclidean distance that achieves minimum efforts in terms of traffic routing length.

3. Placement of MAPs by sorting nodes according to their Euclidean distance to the MPP in descending order however some nodes are not connected to the MPP. The heuristic scheme group the nodes into connected-clusters and for every cluster that is

not connected to the MPP the scheme perform Add and Merge process whereby additional node is added one by one in the cluster to reduce the distance to the MPP. Table 2-8 gives additional characteristics of the scheme.

B. Virtual Force Based Placement Scheme (Wang *et al*, 2008)

A Virtual Force Based Placement (VFPlace) Scheme is a scalable and self-adaptive scheme proposed for determining the appropriate position for placing MAP's.

Unlike the Heuristic placement scheme the VFPlace scheme tackles the placement problem by satisfying geographical and traffic constrains focusing mainly on virtual forces from three objects namely:

1. Other MAP's: forces from other MAP's.
2. Prohibitive Regions: is an area in the network domain where MAP's cannot be placed for example in football fields.
3. Preferential Regions: is an area in the network domain where a dense number of MAP's could be placed for example residence and offices within buildings.

The VFPlace treats the network field as a Virtual Force Field which can be affected by two forces i.e. Repulsive force and Attractive force. A repulsive force maximizes network coverage by pushing MAP's away from each other; conversely the attractive force maximizes network connectivity by pulling MAP's close to each other. The scheme also caters for traffic aggregating distribution to and from MPP's into MAP's. The following table gives a further description of the scheme. It is important to note that a VFPlace scheme tackle solving the

Table 2.9 Characteristics of the VFPlace Scheme (Wang *et al*, 2008)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	Stationary
Distribution of Mesh Clients	Non-uniform distribution
Purpose	To maximize the network connectivity, client coverage and satisfy traffic demand requirements.
Approach	Avoid placing MAP’s in prohibitive regions, favors preferential regions and balance distance between MAP’s.
Evaluation	Matlab used for Simulation; 38 MAP’s, one MPP located (0, 0) centre, network domain was 8 units; transmission range of each MR node was 2 units.

MAP’s placement problem in a more realistic network environment by searching for optimal candidate positions in heterogeneous prohibitive and preferential regions. In a rural context there are a number of prohibitive regions that can be found in any settlement pattern, like rivers, farms and forest etc, hence VFPlace is best representative of Relay based group. In contrast of using a Matlab, NS2 will be used for simulation of the VFPlace MAP placement scheme.

C. Incremental Local Search Scheme (Wang *et al,* 2009)

Incremental Local Search (ILSearch) placement scheme was proposed to determine the optimal candidate positions for placing MAP’s taking into account both multiple transmission rate and co-channel interference. MAP’s are classified into two groups namely:

1. Coverage MAP’s are set of MAP’s to cover all MC’s; however some of them might not be connected to the IGW nodes.
2. Relay MAP’s are set of MAP’s that relay traffic between coverage MAP’s and MPP’s i.e. they connect isolated MAP’s into MPP’s.

Table 2.10 Characteristics of the ILSearch Placement Scheme (Wang *et al*, 2009)

CHARACTERISTICS	ANALYSIS RESULT
Types of Mesh Clients	Stationary
Distribution of Mesh Clients	Non-uniform distribution
Purpose	To determine locations of MAP’s that maximum coverage, connectivity and satisfy traffic demand.
Approach	Mixed integer programming model, Coverage MAP’s determination, Relay MAP’s determination
Evaluation	Matlab and c++ used for Simulation; 1000m x 800m rectangular region size, 497 nodes, 23 MR’s

The effectiveness of a multi-rate (ILSearch) placement scheme was compared with an Ideal fixed-rate based scheme. The authors observed that the number of MAP’s in multi-rate based placement increases as traffic from each MC increases in contrast the ideal fixed-rate MAP’s remain stable. Many Coverage MAP’s needs some dedicated Relay MAP’s to transfer the traffic and these Relay could not share the load from other coverage MAP’s.

The ILSearch scheme is capable of finding MAP’s deployment solution in which MAP’s are placed only at permitted location providing enough bandwidth to meet the traffic demand in the network.

2.3 Classification Framework for Analyzing MPP's Placement Schemes

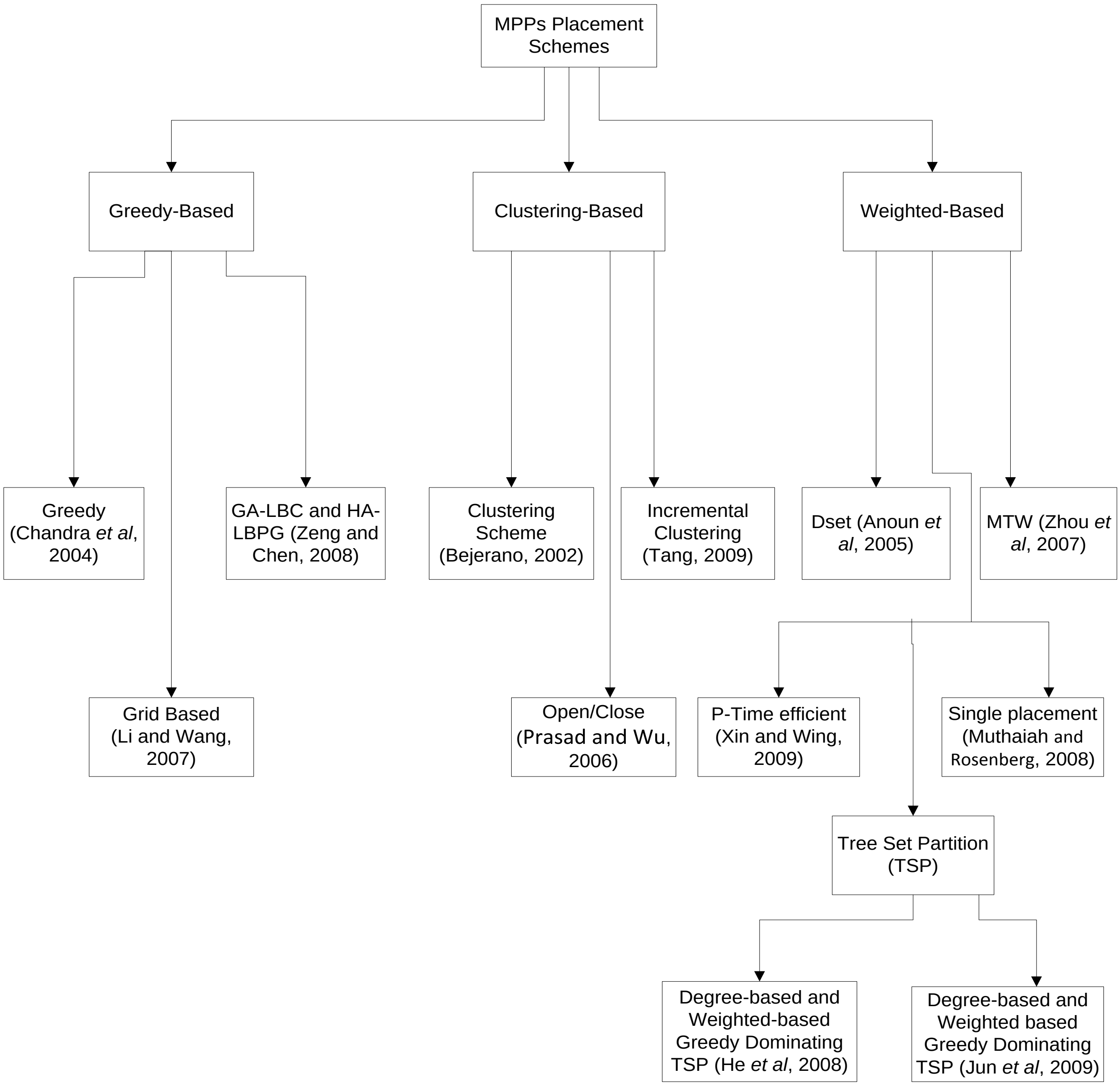

Figure 2.2 MPPs placement schemes classification Diagram

In this section a classification framework for studying and analyzing MPP's placement schemes is developed. The classification framework will help to categorize the schemes, find the trends and select the schemes for simulation from the literature. The review will be based on the features such as the type of MAP's, distribution of MAP's, purpose of the placement scheme, approach used for placement and evaluation used to test the effectiveness of a placement scheme. Three MPP's placement schemes groups were formed namely: Greedy-based, Clustering-based and Weighted-based placement. Figure 2.2 represent the classification diagram for MPP's placement schemes derived using the classification framework.

2.3.1 Greedy-Based Placement

This group tackles the problem of MPP's placement by applying greedy decision-making steps i.e.in each iteration select a node as MPP's (not violating QOS constraints) that can cover maximum number of nodes. However, some nodes might not be covered by this node, therefore the scheme randomly selects the uncovered nodes as the MPP's to cover all the other uncovered nodes. All schemes in this group aim to optimize network performance depending on each scheme's objectives, main focus is ensuring that QOS requirements are satisfied that involve obtaining maximum throughput, load balancing, and fault tolerance.

2.3.1.1 Greedy Placement Scheme (Chandra *et al,* 2004)

The greedy placement schemes investigate methods to efficiently place MPP's such that: (i) The number of required MPP's is minimized while guaranteeing the users' bandwidth requirements; (ii) MPP's provide bandwidth guarantees in the presence of failures and (iii) take into account variable traffic demands since user demands often exhibit periodic changes (e.g., diurnal patterns). The scheme uses ideal link model and general link mode to capture wireless interference and contention among nodes whose paths to MPP's share common links. The models ensure that the amount of flow entering a MAP is equivalent to the flow exiting the node, each MAP has equal amount of flow to send to the MPP and that the MAP does not receive flow sent by itself. The cost of managing such deployment is significant due to the increase of constraints to be fulfilled hence greedy placement scheme might not be suitable for rural deployment since lowering deployment cost is always an issue.

Table 2.11 Characteristics of the Greedy Placement Scheme (Chandra *et al*, 2004)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	Uniform distribution and random distribution.
Purpose	Find optimal MPP's positions and enhance robustness by providing fault tolerance
Approach	Iteratively pick an Internet Transit Access Point (ITAP) that maximizes the total demands satisfied when opened in conjunction with the ITAP randomly chosen in the previous iterations.
Evaluation	1106m*1130m area, 50nodes, 195 to 376m distance

The greedy placement scheme iteratively picks the MPP that maximizes total demands satisfied at a MAP and encourage selecting MAP's with the shortest paths as possible. The MPP's were selected from random topologies by randomly placing houses in a region of size $N*N$ and a neighborhood topology contained 105 houses, spanning over a region of 1106m*1130m. It is important to note that the greedy scheme did not consider the topologies from the rural context. Table 2-11 represent the summary of the greedy placement scheme.

2.3.1.2 Grid-based MPP's placement scheme (Li and Wang, 2007)

The grid based MPP scheme finds optimal positions for placing MPP's such that the network throughput will be maximized. The network deployment area is divided into an axb grid and MPP's are deployed at the cross section of the grid. The effectiveness of the scheme is evaluated using linear programming and finds optimal positions for MPP's. However, the linear programming used does not consider the alteration and deployment evolution therefore for evaluation of the placement schemes NS2 is going to be used.

Table 2.12 Characteristics of a Novel Grid-based internet gateway placement scheme (Li and Wang 2007)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	stationary and random distribution
Purpose	MPP's placement and maximizing throughput
Approach	Divide a network and place MPP's in cross points. The greedy method is applied to design efficient link scheduling.
Evaluation	LP-Flow-Throughput-2 as a evaluation programming tool, 60-100 MAPs, 4-8 MPPs, 500 x500 m area

Throughput was maximized by using greedy link scheduling and fixed protocol interference model whereby links were sorted each according to an earliest time slot which will not cause any interference. This process was iterated till all MPP's were placed on the grids and the MPP's with maximum throughput performance were made as final MPP's positions.

To improve the QoS mechanism involves a lot of network parameters like ensuring maximum throughput, packet delivery ratio, reduced end-to-end delay etc. However the novel grid only optimized network throughput therefore the scheme can be improved by also ensuring high packet delivery ratio and reduced en-to-end delay. Table 2-12 above show a summary of the characteristics Novel Grid-based MPP placement scheme. This work was not evaluated under the different settlement pattern hence it is hard to determine if it is well optimized for deploying MPP's in rural areas.

2.3.1.3 Greedy and Hybrid MPP placement scheme (Zeng and Chen, 2008)

The essence of the greedy and hybrid MPP placement scheme was to introduce load balancing on the MPP's. The hybrid uses roulette wheel selection method to select the MPP's which constitute of selecting the candidate node with the highest or greatest fitness probability as MPP's.

Table 2.13 Characteristics of Greedy and Hybrid placement scheme (Zeng and Chen, 2008)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	Uniform distribution and random distribution
Purpose	Select MPPs positions and ensure load balancing
Approach	Greedy randomly select uncovered nodes as MPP's to build more clusters in order to cover all uncovered nodes. Hybrid is mainly for load balancing.
Evaluation	Number of MPP's, deviation of the load in the MPP, 500 random topologies, 15 x15 area, communication radius =1

When there are uncovered nodes, the greedy algorithm randomly selects MPP's, then the hybrid tests the fitness of the selected node. Greedy and Hybrid MPP placement method only ensures load balancing. However, the other QoS mechanisms are not catered for and the effectiveness of the scheme was not tested using different rural settlement patterns. Fair evaluation is needed in order to judge the suitability of the Greedy and Hybrid on solving MPP placement in rural settlement patterns. Table 2-13 depict a brief summary of the characteristics of Greedy and Hybrid placement scheme Simulation was conducted.

In this category the Novel Grid-based MPP's placement scheme is selected for simulation because it provides the interference model (which prevents interference within links scheduled at the same time slot). The novel grid considered a simple deployment scenario where MAPs are placed on the roof of houses in the neighborhood serving as MAP's for users inside the houses and the roads.

2.3.2 Clustering-Based Placement

This group consists of dividing a network model into groups of cluster and in each cluster selects the cluster head as a MPP's node. Main objectives optimized include QOS constrains such as delay, relay and capacity constraint and reduced cost.

2.3.2.1 Polynomial Time Approximation Clustering Algorithm (Bejerano *et al,* 2002)

Table 2.14 Characteristics of the Polynomial Time Approximation Clustering Algorithm (Bejerano *et al*, 2002)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	Uniform distribution
Purpose	select MPPs positions and ensure QOS requirement such as delay
Approach	At each iteration it select the node that's R-neighborhood contain maximal number of uncovered nodes and uses the shifting strategy for calculating a small set of cluster-heads.
Evaluation	1000 nodes, 30 x30 area, radius = 1

The polynomial time placement scheme select an SP tree at each cluster head, and, if the selected tree violates the weight or the relay load requirements, it is then further divided into smaller trees. The network is partitioned into a minimal number of clusters that satisfy multiple constraints and each cluster is required to be a connected graph with upper bound on its radius.

Table 2-14 illustrate the characteristics of the polynomial time approximation clustering scheme. It can be observed from the analysis, that the schemes only cater for uniform distribution of MAP's and its effectiveness has not been evaluated under nucleated, isolated, linear and dispersed settlement pattern.

The polynomial time approximation clustering scheme only focuses on optimizing one objective which is reduced delay in the network, in this research work the aim is to optimize more than one objective.

2.3.2.2 OPEN/CLOSE Heuristic Algorithm (Prasad and Wu, 2006)

The OPEN/CLOSE Heuristic scheme select the minimum number MPP's to place in a deployment area while maintaining deployment cost, reliability and flexibility. The scheme adopted the shortest path algorithm to select minimum MPP's with bandwidth capacities satisfying total bandwidth requirement of the network.

Table 2-15 present summary of the OPEN/CLOSE heuristic algorithm, the OPEN/CLOSE heuristics consist of four operations which are recursively (recursive updating) applied to obtain optimal result namely; open, close, cost calculation and cluster adjustment. The open and close operations are used during selection of MPP's and cluster adjustment operation was used to re-cluster isolated nodes. The interesting contribution of the OPEN/CLOSE scheme is the diminution of deployment cost which is always an objective in rural areas. However, cost is not the only objective to optimize the need for equal balance while enhancing other QoS mechanisms too, such as increasing throughputs and packet deliver ratio while reducing end-to-end delay.

In the OPEN/CLOSE scheme, MPP's are selected from given MPPs sets considering a MAP's deployed in an urban area, thus the effectiveness of such a random MPP strategy needs to be shaped to be able to fit into the rural context.

Table 2.15 Characteristics of the OPEN/CLOSE Heuristic Algorithm (Prasad and Wu, 2006)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	Uniform distribution and random distribution of mesh clients.
Purpose	Select MPP's positions while maintaining deployment cost, reliability and flexibility
Approach	Applies an open, close, cost calculation and cluster adjustment during the selection of MPP position.
Evaluation	Java programming was used, Pentium 4 Central Processing Unit (CPU) running at 2.26 GHz with 1GB of Random Access Memory (RAM) was used, 3371 area

2.3.2.3 Incremental Clustering MPP's placement algorithm (TANG, 2009)

The Incremental Clustering scheme is an iterative scheme which incrementally identifies MPP's and then assigns MAP's to the identified MPP's. Initially MAP's are grouped into clusters each cluster having a MAP's serving as a head of the MAP's cluster. There are two types of MAP's clusters considered namely covered clusters and uncovered clusters. In each and every uncovered mesh cluster a head is selected as MPP's. However when there is no uncovered mesh cluster the head of mesh cluster that covers the maximum amount of MAP's is selected as the MPP's node. A mesh cluster is a covered cluster if the MAP's it contains can communicate with other neighboring clusters. A mesh cluster is an uncovered cluster if there is a MAP in the mesh cluster that is not present in the other cluster. The Incremental clustering placement scheme outperformed weighted recursive and iterative greedy placement scheme, however, the effectiveness of all the three methods have not been evaluated using rural settlement patterns.

Table 2.16 Characteristics of the Incremental Clustering MPPs placement algorithm (TANG, 2009)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	stationary and random distribution
Purpose	Finding positions of MPP's nodes, reducing delay and maximizing throughput
Approach	Iteratively and incrementally identifies MPP's and assign MAP's to the identified MPP's. Nodes are formed into clusters and cluster head is the node that covers all other nodes and it is chosen to serve as a MPP's.
Evaluation	200 MAP's, 10x10 area, connection radius=1.0, distance = 0.5, MATLAB for simulations and performed 30 run time

2.3.3 Weighted-Based Placement

This group constitutes of computing the weight for each and every set of MAP and the node with the maximum value of weight is chosen as a MPP. This group optimizes the network performance, however, the objective to be optimized varies from each scheme.

2.3.3.1 Weighted Recursive Dominating Set Algorithm (Aoun *et al,* 2005)

Table 2-17 represent a polynomial time near-optimal algorithm. A weight on each MAP is recursively calculated to effectively select a dominating set. The weight helped to reflect the coverage and the distance to the MAP's the MPP covers. A MAP that covers as many uncovered MAP's as possible, is selected as a MPP. The recursive call terminates when the delay of the next iteration is greater than throughput to be gained and this process is referred to as checking feasibility.

Table 2.17 Characteristics of the Weighted Recursive Dominating Set Algorithm (Aoun *et al*, 2005)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	Stationary and random distribution
Purpose	Optimal positioning of MPP's, reducing overhead delay and maximal throughput.
Approach	A weight is computed and a MAP that covers as many uncovered MAP's as possible is selected as MPP's.
Evaluation	25 random topologies, 175 nodes, 10x10 area, communication radius =1, distance = 0.6m

The Weighted Recursive Dominating Set Algorithm only considered random and stationary distribution of MAP's and was not evaluated under different rural settlement patterns. Hence it is not clear if the scheme can be best fit for MPP placement problem in rural areas.

2.3.3.2 Tree Set Partitioning (TSP) (He *et al*, 2008)

Degree and Weight based Greedy Dominating Tree Set Partitioning (He *et al*, 2008)

The Degree and Weight based Greedy Dominating Tree Set Partitioning (DW-GDTSP) aim to find minimum MPP's positions while satisfying the network throughput requirements. DW-GDTSP also focuses on ensuring connectivity degree of MPP's and MAP's whereas the Weight-based GDTSP focuses on minimizing the MAP's – MPP's hops.

During the selection of a MPP's position the DW-GDTSP ensures that only the short path between the MAP's & MPP's is approved however this desirable feature does not cater for RWMN which have long distance between MP's. The Table 2-18 present characteristics of the Degree and Weight based Greedy Dominating Tree Set Partitioning placement algorithm.

Table 2.18 Characteristics of Degree and Weight based Greedy Dominating Tree Set Partitioning (He *et al*, 2008)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	stationary and randomly distributed in the network
Purpose	Selecting MPP's optimal candidates locations while obtaining maximum throughput with the MP's.
Approach	Degree-based selects the node with the largest/ highest connectivity degree as the MPP's node. Weight-based select node with the highest connectivity weight of R-hop as a MPP.
Evaluation	200x200m area, 20 simulations run times, 100-240 nodes, 6 hops

2.3.3.3 Tree-Set Partition (Jun *et al,* 2009)

The heuristic tree-set partition, (TSP), scheme, aims to choose MAP's positions with high throughput. The TSP is either degree-based or weight-based. The former TSP greedily selected MPP's position by computing the degree of each node and then selected the node with the highest connectivity degree as MPP's.

The latter TSP considers the relative distance/hops between the nodes. In a weight-based TSP the path length between the neighboring nodes is computed and the node with shortest hop is selected as MPP's, scientifically each MAP compute its value of the path length and the MAP with the maximum value will be selected to serve as a MPP. When the MPP's have been established the breadth-first search algorithm (BFS) is used to connect MAP's to the selected MPP's.

Table 2.19 Characteristics of Tree-Set Partition Placement Scheme (Jun *et al*, 2009)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	stationary and randomly distributed in the network
Purpose	MPP's placement while maximizing network throughput.
Approach	Degree-based selects the node with the highest connectivity degree as the MPP's node. Weight-based compute the path length between the neighboring nodes and the node with shortest hop is selected as a MPP's
Evaluation	Area of 100- 200x200m, 200 nodes, 20 run time, NS2 was used for simulation

Table 2-19 presents a summary of Tree-Set Partitioning algorithm. The TSP optimizes only network throughput and considers restrictive setting of the realistic applications since it uses randomly distributed MAP's.

2.3.3.4 Multi-Hop Traffic-Flow Weight (MTW) MPP's placement scheme (Zhou *et al,* 2007)

In this work a placement scheme ensure proper placement of MPP's by taking into consideration factors that impact WMN throughput, i.e. the number of clients, number of MAP's, number of MPP's and their locations, traffic demand from mesh clients and possible interference among MPPs.

A MTW is calculated on MAP's and a MAP with a highest weight becomes a MPP, processes include: (i) Weight of Hops number is defined as an estimation average number of hops that the packet travels from the MPP's to the MAP's. (ii) Local traffic demand on each MAP's is determined.

Table 2.20 Characteristics of MTW (Zhou *et al*, 2007)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAPs	Uniformly distributed and random distribution of mesh clients.
Purpose	Select MPP's positions and ensure maximum throughput is obtained.
Approach	A MPP's is placed on router with highest weight
Evaluation	200 mesh clients, 36 MAP's distributed in a square region of 1000mx1000m, cell reuse factor (CRF) =4, slot reuse factor = 3, interference distance of gateways =2, all evaluation was via simulation

The MTW uses a Time Division Multiple Access (TDMA) scheme to all the MPP's in order to avoid interference in each time slot for the simultaneous transmission. Although the MTW has a unique mechanism to mitigate interference among MPP's, it effectiveness still need to be evaluated in the rural context.

2.3.3.5 Polynomial-time weighting algorithm (Xin and Wing, 2009)

Polynomial-time weighting scheme solves MPP's placement and ensure that the network throughput is optimized. Ranking procedure was introduced to indicate the importance of a particular node to be an MPP. MAP's with the largest value of rank were selected as MPP. The ranking strategy used by the polynomial-time weighting placement scheme required frequent change of channels resulting into a large increase of switching end-to-end delay between MPs. Furthermore, the effect of switching delay becomes even more considerable when switching occurs across diverse frequency bands.

Table 2.21 Characteristics of Polynomial-time weighting algorithm (Xin and Wing, 2009)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAP's	Uniform distribution and random distribution of MAPs.
Purpose	Chooses MPP's candidate position while ensuring maximum throughput is obtained.
Approach	All potential MAP's are ranked and the one with the largest value of ranking/ weight is selected as a MPP.
Evaluation	50 to 100 MAPs, 4 to 10 MPPs, area of 500mx500m radius varies from 2 to 5, link capacity rang [Mbps, 54Mbps], transmission range [30m, 90m].

Although the polynomial-time weighting placement scheme aim to improve network throughput it can be observed that the approach still have some pitfalls. The effectiveness of the placement scheme was not covered for rural deployment, since RWMN is already assumed to have increased packet transmission disturbances.

2.3.3.6 Single MPP placement scheme (Muthaiah and Rosenberg, 2008)

The single placement scheme, search for optimal positions for placing a MPP such that the network throughput will be maximized. The scheme employed a Brute force approach for MPP placements which evaluate all possible candidate positions and critically select the optimal position. However, the brute-force method was computationally intensive and cumbersome since all positions needed to be evaluated and resulted to high deployment cost which is a significant issue in RWMN. Four types of networks were considered namely grid, regular sub-compact grids, arbitrary and irregular grid network.

Table 2.22 Characteristics of Single Gateway placement scheme (Muthaiah and Rosenberg, 2008)

CHARACTERISTICS	ANALYSIS RESULT
Distribution of MAP's	Uniform distribution and random distribution of mesh clients.
Purpose	Place single MPP node, maximize throughput
Approach	The brute force techniques and heuristics were used for finding gateways positions.
Evaluation	5x5 area, 14 and 18 nodes

2.4. Summary

The selection of the optimal MPs positions given a WMN deployment is a complex problem which involves many factors such as maintaining QoS requirements and installation cost. MAP's placement schemes were proposed in the literature aiming to select optimal candidate positions for MAP's in such the way that maximum network coverage and connectivity is obtained. On the other hand, MPP's placement schemes aimed to optimize different objectives some maximizing network throughput, some minimizing network delay, some load balancing and fault tolerance. However, none of these works was evaluated in a rural area context in order to judge on their suitability in solving placement problems.

Literature was analyzed using the developed classification framework and MAP's and MPP's placement schemes were categorized each into three groups. Only one placement scheme was selected to represent each group. The placement schemes that provided an interference model and consideration close to the rural context were selected for simulation. In the MAP's placement groups selection results were the following (i) Movement Based MAP's placement: Hill Climbing Scheme (Xhafa *et al*, 2009) (ii) Measure and Place MAP's placement: Time-efficient Local Search Scheme (Antony *et al*, 2007), (iii) Relay Based

MAP's placement: Virtual Force Based Placement Scheme (Wang *et al*, 2008). Hill Climbing MAP's placement scheme was selected because in the literature it is known to work well for problems with many solutions some of which are better than the other ones. It begins by a potential poor solution (potential MAP position), then iteratively search other possible locations that improve the current location until there are no further improvements then terminates. The Local Search MAP's placement scheme was selected because it takes into consideration the attenuation of signal as a function of distance, by ensuring that the selected locations are not affected by the signal obstructions. Attenuation of a signal depends on the topology of the area at which the MP's are located. Some areas in rural areas exist with no possible MAP's locations because of farms or forest, Virtual Force MAP's placement scheme was selected because it consist of methods for tackling the problem of prohibitive regions (area in a network domain where MAP's cannot be placed).

In the MPP's placement category the selection was (i) Greedy-Based Placement: Novel Grid-based internet MPP's placement scheme (Li and Wang, 2007), (ii) Clustering-Based Placement: Incremental Clustering MPP's placement algorithm (TANG, 2009), (iii) Weighted-Based Placement: Multi-Hop Traffic-Flow Weight (MTW) MPP's placement scheme (Zhou *et al*, 2007). The mentioned MPP's placement schemes were selected because they ensure minimal interference among the MPP as possible, these placement scheme does not select an obsolete position for MPP deployment. The details description of the selected placement schemes is discussed in chapter three.

-CHAPTER THREE-

SELECTED MESH POINTS PLACEMENT SCHEMES

3.1 Introduction

In the previous chapter Mesh Points (MP's) placement schemes were investigated by analyzing and classifying different approaches proposed by different scholars. The classification frameworks were developed by focusing on the types and distribution of mesh clients (MC's), distribution of Mesh Access Points (MAP's), purpose, approach and evaluation. Using the attributes of the classification framework MAP's were divided into three groups namely Movement-based, Measure-and-Place and the Relay-based MAP placement schemes. The solutions proposed for Mesh Portal Points (MPP's) placement were also categorized into three groups namely: Greedy-based, Clustering-based and Weighted-based MPP's placement schemes.

Achieving maximum network connectivity and coverage is a major issue for a successful WMN deployment. However, this feature is highly depended on the placement of MPs and affected by the physical obstructions in the network. In this study, the schemes which catered for diminution of interference were given first priority, owing to the fact that in rural areas geographical obstructions, such as long distances, trees and hills, degrade the network performance. Section 3.2 presents the selected MAPs placement schemes description, while section 3.3 discusses the selected MPPs placement scheme and the summary is presented in section 3.4.

3.2 Mesh Access Points (MAP's) Placement Schemes

The following section discusses the detailed description of the selected MAPs placement schemes.

3.2.1 Time-efficient Local Search MAP Placement Scheme

The main aim of the time-efficient Local Search placement scheme is to find the locations of MAP's to be used that maximizes both coverage and the connectivity of the network. Figure 3.1 and Figure 3.2 represent the pseudo-code and flowchart of the process involved when selecting MAPs positions using the Time-efficient Local Search scheme. The deployment area is divided into equal grids and the received signal strength for each candidate is measured. Typically the signal power decays with distance and the client is connected to the network if the average signal strength from the MAP is above the threshold value (T_{min}).

Coverage of Mesh Clients (MCs) with a uniform distribution is achieved as:

$$Coverage_k = 1 - \prod_{\forall i \in N}(1 - Pr_{di}\,[X > T_{min}]) \quad (3.1)$$

Whereby N is the set of MAP's, K is a grid in a deployment area, Pr is the probability that received signal strength exceed the threshold (T_{min}) and *di* is a distance the nodes.

Coverage of clients with non uniform distribution is achieved as:

$$Coverage = \frac{\sum_k \; Coverage_k \; X \; |N_k|}{\sum_k |N_k|} \quad (3.2)$$

Whereby k represent mesh clients.

A MAP is connected to the network if it has at least one route to all other MAP, whereby each link's average signal strength meets the minimum signal strength level T_{min} (i.e. minimum quality requirement).

1. Let k =1

2. Let *MAP's* be the candidate of Mesh Access Points

3. Let *MAPsPlaced* be the current Mesh Access Points placed initialized to empty

4. Divide terrain into grids

5. While k ≤ the number of MAP's to be placed do

6. i is the first MAP in the *MP's*

7. let T_{min} be minimum average signal strength

8. calculate received signal strength at distance d

9. $P_{dBm}(d) = P_{dBm}(d0) - 10\alpha \log 10\ (d/d0) + €$

10. While received signal strength > T_{min}

11. add MAP's temporarily to *MPsPlaced*

12 calculate the Objective Function given by Coverage X Connectivity

13. store Objective Function as OF i

End while

14. i = next mesh access points in *MPsPlacedA*

15. find *i* of the highest OF_i

16. add mesh access points i to *MPsPlaced* permanently

17. remove i from the *MP's*

18. k + +

19. end while

20. *MPsPlaced* is the mesh access points placed with local optimum

Figure 3.1 Time-efficient Local Search Pseudo-code

MAP's connectivity can be achieved as:

$$\Pr[k\ is\ connected] = \prod_{\forall i \in N} \Pr[\exists R \in \{R_{ki}\}: R\ exists] \quad (3.3)$$

Figure 3.2 Time-efficient Local Search Flowchart

The Time-efficient Local Search proposed the objective function (OF) as seen in Figure 3.1 and Figure 3.2 involves getting the product of coverage and connectivity with the aim to maximize both metrics i.e. OF = Coverage X Connectivity (shown in line 14 figure 3.1). This method was tested using parameters taken from measurement at outdoor resident deployment in Houston neighborhood (http://iitagh.org/?location=narins-bombay-brasserie). However the factors affecting the network in the city might not be the same for the rural context. The time-efficient local search method was only evaluated by varying different random locations it was not compared against any other methods and this drives the need to test it performance in rural scenario.

3.2.2 Hill Climbing MAP's Placement Scheme

The Hill climbing MAP's placement scheme aim to selects optimal positions of MAP's such that maximum coverage and connectivity is obtained within the network. Hill Climbing placement scheme is based on improving the fitness of the solution obtained during the search. The scheme starts the search by randomly selecting MAP's positions as a current solution. To improve fitness of the current solution, the scheme uses a simple climbing method which states that the next neighbor is the first that improves the current solution. The pseudocode in Figure 3.3 and flowchart in Figure 3.4 define the three different local movements used during the search process namely:

1. Radom local movement: which randomly select MAP's positions
2. Radius local movement: MAP's of the largest radio coverage is selected and placed in the densest area (where the large concentration of mesh clients)
3. Swap local movement: MAPs with the smallest radio coverage in a most dense area is exchanged with the MAPs with the largest radio coverage in the least dense area.

If the neighbor improves the current solution, the solution is then moved to the configured neighbor, the process of search and movement continues till no further improvements of the current solution can be identified.

The effectiveness of the scheme was only evaluated by comparing the local movements against network sizes. The methods were also evaluated for different distribution of mesh clients which is quite close to our study. However, the effectiveness of Hill Climbing was not compared against other existing search method in literature.

1. Set height and width of the deployment area
2. Set clients, MAP to deploy
3. Declare problem, current solution + n, neighbour solution and movement type
4. Generate the initial solution s_0
5. Random local movement = s_0
6. Current solution = Random local movement
7. Improve fitness of current solution by searching neighbour solution
8. Movement Selection: choose a movement type
9. If (movement type = radius) {
10. Compute the position of the densest area (H_g x W_g)
11. Find the centre of the dense area (x_{dense}, y_{dense})
12. Get MAP of the largest radio coverage ($x_{largest\_coverage}$, $y_{largest\_coverage}$)
13. Move MAP at ($x_{largest\_coverage}$, $y_{largest\_coverage}$) to new position (x_{dense}, y_{dense})
14. Re-establish mesh nodes network connections
15. }
16. Else if (movement type = swap) {
17. Compute the position of the densest area (H_g x W_g)
18. Compute position (x_{dense}, y_{dense}) of the MAP with the smallest radio coverage within a dense area
19. Compute position of the sparsest area (H_g x W_g)
20. Compute the position (x_{sparse}, y_{sparse}) of the most powerful MAP within the sparse area
21. Exchange MAP in (x_{dense}, y_{dense}) with the one in (x_{sparse}, y_{sparse}) positions
22. Re-establish mesh nodes network connections
23. }
24. End if
25. Return current solution
26. Until (stopping condition is met)

Figure 3.3 Hill Climbing Pseudo-code

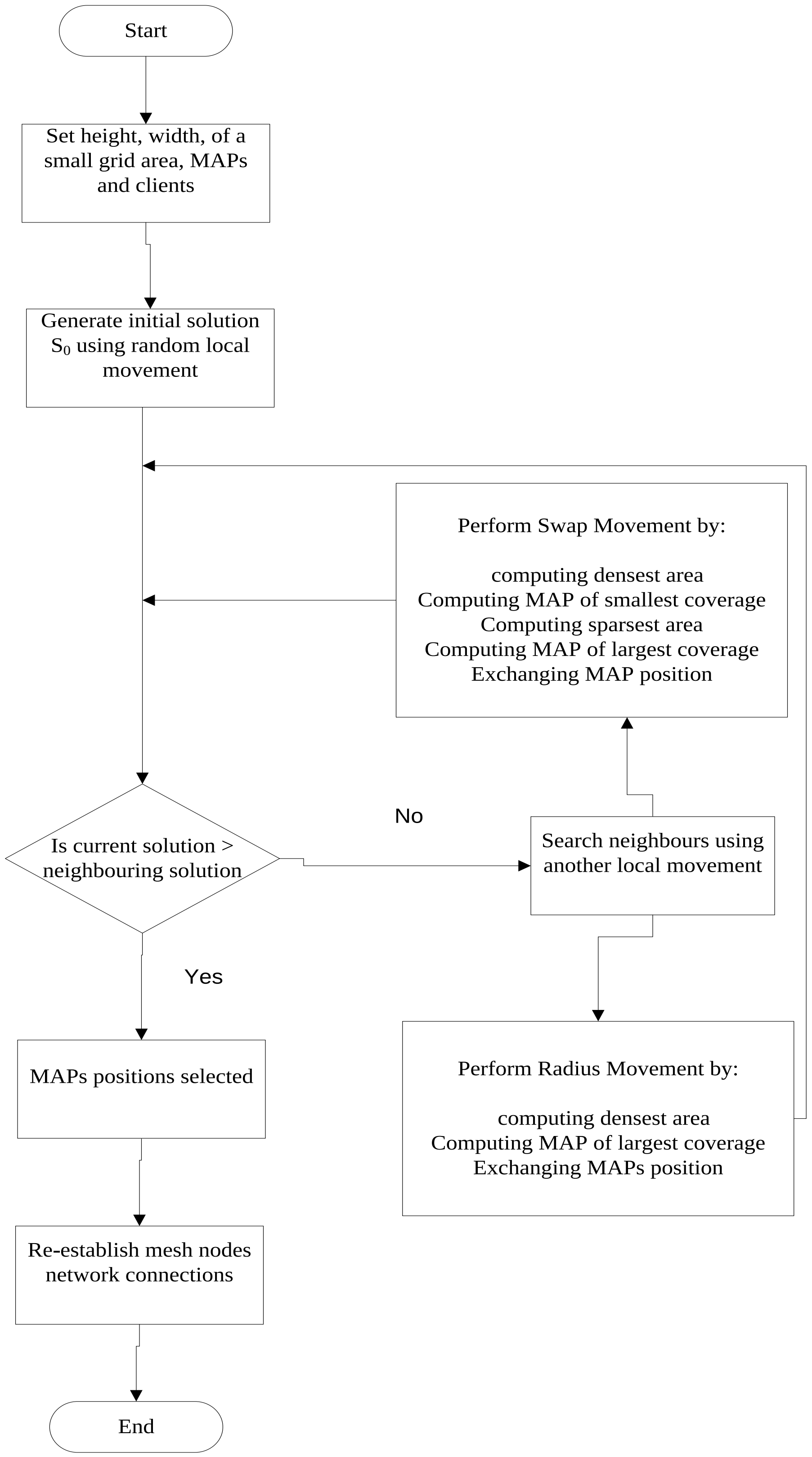

Figure 3.4 Hill Climbing Flowchart

3.2.3 Virtual Force Based (VFPlace) MAP's Placement Scheme

The network deployment area is treated as a virtual force field whereby each MAP acts as a virtual particle, which can be affected by the virtual forces within the field. These forces are exerted on a MAP and are mainly classified as attractive and repulsive force; their primary goal is to increase the network coverage and to strengthen the network connectivity. A Repulsive force helps to maximize the network coverage by reducing the potential interference and avoid prohibitive regions by pushing MAP's away from each other. An attractive force favors preferential regions and strengthens the network connectivity by pulling MAP's closer to each other.

These Forces come from three sources namely: (i) force between MAP's, (ii) forces from prohibitive regions (iii) forces from preferential regions and forces from Virtual Preferential Regions. A prohibitive region is an area in the network domain, where MAP's cannot be deployed whilst preferential region is an area in the network domain with heavy traffic load where MAP's can be deployed.

1. Force between MPs: given a MAP v_i, a node that is not within the coverage area of v_i has no influence on v_i i.e. cannot attract or repel v_i. This effect is determined by a threshold distance ρ, when the distance between v_i and v_j is smaller than ρ the repulsive force pushes MAP's away from each other, otherwise the attractive force is generated attracting MAP's closer to each other.
2. Force from Prohibitive Regions: when MAP v_i approaches a prohibitive region v_t , v_t will exert a repulsive force on v_i. The larger the overlapped area $C(v_i) \cap C(v_t)$ between the MAP and prohibitive area the more the repulsive force strength increases.

Let i be initialized to 1

Set MAP to be deployed as $V_N = \{V_0, V_{1...} V_{n-1}\}$

Set the threshold distance as $p < r$

Locate MPP at (0, 0)

While $i < V_N$ do

  Spread MAPs around MPP

    If $(Dv_i \cap Dv_j) < p$ then

      generate repulsive force

      $Frep = \frac{1}{d_{ij}} X \frac{v_{j-}v_i}{d_{ij}}$

      else if $(Dv_i \cap Dv_j) > p$ then

        generate attractive force

      $F_{attr} = (d_{ij} - p)X \frac{v_j - v_i}{d_{ij}}$

          else $F_{ij} = 0$

      end if

    end if

If region = prohibitive region v_t

$generate\ repulsive\ force = -\frac{|w\ (v_t)|}{(d_{it} - r)(d_{it} - r)} X \frac{F_{t\ -F_i}}{d_{it}}$

    push V_i away from each other

  else if region = preferential region v_k

      $generate\ attractive\ force = \frac{w(v_k)X\ (d_{ik} - r)}{d_{ik}} X \frac{v_{j-}v_i}{d_{ik}}$

      pull V_i close to each other

    end if

  i++

end while

Figure 3.5 VFPlace Pseudocode

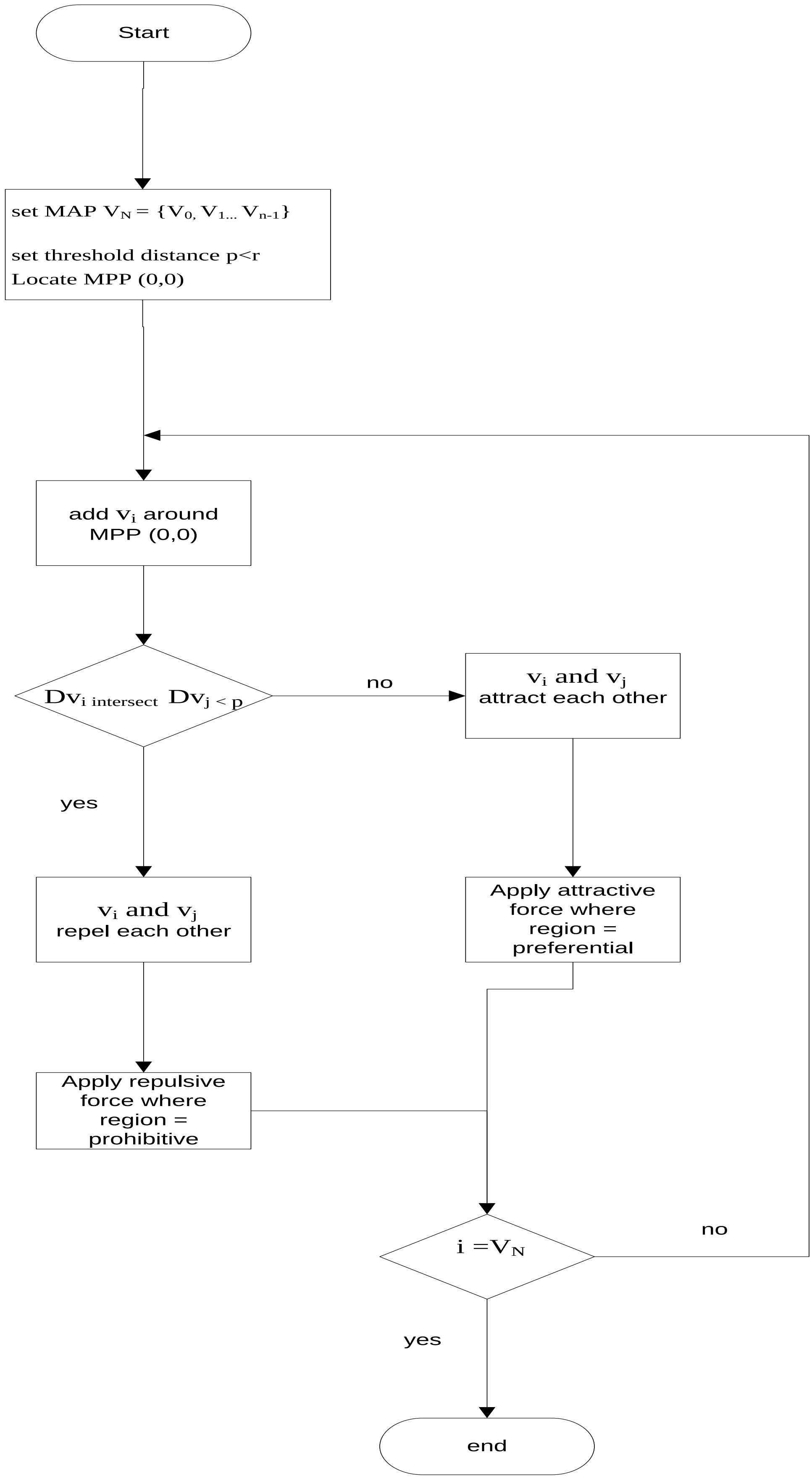

Figure 3.6 VFPlace Flowchart

3. Force from Preferential Regions: when MAP v_i approaches a preferential region v_k (v_i and v_k overlap), v_k exert an attractive force on v_i thus attracting MAPs closer to each other.
4. Force from Virtual Preferential Regions: MAP's closer to the MPP need to maintain more relay traffic than those far away from the MPP; the main challenge is to ensure overload of MAP's is avoided as much as possible. The virtual preferential regions are those regions which when MAP's are allocated the traffic from influential regions and relay traffic exceed the MAP capability. Initially, MAP's are spread around in a small close area around the MPP then attractive force and repulsive force are generated to minimize virtual preferential regions.

Figure 3.5 presents the VFPlace pseudo-code and figure 3.6 VFPlace flowcharts depict the processes involved in VFPlace approach when solving the MAP placement problem. It is important to note that the network performance is highly affected by the distance between the MPs. The idea behind the VFPlace scheme is to ensure that the placement is not affected by the region differences.

3.2.4 Random MAP's Placement Scheme

The random placement scheme selects MAP's position randomly without taking into considerations any of the network effect. Different from the Time-efficient Local Search, Hill Climbing and Virtual Force MAP's placement schemes which first ensure that the selected positions will obtain maximum coverage and connectivity, the random placement picks any random position. Typically, without having to consider obtaining desirable network performance given the deployment area any client position is a potential MAP's location. The aim of the random placement scheme is to investigate the effect of random placement of MAP's in the network performance.

```
Let i=1
Let MAPs be list of assigned Mesh Access Points
Let MRs be the total number of unassigned Mesh Access Points
While i ≤ MRs do
   Random = math.random * size of the MRs
      If position is not assigned
            Select the position
              then store in MAPs
          end if
      i++
   end while
```

Figure 3.7 Random MAPs Placement Pseudocode

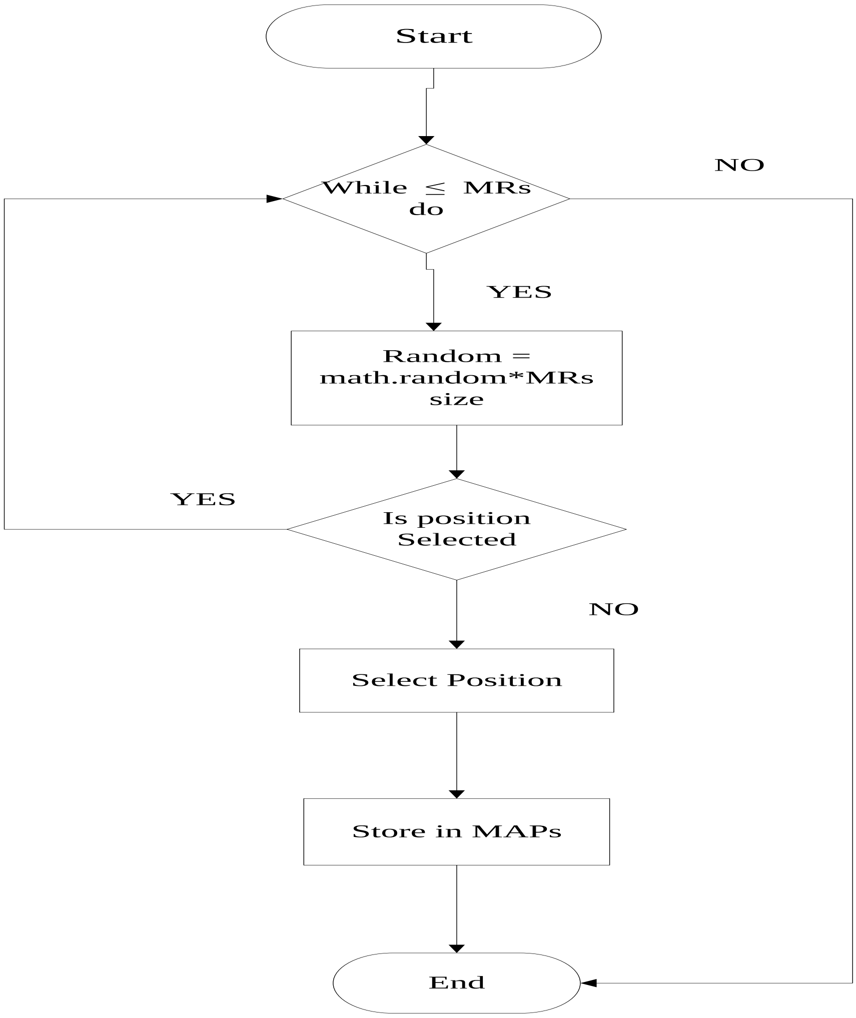

Figure 3.8 Random MAPs Placement Flowchart

3.3. Mesh Portal Points (MPP's) Placement Schemes

The MPP's placement schemes selected are Incremental Clustering which is under a Clustering-Based MPP's placement group, Grid Based MPP's placement scheme, which falls under a Greedy-Based MPP's placement group and MTW MPP's placement scheme, which is a Weighted-Based MPP's placement scheme.

3.3.1 Incremental Clustering MPP's Placement Scheme

The WMN infrastructure is supported by backbone WMN (BWMN), which consists of a collection of MAPs communicating with other MAPs and clients. The Incremental Clustering

Scheme aim to solve the MPP’s placement problem by ensuring that the Quality-of-Service (QoS) constraints are satisfied in the network such as delay, relay load and capacity constraint. The Incremental Clustering placement scheme tackles MPP’s placement problem by iteratively and incrementally identifying MPPs and by assigning MAPs to the identified MPP’s. In each iteration the BWMN directed graph is constructed from the current unassigned MAP’s set U, clusters of MAP’s are formed and the MAP’s with a gateway capability are identified i.e. in a BWMN MAP’s have different coverage radiuses, the MAP’s with larger coverage radius are appointed as MPP’s.

Clusters are categorized into covered and uncovered clusters, a mesh cluster is a uncovered cluster if there is a single MAP in the mesh cluster that is not present in the other mesh clusters otherwise the mesh cluster is considered as covered cluster. In each iteration MPP’s are appointed and MAP’s are assigned to the selected MPP’s and removed from set U, the process is repeated until the set U is empty and at this stage all MAP’s have been assigned.

In the case of uncovered cluster at least one MPP is needed since the head of the cluster cannot use any MAP in the other clusters as it MPP is not covered by MAP’s in the other clusters, therefore the head of the uncovered cluster is selected as the MPP. It is important to observe that the uncovered clusters could refer to those MAP’s which are isolated from others. The covered clusters the head of the cluster that covers maximum number of MAP’s is selected as the MPP. Figure 3.7 and Figure 3.8 below represent a transitive closure of the BWMN directed graph G = (V, E) such that for all <u,v> is the element of E if and only if there exist a non-null path from u to v.

Figure 3.9 A BWMN graph G

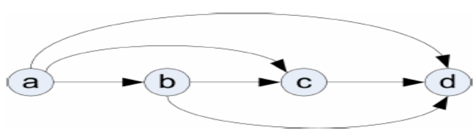

Figure 3.10 The transitive closure of G

1. Let a BWMN directed graph be G = (V, E)

2. Let U be a set of MAPs V_n

3. Let R be delay constraints

4. Let L be relay load constraints

5. Let S be capacity constraints

6. While U≠ empty do

7. Construct a network with V_n stored in U

8. Calculate the coverage radius for each and every V_n

9. Build the R-step transitive closure from G = (V, E)

10. Identify MPP's from the R-step transitive closure

11. For i = 1 to │U│ do

12. If the V_n cluster is the uncovered cluster then

13. The head of the cluster is selected as a gateway

14. Else if there are no uncovered cluster found then

15. Find V_n cluster with the largest or maximum size

16. Choose the head of that cluster as a MPP

17. 17.End if

18. End for

19. For each MPP g do

20. For h = 0 to R do

21. For any V_n that is covered by g do

22. If g does not violate constraints then

23. Assign V_n to g

24. Remove the assigned V_n from the set U

25. End if

26. End for

27. End for

28. End while

Figure 3.11 Incremental Clustering Pseudo -code

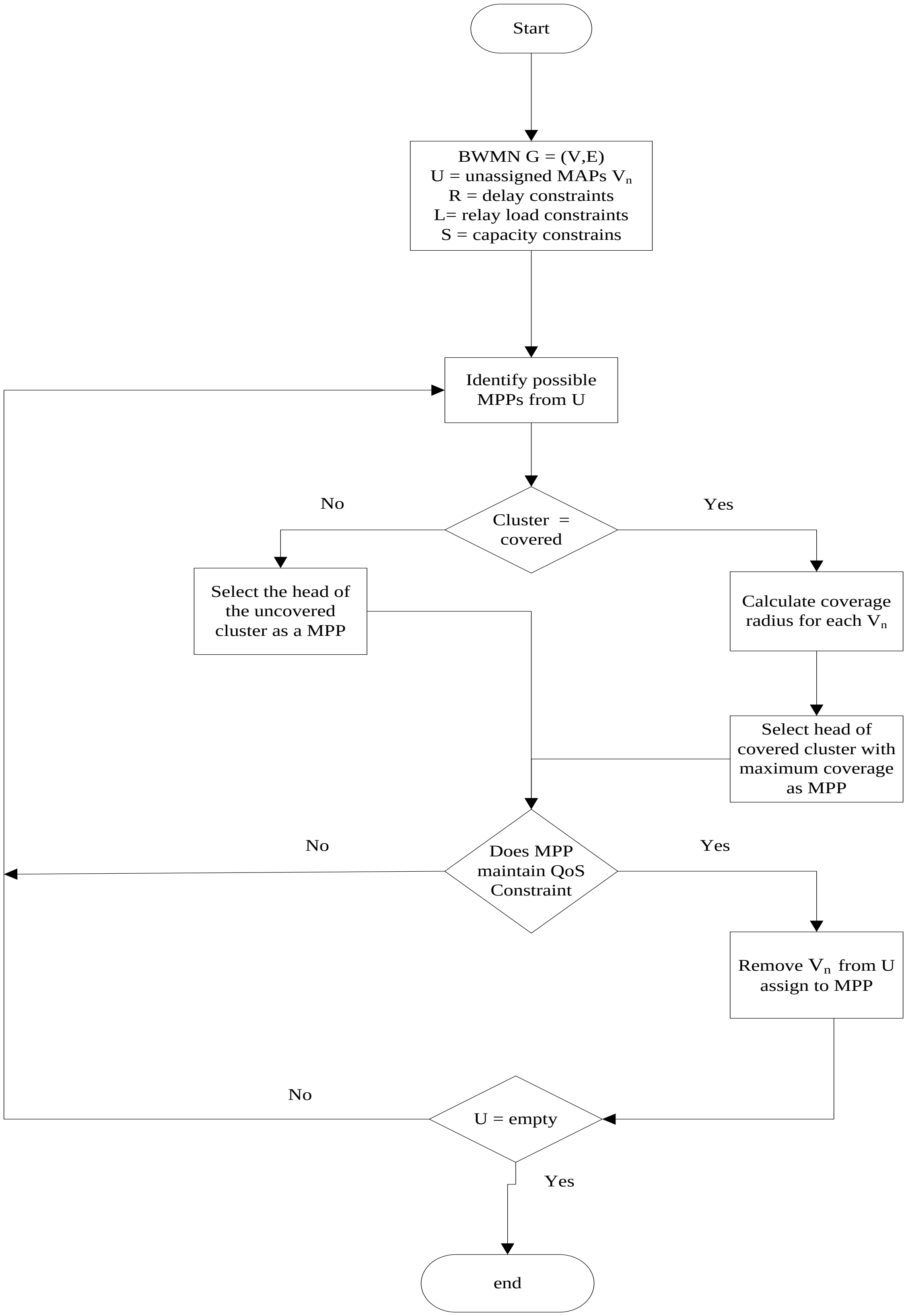

Figure 3.12 Incremental Clustering Flowcharts

3.3.2 Grid-based MPP's Placement Scheme

Given a network with n-k fixed MAP's and a Fixed Protocol Interference Model (fPrIM) the Grid-based MPP's placement method aim to deploy k MPP's such that the network throughput is maximized. Figure 3.11 presents pseudo-code and Figure 3.12 presents flowchart of a grid-based scheme. The deployment area is divided into an area of a x b grid and the MPPs are placed in cross points on the grid.

All the possible combinations are being evaluated based on the fPrIM to ensure that the final selected positions obtain maximum throughput. Among n-k fixed MAP's, some of them are selected as MPP's giving the functionality and providing connectivity to the Internet. Remaining MAP's act as ordinary MAP's responsible for aggregating traffic from all its users and routing it to the internet using the selected MPP's.

Each MAP v_i has an interference range R_I (i), v_j is interfered by the signal from v_i only and only if the strength between v_i and v_j is less than R_I (i) and v_j is not the intended receiver. When the two MAP's are scheduled to transmit at the same time slot the link interference must be avoided as much as possible.

The novel grid method adopt the fPrIM, which ensure that the schedule between any simultaneously transmitting node avoid the interference. When MAP's has a traffic demand that needs to be routed to the internet via some MPP's, each link l (v) is given an interference-aware transmission schedule, which will maximize the network throughput by assigning the time slot T at which every node will transmit.

1. Divide deployment area into a x b grid
2. Place MPP's into cross points
3. Combinations ← C^{k}_{axb} where k is the number of MPP's
4. For int i = 1 to combinations do
5. Compute maximum throughput for (i)
6. Let v be set of MAP's
7. Let s be set of MPP's
8. Let e be set of communication links
9. $N(e_i) = T.\alpha(e_i)$ be the number of time slots that link e_i is active
10. I(e) denote set e' that will cause interference when links are scheduled at same time slot
11. Assume $e_i = (u, v)$
12. Set allocated ← 0
13. Set t ← 1
14. Sort the links using fPrIM model
15. If $\|v_k - v_j\| \leq$ interference range $R_I(k)$ then
16. Remove vertex and its incident edges
17. else place s
18. Let $(e_1, e_2 \ldots e_m)$ be sorted list of links
19. end if
20. While allocated < N (e) do
21. if $X_{e,t} + X_{e',t} \leq 1$ where $X_{e',t} = 0$ for every conflicting link e' € $I_m(e_i)$
22. Schedule is interference-free then
23. Set $X_{e,t}$ ← 1
24. Set allocated ← allocated + 1
25. Set t ← t +1
26. Choose vertex with the largest value $L_I(v) - L_O(v)$
27. Allocate final MPPs positions
28. End if

Figure 3.13 Grid-based Pseudo-code

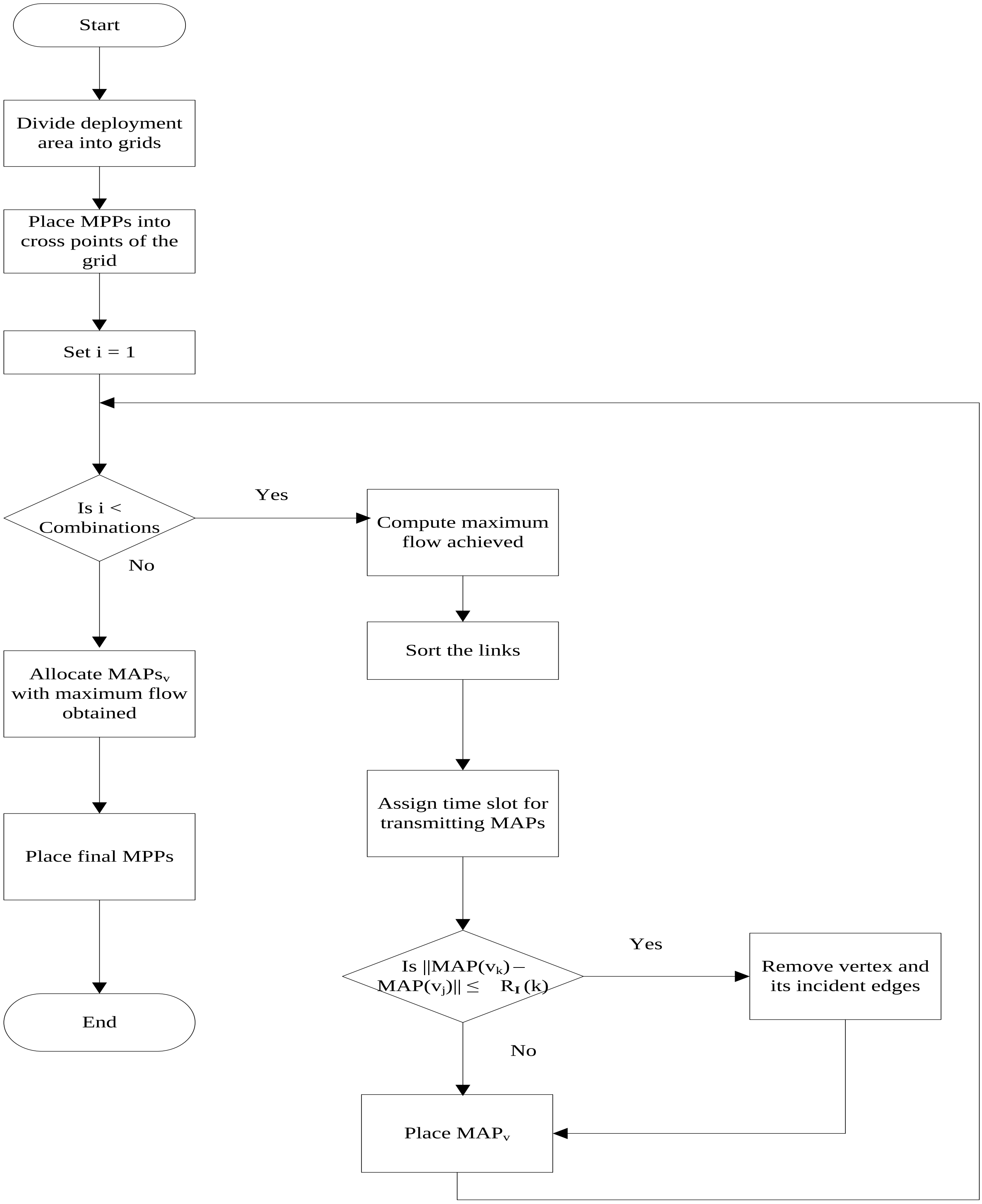

Figure 3.14 Grid-based Flowchart

A transmission is interference-aware only and only if it will not result into collision at either MAP v_i or MAP v_j (any node) due to simultaneous transmission of other links. Let $X_{e,t}$ € {0,1} be the indicator variable, e (communication link) will transmit at T only when the indicator variable is 1 (i.e. $X_{e,t} = X_{e,t} + i.T$ for any integer $i \geq 0$). The achieved flow throughput is maximized under certain fairness constraint defined as a minimum ratio of obtained flow over the required load of all MAPs in the network. The achieved flow is given by the product of the fraction of time slot T in a scheduling-period that the link e is transmitting (i.e. f (e) = α (e).c (e)). After sorting the links based on the fPrIM the grid based placement method select the possible combinations resulting into maximum obtainable throughput.

3.3.3 Multi-hop Traffic-flow Weight (MTW) MPP Placement Scheme

A good placement scheme should be adaptive to any number of MPP's being deployed. Typically deploying fewer MPP's results in large number of hops a packet travels to access its MPP, however placement of MPP's in areas with most traffic load might be a simple solution to mitigate the fore mentioned problem. The MTW considers the number of MCs, MAP's, MPP's, traffic demand from clients, location of MPP's and possible interference in the network. The factors of the scheme are depicted by the pseudo-code in figure 3.13 and flowchart in figure 3.14. In a first step the average number of hops that a packet ought to travel from a MPP to MAP is decided and this process is referred to as Weight of hops' number (W_{hop}); which is given by function of the number of MAPs and the number MPPs to be deployed. $W_{hop} =$ round $((\sqrt{N_r}) / (^2\sqrt{N_g}))$

In the second step the traffic demand on each MAP is calculated denoted by D (j) which is also based on the demand of the mesh clients. In the third step the MTW is finally calculated using the D (j) and $W_{hop.}$

$$MTW (j) = (W_{hop} + 1) * D (j) + W_{hop} * (\text{traffic demand of all 1-hop the neighbours of } R^j) + (W_{hop} - 1) * (\text{traffic demand of all 2-hop the neighbours of } R^j) + (W_{hop} - 2) * (\text{traffic demand of all 2-hop the neighbours of } R^j) + \ldots$$

The MAP with the highest weight is selected as the MPP position, the placement scheme places MPP's on MAP's with highest weight until the number of MPP's to be deployed is reached. When more than one MPP is deployed in a network the scheme ensure that the chances of interference are reduced as highly as possible. Two MPP's interfere with one another if they are within an interfering distance of MPP's in a backbone communication (IntD-hops).

In order to reduce chances of interference in a backbone communication equivalent time slot is assigned to each MPP for a successful transmission. Reducing chances of interference for local communication involve assigning separate timeslot to different MAP's, consequently simultaneous transmission can only be possible in MAP's with enough distance in between.

```
Let C denote set of mesh clients
Let V denote set of MAP's
Let S denote set of MPP's
Let V ≤ C and S ≤ V
Let R_i be transmission range
While S < > deployed
decide W_hop from S_i to V_n
compute local traffic demand D (j) for each V_n
compute MTW for all V_n
select V_n with the highest MTW as a MPP
end while
For all deployed S do
    assign separate timeslot T_i to every S_i
        if S_i-thresh > IntD-hops then
            no simultaneous transmission from S_i to V_i
            V_i= (connected C_i * hop_i) small timeslot T_i
        else if simultaneous transmission from S_i to V_i then
            V_i > slot reuse distance SRD-hops away from S
                if C_i and C_j are associated with same S then
                    throughput (C_i, S) = throughput (C_j, S)
                If |V_i - V_j| ≤ R_i for every other transmitting node S_k then
                    transmission is successful
                else transmission unsuccessful
            end if
        end if
```

Figure 3.15 MTW Pseudo-code

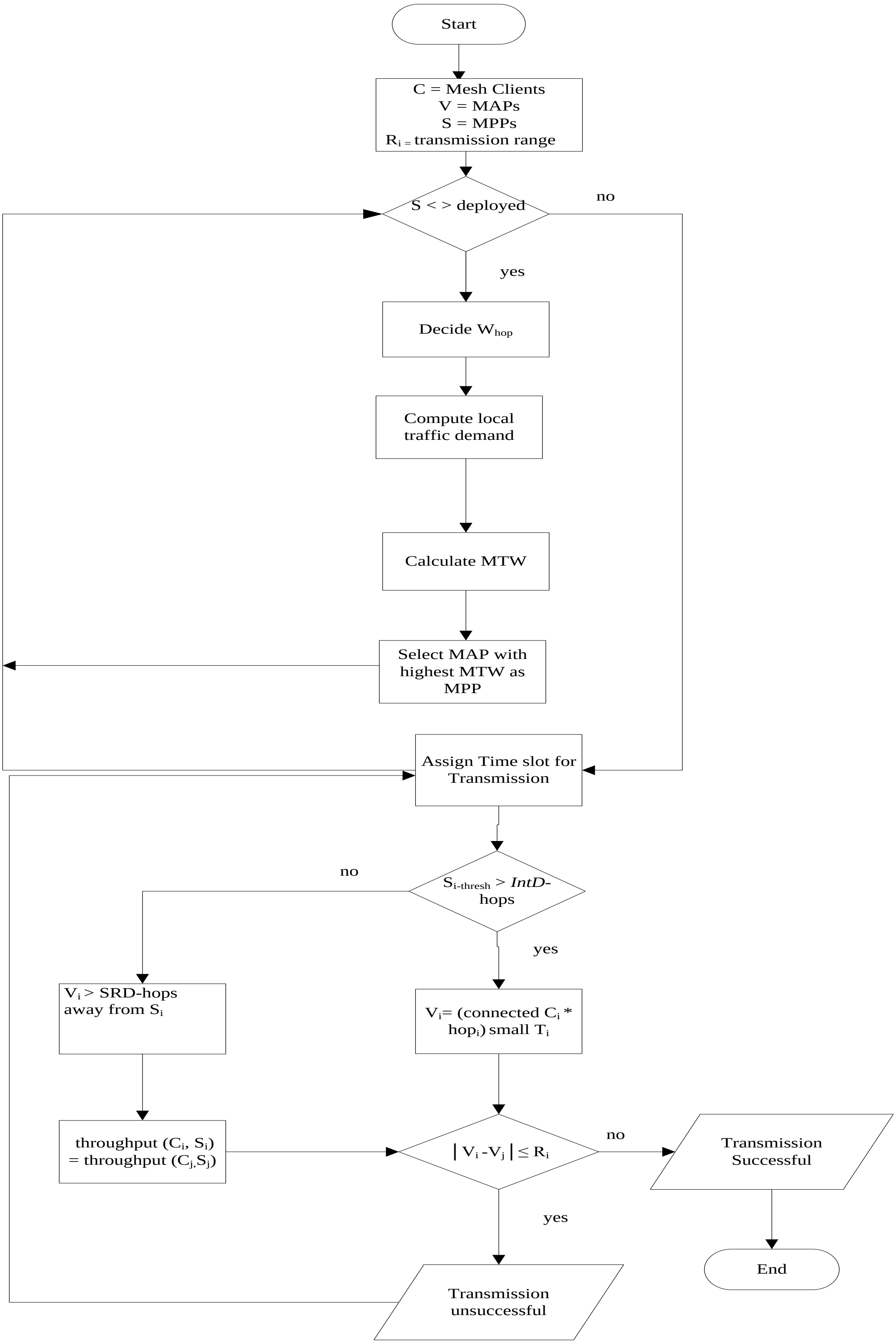

Figure 3.16 MTW Flowchart

3.3.4 Random MPP's Placement Scheme

The aim of the random MPP's placement scheme is to randomly select candidate positions for deploying MPP's. Figure 3.17 and 3.18 represent the pseudo-code and the flowchart of the random placement scheme.

```
1.  Let i=1
2.  Let MPPs be list of assigned Mesh Portal Point
3.  Let Points be the total number of unassigned Mesh Portal Point
4.  While i ≤ Points do
5.     Random = math.random * size of the Points
6.   If position is not assigned
7.     Select the position
8.        then store in MPP's
9.         End if
10.    i++
11.  end while
```

Figure 3.17 Random MPP placement Pseudo-code

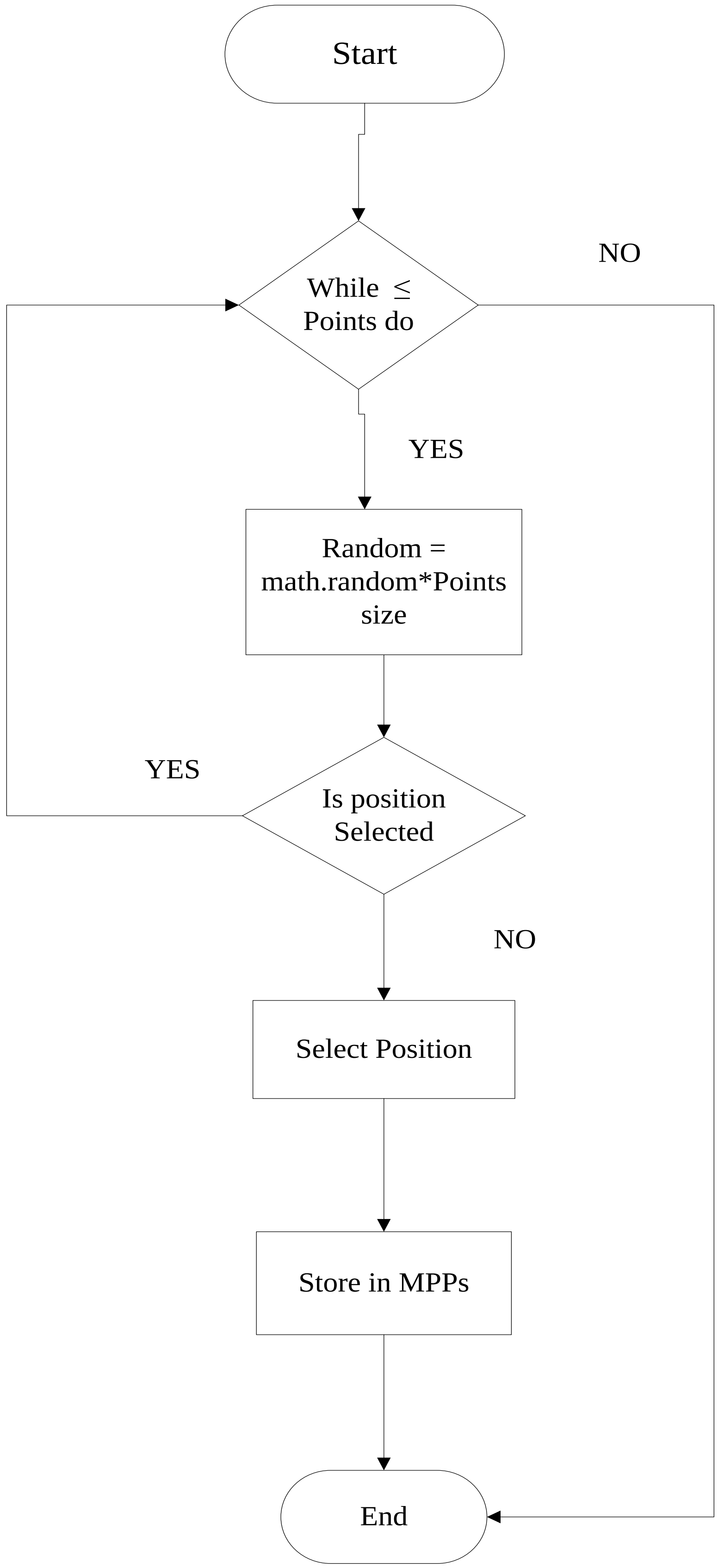

Figure 3.18 Random MPP placement Flowchart

3.4 Summary

The placement of MP's in a regular pattern can reduce the number of deployed MAP's than the random placement. Various studies have proven that the placement of MN's needs proper study of the terrain area prior to deployment i.e. nodes require safe locations with continuous power supply, possible candidate locations which will lead to minimum rate of interference. Typically the terrain contributes to the possible locations, of MAP's and contributes to the selection of MPP's. These affect the performance of the entire network. In this chapter MP's placement schemes that were selected in chapter 02 have been described in detail. In chapter four and chapter five the effectiveness of the MAP's and MPP's placement schemes will be simulated and evaluated under rural settlement patterns.

CHAPTER FOUR

PERFORMANCE EVALUATION OF MESH ACCESS POINTS PLACEMENT SCHEMES

4.1 Introduction

The previous chapter addressed the description of MP's placement schemes in terms of how MAP's placement problem is tackled. This chapter presents the results obtained from the simulation and evaluation of the selected MAP's placement schemes: Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement schemes. These schemes are simulated, evaluated and compared against each other, using a nucleated, isolated, dispersed and linear settlement pattern. This is necessary due to the fact that these placement schemes have not been evaluated and compared according to the effects of the rural settlement patterns.

The chapter focuses on the traditional mesh network infrastructure with only the local peer to peer traffic whereby MAPs communicate and exchange packets without passing through the internet. This is more important, because in many instances a community with few mesh clients will have traffic flow between clients rather than going to the internet. Section 4.2 represent the environment that was used for simulation of MAP's placement schemes while section 4.3 presents the results analysis of the experiment conducted. In section 4.4 the summary and recommendations are presented.

4.2 Simulation Environment

The four Rural Settlement Patterns and all the four MAP's placement schemes was implemented using java Netbeans IDE 6.9.1. This tool was used in order to give the visual layout of the rural settlement patterns as well as the selected MAP's positions. Network Simulator tool (NS2) version 2.34 running on Ubuntu Linux version 10.4 was used for the simulation of the selected placement schemes. Candidate positions (x, y and z co-ordinates) selected by all the four placement schemes were extracted from the java application into the NS2 scenario file and then used during simulation. NS2 is a discrete event simulator which provides substantial support for different transport, routing, multicast protocols and application etc. for both wired and wireless networks. An object oriented simulator (written in C++), and an OTcl (object oriented extension of Tool Command Language (Tcl)) interpreter are two the languages used. The wireless simulation Tcl script used considered the following components:

1. Static Nodes were used because rural settlement patterns must not lose topology in order to fulfill the purpose of this study and the deployed MAP's and MPP must not be mobile.
2. Link layer model based on the IEEE 802.11 Media Access Control (MAC) protocol was used to provide addressing and channel access control mechanisms that would make it possible for MPs to communicate.
3. Omni directional antenna (Two Ray Ground radio-propagation model) was used in order to uniformly radiate radio wave power in all directions in one plane.
4. Wireless Channel and Wireless Physical network interface type was used to reduce interference with other networks.
5. Queue/DropTail/PriQueue interface queue type managed the 50 packet transmission.

Table 4.1 Simulation parameters for all the experiments

Parameter(s)	Value(s)
Number of Buildings	500
Number of MAPs	20,40,50,60,80,100,120,140,160,180 and 200
Area	722m x 580m
Simulation Time	120 seconds
Packet Size	512 byte
Packet Rate	4 packets/sec
Routing Protocol	DSDV
Performance Metrics	Coverage, Connectivity, Throughput, Delay and Packet Delivery Ratio.
MAPs Placement Schemes	HillClimbing, VFPlace, LocalSearch and Random MAPs placement Scheme.
Settlement Patterns	Dispersed, Nucleated, Isolated and Linear

6. The Destination-Sequenced Distance-Vector (DSDV) routing protocol was used because contains a sequence number of every entry on the nodes routing table and whenever the topology changes the table is periodically updated.

The cbrgen tcl script was used to generate the Constant Bit Rate (CBR) and TCL traffic using the File Transfer Protocol (FTP) connection and 512 fixed packets per second. Transmission Control Protocol (TCP) was chosen against User Datagram Protocol (UDP) because it provides reliable delivery by guaranteeing that all the bytes received at the destination will be indistinguishable and in the same correct order with the bytes sent by the source and in the correct order. Each settlement was made up by 500 buildings spread in an area of 722m X 580m and the four placement schemes were used to select candidate positions of MAP's.

Table 4.1 shows the summary of the simulation parameters used for all the experiments. In each simulation performed, a trace file was generated and awk script was used to analyze the results. The simulation was conducted 10 times for each scheme and the average of the obtained result was used for analysis for each instance. Microsoft Excel was used to plot the graphs of the simulation result obtained. The following section discusses the simulation analysis of the result.

4.3 Simulation Experiments and Analysis

The performance of the four placement schemes: Hill Climbing, Time-efficient Local Search, Virtual Force and general Random MAPs were simulated based on the candidate position selected from nucleated, dispersed, isolated and linear settlement patterns. This section studies the performance of the network on all the four scenarios.

4.3.1 The effectiveness of MAP's placement Schemes in Nucleated Settlement Pattern

In this scenario we study the performance of the MAPs placement schemes in the nucleated settlement pattern. The effectiveness of the schemes is evaluated by comparing them against each other in terms of how much coverage, connectivity, throughput, end-to-end delay and packet delivery ratio each scheme can obtain. Figure 4.1 represent a typical nucleated settlement pattern scenario extracted from the netbeans java application before the selection of MAP's. Tables 4.2 to 4.6 present simulation results obtained by each placement schemes for all the mentioned performance metrics.

Experiment 1: The effect of MAP's placement schemes on the network coverage in nucleated settlement pattern

The purpose of this experiment was to find the area covered by the selected MAP's on the entire network using the nucleated settlement pattern.

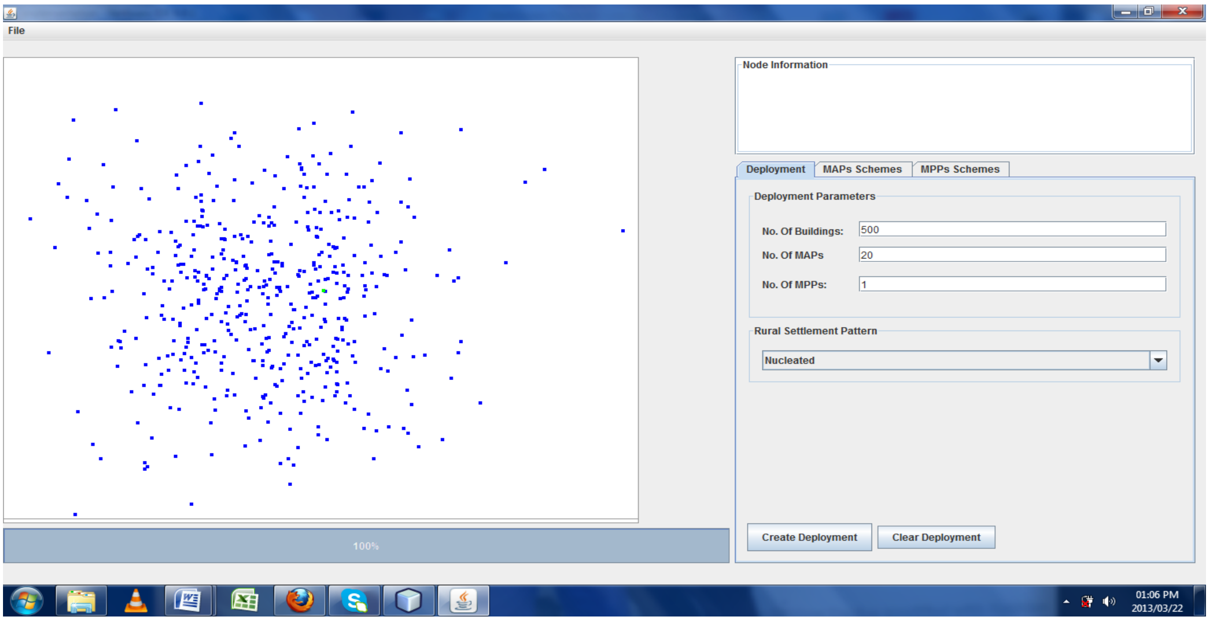

Figure 4.1 Nucleated Settlement Pattern

Coverage is a major performance metric during the deployment of WMN's and it is important to note that the obtained coverage highly depends on the selected candidates' position of MAP's i.e. poor placement of MAP's leads to poor network coverage, leading to deprived network performance. Coverage is a measure of the interconnected area at which MP's and MC's communicate in the network i.e. the probability that the client is connected to any of the MAP's. Typically a MAP would only influence a client within its own coverage range. Equation 4.1 was used to calculate coverage of the network.

$$Coverage = \frac{Sum\ of\ MAPs\ Area - (\sum overlap)/2}{Network\ Area} \qquad (4.1)$$

Where the network area is given by the product of the height and the width of the network. The area of overlap was calculated and half of it was removed from the network coverage in order to make sure that it is not duplicated

$$Network\ Area = 722 * 580 \qquad (4.2)$$

Table 4.2 Network Coverage in Nucleated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	52%	54.6%	51.1%	50.9%
40	54.3%	56.9%	53%	52.1%
60	63.1%	68.1%	61.1%	59.1%
80	67.4%	75%	64.8%	58.8%
100	75.4%	79.1%	69.4%	64%
120	79.5%	87.2%	74.3%	66.6%
140	80.1%	89.2%	74.7%	71.7%
160	85.9%	90%	78.1%	74.5%
180	88.9%	93.6%	80%	76.3%
200	89.9%	95%	81.3%	76.6%

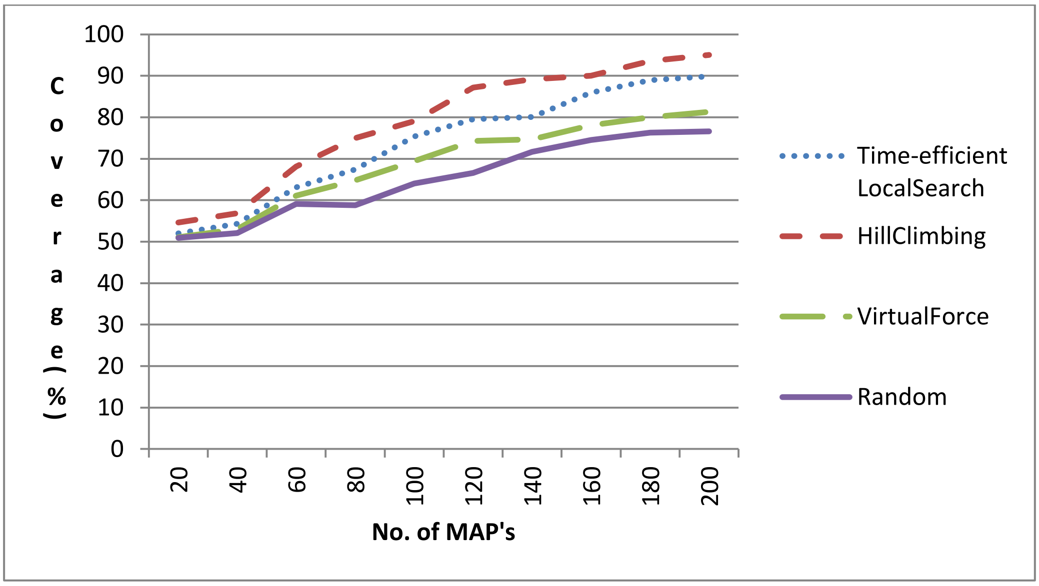

Figure 4.2: Network Coverage in Nucleated Settlement Pattern

Table 4.2 depicts the simulation result of the coverage area obtain by the entire network and a graphical presentation is presented in Figure 4.2. It can be observed that the increase in the number of MAP’s will result in high coverage of clients’ nodes. One of the reasons why such a performance is observed is because the considered network have the fixed number of clients and as well as the fixed deployment area. When few MAP’s are deployed there is less coverage of mesh clients even though the positions were strategically selected. As more MAP’s are being deployed the terrain area would be shared among the MAP’s and each MAP would have to cover the minimum number of mesh clients resulting in high gain of signal strength for nearby clients. Figure 4.2 illustrate that the four placement schemes reached better values of coverage in this settlement pattern. The reason behind such behavior is the fact that the MAP's are clustered towards each other because of the nature of the terrain; the pattern is depicted in figure 4.1. The Hill Climbing placement scheme outperforms the Time-efficient Local Search, Virtual Force and Random placement scheme in a nucleated settlement. This behavior is expected because at most dense regions with high concentration of mesh clients, the Hill Climbing places the MAP's with the largest radio coverage providing maximum coverage to all the nearest clients and then the rest of the MAP's are placed on the clients further away from the cluster.

Experiment 2: The effect of MAPs placement schemes on the network connectivity in nucleated settlement pattern

The aim of this experiment was to find the total number of connected MAP's in a network considering a nucleated settlement scenario. This was achieved by using a proactive DSDV which stores the route entries into the routing table together with their sequence numbers and shares the routing information among the other MAP's. To obtain the number of total connections for the entire network the number of entries into the routing table were added giving all available and connected paths in the network.

The maximum network connection is obtained when all the deployed MAP's can communicate with each other. That involves full communication and connection of a MAP with every other MAP. The total connections can be represented as n^2-n, where n refers to the number of MAP's. Figure 4.3 represents the behavior of the Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement scheme in terms of the total connections that each scheme can obtain.

Table 4.3 Network Connectivity in Nucleated Settlement Pattern

No. Of Mesh Points	Time- efficient Local Search	Hill Climbing	Virtual Force	Random	Maximum Connection
20	361 n	370 n	355 n	350 n	380 n
40	1507 n	1554 n	1497 n	1465 n	1560 n
60	3348 n	3400 n	2990 n	2631 n	3540 n
80	6177n	6314 n	5994 n	5787 n	6320 n
100	9190 n	9626 n	8905 n	8687 n	9900 n
120	13952 n	14108 n	13642 n	12096 n	14280 n
140	18703 n	19510 n	18536 n	17475n	19460 n
160	23095 n	24128 n	20153 n	20211 n	25440 n
180	30219 n	31150 n	29453 n	28899 n	32220 n
200	35874 n	38578 n	34965 n	32299 n	39800 n

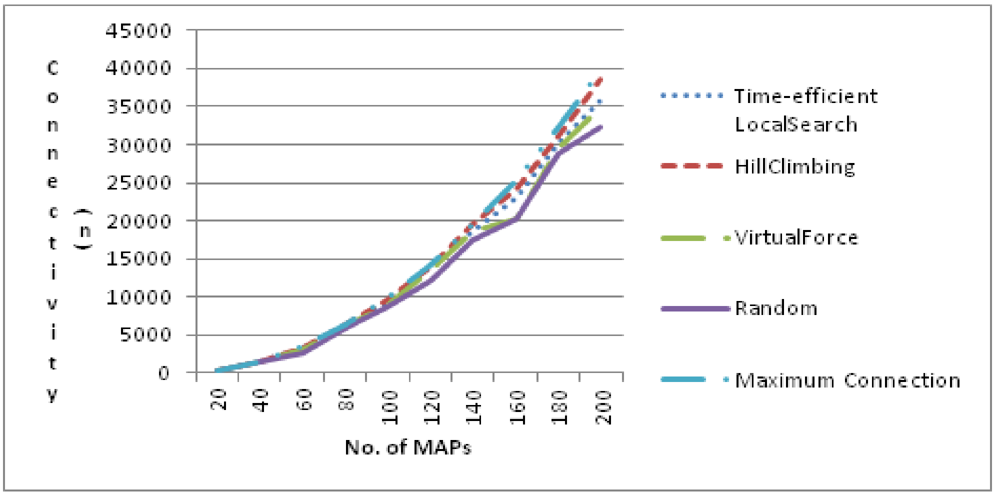

Figure 4.3 Network Connectivity in Nucleated Settlement Pattern

It can be observed from Table 4.3 that all the placement schemes have a linearly progression and none of the placement schemes was able to achieve full network connection. This can be attributed to the fact that wireless connectivity changes over time and different MAP's give better connection to different clients depending on the topology of the network. It is important to recall that in this scenario mesh clients are clustered towards the center and MAP's also adapt to the same structure (depicted in Figure 4.1). When few MAP's are deployed the most challenging factor is to cover and connect all the clients in the network hence distance becomes relatively long, weakening the strength of connection, however as more MAP's are deployed the effect is opposite. The Hill Climbing has better network connection than the other approaches. This is because the use of radius local movement allows worst MAP's to be placed in less dense area and the powerful MAP's to be deployed on the most dense area. This attribute makes it easy for this approach to share the medium effectively and fairly among clients' nodes.

Experiment 3: The effect of MAP's placement schemes on the network throughput in Nucleated Settlement Pattern

The purpose of this experiment was to determine throughput of the entire network gained in the nucleated settlement pattern scenario. In this case we measured the number of packets that were received over a period of time considering a network with twenty to two hundred nodes. MAP's positioning plays a vital role in the overall throughput obtained in the network at any instance, a successful network would obtain high gain of throughput as much as possible. Equation 4.3 was used to calculate throughput: Average throughput per unit time.

$$Average\ throughput = \frac{total\_\ received\ packet}{total\_simulation\ time} \tag{4.3}$$

The simulation result of the total average throughput is given on Table 4.4 and Figure 4.4 showing the variation of throughput throughout the entire experiment. It can be observed that the increase in the number of MAP's deployed in the network caused an increase in the throughput gained. The cause of such behavior is that the required transmission hop count reduces as more MAP's are deployed as a result of an exponential throughput growth. On the contrary, the large percentage of deployed MAP's without increasing the network size causes mesh clients to initiate a high degree of contention among neighboring MAP's. This resulted to the degradation of the entire network throughput.

Table 4.4 Network Throughput in Nucleated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	50.7 kbps	61.1 kbps	45.9 kbps	41.1 kbps
40	85.6 kbps	94.8 kbps	85.1 kbps	84.8 kbps
60	105 kbps	191.7 kbps	95.6 kbps	100.2 kbps
80	267.6 kbps	391.1 kbps	247.1 kbps	158.6 kbps
100	385.1 kbps	472.1 kbps	375.5 kbps	215.1 kbps
120	419.6 kbps	482.1 kbps	398.3 kbps	353.7 kbps
140	473.8 kbps	552.8 kbps	451.7 kbps	430.2 kbps
160	557.1 kbps	622.5 kbps	458.5 kbps	450.2 kbps
180	568.1 kbps	645.9 kbps	488.9 kbps	467.1 kbps
200	560.8 kbps	640.1 kbps	473.2 kbps	465 kbps

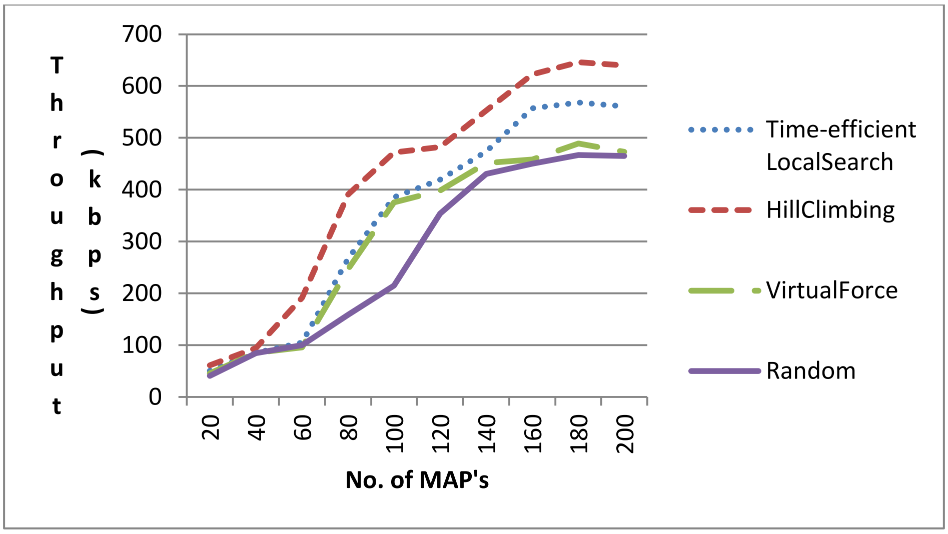

Figure 4.4: Network Throughput in Nucleated Settlement Pattern

It can be observed in Table 4.4 that the network average throughput increased and reached a certain point (from 20 nodes to 160 nodes) and then started decelerating. Some packets were lost along the way due to the conflict among the neighboring nodes. Hill Climbing outperforms other methods in terms of achieving the maximum average network throughput. The way the topology of the network is structured makes it easier for the Hill Climbing to track most dense area through the application of radius local movement. It is important to note that the structure of the network is highly influenced by the type of settlement pattern formed by positions of mesh clients as we assumed they are fixed. The random placement scheme turn to achieve the lowest throughput peak compared to the other placement schemes. This is due to the fact that it does not consider how the distribution of MCs in a deployment area is.

Experiment 4: The Network End-to-end Delay in Nucleated Settlement Pattern

The purpose of this experiment was to measure how much time is taken to transmit the data packet from the source node to the intended destination node. The end-to-end delay incurred by the Hill Climbing, Virtual Force, Time-efficient Local Search and Random MAP's placement schemes is illustrated in Table 4.5 and Figure 4.5. A network with good performance would ensure low end-to-end delay as much as possible. The end-to-end delay can be achieved by subtracting time at which first data packet was transmitted by source node by the time at which first data packet arrived to destination node.

The simulation result reported that there was a huge amount of end-to-end delay when only few MAP's are being deployed in the network. However, the increase in the number of MAP's decreases the amount of end-to-end delay for all the four schemes. High percentage of delay is caused by the increase in the number of hops a packet needs to travel to reach the intended destination node. The channel access caused the nodes to compete in order to gain access to the wireless channel, thus leading to high delay. Other types of delays are queuing delays, processing delays and aggregation delays which might be caused by the use of the DSDV while it tracing the shortest route of the nodes for the destination of the packet.

The scarcity of route a packet needs to travel to the intended receiver in the network leads to network congestion. This is due to the facts that many packets need to travel in the network and may have to wait on long queues to access the channel.

Table 4.5 Network end-to-end delay in Nucleated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	167.2 ms	162.7 ms	179.6 ms	221.2 ms
40	151.2 ms	144.8 ms	167.6 ms	183.9 ms
60	146 ms	129.8 ms	157.5 ms	183.1 ms
80	135.2 ms	127.6 ms	147 ms	176.2 ms
100	118.4 ms	87.1 ms	128.1 ms	130.1 ms
120	105.2 ms	78.9 ms	115 ms	124.3 ms
140	85.7 ms	65.2 ms	95.8 ms	106.7 ms
160	67.6 ms	54.5 ms	78.3 ms	89 ms
180	68.5 ms	55.5 ms	78.5 ms	89.1 ms
200	68.7 ms	55.8 ms	78.7 ms	89.2 ms

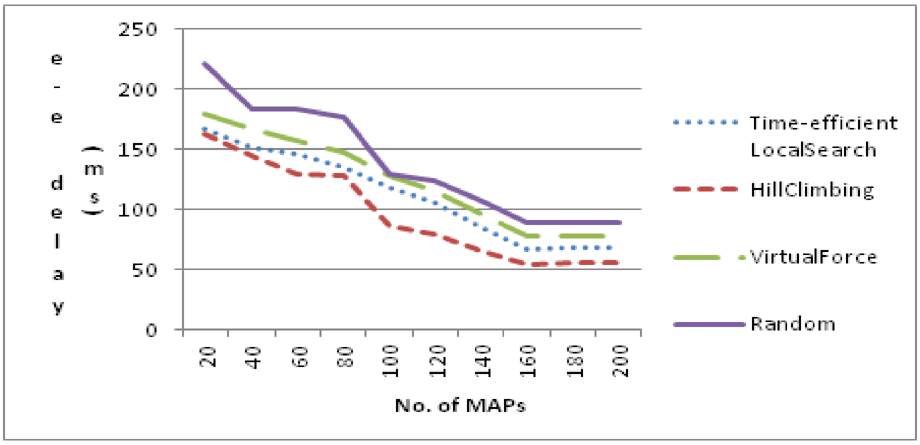

Figure 4.5 :Network end-to-end delay in Nucleated Settlement Pattern

It is important to note that in the nucleated pattern nodes are clustered toward each other which might cause conflict when more MAP's are being deployed as result TCP consume lot of time trying to re-configure the packet to the original format in the network. In a nucleated settlement scenario as presented by the simulation results the Random placement scheme resulted in the worse network performance since it incurred higher end-to-end delay compared to other schemes. The Virtual Force is the second worst performer, followed by the Time-efficient Local Search scheme then Hill Climbing.

Experiment5: The effect of MAP's placement schemes on the network Packet Delivery Ratio in Nucleated Settlement Pattern

This experiment was carried out to determine what effect do placement schemes have on the amount of successfully delivered data packet from source to the intended destination node. For any successful network, it is important to know whether packet are being delivered or lost during transmission. A network can have good coverage and good connectivity, but if the packet delivery ratio (PDR) is very small then network performance is determined to be very poor. Maximum successful network PDR is normally 100%, a zero ratio implies a failure of delivery. Table 4.6 and Figure 4.6 depict the PDR that was incurred in the network. It can be observed that the performance of all the placement schemes on packet delivery is outstanding (performance is merely the same for all methods). This is due to the fact that in this settlement, the MAPs are clustered towards the center and thus there is short distance between the nodes. In this case, there will be a very slight chance of obstruction within the network leading to less packet loss which then caused the high rate of delivered packets. It can be noted that the channel capacity is not fully utilized, there is high availability of route for the data packet to travel; packet delivery is smoothly achieved without having to wait for the availability of channel bandwidth.

The simulation result shows that Hill Climbing outperformed other methods in this settlement by the total percentage of up to 98.5% packet delivered compared to 95.1% of Time-efficient Local search, 90.4% of Virtual Force and 89.7% of Random MAP placement schemes. The other interesting fact is that even the Random method incurs high percentage of packet delivery which usually gains poor performance in other network metrics like delay and throughput; this is a sign of a good network performance. The slopes of the PDR graph gradually increased from 20 to 200 MAP's for all the placement schemes because of the use of TCP which always fights for accuracy of the transmission of data packet in the network.

Table 4.6 Network Packet Delivery Ratio in Nucleated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	82.1%	84.8 %	80 %	78.1 %
40	85.4 %	86.2 %	84.1 %	82.2 %
60	86.5 %	87 %	86.5 %	84 %
80	87.5 %	88.4 %	87 %	85.1 %
100	88.7 %	88.9 %	88.3 %	85.5 %
120	88 %	89 %	88.3 %	86.9 %
140	88.9 %	92.1 %	89 %	88.1 %
160	89.2 %	94.2 %	89.5 %	89 %
180	92.3 %	96.4 %	89.7 %	89.4 %
200	95.1 %	98.5 %	90.4 %	89.7 %

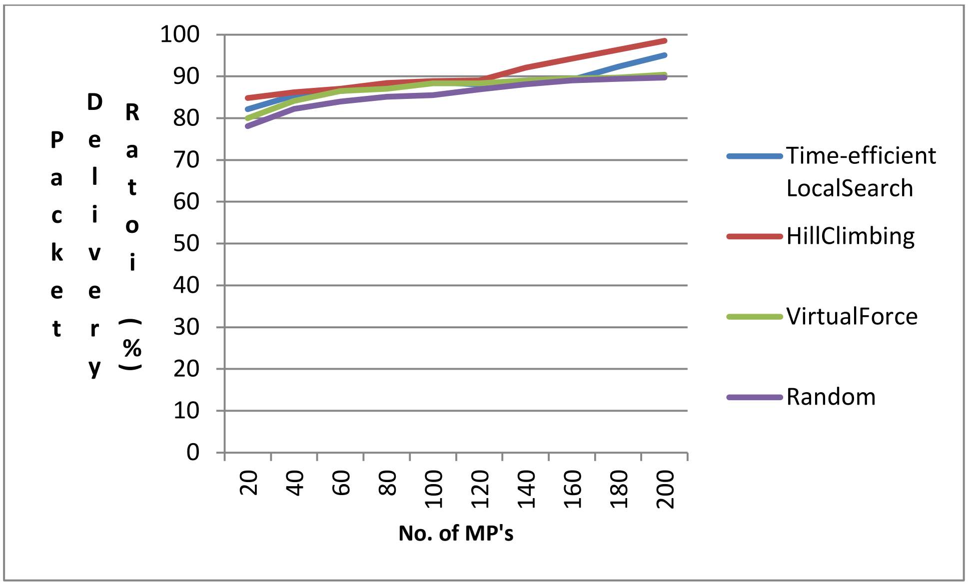

Figure 4.6: Network Packet Delivery Ratio in Nucleated Settlement Pattern

This is also the evidence that even though the network delay might be very high at some point in the network, it does not imply that the packet would not reach the intended destination node.

The PDR was measured by the equation 4.5

$$PDR = \frac{packet\_received}{packet\_sent} \qquad (4.5)$$

4.3.2 The effectiveness of MAP's placement Schemes in Dispersed Settlement Pattern

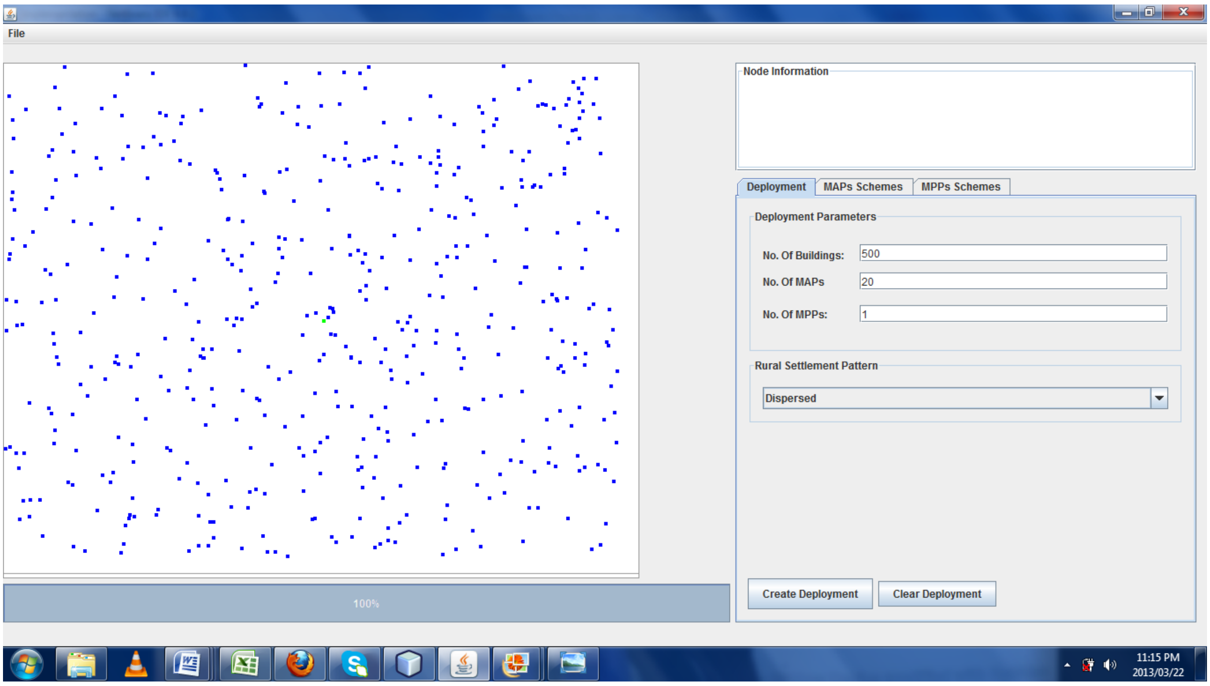

Figure 4.7 Dispersed Settlement Pattern

In this section we compare the performance of Time-efficient Local Search Scheme, Hill Climbing, Virtual Force and Random placement schemes in terms of how much coverage, connectivity, throughput, end-to-end delay and packet delivery ratio in dispersed settlement pattern scenario. Figure 4.7 represent a typical dispersed settlement pattern that was created on the java application before MAPs were selected.

Experiment 6: The effect of MAP's placement schemes on network coverage in Dispersed Settlement Pattern

This experiment determines the effect of the MAP's placement schemes on the average coverage of the network when considering network scenario of the dispersed settlement pattern.

Table 4.7 Network Coverage in Dispersed Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	43.9%	50.3%	38.3%	29.3%
40	45%	55.2%	42.2%	38.4%
60	51.1%	56.6%	45.5%	36.6%
80	55.4%	58.8%	47.4%	40.3%
100	59.8%	64.2%	51.3%	47.2%
120	60.6%	65.3%	54.2%	51.6%
140	63.9%	69.5%	58.3%	53.9%
160	70.3%	73.1%	64.6%	58.6%
180	75.6%	79.2%	66.1%	62.7%
200	77.8%	80.8%	70.6%	67%

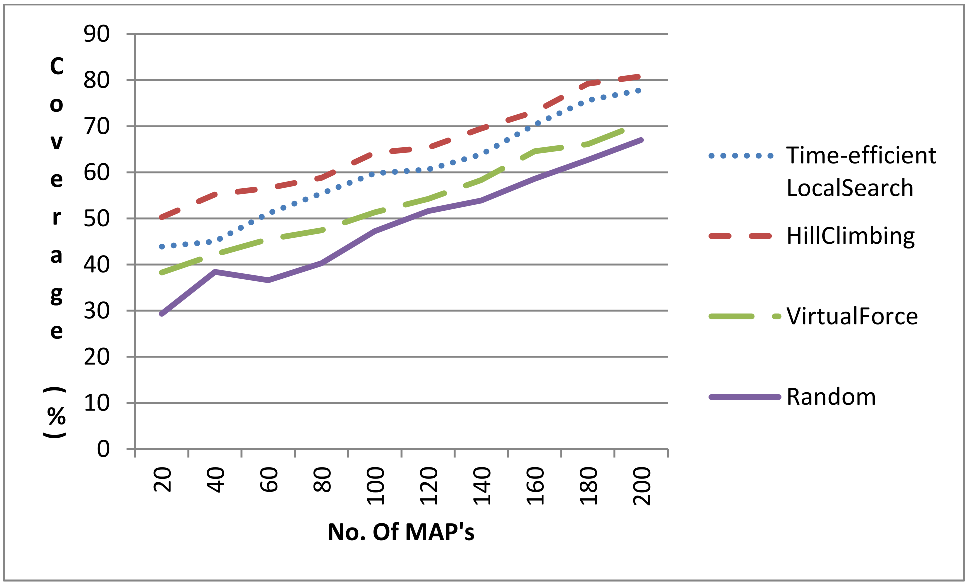

Figure 4.8: Network Coverage in Dispersed Settlement Pattern

The formula for measuring network coverage is the same as the one used in the nucleated settlement pattern. Table 4.7 and Figure 4.8 depict the simulation result of average network coverage. The result revealed that very low MAP's deployed would only cover a small area; network coverage would be very weak but as the number of deployed MAP's increases the network coverage gradually increased as well. Table 4.7 reports that the Hill Climbing achieved highest coverage compared to the other methods. Hill Climbing gave maximum coverage of up to 80.8%; the Time-efficient Local Search covered 77.8%, Virtual Force covered 70.6% while the Random placement scheme obtained 67% of network area covered. The average coverage achieved by the four schemes is very low compared to the nucleated settlement pattern. The reason behind this observation is because the area at which MAP's are deployed is scattered or dispersed, which causes the selection of position of MAP's to be uneven since the arrangement of clients is irregular and some of the nodes result in being out of communication range of the other nodes, the strength for communication lowers as the distance between the nodes increase, in that way degrading the performance.

The Hill Climbing is able to attain better network average coverage by applying it local movement. This allows it to be able to swap MAP's in order to ensure that those with highest radius are concentrated on the mostly dense areas and the MAP's with lowest radio coverage are concentrated on the less dense regions (in terms of the concentration of mesh clients). Swap methods for Hill Climbing are known of their fitness in outperforming in an area with diversity of mesh clients positions.

Experiment 7: The effect of MAP's placement schemes on network connectivity in Dispersed Settlement Pattern

The purpose of this experiment was to measure the connectivity level between the MAP's of the entire network taking into consideration all four MAP's placement schemes. It can be observed from Figure 4.9 that all placement schemes improved as more MAP's are being deployed in the network.

Table 4.8 Network Connectivity in Dispersed Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random	Maximum Connection
20	361 n	361 n	303 n	284 n	380 n
40	1287 n	1300 n	1273 n	1270 n	1560 n
60	2658 n	2798 n	2421 n	2536 n	3540 n
80	4961 n	5009 n	4512 n	4173 n	6320 n
100	7487 n	8124 n	7253 n	7124 n	9900 n
120	9836 n	10502n	9070 n	8797 n	14280 n
140	16967 n	17907 n	15586 n	13586 n	19460 n
160	18738 n	19385 n	17839 n	17089 n	25440 n
180	25415 n	26054 n	23397 n	22829 n	32220 n
200	29043 n	30551 n	28517 n	27261 n	39800 n

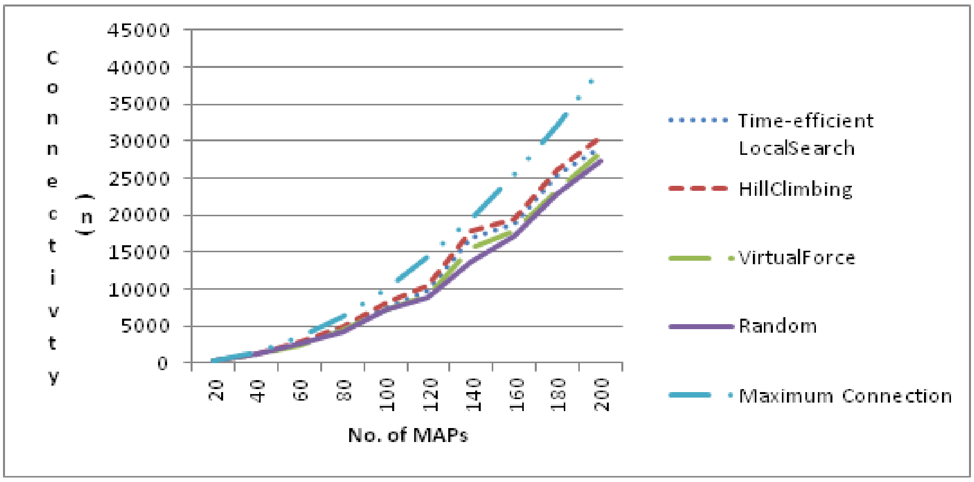

Figure 4.9: Network Connectivity in Dispersed Settlement Pattern

The reason for such behavior is due to the fact that the increase in MAP's brings balance in the network, long route length weakens connection between the MAP's. It is observed that although there is a linear sequence on the connectivity obtained by the schemes, the graph for each placement scheme is not smooth. This is caused by the diversity of mesh clients location resulting into the same effect to the MAP's, the distribution of nodes is not even and will result in the connectivity strength dropping. The performance of all the placement schemes is very hard to distinguish for small instances.

However, as more MAP's are deployed, Hill Climbing outperformed other approaches in terms of maintaining network connection among MAP's. When a deployment area consists of sparse mesh clients distribution, the Hill Climbing apply simple climbing which would allow comparison among various possible location and swap MAP's. Swap movement exchanges MAP's with the largest radio coverage at a less dense area with the MAP's with the smallest radio coverage at a highest dense area. This technique makes the Hill Climbing more privileged than the other approaches in a dispersed settlement pattern. It can also be observed that none of the approaches obtained the full network connectivity.

Experiment 8: The effect of MAP's placement schemes on network throughput in Dispersed Settlement Pattern

The purpose of this experiment was to measure the effect of the Hill Climbing, Time-efficient Local Search, Virtual Force and Random MAP's placement schemes on the network throughput in the scenario of dispersed settlement pattern. The network throughput was achieved using the same formula used for nucleated settlement pattern. The simulation results revealed a lot of variation between the network throughputs gained by the placement schemes at different MAP's sizes. In the beginning of the simulation the network throughput was very low, but as the number of MAP's increased the throughput also increased. At node 80 the throughput dropped and picked up again at 100 to 120 nodes then after that there was a gradual throughput increase for the all placement schemes.

In this scenario, MAP's are scattered in a region, typically the positions are selected at the convenience of mesh clients. In some of the region, the distribution may not be even, which might cause signal obstructions by various factors, for instance hills, trees and the elongation of distance weakens the signal strength thus affecting packet transmission, resulting in increase rate of packet loss.

Table 4.9 Network Throughput in Dispersed Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	16.4 kbps	31.6 kbps	12 kbps	10.5 kbps
40	61.6 kbps	121.8 kbps	34 kbps	15.5 kbps
60	203.6 kbps	273.4 kbps	120.5 kbps	51.9 kbps
80	161.3 kbps	266.4 kbps	102.7 kbps	31.6 kbps
100	371.1 kbps	419.7 kbps	341.9 kbps	273.9 kbps
120	439 kbps	467.2 kbps	403.1 kbps	240.8 kbps
140	438.1 kbps	456.3 kbps	401.1 kbps	335.7 kbps
160	420.5 kbps	442.3 kbps	396.9 kbps	324.7 kbps
180	410.8 kbps	439 kbps	383.6 kbps	312 kbps
200	402.9 kbps	435.7 kbps	375.2 kbps	305.4 kbps

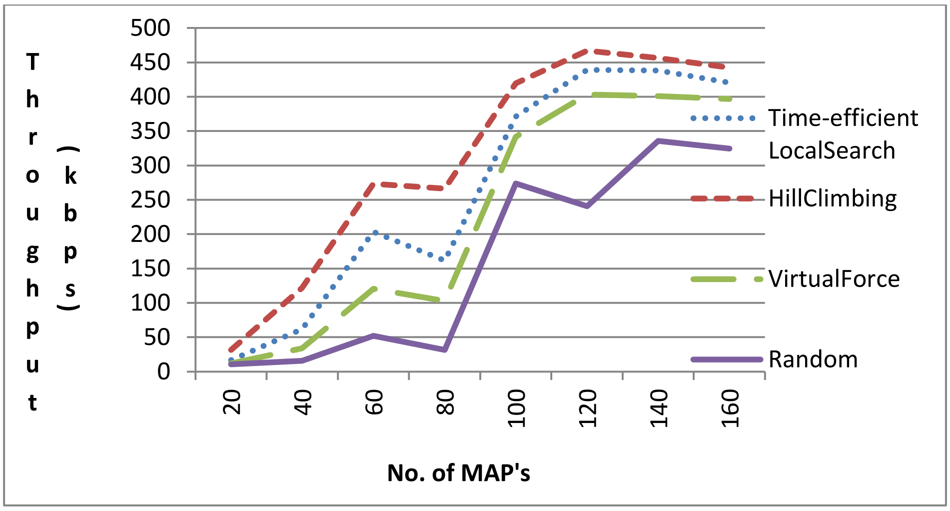

Figure 4.10: Network Throughput in Dispersed Settlement Pattern

When the distance between the nodes is large, the impact of interference is more severe as the result of performance deterioration. Another reason for the decrease of throughput is that as more MAP's are deployed in a fixed area transmission signals will begin to interfere with one another resulting into packet drop. As clearly indicated on the graph, the Hill Climbing placement approach outperforms the other three approaches in this settlement because of its privilege on usage of the local movements.

Experiment 9: The effect of MAP's placement schemes on network end-to-end Delay in Dispersed Settlement Pattern

Table 4.10 Network end-to-end Delay in Dispersed Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	242.9 ms	201.6 ms	320 ms	365.8 ms
40	173.4 ms	163.5 ms	282.9 ms	342.5 ms
60	163 ms	132.1 ms	190.2 ms	283.53 ms
80	164.2 ms	149.4 ms	197.6 ms	290.8 ms
100	141.7 ms	119.1 ms	162.4 ms	206.6 ms
120	133.7 ms	115.9 ms	158.6 ms	219.7 ms
140	131.7 ms	112.9 ms	154.8 ms	220.4 ms
160	128.4 ms	113.2 ms	147.7 ms	165.5 ms
180	130.3 ms	112.2 ms	148.3 ms	168.7 ms
200	138.7 ms	119.8 ms	151.04 ms	168.4 ms

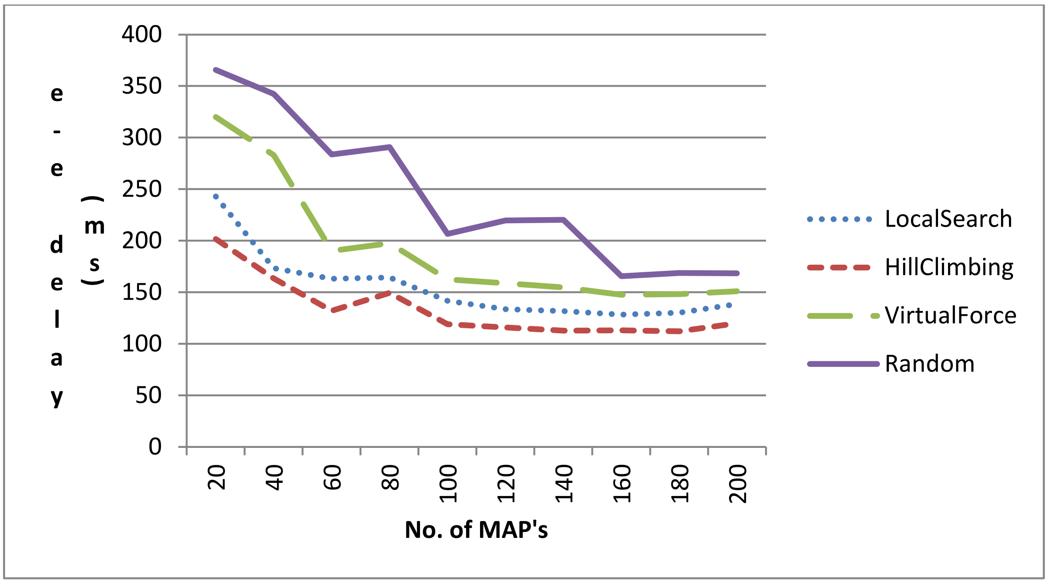

Figure 4.11: Network end-to-end Delay in Dispersed Settlement Pattern

In this scenario we found out how much network end-to-end delay is incurred by the placement schemes on the dispersed settlement pattern. Table 4.10 and Figure 4.11 present the simulation result obtained. The simulation results revealed that the network suffered a significant amount of end-to-end delay, which resulted into decreased overall network performance. When fewer MAP’s are deployed there would be high rate of congestion in the network caused by conflict of transmission from client nodes and lot of time would be consumed as a result of high rate of end-to-end delay when TCP handles the collision by using a connection-based messaging strategy to ensure that packet are delivered in order. Another interesting fact which causes such behavior is the terrain as can be recalled that in this scenario the distribution of MAP’s is uneven which causes variance during packet transmission. Some route may have long distance between the nodes which might cause the impact of the interference to be more severe thus deteriorating the network performance. Some route may be broken due to interference and packet may have to choose a different route. It can be remarked that Hill Climbing suffers less end-to-end delay than the other three approaches.

Experiment 10: The effect of MAP’s placement schemes on network Packet Delivery Ratio in Dispersed Settlement Pattern

This section presents the effect of MAPs placement on network packet delivery ratio given a dispersed settlement pattern scenario. The illustration of the achieved PDR for the Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement scheme is depicted in Figure 4.12. The packet delivery ratio for all placement approaches is merely the same for all the placement schemes. Table 4.11 shows that there is an increase in the PDR as the number of MAP’s increased. Hill Climbing obtained better packet delivery than the other approaches and the random approach is the worst.

Table 4.11: Network Packet Delivery Ratio in Dispersed Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	67.8 %	71.5 %	65.8 %	62.5 %
40	75.5 %	78.2 %	73.7 %	70 %
60	78.8 %	80 %	78.8 %	74.6 %
80	82.3 %	85.5 %	80.9 %	76.9 %
100	83.7 %	86 %	82.6 %	78.5 %
120	85.1 %	87.2 %	84.9 %	83.4 %
140	86.7 %	88.1 %	85.3 %	85 %
160	87.9 %	88.5 %	86.8 %	85.8 %
180	88 %	88.7 %	87.5 %	86 %
200	88.5 %	89.4 %	87.9 %	86.7 %

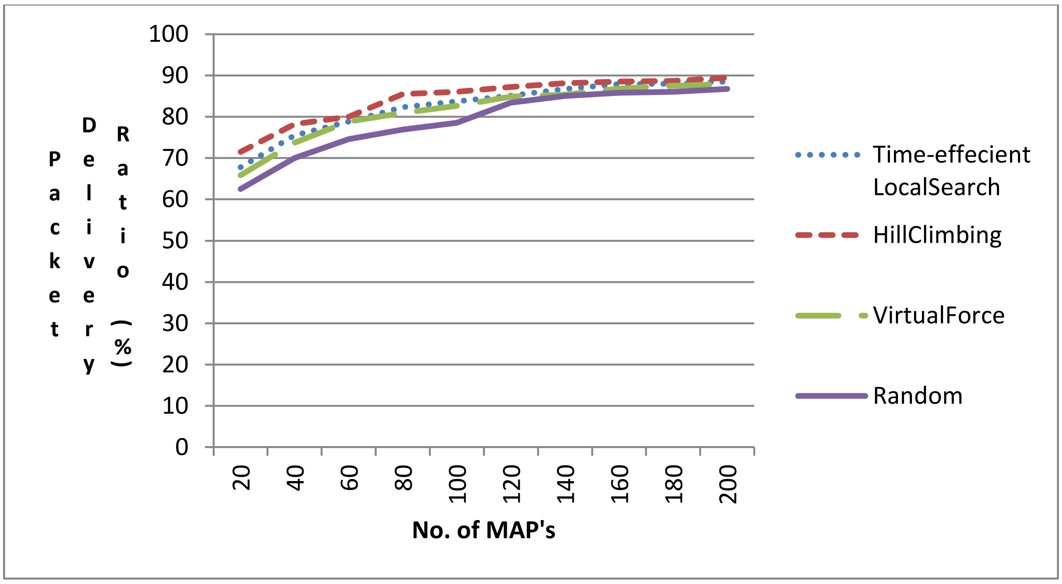

Figure 4.12: Network Packet Delivery Ratio in Dispersed Settlement Pattern

This section presents the result for the evaluation and comparison of Time-efficient Local Search, Hill Climbing, Virtual Force and Random MAP's using positions selected on a linear settlement pattern scenario. The performance of the schemes was measured by evaluating exactly how much each scheme obtains network coverage, connectivity, throughput, packet delivery ratio and end-to-end delay.

4.3.3 The effectiveness of MAP's placement Schemes in Linear Settlement Pattern

In this scenario we study the performance of the MAP's placement schemes in the linear settlement pattern. The effectiveness of the schemes is evaluated by comparing them against each other in terms of how much coverage, connectivity, throughput, end-to-end delay and packet delivery ratio each scheme can obtain. Figure 4.13 represent a typical linear settlement pattern scenario extracted from the java application before the selection of MAP's. Tables 4.12 to 4.16 present simulation results obtained by each placement schemes for all the mentioned performance metrics.

Experiment 11: The effect of MAP's placement schemes on network coverage in linear settlement pattern

The aim of this experiment was to find the area covered by MAP's selected by each scheme in the linear settlement pattern; Figure 4.14 illustrates the simulation results that were obtained. The coverage was measured using the same approach that was applied in experiment one. As depicted in Figure 4.14 and Table 4.12, the network coverage for all the placement schemes have a linear progression as the number of deployed MAP's increased the network coverage also increased. When few MAP's are deployed network coverage obtained by all the placement schemes is very low, the linearity of the settlement makes it not feasible for few MAP's to cover a large area.

It can be observed that the Virtual Force placement scheme outperformed other approaches. One of the reasons this behavior is expected is because Virtual Force has got ways to escape prohibitive regions it avoids placing MAP's in these regions by applying a repulsive force which pushes MAP's apart from each other thus maximizing the coverage for mesh clients.

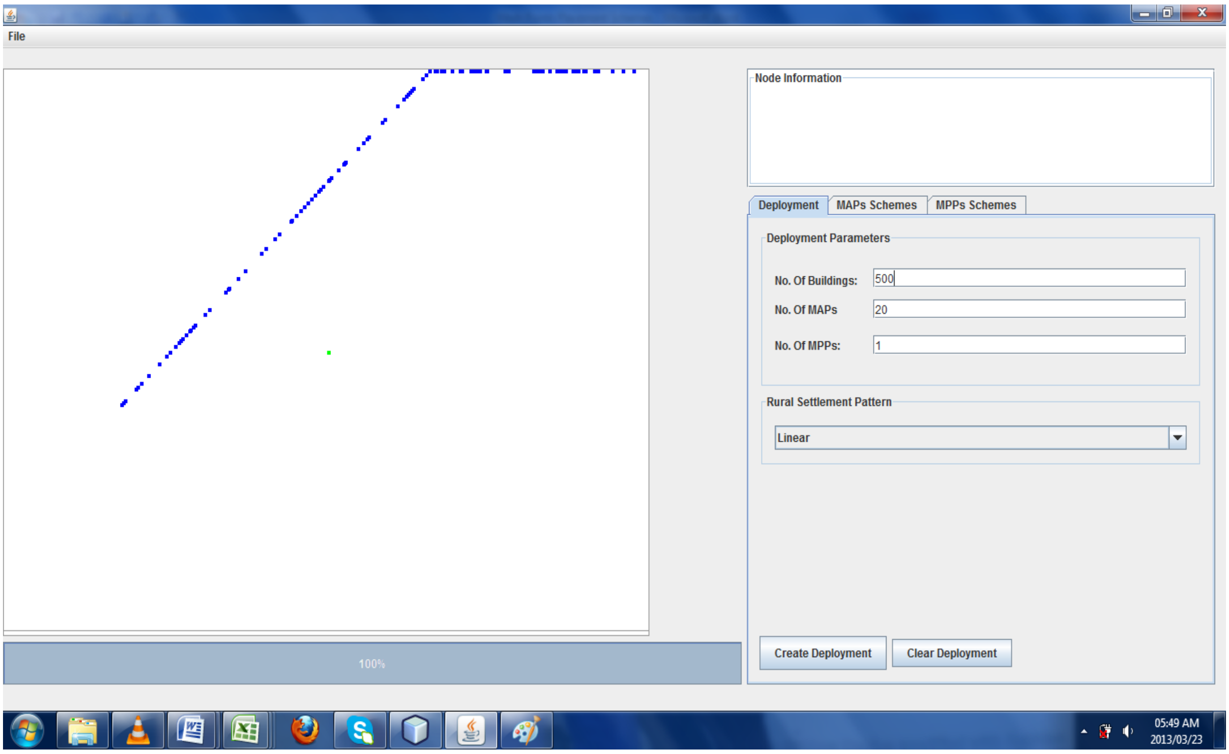

Figure 4.13: Linear Settlement Pattern

Table 4.12: Network Coverage in Linear Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	41.5%	45.1%	51.6%	38.8%
40	46.7%	50.4%	55.2%	44.1%
60	51%	54.2%	58.5%	47%
80	55.8%	58.9%	65.5%	50.9%
100	57.6%	63.2%	69.9%	52.4%
120	61.2%	65.6%	70.1%	58%
140	66.3%	68.7%	72.7%	60.4%
160	69.3%	71.5%	75.8%	65.8%
180	73.3%	75.3%	78.9%	66.6%
200	77%	79.9%	83.7%	68%

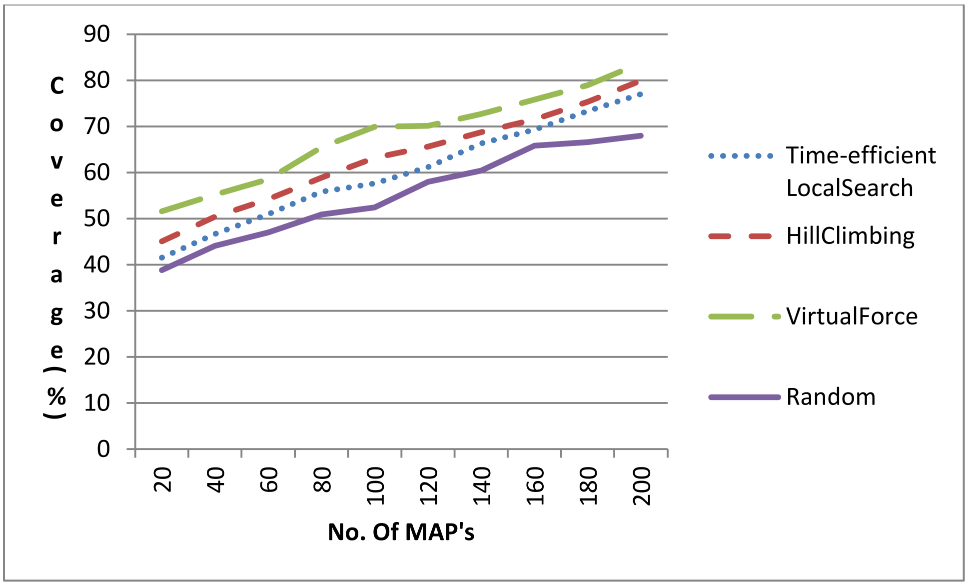

Figure 4.14: Network Coverage in Linear Settlement Pattern

The Random placement method achieved the lowest coverage of mesh clients as compared to other three schemes. The reason behind such behavior is because there is a very high probability that it selected a locations that were obsolete which may not even cover the minimum number of expected mesh clients.

Experiment 12: The effect of MAP's placement schemes on network connectivity in linear settlement pattern

In this subsection, the performance of the placement schemes on selecting MAP's is studied by measuring connectivity given a network domain in linear settlement pattern. This is achieved using the same approach used in experiment 2 of this chapter. Figure 4.15 presents the simulation result for measuring network connectivity. It can be observed that the connectivity obtained by all MAP's have a common linearly scale except for random placement which start to vary after 140 MAP's have been deployed. The increase in the number of deployed MAP's led to higher degree of connectivity by all schemes; however none of them achieve a full network connection given by n^2-n.

Table 4.13: Network Connectivity in Linear Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random	Maximum Connection
20	315 n	320 n	330 n	310 n	380 n
40	1436 n	1476 n	1520 n	1413 n	1560 n
60	2042 n	2440 n	3240 n	2111 n	3540 n
80	5077 n	5598 n	6124 n	5030 n	6320 n
100	7854 n	7899 n	8999 n	7900 n	9900 n
120	11489 n	11678 n	12580 n	10289 n	14280 n
140	16338 n	17897 n	18068 n	15866 n	19460 n
160	19935 n	20515 n	23106 n	16515 n	25440 n
180	28271 n	29333 n	30004 n	27127 n	32220 n
200	33072 n	35513 n	36854 n	30232 n	39800 n

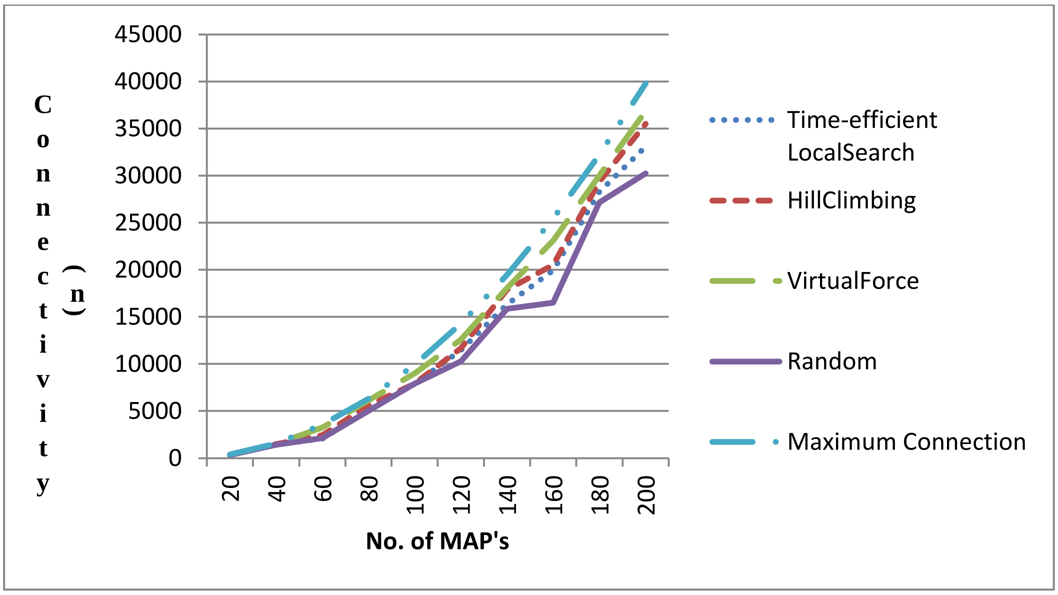

Figure 4.15: Network Connectivity in Linear Settlement Pattern

It can be noted that the Virtual force placement scheme obtained values close to the expected full network connection at all stage from 20 to 200 MAP's refer to Table 4.13. The reason for such behavior is that the Virtual Force bypasses the prohibitive region by pushing MAP's ensuring all areas of clients are covered and to ensure that connectivity will be maintained, the attractive force is applied pulling MAP's closer to each other in order to strengthen connection within the network. The Virtual Force ensures that the preferential regions are always favored.

Experiment 13: The effect of MAP's placement schemes on network throughput in linear settlement pattern

Table 4.14: Network Throughput in Linear Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	25.8 kbps	29.6 kbps	61.6 kbps	15.6 kbps
40	72.1 kbps	92.6 kbps	93.2 kbps	38.3 kbps
60	97.3 kbps	124.9 kbps	126.3 kbps	82.2 kbps
80	135.7 kbps	154.4 kbps	182.3 kbps	105.9 kbps
100	156.4 kbps	191.1 kbps	231.6 kbps	142.3 kbps
120	276.9 kbps	384.6 kbps	445.1 kbps	202.3 kbps
140	424.1 kbps	427.5 kbps	458.6 kbps	415.1 kbps
160	465 kbps	497.2 kbps	589.3 kbps	410.6 kbps
180	455 kbps	487.3 kbps	590 kbps	405.7 kbps
200	443.8 kbps	477.1 kbps	595 kbps	388.2 kbps

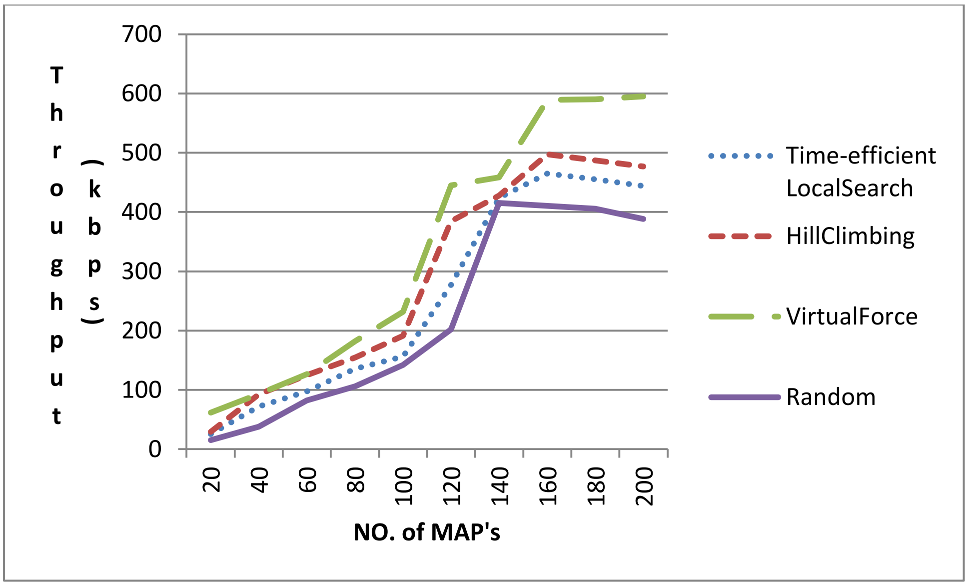

Figure 4.16 :Network Throughput in Linear Settlement Pattern

This section presents the throughput gained by the MAP's in a linear settlement pattern scenario. We study the effect of Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement scheme on the network throughput. Figure 4.16 and Table 4.14

represent the overall network throughput gained by each scheme. The network throughput is directly proportional to the number of deployed MAP's the increase in the number of deployed MAP's led to the increase in the network throughput. The MAC layer attribute in the network throughput gain when more nodes are added in the network, the higher the availability of the bandwidth therefore packet easily flow through within the network. However, the increase reached a certain pick then the throughput gradually starts decreasing reference to Table 4.14 for simulation values. This is due to the fact that the transmission medium might be crowded and some of the packets were dropped while waiting for availability of the channel, interference also reduces the performance of the deployed MAP's.

The DSDV routing protocol also enhances the network throughput since it already stored list of addresses of all neighboring nodes which makes transmission easier it would not have to waste time trying to discover route to the destination node. However, the benefit of using DSDV also has some drawbacks, periodically updating the table consumes some portion of the network bandwidth thus affecting throughput of a network. Virtual Force placement scheme achieved the best throughput compared to other placement schemes in a linear settlement pattern and it is interesting to also note that the network throughput gradually increased from node 20 to 200 without any drop. The reason for this is because the VFPLace placement scheme takes into consideration some special interference controlling techniques like directional antennas.

Experiment 14: The effect of MAP's placement schemes on network end-to-end delay in linear settlement pattern

The purpose of this experiment was to study the effect of selected MAPs positions on the network end-to-end delay. Figure 4.17 represent the network end-to-end delay that was incurred by each scheme.

Table 4.15: Network end-to-end Delay in Linear Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	268.8 ms	235 ms	156.1 ms	376.5 ms
40	173.7 ms	149.3 ms	136 ms	211.1 ms
60	172.8 ms	146.8 ms	129.2 ms	183.7 ms
80	162.9 ms	141.8 ms	128.9 ms	180.5 ms
100	161 ms	139.4 ms	122.5 ms	175.2 ms
120	147.6 ms	129.5 ms	118.6 ms	166.7 ms
140	125 ms	118.6 ms	94.1 ms	160.1 ms
160	123.2 ms	96.1 ms	76.9 ms	151.2 ms
180	123.5 ms	98.3 ms	73.4 ms	153.6 ms
200	128.3 ms	98.8 ms	70.9 ms	158.1 ms

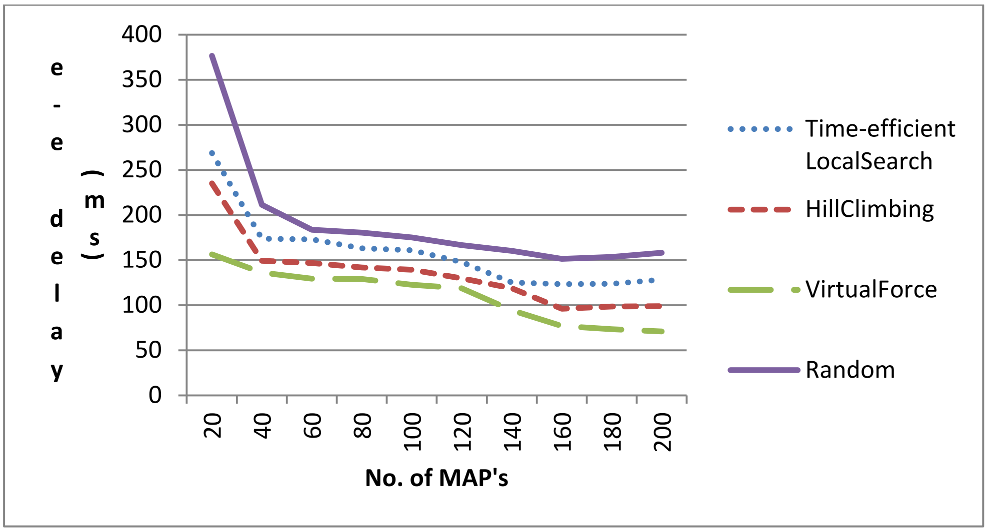

Figure 4.17: Network end-to-end Delay in Linear Settlement Pattern

When few MAP's were deployed the network suffered from high end-to-end delay. This can be attributed to the delay in the course of link or route discovery among the MAP's. If a MAP has a low transmission range and the distances to the neighbors are very long, there would be high delay in trying to access the closest neighbor. The behavior is attributed to the fact that the network throughput is very low when few MAP's are deployed in the network (reference to experiment). As more MAP's are added in the network the end-to-end delay incurred reduced. This is due to the fact that now the distance between the neighbors will be reduced making communication much stronger and faster. The other reason that could lead to high end-to-end delay is the routing table updates by the DSDV (route fluctuations due to route updates). It is very difficult to manage time for table updates. It might lead to too much communication overhead due to periodic and triggered updates. The Random placement scheme suffered high end-to-end delay than the other approaches. This is due to the fact that random placement have no structure and does not cater for the factors that may affect the environment. The selected MAP's could be placed very far from each other which may increase obstructions and selected positions may not be efficient to cover a minimum expected number of clients.

Experiment 15: The effect of MAP's placement schemes on network Packet Delivery Ratio in Linear Settlement Pattern

This subsection presents the effect of MAP's placement on network packet delivery ratio given a linear settlement pattern scenario. It can be observed from Figure 4.18 that the packet delivery ratio for all the placement schemes is merely the same, they all provide linearly progression, as the number of MAP's increase the more the guarantee in delivery. Even though as can be depicted by the previous experiment (14) that at some point the network suffers from high end-to-end delay, however, that does not guarantee that the packet would not be delivered.

The effect of DSDV on the packet delivered is the fact that the route of the MAP's is immediately available ensuring the ease in packet transmission for the up to date route. However, the drawback of DSDV on packet delivery is that at some instance when the delivery of the packet to a destination is not feasible it would drop them, hence decrease the 100% packet delivery ratio. That is one of the reasons that almost all the schemes do no reach full level of packet delivery. However, the TCP assists in the retransmission of lost packet or dropped packet which thus maintain the packet delivery ratio.

Table 4.16 :Network Packet Delivery Ratio in Linear Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	73.3 %	78%	81.8%	73.2%
40	80.1%	82.5%	83.6%	77.1%
60	81.6%	83.7%	84.8%	78%
80	83.6%	84.9%	86.3%	80.9%
100	84.9%	85.5%	86.6%	82.7%
120	84.9%	86.3%	87.7%	82.7%
140	85.9%	86.9%	88.6%	83%
160	87.4%	88%	89.7%	84.1%
180	87.8%	88.5%	89.3%	86.1%
200	88.4 %	89.5%	90.4%	87%

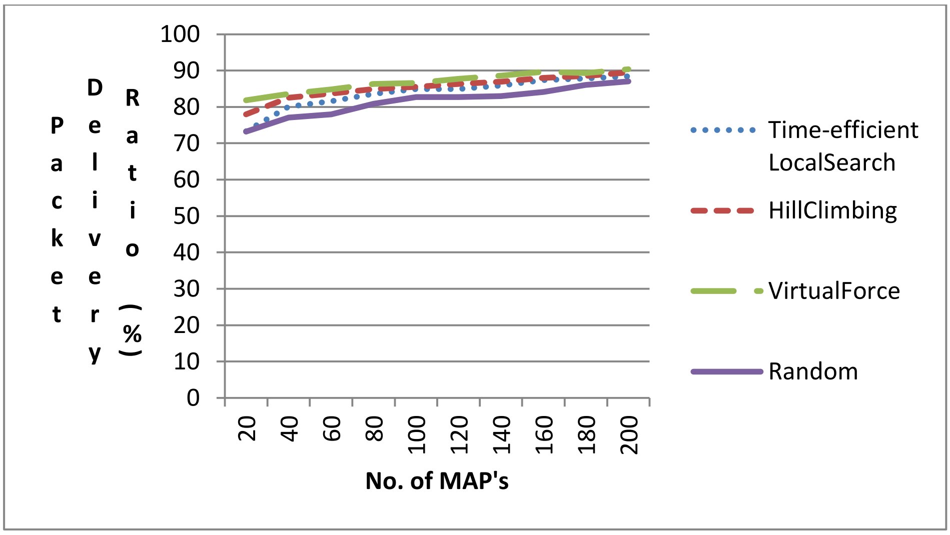

Figure 4.18: Network Packet Delivery Ratio in Linear Settlement Pattern

Table 4.16 clearly depict that Virtual Force placement scheme provided better packet delivery rate ratio than the other placement approaches, it was able to obtain up to 90.4% of packet delivered. The random placement scheme provided an improved performance at this stage as it was able to even deliver 87% of packets.

4.3.4 The effectiveness of MAP's placement Schemes in Isolated Settlement Pattern

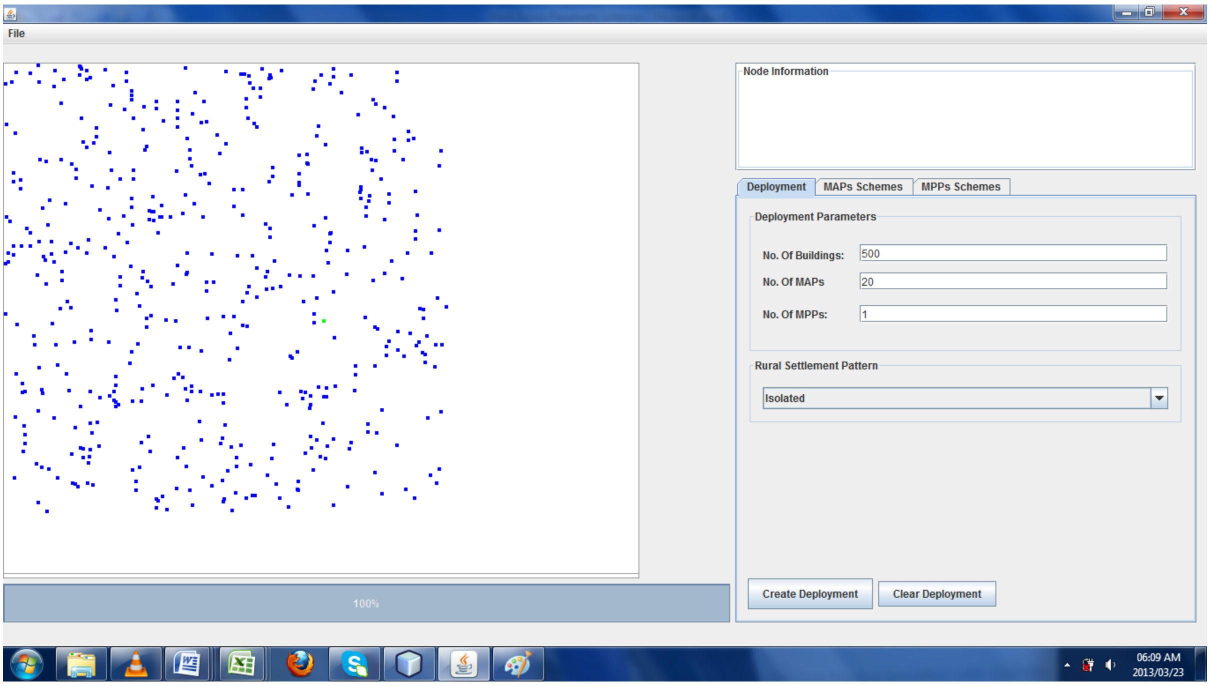

Figure 4.19:Network Coverage in Isolated Settlement Pattern

This section focus on comparing the Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement schemes on isolated settlement pattern scenario presented in figure 4.19. We dwelt on how much coverage, connectivity, throughput, end-to-end delay and packet delivery ratio each approach can gain.

Experiment 16: The effect of MAP's placement schemes on network coverage in Isolated Settlement Pattern

Figure 4.20 depicts simulation result of the Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement scheme evaluated based on network coverage given an Isolated Settlement Pattern. The network coverage obtained by all placement schemes have a linear progression as the number of MAP's deployed increase the more area is covered in the network.

Table 4.17 :Network Coverage in Isolated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	35.5%	33.7%	30.1%	21.2%
40	50.9%	34.4%	32.7%	27.5%
60	51.2%	47.2%	40.4%	33.9%
80	57.5%	52.9%	48.3%	45.4%
100	59.2%	54.5%	50.1%	48%
120	63.7%	60.3%	51.3%	49.3%
140	67.7%	64.6%	63.4%	57.7%
160	72.9%	67.8%	63.2%	59%
180	74.3%	68%	65.7%	62.9%
200	78.7%	70.2%	66.2%	63.1%

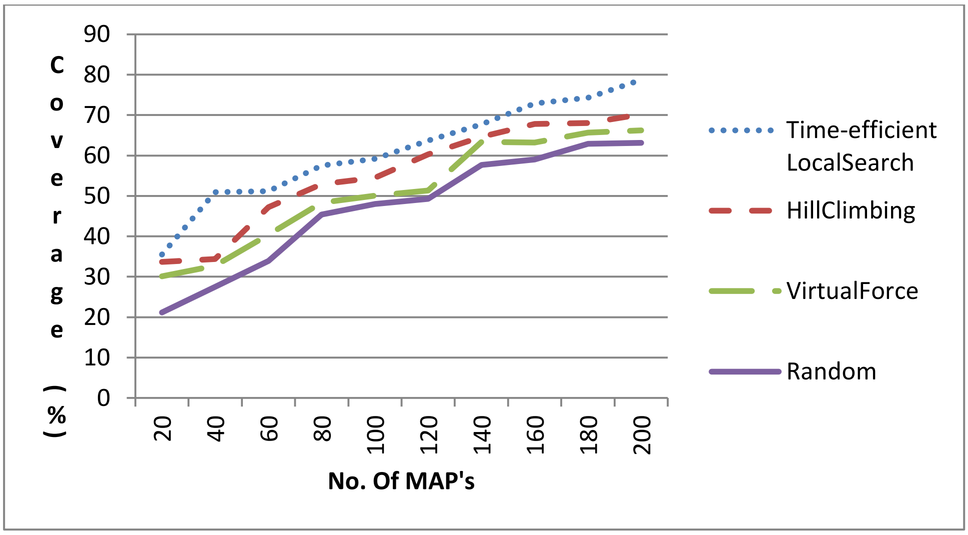

Figure 4.20: Network Coverage in Isolated Settlement Pattern

It can be observed (Table 4.17) that all the four placement schemes performed poorly as the area covered by each of these MAP's is very low when few MAP's are deployed. This behavior is expected because the structure of the terrain affects the positioning of nodes. The distance between these nodes leads to weak signal strength. For every instance (20 to 200MAP's), the Time-efficient Local Search obtained a better average area covered compared to the other approaches, although improvement can be observed in the other schemes as well.

This attribute can be explained to the fact that in the Time-efficient Local Search before a position is selected all the possible position are measured to ensure that the MAP's that can give maximum required signal strength which can cover large area is selected and this contribute in overpowering the effect of the long distance between the MAP's.

Experiment 17: The effect of MAP's placement schemes on Network Connectivity in Isolated Settlement Pattern

This section presents the network connectivity that was obtained by the MAP's placement methods in an isolated settlement pattern. Figure 4.21depict the performance of the Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement schemes on connection of the network. The performance is difficult to distinguish for small instance and all four placement scheme have the same linearly smooth progression. The increase in the number of MAP's led to an increased in network connectivity. It can be observed in Table 4.18 that no scheme managed to obtain full network connection. This might be caused by the harshness of the terrain and long distance between the MAPs increasing the chances of interference, hindering signal transmission.

Local Search placement schemes provided better network connection compared to other placement approaches, the reason for this behavior is that theoretically maximizing network coverage by deploying MAP's further away from each other results into low connectivity strengths. However, Time-efficient Local Search placement scheme provides techniques of overcoming this problem by deploying MAP's on positions with the largest objective function which is the product of coverage and connectivity, in this way both metrics are catered for.

Table 4.18: Network Connectivity in Isolated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random	Maximum Connection
20	310 n	295 n	280 n	275 n	380 n
40	1543 n	1382 n	1370 n	1080 n	1560 n
60	3093 n	2832 n	2353 n	1932 n	3540 n
80	5032 n	4793 n	4199 n	4122 n	6320 n
100	7240 n	6775 n	5932 n	5885 n	9900 n
120	11616 n	9313 n	8494 n	7240 n	14280 n
140	16006 n	15480 n	13624 n	12964 n	19460 n
160	22217 n	21009 n	18447 n	18245 n	25440 n
180	26252 n	24252 n	22299 n	21759 n	32220 n
200	31628 n	31102 n	30039 n	29697 n	39800 n

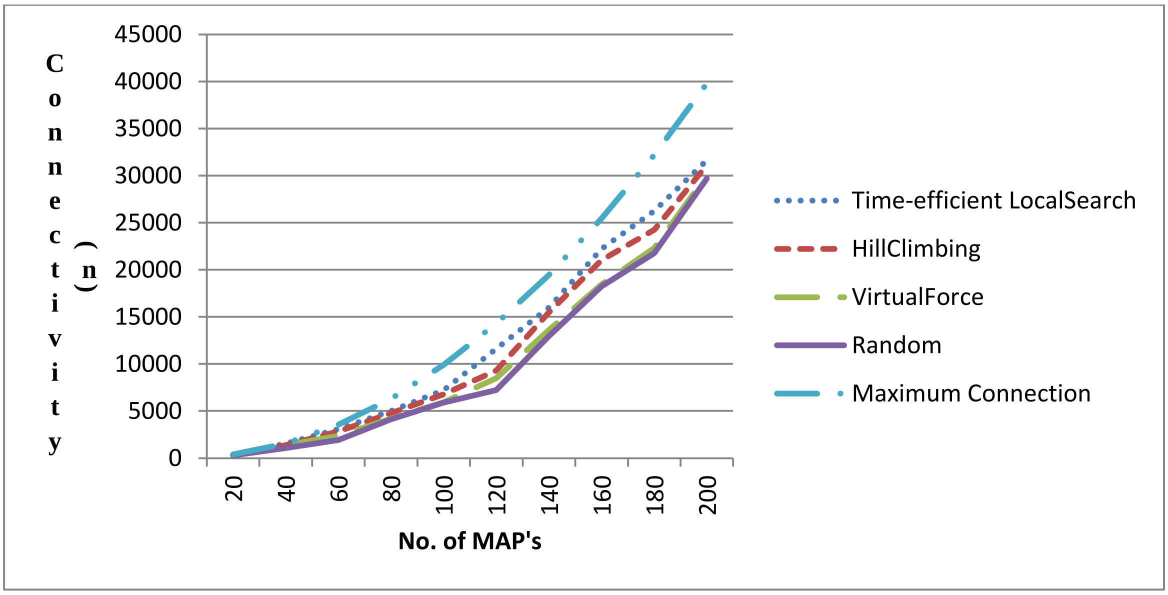

Figure 4.21: Network Connectivity in Isolated Settlement Pattern

Experiment 18: The effect of MAP's placement schemes on Network Throughput in Isolated Settlement Pattern

In this section the performance of placement schemes in terms of the network throughput by selected MAP's is studied. Figure 4.22 presents the performance of the placement schemes, when there are few MAP's in the network.

Table 4.19: Network Throughput in Isolated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	37.1 kbps	18.9 kbps	18.8 kbps	14.1 kbps
40	44.4 kbps	37.1 kbps	29.6 kbps	23.3 kbps
60	167 kbps	126 kbps	123.5 kbps	106.9 kbps
80	215.7 kbps	175.6 kbps	134.3 kbps	126.3 kbps
100	331.4 kbps	227.8 kbps	219.5 kbps	141.6 kbps
120	407.5 kbps	360.4 kbps	291.3 kbps	215.6 kbps
140	454.1 kbps	429 kbps	404.9 kbps	274.5 kbps
160	440.8 kbps	412.3 kbps	338 kbps	277.7 kbps
180	422.2 kbps	379.1 kbps	306.4 kbps	228.4 kbps
200	418 kbps	360 kbps	300.5 kbps	220.5 kbps

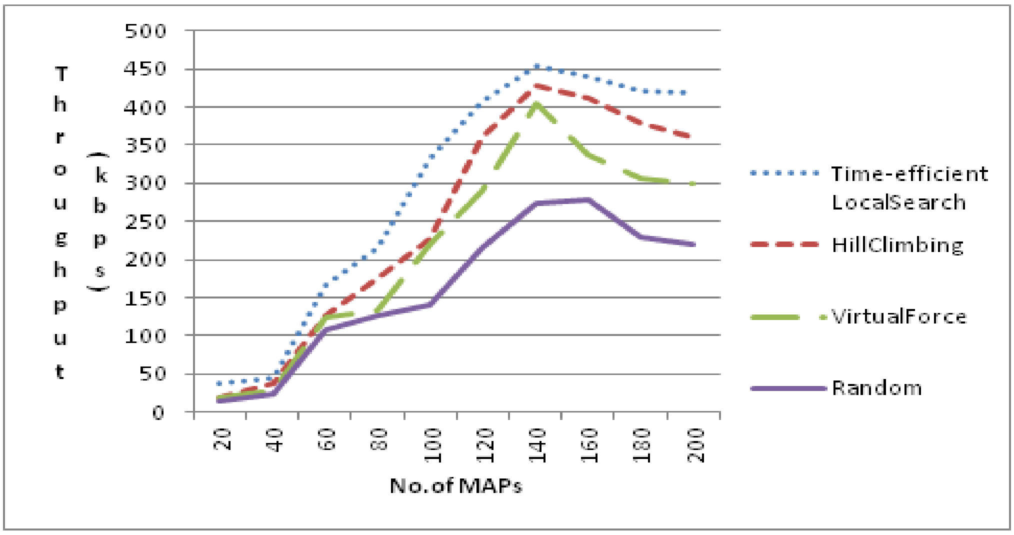

Figure 4.22 :Network Throughput in Isolated Settlement Pattern

The throughput is very small initially and as more MAP's are added, the throughput started to increase and reached a peak, then it started decreasing again as can be observed from 160 to 200MAP's in Table 4.19. When the network domain consists of few MAP's there will be a high rate of contention in the medium, some flows might even shut down due to the fact that the medium would be occupied, leading to packet drop or packet transmission failure as a result of low network throughput.

The other important factor that affects the network throughput is the use of Omni-direction antennas. Given a network domain, with a long distance between the MAP's like an Isolated settlement pattern, Omni-directional antennas allow a packet to travel via a long route to the intended destination node, even if there is a short route available. This contributes in decreasing the network throughput because the more the number of hops, the more the medium contention, therefore increasing the chances of interference. The Time-efficient Local Search placement scheme was able to achieve better network throughput compared to other approaches in this settlement.

Experiment 19: The effect of MAP's placement schemes on Network End-to-end Delay in Isolated Settlement Pattern

The purpose of this experiment was to study the effect of the selected MAP's positions on the network end-to-end delay. It is important for a network to ensure as much as low end-to-end delay in the network as possible (especially for applications that are delay sensitive e.g., Voice over Internet Protocol (VoIP), telnet,). Figure 4.23 represents the simulation result obtained when evaluating Time-efficient Local Search, Hill Climbing, Virtual Force and Random MAP placement schemes. Firstly, we observed that when few MAP's are deployed the network suffered from high rate of end-to-end delay. The reason for this behavior is due to link failure or route breakdown because the clients are spread over long distance making it difficult for few MAP's to cover all of them.

Secondly, we observed that there was a decrease in the end-to-end delay as more MAP's were added. However, the end-to-end delay started to picks up when the MAP's are too sufficient in a fixed deployment area the cause of such behavior is that now packet would have to travel many hops to reach the intended destination node.

Table 4.20: Network end-to-end Delay in Isolated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	285.8 ms	293.1 ms	325 ms	346.5 ms
40	271.9 ms	287.1 ms	305.1 ms	322.2 ms
60	189.6 ms	229.6 ms	262.9 ms	292.2 ms
80	161 ms	186.8 ms	240.5 ms	287 ms
100	150.2 ms	180.6 ms	188.9 ms	283.8 ms
120	133.2 ms	158 ms	170.5 ms	244.5 ms
140	113.5 ms	149.1 ms	161.8 ms	234.4 ms
160	114.4 ms	147.2 ms	160.2 ms	209.9 ms
180	122.1 ms	136.5 ms	148.7 ms	210.5 ms
200	125 ms	140.4 ms	150.7 ms	226.7 ms

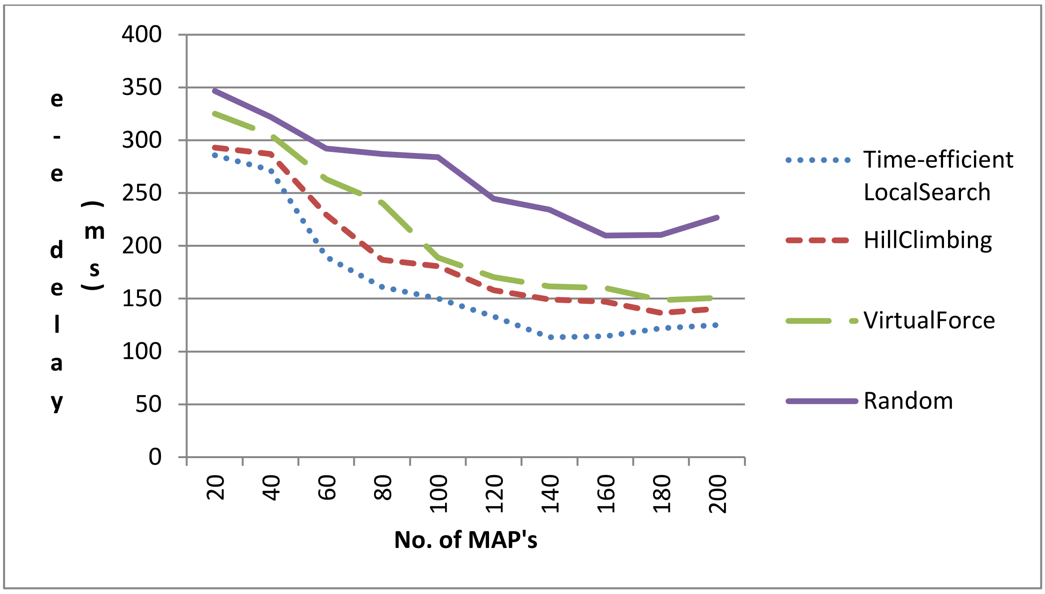

Figure 4.23: Network end-to-end Delay in Isolated Settlement Pattern

What can be further attributed to this behavior is routing discovery, which results into significant latency and overhead due to the fact that there are many MAP's in the network. Although DSDV already stores route addresses, however, there would be many paths available for each destination. It can also be observed that the Time-efficient Local Search placement scheme outperformed Virtual Force, Hill Climbing and Random MAP placement schemes in all cases by providing lower time complexity.

Local Search (Antony et al, 2007) is known for its techniques to excel in small size network as can be observed that in an Isolate Settlement pattern Time-efficient Local Search is a leading placement scheme, clients are clustered into small dispersed groups making it easier for the Time-efficient Local search approach to get close optimal values.

Experiment 20: The effect of MAP's placement schemes on Network Packet Delivery Ratio in Isolated Settlement Pattern

The main objective of this experiment is to find out the state of the network in terms of packet delivery ratio. In Figure 4.24 we compare the Time-efficient Local Search, Hill Climbing, Virtual Force and Random placement schemes based on the packet delivery ratio they achieve in an isolated settlement pattern. Results in Table 4.21 show that in the early stages of deployment packet delivery ratio is too small and below expected average packet delivery ratio. However, as more MAP's are deployed in the network the packet delivery ratio gradually increases.

The cause of low packet delivery is due to the fact that there are only few MAP's deployed in a large area with many clients. This would result in a long route with a significant distance between the substantial MAP's causing signal obstructions and increasing the chances of packet loss and route conflict. Improvement in the packet delivery ratio is observed as the number of MAP's increase because now the distance between the MAP's would be shorter and the paths would be less prone to link failures caused by long average path length. The results also reveal that the Time-efficient Local Search placement scheme outperforms all other schemes and Random placement scheme obtained the least packet delivery because of the un-strategic placement of MAP's.

Table 4.21: Network Packet Delivery Ratio in Isolated Settlement Pattern

No. Of Mesh Points	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
20	44.5 %	38.1 %	35.8 %	28.8 %
40	46.7 %	39.2 %	36.1 %	31.5 %
60	57 %	48.2 %	45.8 %	40.6 %
80	59.8 %	55.7 %	53.2 %	51.1 %
100	60.9 %	58.4 %	54.5 %	52.5 %
120	65.8 %	62.6 %	56.4 %	55 %
140	67.5 %	65.8 %	58.2 %	56.9 %
160	69.1 %	66.6 %	61.3 %	59.4 %
180	71.8 %	70.3 %	62.4 %	59.9 %
200	72.9 %	70.6 %	66.2 %	60.2 %

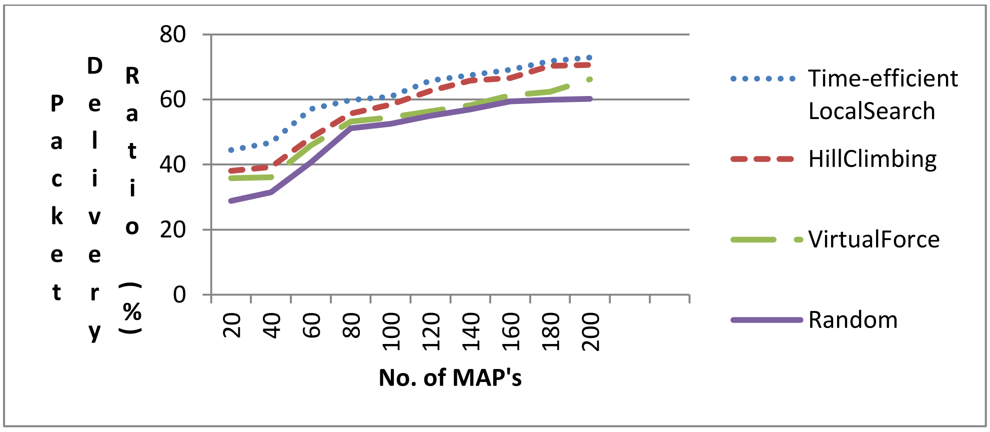

Figure 4.24 :Network Packet Delivery Ratio in Isolated Settlement Pattern

4.4 Simulation Summary and Recommendations

This subsection gives a general overview of the MAP's placement schemes performance in the isolated, nucleated, linear and dispersed settlement scenarios. The placement schemes are rated in ascending order number 1 representing the best scheme and number 4 representing the worst scheme in a settlement pattern. It can be observed in Table 4.22 and Table 4.23 that Hill Climbing outperforms the Time-efficient Local Search, Virtual Force and Random placement schemes in a nucleated and dispersed settlement pattern. This performance is expected because Hill Climbing makes use of radius and swap local movements leading search to better solution space in clustered and scattered layout. Table 4.24 shows that Virtual

Force outperforms Hill Climbing, Time-efficient Local Search and Random placement schemes in linear settlement pattern.

In the Linear Settlements pattern, mesh clients are positioned following a linear pattern and this makes the deployment better for Virtual Force to push MAP's away from the areas with very fewer mesh clients thus increasing coverage and then pulls MAP's closer to the areas with more clients hence bypassing the prohibitive areas in a deployment space and thus increasing connectivity. Table 4.25 reveals that the Time-efficient Local Search outperforms the Hill Climbing, Virtual Force and Random placement schemes in the isolated settlement pattern. Isolated settlement is a combination of the small clustered group of mesh clients scattered within a deployment area.

This scenario favors Time-efficient Local Search method as it ensures that the node signal strength from the current cluster will be able to reach the destination node on the other clusters, thus ensuring connection and coverage is maintained. It is interesting to note that the Hill Climbing is the second best scheme on the isolated settlement serving as a confirmation of the scheme's best performance as shown in Table 4.22 and Table 4.23.

Table 4.22: Performance of MAPs placement schemes in Nucleated Settlement Pattern

Performance Metrics	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
Coverage	2	1	3	4
Connectivity	2	1	3	4
Throughput	2	1	3	4
End-to-end Delay	2	1	3	4
Packet Delivery Ratio	2	1	3	4

Table 4.23: Performance of MAPs placement schemes in Dispersed Settlement Pattern

Performance Metrics	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
Coverage	2	1	3	4
Connectivity	2	1	3	4
Throughput	2	1	3	4
End-to-end Delay	2	1	3	4
Packet Delivery Ratio	2	1	3	4

Table 4.24: Performance of MAP's placement schemes in Linear Settlement Pattern

Performance Metrics	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
Coverage	3	2	1	4
Connectivity	3	2	1	4
Throughput	3	2	1	4
End-to-end Delay	3	2	1	4
Packet Delivery Ratio	3	2	1	4

Table 1.25 :Performance of MAP's placement schemes in Isolated Settlement Pattern

Performance Metrics	Time-efficient Local Search	Hill Climbing	Virtual Force	Random
Coverage	1	2	3	4
Connectivity	1	2	3	4
Throughput	1	2	3	4
End-to-end Delay	1	2	3	4
Packet Delivery Ratio	1	2	3	4

Comparing simulation results from Table 4.2 to Table 4.21, it can be observed that all the four placement schemes gain outstanding network performance in terms of coverage, connectivity, throughput packet delivery ratio and reduced end-to-end delay in a nucleated settlement pattern than the performance obtained in dispersed, isolated, linear settlement patterns. The main goal of this chapter was to compare the performance of each placement scheme in all four settlement patterns.

According to the results obtained from the experiments, it can be recommended that the Hill Climbing placement scheme be used for MAP's placement in the nucleated and dispersed settlement patterns. Time-efficient Local Search placement scheme be used for searching optimal MAP's candidate locations in the isolated settlement pattern and Virtual Force placement scheme be used for linear settlement pattern during the deployment of MAP's in rural areas. The recommended MAP's placement schemes are used for selection of MAPs positions in rural settlement patterns and serve as bases for MPP placement in the following chapter.

- CHAPTER FIVE-

MESH PORTAL POINTS PERFORMANCE EVALUATION

5.1 Introduction

The previous chapter presented evaluation and comparison of MAP's placement schemes in four rural settlement patterns. Best schemes for each pattern were recommended and are applied in this chapter as bases for the MPP's placement. This only solves the first portion of the WMN deployment problem and contributes significant role because, even if a good MPP's placement scheme is used, improper placement of MAPs devastates the whole network performance. A detailed description of the MPP,s placement schemes was given in chapter three; this seeks to solve the last portion of WMN deployment problem which involves selecting optimal position for MPP's (MAP's acting as a gateway to the internet).

The chapter investigates the effectiveness of four MPP's placement scheme namely: Grid Based, Incremental Clustering, Multi-hop Traffic-Flow Weight (MTW) and Random MPP's placement schemes in nucleated, dispersed, linear and isolated settlement patterns, in order to determine the best scheme that can be adopted for deployment in rural areas. A good MPP placement scheme should be adaptive to the number of MPP's deployed; hence the number of MPP's is also varied. The simulation environment and parameters are discussed in section 5.2. The simulation experiments and analysis of the results are presented in section 5.3. Recommendations and simulation summary are discussed in section 5.4.

5.2 Simulation Environment

The focus of this section is on evaluating the effectiveness of the MPP's placement schemes on the nucleated, dispersed, isolated and linear settlement patterns. The bases of the evaluation is on assessing the amount of network throughput gain, end-to-end delay incurred, and the amount of packet delivery each placement scheme can obtain. The prototype of the placement schemes was implemented in java Netbeans IDE 6.9.1 and the simulation of the placement schemes was done in NS2 running on Ubuntu Linux version 10.4. The TCL found in appendix A and Awk scripts used to analyze the results can be found in the appendix B. Table 5.1 shows the summary of the simulation parameters used for all the experiments.

Table 5.1 Simulation parameters for all the experiments

Parameter(s)	Value(s)
Number of MAP's	20,40,50,60,80,100,120,140,160,180 and 200
Number of MPP's	1, 2 and 3
Area	722m x 580m
Simulation Time	120 seconds
Packet Size	512 byte
Packet Rate	4 packets/sec
Routing Protocol	DSDV
Performance Metrics	Throughput, Delay and Packet Delivery Ratio.
MPP's Placement Schemes	Grid, Incremental, MTW and Random MPP's placement Scheme.
Settlement Patterns	Dispersed, Nucleated, Isolated and Linear

5.3 Simulation Experiments and Analysis

The following section presents the simulation analysis of MPP's placement schemes.

5.3.1 The effectiveness of MPP's placement Schemes in Nucleated Settlement Pattern

This subsection focuses on studying the performance of placement schemes in a nucleated settlement pattern. The performance metrics that were used are network throughput, end-to-end delay and packet delivery ratio and in addition to this, the number of MPP's was varied. The purpose of varying the number of MPP's was to evaluate and compare the effect of deploying more than one MPP in the network and to find out if only one MPP will be adequate or not.

Experiment 1: The effect of MPP's placement schemes on Network Throughput in Nucleated Settlement Pattern

Tables 5.2, 5.3 and Table 5.4 represent the impact of the MPP's placement schemes on network throughput when varying the number of deployed MPP's. Figure 5.1, Figure 5.2 and Figure 5.3 show the relative throughput results for the different MPP's placement schemes in a nucleated settlement pattern scenario. It can be observed that the network throughput was very high when there were few MAP's in the network; however, the increase in the number of MAP's caused the decrease in the network throughput.

This behavior is expected because network throughput is highly constrained by MAP's when they contend to access the same wireless channel capacity. When there are only few MAP's there is enough available channel capacity and as more MAP's communicate, channels become congested thus degrading the success of packet transmission. The MPP's has a fixed bandwidth to be shared by all its Mesh Clients (MC's) which is accessed via MAP's.

The throughput per client is reduced as the number of MAP’s increases due to the MPP bottleneck when it has many requests from several MAP’s. This can be referred from Table 5.2 when there is a single MPP deployed, the network throughput is very low but as more MPP’s are deployed in Table 5.3 and Table 5.4, the network throughput improved although, for the entire scenario the slope of the graphs is actually decelerating. However, the effect of increasing the number of MPP’s is not always good as can be seen in Table 5.4 and Figure 5.3. When three MPP’s are deployed the effect in network throughput is not smooth.

At the beginning of the simulation the network throughput is increasing and dropped at 80 MAP’s, increased again at 100 MAP’s and dropped again at 140 MAP’s. This can be attributed due the fact that addition of MPP’s causes interference among the existing MPP’s bearing in mind that in this settlements MAP’s positions are very closely located towards one another. This does not give enough distance between the deployed MPP’s, thus degrading the network performance.

MTW placement scheme outperformed the Grid-based and the Incremental Clustering placement scheme for all the three scenarios in a nucleated settlement pattern with regards to improving the network throughput. This behavior is due to the fact that MTW selects more powerful MAP’s with the highest weight of hops and ensures that additional MPP’s are placed far away from the existing ones by setting the traffic demand of the already deployed MPP and all its neighbors within its hop into half. The fact that MAP’s are located towards each other increase the chances of the MPP’s interference.

Table 5.2: Network Throughput when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	493.5 kbps	491.4 kbps	499.9 kbps	486.8 kbps
40	488.5 kbps	487.3 kbps	491.6 kbps	477.4 kbps
60	486.4 kbps	481.7 kbps	487.3 kbps	470 kbps
80	483.8 kbps	474.4 kbps	484.6 kbps	464.9 kbps
100	462.3 kbps	457.1 kbps	474.3 kbps	449.1 kbps
120	434.3 kbps	429.9 kbps	448.6 kbps	383.3 kbps
140	407.8 kbps	383.3 kbps	444.5 kbps	350.8 kbps
160	383.3 kbps	350.8 kbps	436.2 kbps	327.2 kbps
180	368.8 kbps	337.1 kbps	423.3 kbps	303.1 kbps
200	276.1 kbps	251.6 kbps	344.3 kbps	243.4 kbps

Table 5.3: Network Throughput when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	795.2 kbps	793.1 kbps	799.9 kbps	784.9 kbps
40	788 kbps	778.3 kbps	790.6 kbps	767.4 kbps
60	676.4 kbps	681.7 kbps	687.6 kbps	660 kbps
80	667.8 kbps	668.3 kbps	664.5 kbps	640.8 kbps
100	563.2 kbps	540.8 kbps	583.3 kbps	497.2 kbps
120	523.3 kbps	464.9 kbps	568.8 kbps	437.1 kbps
140	496.1 kbps	451.6 kbps	544.3 kbps	403.9 kbps
160	463.8 kbps	444.4 kbps	484.6 kbps	403.4 kbps
180	452.3 kbps	399.1 kbps	474.3 kbps	359.1 kbps
200	424.3 kbps	383.3 kbps	448.6 kbps	329.9 kbps

Table 5.4: Network Throughput when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	658.8 kbps	658.3 kbps	676.5 kbps	647.8 kbps
40	684.7 kbps	671.7 kbps	697.6 kbps	670 kbps
60	796.2 kbps	793.5 kbps	799.9 kbps	783 kbps
80	788 kbps	778.3 kbps	790.6 kbps	767.4 kbps
100	795.6 kbps	780.2 kbps	810.5 kbps	769.4 kbps
120	800.5 kbps	799.5 kbps	850.1 kbps	770.7 kbps
140	799.8 kbps	763.1 kbps	836.8 kbps	707.8 kbps
160	682.3 kbps	650 kbps	807.3 kbps	620 kbps
180	647.2 kbps	563.2 kbps	733.3 kbps	510.8 kbps
200	583.3 kbps	524.9 kbps	668.8 kbps	437.1 kbps

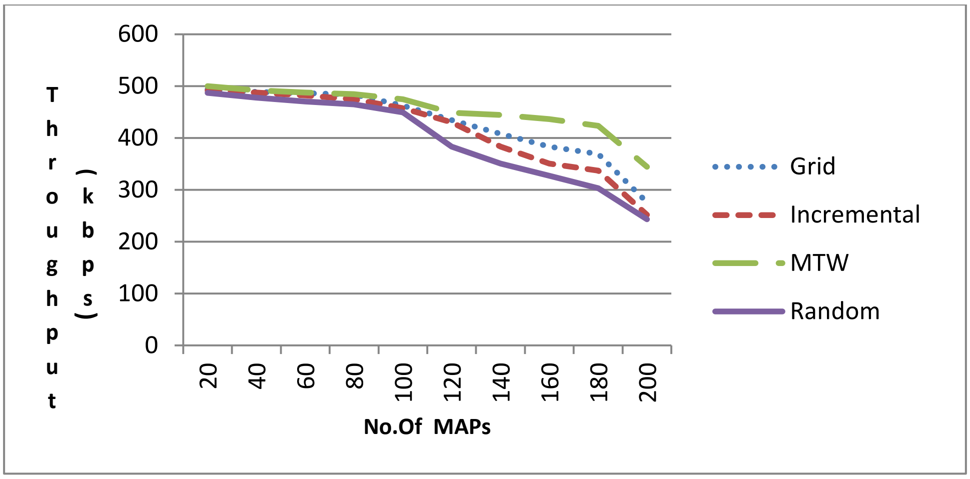

Figure 5.1: Network Throughput when One MPP is deployed

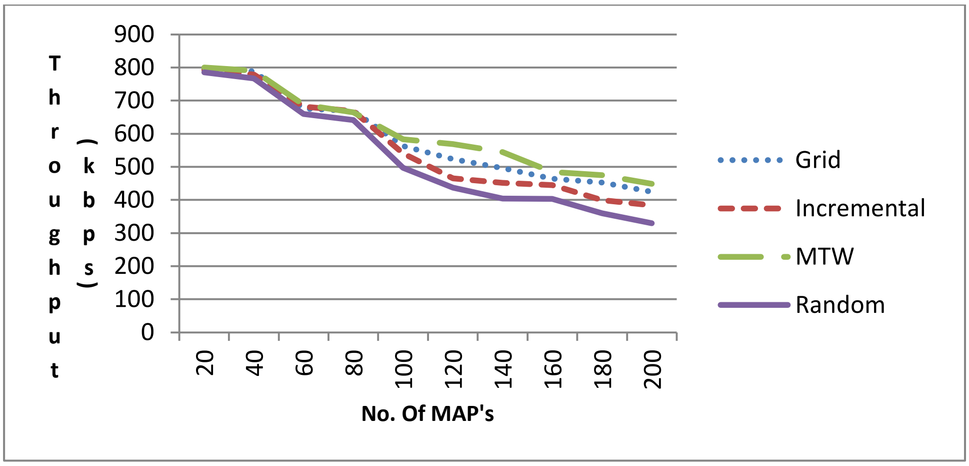

Figure 5.2: Network Throughput when Two MPP's are deployed

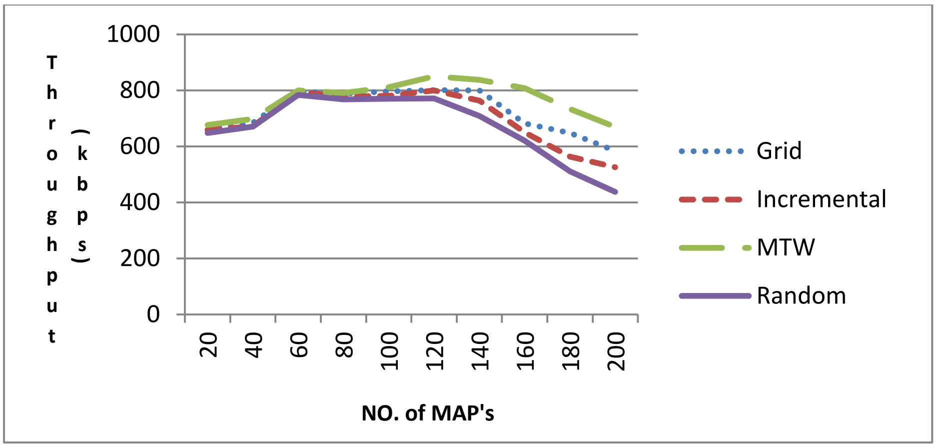

Figure 5.3 :Network Throughput when Three MPP's are deployed

Experiment 2: The effect of MPP's placement schemes on Network End-to-end Delay in Nucleated Settlement Pattern

The purpose of this experiment was to investigate the network end-to-end delay that was incurred during the evaluation of MPP's placement schemes on the nucleated settlement pattern scenario. The simulation results in Table 5.5 and Figure 5.4 represent the network scenario with a single MPP deployed in a nucleated settlement pattern. Two common points can be learnt from the simulation results obtained. The first point is that few deployed MAP's in the network result into low network end-to-end delay; packets easily flow in the network because of a high percentage of available routes. The second point is that many deployed MAP's results into high network end-to-end delay. The reason is that, although there would be enough MAP's to/for easy transmission for the backbone communication but there would still be delays when many packets have to be sent to the single MPP.

This can be understood by the fact that when there is a high percentage of packet request or communication request from the MAP's, the busier the MPP would be and most packets would have to stay in long queues, delaying the packet transmission. It can also be observed that increase in the number of deployed MPP's resulted in low end-to-end delay when few MAP's are deployed, and as more MAP's are being deployed, the end-to-end delay gradually increased. This behavior is illustrated in Table 5.6 and Figure 5.5 representing a network scenario with two deployed MPP's and simulation scenario with three MPPs in Table 5.7 and Figure 5.6. There is a better performance in the network in terms of reduced end-to-end delay when more than one MPP is deployed. This is caused by the fact that each MPP would now receive less traffic since traffic from MAP's would now be shared among the existing MPP's.

Table 5.5: Network end-to-end delay when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.5 ms	89.42 ms	79.4 ms	109.3 ms
40	112 ms	113.5 ms	109.2 ms	118 ms
60	118.9 ms	119.3 ms	117.2 ms	122.5 ms
80	119.8 ms	119.8 ms	118.93 ms	126.4 ms
100	123.06 ms	130.9 ms	125.3 ms	141.5 ms
120	131.38 ms	138 ms	125.9 ms	148.8 ms
140	134.3 ms	148.2 ms	126.5 ms	155.4 ms
160	138.04 ms	153.7 ms	127.9 ms	178.5 ms
180	144.2 ms	168.1 ms	137.3 ms	189.1 ms
200	171.03 ms	190.3 ms	147.4 ms	198.8 ms

Table 5.6: Network end-to-end delay when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	58.5 ms	59.4 ms	55.6 ms	66.3 ms
40	61.2 ms	66.5 ms	59.2 ms	70.9 ms
60	69.9 ms	79.3 ms	67.2 ms	86.5 ms
80	98.1 ms	119.8 ms	78.7 ms	126.4 ms
100	103 ms	128.9 ms	85.3 ms	138.1 ms
120	111.3 ms	138 ms	97.2 ms	148.8 ms
140	124 ms	138.2 ms	108.6 ms	149.5 ms
160	128.4 ms	143.7 ms	117.9 ms	165 ms
180	149.7 ms	160.1 ms	123.3 ms	171.5 ms
200	151 ms	160.3 ms	129.2 ms	176 ms

Table 5.7: Network end-to-end delay when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	62.9 ms	64.4 ms	61.6 ms	68.4 ms
40	61.2 ms	63.5 ms	60.2 ms	65.7 ms
60	60.1 ms	62.1 ms	58 ms	62.5 ms
80	59.8 ms	60.8 ms	56.7 ms	62.1 ms
100	57.3 ms	60 ms	53.8 ms	61.9 ms
120	55.1 ms	58.3 ms	47.5 ms	60.8 ms
140	58.4 ms	62.8 ms	50.6 ms	79.5 ms
160	78.4 ms	93.7 ms	67.8 ms	105 ms
180	88.7 ms	108.1 ms	73.9 ms	125.5 ms
200	125.2 ms	138.2 ms	102.5 ms	143.6 ms

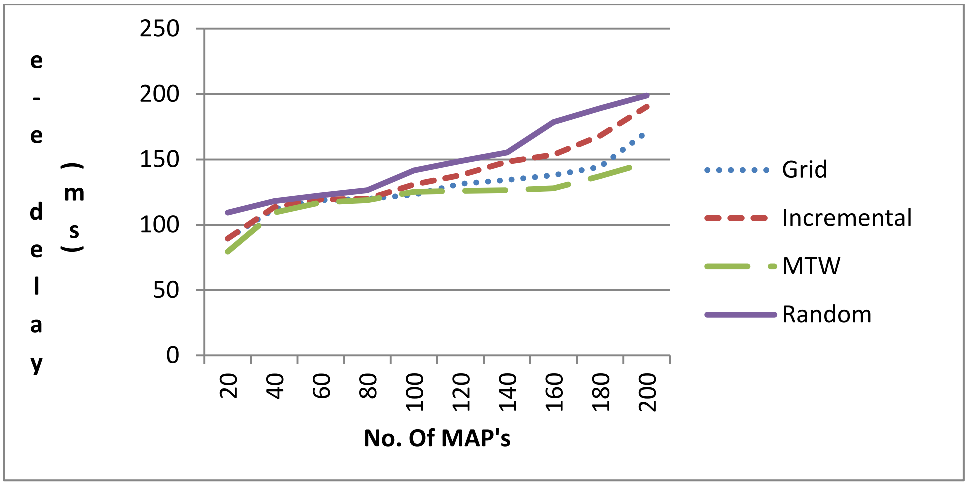

Figure 5.4: Network end-to-end delay when One MPP is deployed

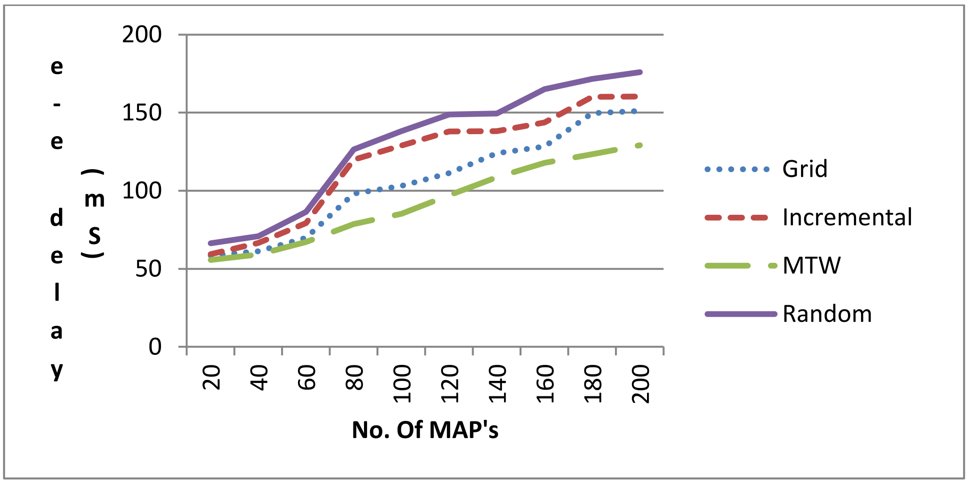

Figure 5.5: Network end-to-end delay when Two MPP's are deployed

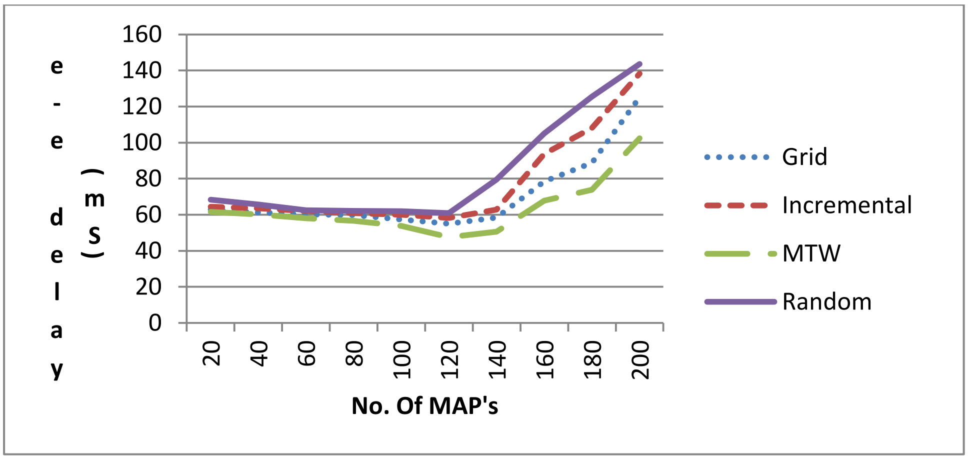

Figure 5.6: Network end-to-end delay when Three MPP's are deployed

The MAP's choose the route that is nearest to MPP in order to ease network communication and connection. In all the three network scenarios the MTW incurred less network end-to-end delay than the Incremental Clustering, Novel Grid Based and Random placement schemes. The Random placement scheme was the worst performer in all the scenarios which implies really poor MPP selection where only few MAP's would be covered degrading the network performance.

Experiment 3: The effect of MPP's placement schemes on Network Packet Delivery Ratio in Nucleated Settlement Pattern

The purpose of this experiment was to measure the MPP's ability to deliver the traffic from source node to the intended destination node. Table 5.8 to 5.10 illustrate the incurred packet delivery ratio simulation results for the Grid Based, Incremental Clustering, MTW and Random Placement scheme considering an ideal nucleated settlement pattern scenario while varying the number of deployed MPP's. All the tables depict the same sequence narration when few MAP's are deployed showing high packet delivery ratio. As more MAP's are deployed, there is a gradual decrease in the percentage number of successful packet delivered.

The decrease in the amount of successful packet delivered as more MAP's are deployed is caused by the fact that there would be increase in the demand on the MPP's. Also as the MAP's compete for traffic transmission some packet would be dropped. It can be observed in Table 5.8 and Figure 5.7 that a network with a single MPP resulted in a very small capacity of radio interface, which would not be sufficient enough to transmit the traffic generated by MAP's and this counter factor decreases the packet delivery ratio.

Table 5.8: Network Packet Delivery Ratio when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.2%	88.6%	89.8%	88.2%
40	87.8%	86.5%	88.8%	83.8%
60	87.5%	85.3%	87.7%	83.6%
80	87%	85.2%	87.7%	82.9%
100	86.2%	84.8%	86.8%	82.3%
120	85.7%	83.2%	86.7%	80.7%
140	84.4%	81.3%	85.2%	80.3%
160	82.3%	81.2%	84.1%	79.9%
180	81.3%	80%	83.7%	78.8%
200	80.6%	79.8%	82%	78.7%

Table 5.9 :Network Packet Delivery Ratio when Two MPP's is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.8%	89.5%	90.2%	89.3%
40	89.8%	89.6%	89.9%	89.2%
60	89.6%	88.5%	89.8%	86.6%
80	88.5%	87.8%	89.7%	85.9%
100	88.2%	87.5%	89.6%	85.3%
120	86.7%	85.5%	89.5%	84.7%
140	85.4%	84.8%	88.7%	84.3%
160	85.3%	84.2%	88.6%	82.9%
180	85.2%	84.3%	88.5%	82.8%
200	84.1%	82.9%	88.2%	80.7%

Table 5. 10: Network Packet Delivery Ratio when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	93.9%	93.8%	94.1%	92.9%
40	93.9%	93.8%	94%	92.9%
60	91.3%	90.2%	92.9%	89.8%
80	90.8%	89.4%	92.8%	89.2%
100	90%	89.4%	90.6%	88.9%
120	88.4%	88.3%	90.3%	87.3%
140	88.3%	87.3%	90%	86.7%
160	88.2%	87.2%	89.9%	85.3%
180	87.7%	86.5%	89.9%	84.9%
200	87.5%	85.3%	89.5%	83.8%

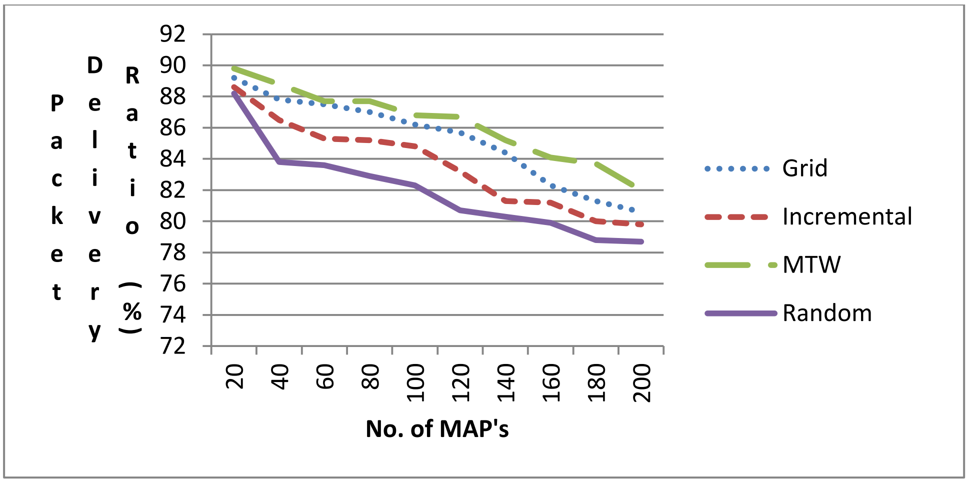

Figure 5.7 :Network Packet Delivery Ratio when One MPP is deployed

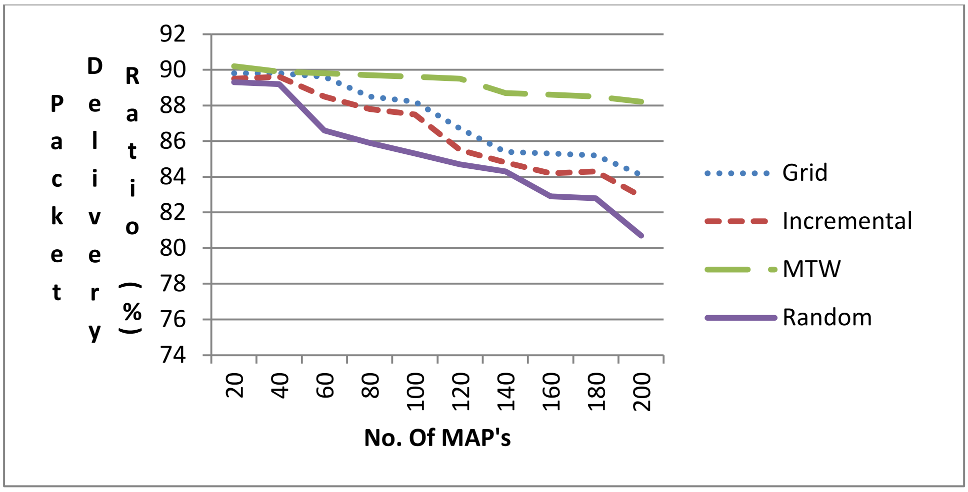

Figure 5.8 :Network Packet Delivery Ratio when Two MPP's are deployed

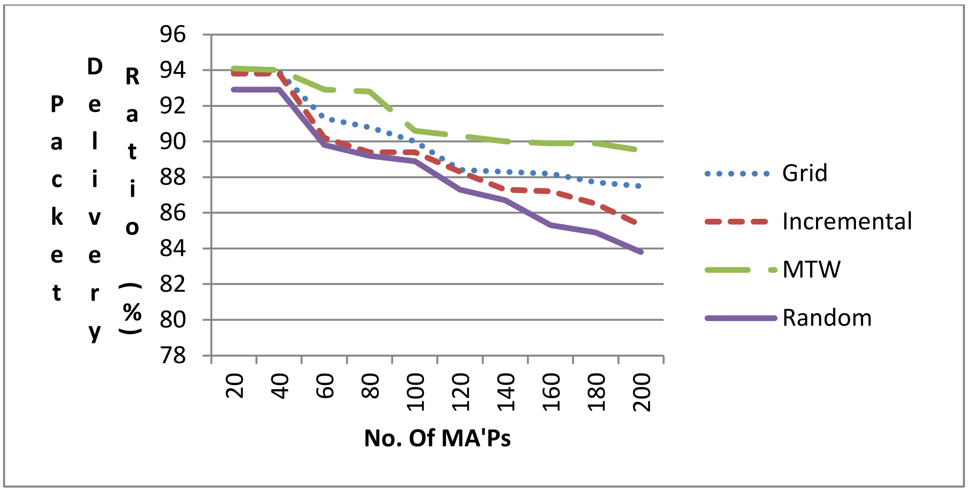

Figure 5.9 :Network Packet Delivery Ratio when Three MPP's are deployed

However, although the packet delivery ratio started to decrease at certain point intervals, it can be observed that the effect is not huge. It can be observed from Table 5.8 that the packet delivery ratio at 200MAP's is still above average which is up to 82% for the best performer and 78.7% for the least performer. The same effect can also be seen when two MPP's are deployed the least performing Random placement scheme can reach up to 80.7% of packet delivery in Table 5.9 and 83.8% on Table 5.10 when three MPP's are deployed.

The increase in the number of deployed MPP's in a same deployment area would improve the packet delivery performance compared to when only one MPP is deployed. Such a behavior is caused by the fact that the average distance that is between MAP's and the MPP's decreased and hence the traffic route would be less prone to link failures (refer to Table 5.8, Table 5.9 and Table 5.10). However, this privilege is also a limiting factor because even though the packet delivery improves, compared to when there is a single MPP, the packet delivery ratio gradually decelerate as more MPP's are deployed. This is due to the fact that, in a nucleated settlement pattern the nodes are already clustered towards each other thus increasing the probability of MPP's interference, this leads to gradual packet loss.

5.3.2 The effectiveness of MPP's placement Schemes in Linear Settlement Pattern

In this subsection the effectiveness of the placement schemes in selecting the optimal candidates' position of MPP's is studied. The impact of these placement schemes is evaluated focusing on network throughput, packet delivery ratio and end-to-end delay, while varying the number of deployed MPP's from one to three. The positions of MAP's were selected using Virtual Force MAP's placement scheme that was recommended in the previous chapter.

Experiment 4: The effect of MPP's placement schemes on Network Throughput in Linear Settlement Pattern

Tables 5.11 to 5.13 and Figure 5.10 to Figure 5.12 represent the relative network throughput comparison of the novel Grid Based, Incremental Clustering, MTW and Random MPP's placement scheme in a linear settlement pattern varying the number of deployed MPP's in the network. Simulation results revealed that the placement schemes achieved better throughput when there are fewer MAP's deployed in the network. However, increase in the number of deployed MAP's diminishes the amount of throughput gain. High throughput gain with few MAP's is caused by the fact that there is enough bandwidth shared within the network spectrum there will be very short hop length the packet will have to travel to reach or access the MPP.

The gradual drop in the network throughput as more MAP's are deployed is caused by the fact that there would be a high increase in the total spatial reuse available in the network. It can be noted in Figure 5.10 that the increase in number of MAP's when only one MPP is deployed led to degraded network throughput because the single MPP would have to process too many MAP's data request.

There is an improvement on network throughput in Figure 5.12 when three MPP's are deployed. The throughput reached a peak of approximately 690.8 for Grid placement scheme, 718.9 for Incremental Clustering, 752.3 for MTW, and 612.1 for Random MPP placement schemes. After this increase, the network throughput gradually decreases. Comparing the three throughput scenarios Figure 5.10, Figure 5.11and Figure 5.12 it can be noted that all the four MPP's placement schemes obtained much improved performance when three MPP's are deployed than when one or two MPP's are deployed.

Table 5.11 :Network Throughput when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	490.5 kbps	491 kbps	492.5 kbps	487.7 kbps
40	488.5 kbps	491.7 kbps	491.7 kbps	486.3 kbps
60	487.8 kbps	488.8 kbps	489.3 kbps	483.9 kbps
80	475.4 kbps	480 kbps	485.5 kbps	462.4 kbps
100	399.1 kbps	451.8 kbps	482.6 kbps	369.8 kbps
120	373.9 kbps	400 kbps	482.6 kbps	340.8 kbps
140	310.8 kbps	360.9 kbps	400 kbps	299.1 kbps
160	292.9 kbps	337.1 kbps	359.1 kbps	258.5 kbps
180	196.8 kbps	278.9 kbps	299.1 kbps	158.8 kbps
200	162 kbps	253.1 kbps	276.4 kbps	152 kbps

Table 5.12 :Network Throughput when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	670.5 kbps	688.5 kbps	699.9 kbps	668.7 kbps
40	688.5 kbps	692.8 kbps	695.7 kbps	608.3 kbps
60	587.8 kbps	680 kbps	689.3 kbps	483.9 kbps
80	575.4 kbps	628.8 kbps	655.5 kbps	462.4 kbps
100	499.1 kbps	591.8 kbps	602.6 kbps	369.8 kbps
120	473.9 kbps	560.9 kbps	582.6 kbps	340.8 kbps
140	437.1 kbps	459.9 kbps	559.1 kbps	299.1 kbps
160	310.8 kbps	400 kbps	499.1 kbps	258.5 kbps
180	296.8 kbps	378.9 kbps	476.4 kbps	158.8 kbps
200	180.8 kbps	253.1 kbps	300 kbps	152 kbps

Table 5.13: Network Throughput when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	575.4 kbps	628.8 kbps	655.5 kbps	526.4 kbps
40	587.8 kbps	659.3 kbps	692.8 kbps	548.9 kbps
60	628.5 kbps	670 kbps	695.7 kbps	608.3 kbps
80	650.5 kbps	681.5 kbps	699.9 kbps	638.7 kbps
100	679.8 kbps	693 kbps	712.5 kbps	650 kbps
120	690.8 kbps	718.9 kbps	753.2 kbps	672.1 kbps
140	599.1 kbps	651.8 kbps	700.6 kbps	529.8 kbps
160	470.3 kbps	560.9 kbps	652.6 kbps	340.8 kbps
180	437.1 kbps	459.9 kbps	559.1 kbps	299.1 kbps
200	310.8 kbps	350.2 kbps	499.1 kbps	258.5 kbps

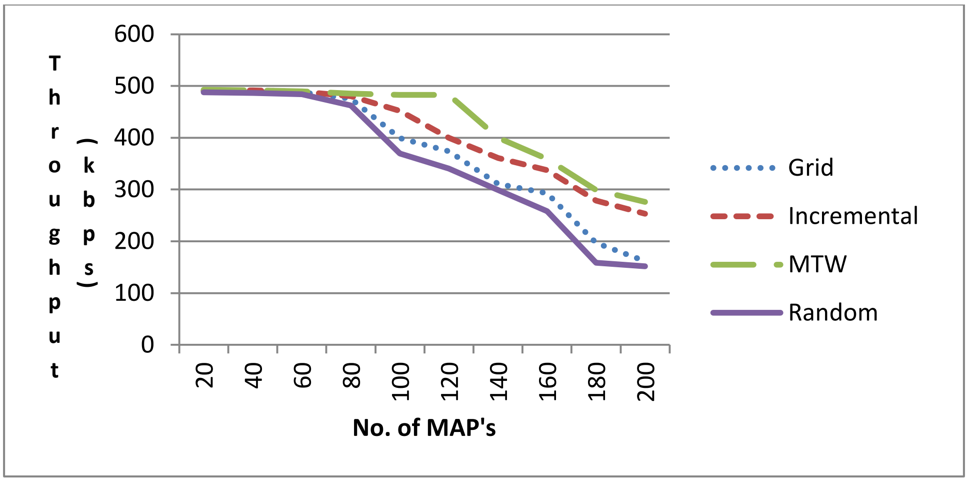

Figure 5.10: Network Throughput when One MPP is deployed

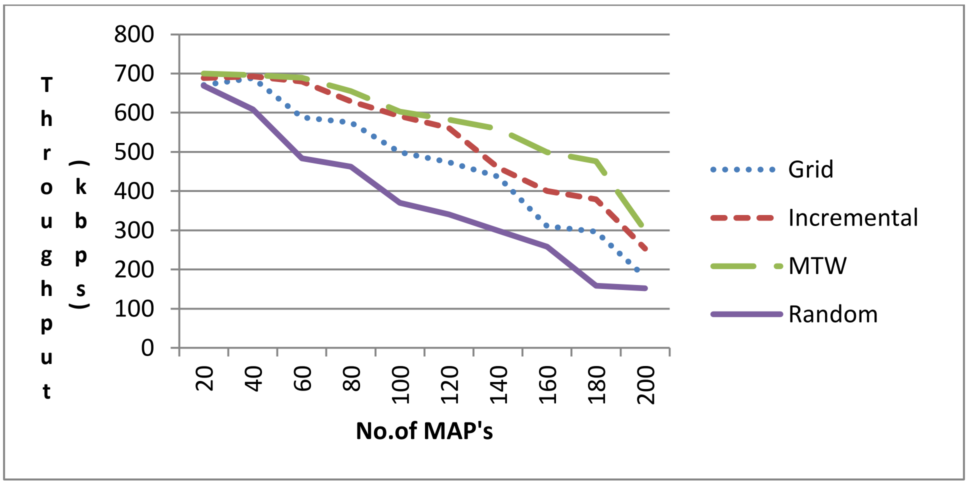

Figure 5.11: Network Throughput when Two MPP's are deployed

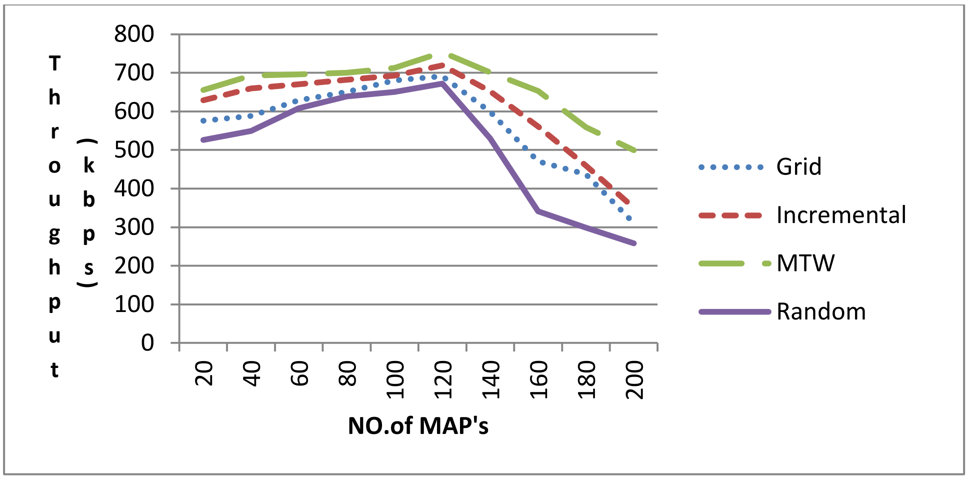

Figure 5.12: Network Throughput when Three MPP's are deployed

This is due to the fact that now there will be reduced number of hops the packet would have to travel to access to the closest MPP since the three MPP's would divide the available MAP's and serve the closest node. The location of the MPP(s) contributes to variation of the obtained network throughput. For instance, in linear settlement patterns MAP's are positioned in a linearly form they are not spread over the entire deployment area and the MPP's placement schemes would have to find the optimal positions to deploy MPP's to connect to the wired internet. In this settlement pattern, a good placement scheme would have to ensure that MPP's does not interfere and if a single MPP is deployed it should be able to cater for the entire network. The MTW - MPP placement scheme outperformed the Grid Based, Incremental Clustering and Random approaches in all the scenarios in this experiment. The reason behind this behavior is that the MTW preliminarily evaluates the possible MPP's position for interference to ensure that the final positions of MPP(s) would be interference free. This is achieved by constructing a table of interfering MPP's and ensuring that each MPP appears only once as single line in the table.

Experiment 5: The effect of MPP's placement schemes on Network End-to-end Delay in Linear Settlement Pattern

This section studies and compares the effectiveness of the MPP's placement schemes in a linear settlement pattern by measuring the end-to-end delay incurred when one to three MPP's are deployed. Simulation results that were obtained are illustrated on Table 5.14, Table 5.15 and Table 5.16. The network end-end-end delay increased as the number of deployed MAP's increased, in figure 5.15 and table 5.14 it can be noted the when few MAP's are deployed the network end-to-end delay is substantial low, however, as more MAP's are deployed the end-to-end delay increased.

Table 5.14 :Network end-to-end delay when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	91.6 ms	90.9 ms	83.9 ms	96.4 ms
40	105.2 ms	102.9 ms	84.357 ms	112.8 ms
60	115.7 ms	114.3 ms	104.1 ms	123.3 ms
80	125.9 ms	121.8 ms	107.3 ms	132.7 ms
100	133.6 ms	124.3 ms	116.4 ms	137.6 ms
120	137.7 ms	124.4 ms	117.2 ms	153.8 ms
140	156.4 ms	138.1 ms	131.7 ms	169.5 ms
160	158.8 ms	141.8 ms	135.7 ms	179.6 ms
180	188.6 ms	169.03 ms	154.2 ms	236.7 ms
200	257 ms	224.5 ms	187.6 ms	273.2 ms

Table 5.15: Network end-to-end delay when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	90.5 ms	89.9 ms	80.2 ms	92.1 ms
40	88.2 ms	86.2 ms	78.3 ms	90.8 ms
60	84.7 ms	80.3 ms	75.1 ms	123.3 ms
80	88.9 ms	81.2 ms	78.3 ms	129.2 ms
100	123.5 ms	104.3 ms	80.4 ms	130 ms
120	127.7 ms	110.7 ms	100 ms	143.7 ms
140	136.4 ms	122.1 ms	111.1 ms	149.5 ms
160	141.7 ms	132.8 ms	125.5 ms	159.8 ms
180	156.1 ms	149 ms	126.4 ms	186.3 ms
200	172.8 ms	154.3 ms	128.7 ms	199.1 ms

Table 5.16 :Network end-to-end delay when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.5 ms	87.9 ms	78.2 ms	90.4 ms
40	87.7 ms	85.1 ms	76.5 ms	89 ms
60	82.7 ms	78.7 ms	73.3 ms	90.8 ms
80	79.5 ms	75.2 ms	70.5 ms	98.3 ms
100	75.9 ms	73.8 ms	68.7 ms	97.2 ms
120	83.3 ms	75.2 ms	65 ms	94.2 ms
140	86.4 ms	78.8 ms	68.1 ms	96.5 ms
160	95.3 ms	88.8 ms	77.8 ms	100.8 ms
180	100 ms	93.2 ms	80.9 ms	120.5 ms
200	122.8 ms	100.5 ms	83.8 ms	140.7 ms

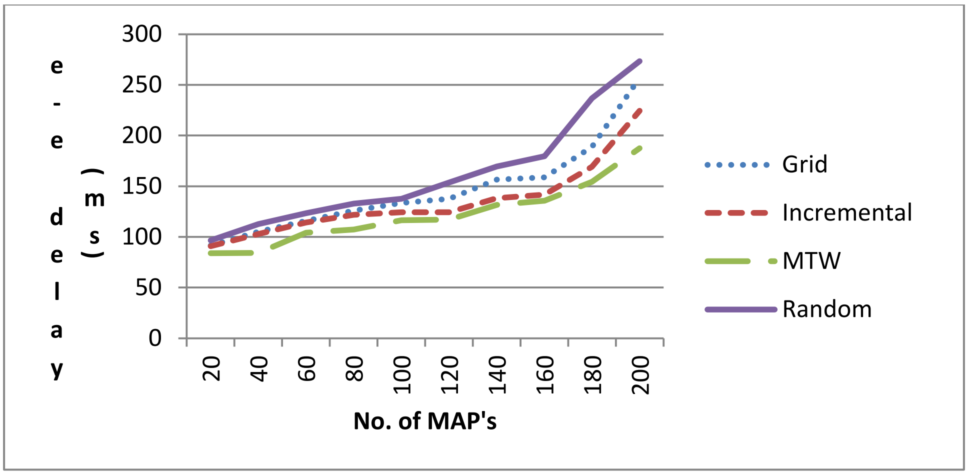

Figure 5.13: Network end-to-end delay when One MPP is deployed

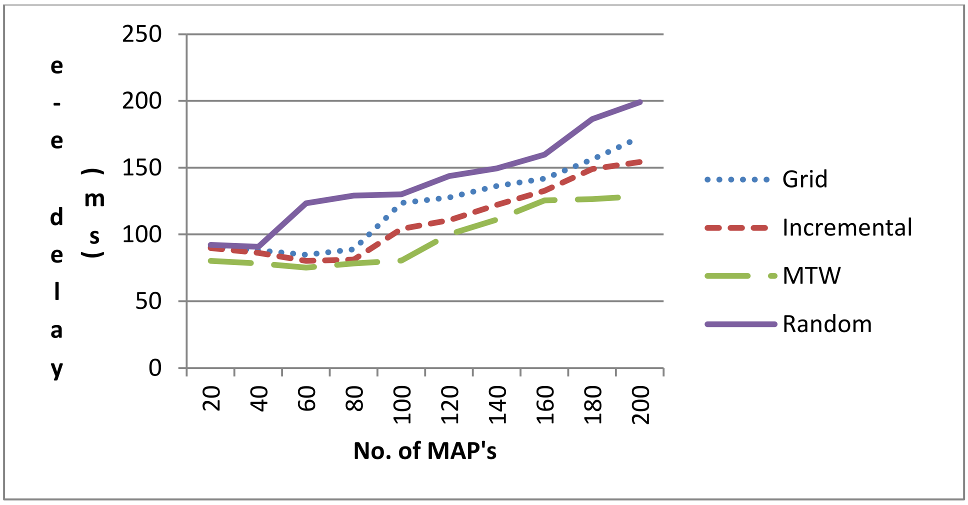

Figure 5.14: Network end-to-end delay when Two MPP's are deployed

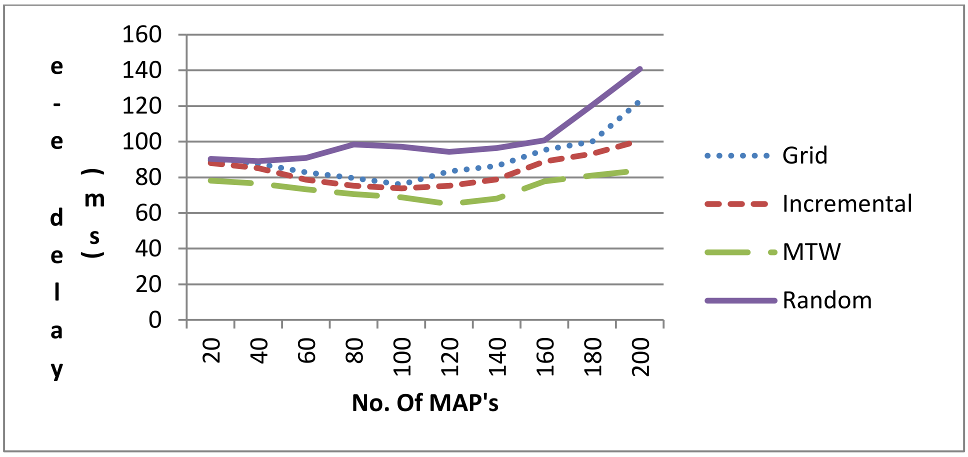

Figure 5.15 :Network end-to-end delay when Three MPP's are deployed

Low end-to-end delay can be explained by the fact that when there are few MAP's in the network there would be less probing overhead which decreases the delay at each hop hence MAP's would face less contention for the wireless channel. High end-to-end delay can be explained by the fact that as more MAP's are added in the network there would be a bottleneck delay on the single MPP as it would have to handle more MAP's transmission requests. The other cause of high end-to-end delay is that there would be long traffic/packet queues from many MAP's to a single MPP. The higher the data request arrival rate, the busier the MPP node would be as it can only attend to one data request at a time.

The same pattern can also be observed in Figure 5.14 and Figure 5.15 except that end-to-end delay decreased as more MPP's are deployed. The addition of multiple MPP's implies that the traffic from different MAP's would be split into different paths hence there would be better spatial re-use of the wireless bandwidth and there would be reduced route congestion. However, it can be noted that even though the network is improved, at some point the end-to-end delay begins to scale up as more and more MAP's are added into the network. The effect is not worse than the one incurred when only a single MPP is used. The random placement scheme suffers from high end-to-end delay than the other placement approaches. This can be explained by the fact that since the placement is random, the selected MPP(s) position(s) does not cover as enough MAP's as possible. The MTW experienced low end-to-end delay in these scenarios. This observation also implies that the MTW would have higher network throughput in all scenarios, while the Incremental and the Grid placement schemes experienced moderate end-to-end delay.

Experiment 6: The Network Packet Delivery Ratio in Linear Settlement Pattern

The aim of this experiment is to measure the ratio between the number of packets that are successfully received and the total number of packets sent on the network. This involves all traffic send to and from the MPP(s) via MAP's. In this way, the effectiveness of novel Grid Based, Incremental Clustering, MTW and Random MPP's placement schemes is evaluated, if they improve the network performance in the linear settlement pattern, focusing on the packet deliver ratio. Tables 5.17 to 5.19 represent the packet delivery ratio incurred by the placement schemes when the number of deployed MPP's was varied from 1 to 3.

Simulation results in Figure 5.16 reveal that the packet delivery ratio of the four placement scheme drops linearly as the number of MAP's deployed increased. This can be explained by the fact that there would be an increased routing overhead as MAP's compete for the single MPP and the MPP processes much traffic from the MAP's. There would be high routing load in the MPP leading to some packet drop as some of the links will break due to congestion. The same trend in the packet delivery ratio can be observed when two MPP's in Figure 5.17 and three MPP's in Figure 5.18 are deployed. Exception to this is that the degradation of the packet delivery ratio is lower than that incurred in Figure 5.16 at every rate for all the four MPP's placement schemes.

When comparing the packet delivery ratio incurred by each placement scheme, it can be observed that MTW outperformed the other placement approaches at every instance. When one MPP is deployed it delivered approximately 81.3%, while Incremental delivery 80.6%, Grid 79.8% and Random 76.5% at 200MAP's.

Table 5.17: Network Packet Delivery Ratio when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	88.6%	88.8%	89.2%	88.1%
40	86.5%	87.8%	87.8%	86.1%
60	85.3%	85.7%	87.5%	83.6%
80	85.2%	85.5%	87%	81.7%
100	84.8%	85.2%	86.2%	80.3%
120	83.2%	85.1%	85.7%	80.5%
140	81.3%	84.4%	84.8%	80%
160	81.2%	82.3%	84.6%	78.9%
180	80%	81.3%	82.7%	76.8%
200	79.8%	80.6%	81.3%	76.5%

Table 5.18 :Network Packet Delivery Ratio when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.4%	89.9%	90.2%	89.1%
40	88.5%	89.6%	89.9%	87.1%
60	87.9%	88.7%	89.8%	86.6%
80	87.3%	88%	88.6%	86.2%
100	86.8%	87.2%	88.6%	85.7%
120	86.2%	87.1%	88.3%	85.3%
140	84.9%	85.4%	87.8%	83.5%
160	82.2%	83.9%	86.6%	81%
180	82%	83.5%	84.7%	80.5%
200	80.8%	81.3%	84.3%	79.9%

Table 5.19 :Network Packet Delivery Ratio when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.9%	89.9%	91.2%	89.8%
40	88.8%	89.9%	90.2%	88.1%
60	88.1%	88.8%	89.9%	87.6%
80	87.8%	88.6%	88.9%	86.9%
100	87.2%	87.8%	88.8%	85.9%
120	87%	87.6%	88.5%	85.8%
140	85%	86.7%	88.2%	84.5%
160	83.9%	85.9%	87.8%	82.1%
180	82.9%	84.5%	85.7%	81.5%
200	82%	83.4%	85.3%	80.9%

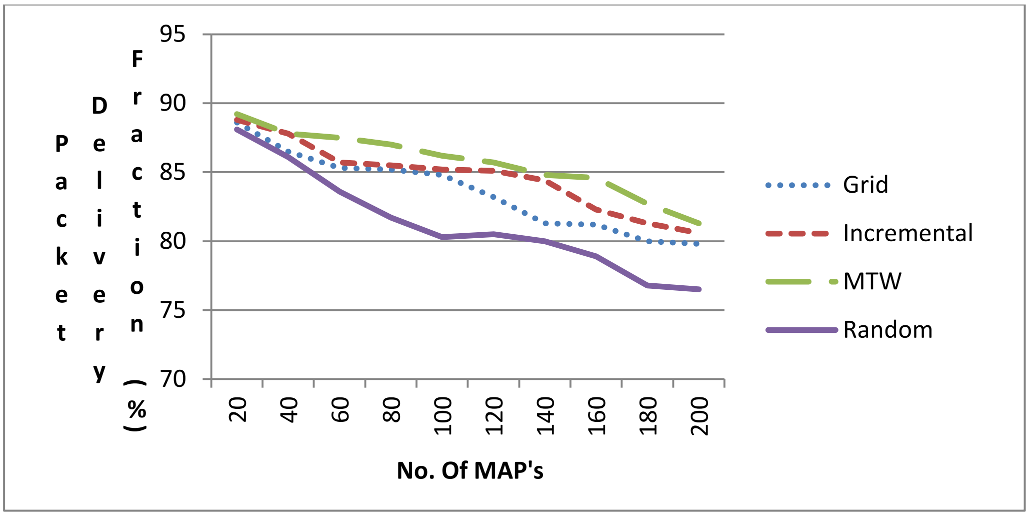

Figure 5.16 :Network Packet Delivery Ratio when One MPP is deployed

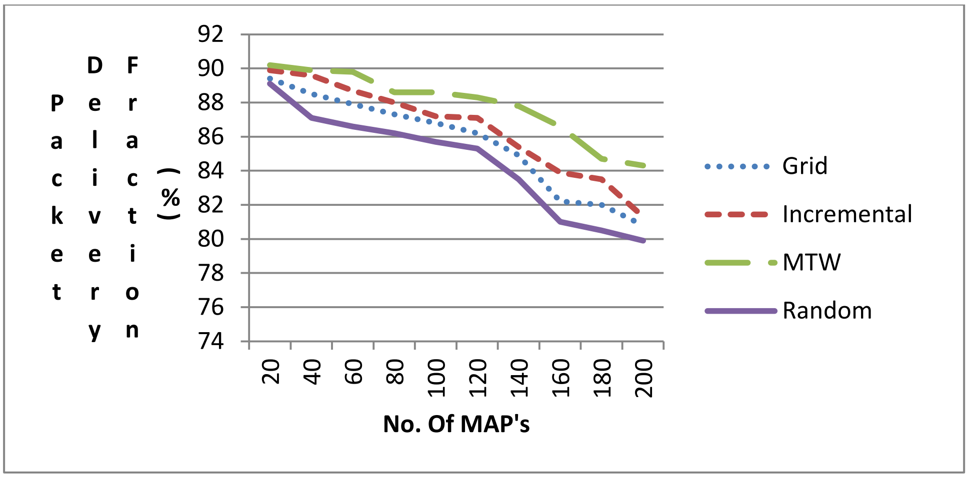

Figure 5.17: Network Packet Delivery Ratio when Two MPP's are deployed

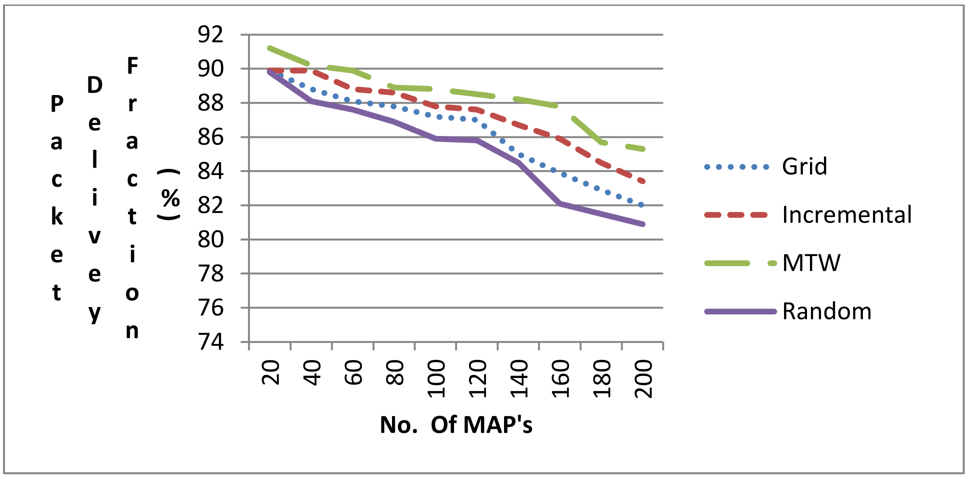

Figure 5.18: Network Packet Delivery Ratio when Three MPP's are deployed

Introducing more MPP's brought an excellent performance as can be observed when in Figure 5.18, Random placement which is usually worst in improving the network performance can reach approximately 80.9% packet delivery. Compactness of the MAP's in a linear topology also contribute in maintaining the connection among the MAP's, up to the MPP making it easier for relaying each other's traffic. In this way, the links will be less prone to failures or breakage.

5.3.3 The effectiveness of MPP's placement Schemes in Dispersed Settlement Pattern

The goal of this subsection is to evaluate and compare the effectiveness of the MPP's placement schemes in order to recommend the placement scheme that improves the network performance by selecting optimal MPP's candidate positions in a dispersed settlement pattern. The performance evaluation focuses on measuring each schemes network throughput, end-to-end delay and packet delivery ratio. The best scheme would ensure that maximum throughput and packet delivery ratio is achieved while reducing the end-to-end delay in the network.

Experiment 7: The effect of MPP's placement schemes on the Network Throughput in Dispersed Settlement Pattern

Tables below represent the throughput values incurred by the MPP's placement scheme in the dispersed settlement pattern while varying the number of deployed MPP's. Simulation results in Figure 5.19, Figure 5.20 and Figure 5.21 reveal that when there are few MAP's in the network, the network throughput is high and when there is an increased in the number of MAP's network throughput decreased.

Table 5.20: Network Throughput when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	487.7 kbps	483.8 kbps	446.9 kbps	370.5 kbps
40	484.6 kbps	483.4 kbps	419.2 kbps	364.1 kbps
60	462.4 kbps	480.5 kbps	400 kbps	260.5 kbps
80	453.8 kbps	471.4 kbps	394.3 kbps	258.5 kbps
100	433.6 kbps	401.7 kbps	370.6 kbps	240.2 kbps
120	394.4 kbps	383.3 kbps	203.59 kbps	131.8 kbps
140	354.5 kbps	338 kbps	256.8 kbps	128.7 kbps
160	337.7 kbps	276.1 kbps	161.4 kbps	119.2 kbps
180	286 kbps	211.2 kbps	140.8 kbps	91.2 kbps
200	132.8 kbps	106.3 kbps	98.9 kbps	80.5 kbps

Table 5.21: Network Throughput when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	598.4 kbps	583.8 kbps	522.9 kbps	480.4 kbps
40	552.9 kbps	543.8 kbps	495.2 kbps	424.1 kbps
60	584.8 kbps	470.5 kbps	412 kbps	390.2 kbps
80	471.4 kbps	453.8 kbps	394.3 kbps	300 kbps
100	433.7 kbps	411 kbps	338.8 kbps	272.2 kbps
120	394.4 kbps	363.7 kbps	244.2 kbps	223.5 kbps
140	384.1 kbps	276.1 kbps	216.8 kbps	128.7 kbps
160	317.8 kbps	308.6 kbps	199.9 kbps	119.2 kbps
180	268.4 kbps	171.2 kbps	150.8 kbps	119 kbps
200	198.8 kbps	156.3 kbps	118.5 kbps	108.5 kbps

Table 5.22: Network Throughput when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	638.4 kbps	601.7 kbps	550.8 kbps	499.1 kbps
40	612.9 kbps	585.3 kbps	518.5 kbps	480 kbps
60	598.4 kbps	583.8 kbps	522.9 kbps	480.4 kbps
80	585.9 kbps	553.2 kbps	455.2 kbps	444.1 kbps
100	587.2 kbps	540.5 kbps	432.3 kbps	400.2 kbps
120	499.6 kbps	453.8 kbps	409.4 kbps	300 kbps
140	473.7 kbps	411 kbps	356.6 kbps	244.2 kbps
160	394.4 kbps	363.7 kbps	282.8 kbps	253.5 kbps
180	374.9 kbps	308.6 kbps	216.8 kbps	128.7 kbps
200	317.8 kbps	276.1 kbps	199.9 kbps	119.2 kbps

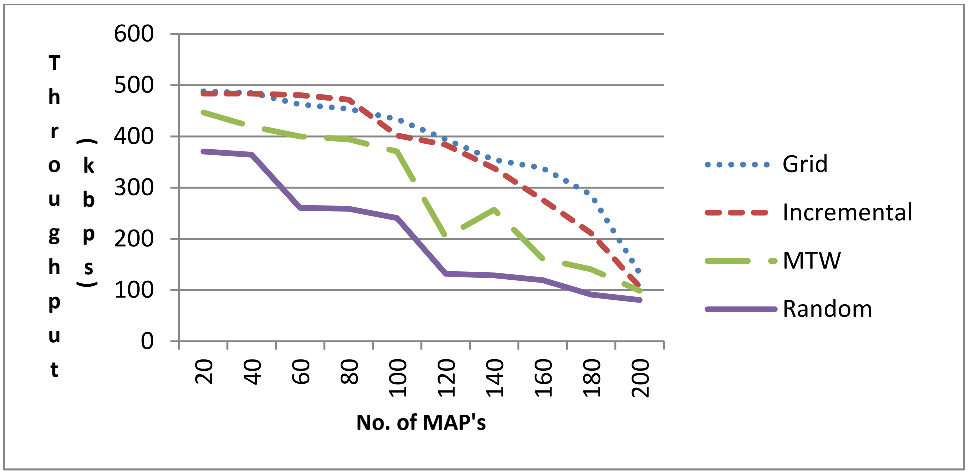

Figure 5.19 :Network Throughput when One MPP is deployed

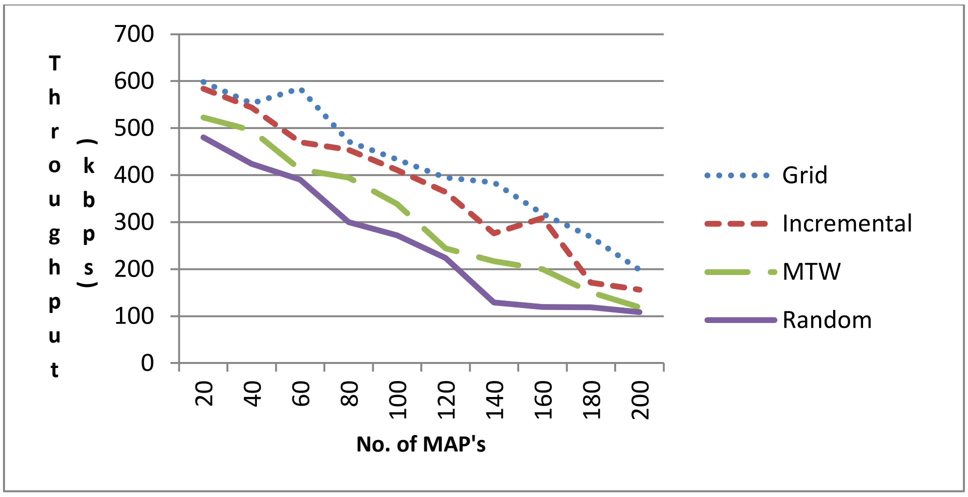

Figure 5.20: Network Throughput when Two MPP's are deployed

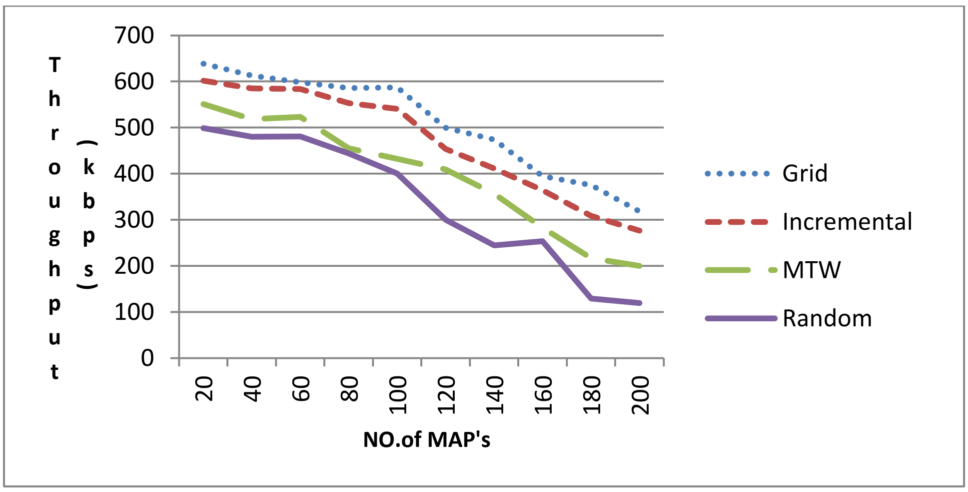

Figure 5.21 :Network Throughput when Three MPP's are deployed

This behavior is to be expected because increase in the number of MAP’s implies the increase in the number of hops the packet or traffic would have to travel before reaching the MPP(s). This effect results into route congestions. The other interesting fact is that, MAP’s placement follows the dispersed pattern/topology; the unevenness of the distance between the hops exposes the packet into medium interference which degrades the network throughput. More hops also lead to high spatial re-use available in the network thus degrading the network throughput. Long links reduces network throughput as it introduces fading of the signal as it travel in the network which can cause a packet that would have been dropped to be received and vice versa.

In Table 5.20, it can be observed that the network throughput gain is very low when only one MPP is deployed in the network compared to the network throughput gain when two MPP’s (refer to Table 5.21) and three MPP’s (refer in Table 5.22) are deployed. This behavior is caused by the fact that there would be reduced delay bottleneck in the MPP; since traffic from the MAP’s would be divided and shared amongst the available MPP’s, hence increasing the available bandwidth between each MPP.

It can be observed from Figure 5.19, Figure 5.20 and Figure 5.21 that novel Grid Based MPP’s placement scheme achieved better values of network throughput than the other approaches. This behavior is caused by the fact that for a dispersed spatial area, the Grid Based placement method divides the area into enough square grid covering all the nodes in the network; then ensures that the MPP’s is placed at center of each grid. When only one MPP is deployed the scheme would ensure that it locate it at the center where all MAP’s would have equal access into the MPP. The Fixed Protocol Interference Model is adapted by this approach which ensures that the packet transmission would be interference-free, irrespective of the location and number of deployed MPP’s. Each link is assigned interference-aware transmission to maximize the network throughput.

Experiment 8: The effect of MPP's placement schemes on the Network End-to-end Delay in Dispersed Settlement Pattern

Tables 5.23 to 5.25 illustrate the network end-to-end delay incurred by the novel Grid Based, Incremental Clustering, MTW and Random MPP's placement schemes in a dispersed settlement pattern when one to three MPP's are deployed. Figures 5.22 to 5.24 reveal that the network end-to-end delay is low when few MAP's are deployed and increased as more MAP's are deployed.

The first reason for high end-to-end delay is due to long queues to the MPP's, while traffic from diverse MAP's waits to interact with the MPP's. The second reason for the increased end-to-end delay is the increased number of hops that the packet travel to access the MPP's which is prone to link failures. End-to-end delay drastically increase when the TCP retransmit the failed packet transmission. Less congestion when only few MAP's are deployed reduces the packet transmission delay.

Increase in the number of MPP's in the network alleviates the burden on the single MPP. That is a reason there is a reduced end-to-end delay as more MPP's are deployed (refer to table 5.24 and table 5.25) compared to the delay incurred in table 5.23. It can be observed from the simulation result that, again, the Grid based placement scheme achieved the improved network performance since in all the scenarios it incurred less end-to-end delay; which confirms the high network throughput that was achieved in the previous experiment.

Table 5.23 :Network End-to-end when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	98.2 ms	102.2 ms	122.9 ms	125.2 ms
40	100.2 ms	120.1 ms	132.6 ms	138.2 ms
60	106 ms	121.4 ms	141.8 ms	151.6 ms
80	120.9 ms	125.3 ms	149.5 ms	154.4 ms
100	121.6 ms	126.2 ms	157.1 ms	176.6 ms
120	122.2 ms	152.4 ms	212.5 ms	220.2 ms
140	127.3 ms	165.3 ms	230.1 ms	282.5 ms
160	183.8 ms	253.9 ms	308.5 ms	324.2 ms
180	250.6 ms	286.6 ms	324.6 ms	346.8 ms
200	259.1 ms	300.8 ms	340 ms	360.1 ms

Table 5.24: Network End-to-end when Two MPP’s are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	90.2 ms	98.9 ms	100.9 ms	115.5 ms
40	95.3 ms	100.1 ms	122.6 ms	130.8 ms
60	98.9 ms	101.8 ms	131.2 ms	141.6 ms
80	101 ms	115.7 ms	138.6 ms	148.8 ms
100	111.1 ms	120.1 ms	147.7 ms	160.8 ms
120	112.2 ms	122.5 ms	152.5 ms	180.2 ms
140	119.1 ms	130.5 ms	185.7 ms	200.2 ms
160	123.5 ms	163.1 ms	248.8 ms	282.7 ms
180	160.7 ms	186.6 ms	254.2 ms	300.8 ms
200	178.8 ms	250.8 ms	260.1 ms	301.7 ms

Table 5.25: Network End-to-end when Three MPP’s are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	70.2 ms	76.5 ms	84.8 ms	94.5 ms
40	78.5 ms	83.1 ms	85.6 ms	98.5 ms
60	80.3 ms	88.8 ms	89.4 ms	99.6 ms
80	82.4 ms	90.5 ms	92.7 ms	101.6 ms
100	86.7 ms	95.2 ms	97.8 ms	113 ms
120	89.2 ms	98.6 ms	101.5 ms	120.7 ms
140	90.9 ms	100.4 ms	115.5 ms	147.2 ms
160	98.7 ms	111.2 ms	134.2 ms	182.1 ms
180	101.8 ms	126.2 ms	154.8 ms	195.5 ms
200	118.8 ms	185 ms	230.1 ms	251.1 ms

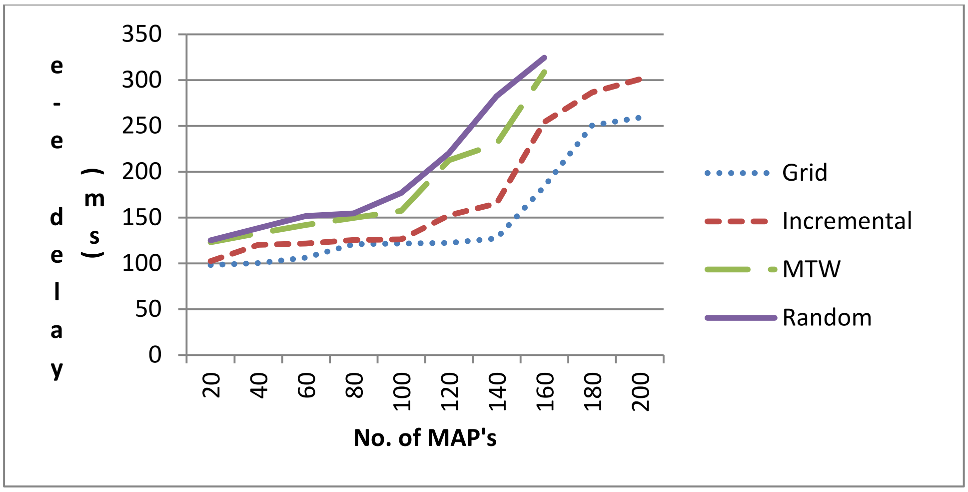

Figure 5.22 :Network End-to-end when One MPP is deployed

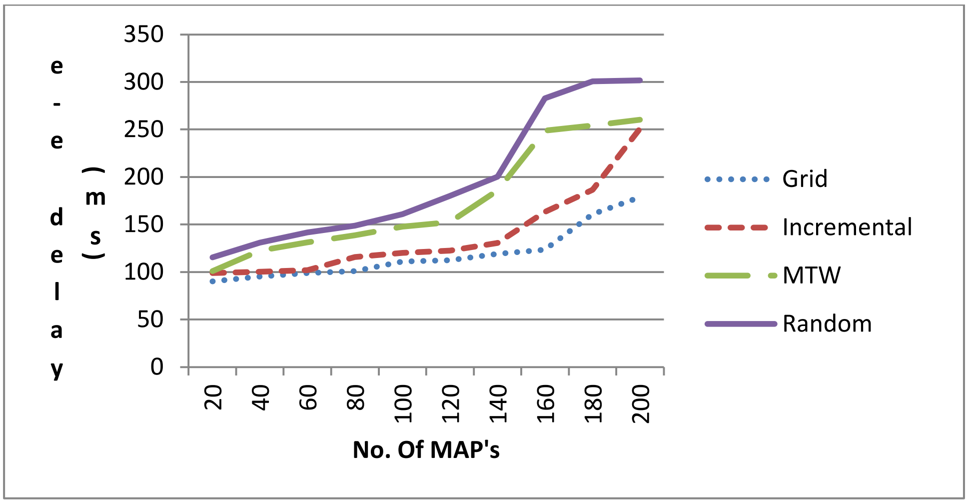

Figure 5.23: Network End-to-end when Two MPP's are deployed

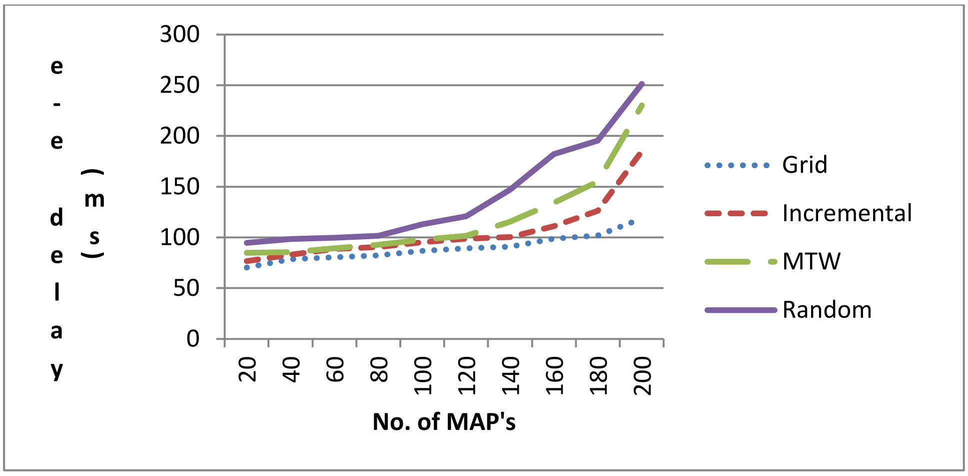

Figure 5.24 :Network End-to-end when Three MPP's are deployed

Experiment 9: The effect of MPP's placement schemes on the Network Packet Delivery Ratio in Dispersed Settlement Pattern

This subsection presents the packet delivery ratio achieved by the novel Grid Based, Incremental Clustering, MTW and Random MPP's placement schemes in a dispersed settlement pattern when one to three MPPs are deployed. Table 5.26, 5.27 and 5.28 illustrate the simulation values that were obtained. Figure 5.25 represents a scenario where only one MPP is deployed in the network. It can be observed that at small number of MAP's, the packet delivery ratio is very high, this can be explained by the fact that at this point there is enough available MPP bandwidth shared among the MAP's. However, increase in the number of MAP's causes congestion along the common links and at the MPP which leads to MAC buffer overflow and thus packet drops.

Figures 5.26 and 5.27 represent the effect of increasing the number of deployed MPP's on packet delivery ratio when 20 to 200 MAP's are sparsely distributed in a deployment area. It is clear that increasing the number of MPP's improves the percentage of the successfully delivered packet than when only one MPP is used. Referring to Table 5.26 to Table 5.28, it can be seen that there is an improvement at every instance. For example, Grid based at 20 MAP's in table 5.26 only achieved up to 82.7% packet delivery but when two MPP's are deployed in Table 5.27 the packet delivery increased to 86.8%. Again deploying three MPP's increased the packet delivery ratio to 89.8%. The same effect can be observed for all the placement schemes from 20 to 200 MAPs. Even though increasing MPP's improves performance than one MPP the increase in the number of MAP's provides merely same effect. It can be observed that there is a drop of the successfully delivered packet as more MAP's are deployed based on the same reason that congestion rate increases as number of MAP's increase leading to errors in delivery.

Table 5.26 :Network packet delivery ratio when one MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	82.7%	81.2%	80.8%	79.9%
40	82.3%	81.1%	80.2%	79.9%
60	80.2%	78.5%	72.3%	63.6%
80	79.8%	78%	70.5%	62.8%
100	76.7%	68.3%	62.8%	58.2%
120	68.8%	58.6%	55.4%	48.7%
140	65.3%	58.4%	50.8%	48.9%
160	58.8%	55.2%	49.9%	48.2%
180	52.3%	50%	47.8%	46.7%
200	50.1%	48.4%	46.2%	44.9%

Table 5.27: Network packet delivery ratio when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	86.8%	85.9%	84.8%	83.9%
40	84.7%	83.2%	82.2%	80.9%
60	82.5%	81.8%	80.3%	76.8%
80	80.7%	79.2%	73.5%	68%
100	78.8%	70.8%	68.8%	62.8%
120	69.8%	62.2%	60%	58.9%
140	68.4%	60.6%	55.8%	51.7%
160	65.2%	58.9%	51.2%	49.9%
180	62.3%	55.8%	49.9%	49.3%
200	58.9%	50.8%	49%	48.8%

Table 5.28 :Network packet delivery ratio when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.8%	89%	88.9%	88.8%
40	89.7%	88.8%	86.2%	83.9%
60	88.5%	85.8%	83.3%	80.6%
80	84.7%	80.9%	78.4%	72.8%
100	79.9%	75.9%	70.8%	68.7%
120	72.8%	68.2%	64.8%	62.5%
140	70.4%	65.9%	60.9%	61.9%
160	68.9%	60.8%	58.2%	50.9%
180	66.7%	58.8%	58.5%	49.9%
200	60.9%	55.9%	52.5%	49.3%

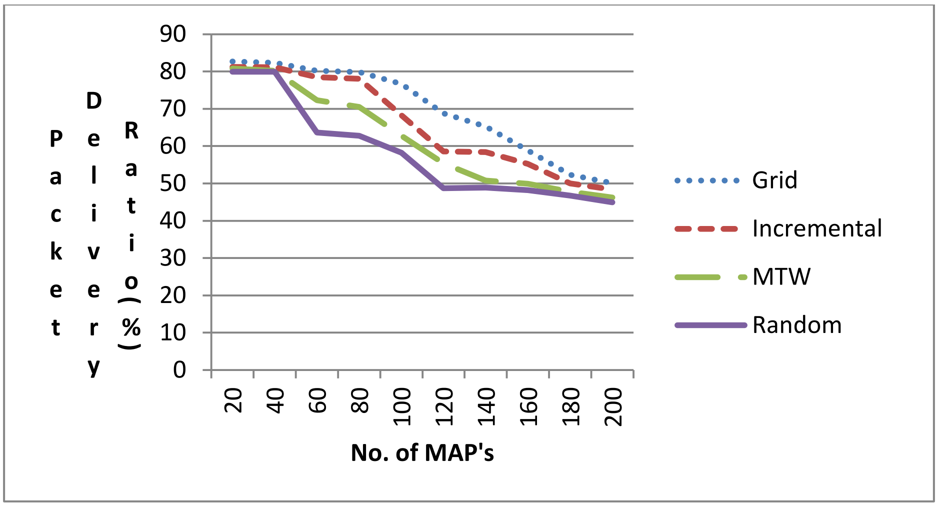

Figure 5.25 :Network packet delivery ratio when one MPP is deployed

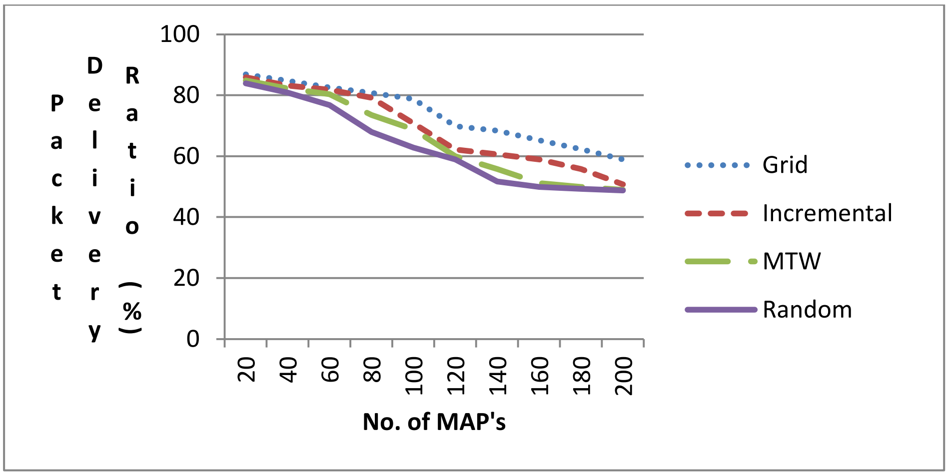

Figure 5.26: Network packet delivery ratio when Two MPP's are deployed

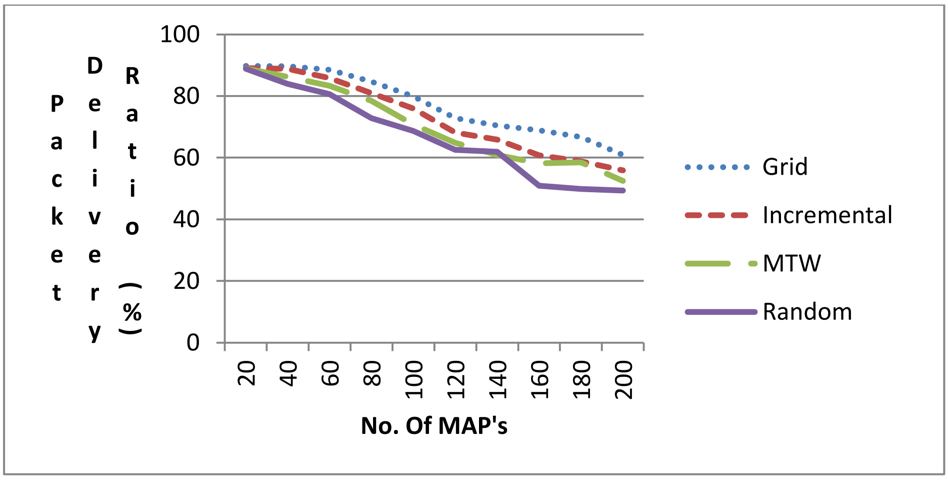

Figure 5.27 :Network packet delivery ratio when Three MPP's are deployed

As shown in the Figures by this experiment, the Grid based MPPs placement scheme shows a higher packet delivery ratio than other placement schemes. This is because the Grid based scheme sends interference aware transmissions among the MP's in this way ensuring that the available bandwidth is equally shared at each node and by assigning timeslot for every transmission so that the selected paths would not collide.

5.3.4 The effectiveness of MPP's placement Schemes in Isolated Settlement Pattern

The purpose of this subsection is to evaluate and compare the MPP's placement schemes in isolated settlement pattern by assessing their performance using three metrics namely network throughput, network end-to-end delay and network packet delivery ratio.

Experiment 10: The Network Throughput in Isolated Settlement Pattern

Tables 5.29 to 5.31 illustrate the network throughput that was obtained by novel Grid Based, Incremental Clustering, MTW and Random MPP's placement schemes in an isolated settlement pattern considering a network scenario with one to three MPP's being deployed. It can be observed from the above figures that the better network throughput is only when there are few MAP's in the network and worse when there is an increase in the number of deployed MAP's. It can also be observed that increase in the number of deployed MPP's improved the network throughput at each node level. The simulation results reveal that the Incremental clustering placement scheme outperforms other approaches by obtaining better throughput values. This is due to the fact that the incremental clustering scheme caters even for the isolated MAP's. It does this by ensuring that, for all nodes that are not covered by the MPP, a new MPP will be selected to act as a cluster head of the all the isolated MAP's, hence at the end of the network simulation all the MAP's (covered and uncovered) would be able to access the internet via cluster head acting as a MPP of the entire network.

Table 5.29 : Network Throughput when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	482.9 kbps	486.9 kbps	478.5 kbps	460.5 kbps
40	480.4 kbps	484.4 kbps	474 kbps	455 kbps
60	475.7 kbps	482.6 kbps	462.79 kbps	445.2 kbps
80	463.3 kbps	478.4 kbps	455.6 kbps	398.9 kbps
100	448.9 kbps	471.8 kbps	438.3 kbps	364.5 kbps
120	433.5 kbps	444.9 kbps	413.2 kbps	303.4 kbps
140	380.7 kbps	438.3 kbps	350.7 kbps	232.4 kbps
160	350.8 kbps	397.4 kbps	260.8 kbps	226.5 kbps
180	314.2 kbps	327.3 kbps	282 kbps	221 kbps
200	164 kbps	288 kbps	139.4 kbps	105.8 kbps

Table 5.30 : Network Throughput when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	532.9 kbps	598.6 kbps	507.5 kbps	499.7 kbps
40	530.4 kbps	584.4 kbps	502.7 kbps	455 kbps
60	520.5 kbps	576.2 kbps	500.6 kbps	445.8 kbps
80	486.3 kbps	563.4 kbps	455.6 kbps	425.5 kbps
100	478.9 kbps	499.8 kbps	423 kbps	394.5 kbps
120	453.5 kbps	484.1 kbps	410.2 kbps	350.2 kbps
140	430.3 kbps	477.3 kbps	400.7 kbps	282.4 kbps
160	376.8 kbps	399.7 kbps	366.8 kbps	276.5 kbps
180	350.2 kbps	399.5 kbps	292.5 kbps	230.1 kbps
200	284 kbps	388 kbps	189.4 kbps	138.5 kbps

Table 5.31: Network Throughput when Three MPPs are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	661.9 kbps	695.6 kbps	650.7 kbps	599.7 kbps
40	648.4 kbps	684.4 kbps	621.2 kbps	495.9 kbps
60	610.5 kbps	676.2 kbps	601.6 kbps	486.8 kbps
80	596.3 kbps	653.4 kbps	575.6 kbps	475.5 kbps
100	587.8 kbps	649.2 kbps	560.3 kbps	455 kbps
120	563.5 kbps	610.8 kbps	510.8 kbps	450.2 kbps
140	505.2 kbps	597.8 kbps	488.7 kbps	398.2 kbps
160	446.1 kbps	560.7 kbps	396.8 kbps	276.5 kbps
180	423.2 kbps	479.5 kbps	292.5 kbps	230.1 kbps
200	400.8 kbps	456.7 kbps	289.4 kbps	188.5 kbps

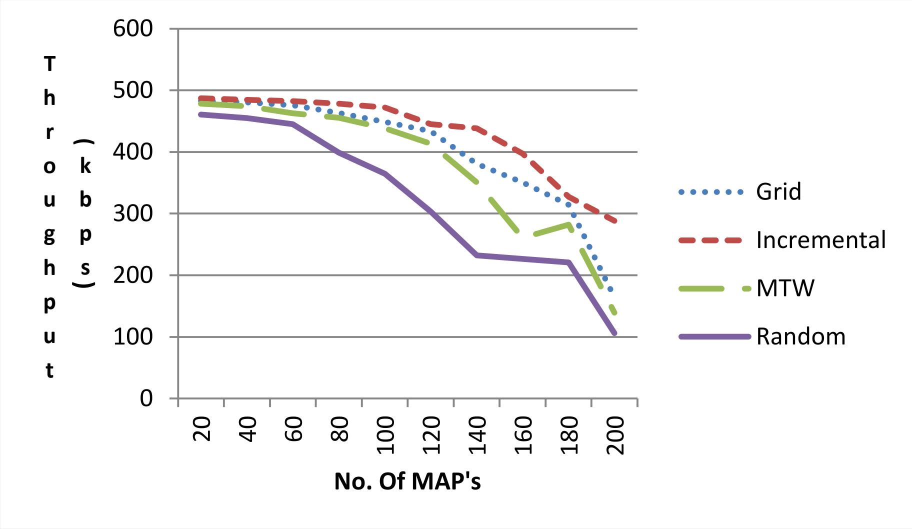

Figure 5.28 :Network Throughput when One MPP is deployed

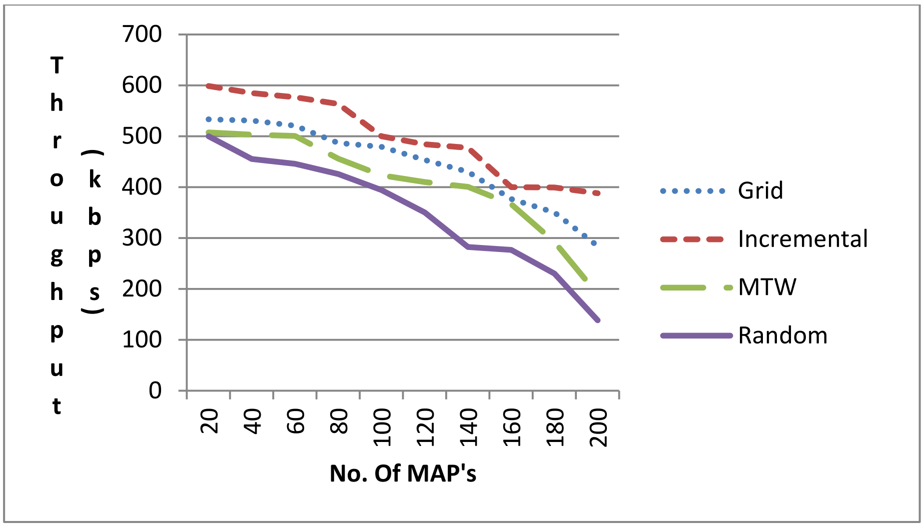

Figure 5.29: Network Throughput when Two MPP's are deployed

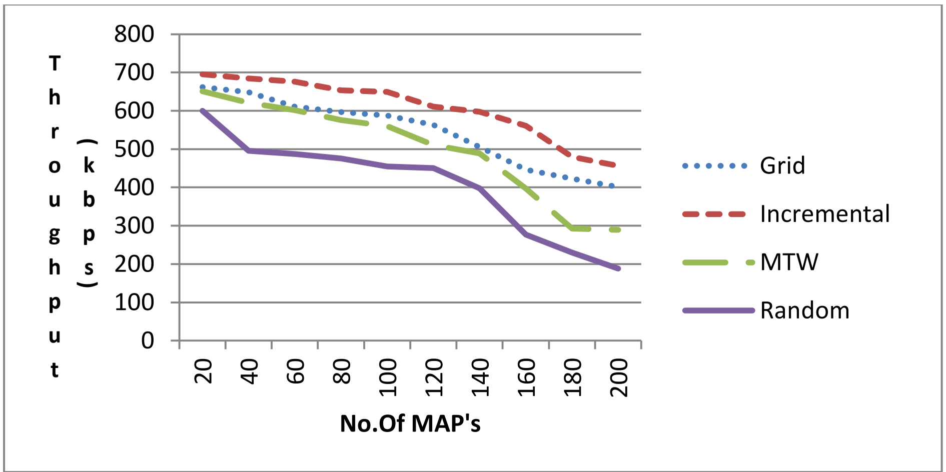

Figure 5.30 :Network Throughput when Three MPPs are deployed

Experiment 11: The Network End-to-end Delay in Isolated Settlement Pattern

Tables 5.32 to 5.34 illustrate the network end-to-end delay incurred by the novel Grid Based, Incremental Clustering, MTW and Random MPP's placement schemes while the number of MPP's was varied. When few MAP's are deployed, the network end-to-end delays is low due to the fact that there will be very low probing overhead, which reduces the delay at each hop because each node faces less contention for the channel.

When more MPP's are deployed (As shown in figure 5.32 and figure 5.33) the traffic is split along different paths, therefore there would be better spatial usage of wireless bandwidth and consequently a decrease in the number of congested routes. This is one of the reasons why the network end-to-end delay decreased compared to the one obtained in figure 5.31, which was drastically high at every MAP deployed rate. Again as expected the Incremental clustering algorithm obtained less end-to-end delay in the network.

Table 5.32: Network End-to-end Delay when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	95.8 ms	89.2 ms	100.3 ms	117.1 ms
40	120.7 ms	112.8 ms	130.4 ms	129.8 ms
60	130.4 ms	123.5 ms	138.6 ms	140.2 ms
80	139.5 ms	127.6 ms	146.3 ms	145.9 ms
100	143.3 ms	133 ms	149.3 ms	149.4 ms
120	148.2 ms	136.3 ms	164.5 ms	169.2 ms
140	156.8 ms	142.7 ms	168.3 ms	182.3 ms
160	163.7 ms	148.3 ms	171.2 ms	245.1 ms
180	234.6 ms	161.5 ms	289.5 ms	308.4 ms
200	247.6 ms	220.5 ms	312 ms	364.2 ms

Table 5.33: Network End-to-end Delay when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	85.8 ms	70.2 ms	95.3 ms	100.1 ms
40	88.1 ms	72.2 ms	98.2 ms	109.1 ms
60	90.4 ms	80.1 ms	108.6 ms	119.1 ms
80	95.2 ms	97.2 ms	116.3 ms	125.1 ms
100	103.3 ms	98.9 ms	129.1 ms	139.8 ms
120	128.7 ms	100.9 ms	144.5 ms	159.2 ms
140	138.2 ms	130 ms	158.3 ms	162.4 ms
160	163.8 ms	153.3 ms	167.4 ms	189.5 ms
180	189.6 ms	165.1 ms	188.8 ms	208.2 ms
200	199.4 ms	180.9 ms	200.8 ms	224.8 ms

Table 5.34 :Network End-to-end Delay when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	75.2 ms	72 ms	78.3 ms	84.8 ms
40	78.7 ms	74.2 ms	88.3 ms	95.5 ms
60	80.4 ms	78.9 ms	90.7 ms	98.8 ms
80	85.2 ms	87.6 ms	95.3 ms	100.2 ms
100	92.5 ms	88.4 ms	103.7 ms	110.7 ms
120	98.4 ms	90.2 ms	114.8 ms	129 ms
140	110.8 ms	98.4 ms	118.1 ms	146.2 ms
160	123.4 ms	100.2 ms	137.7 ms	159.2 ms
180	137.1 ms	115.7 ms	158.7 ms	178.7 ms
200	159 ms	130.2 ms	178.8 ms	204.5 ms

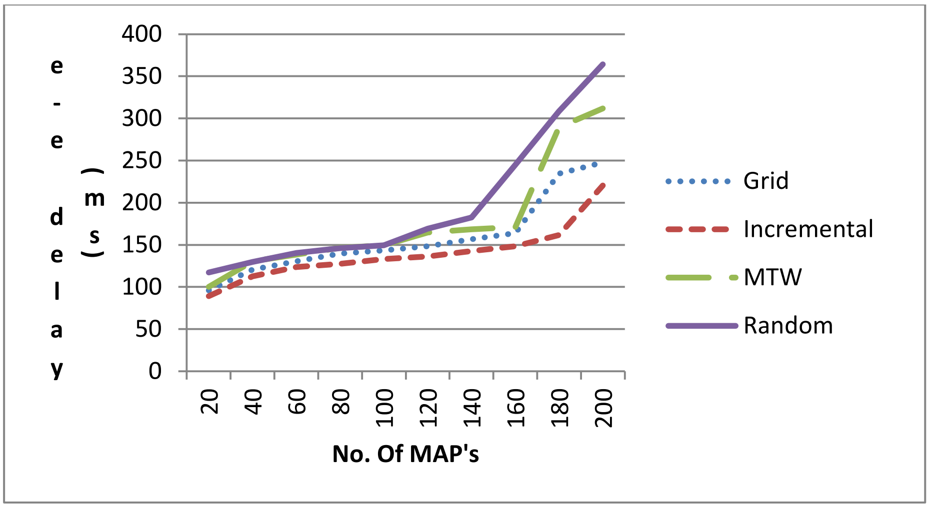

Figure 5.31:Network End-to-end Delay when One MPP is deployed

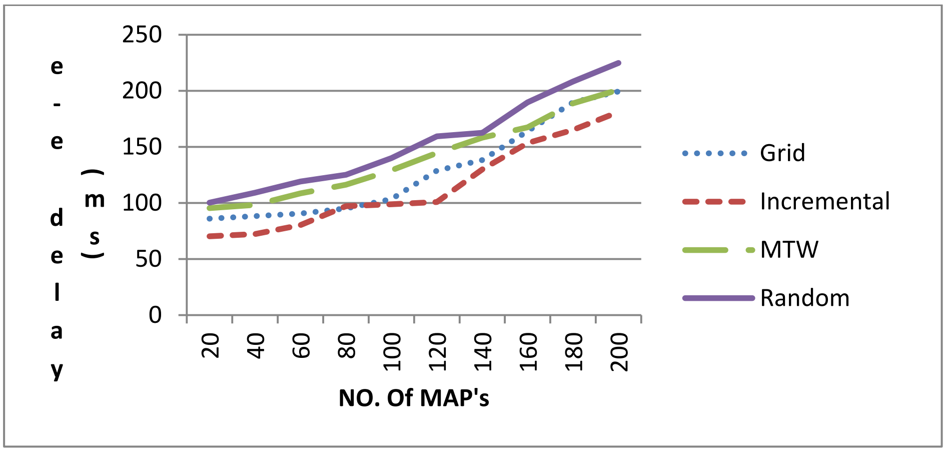

Figure 5.32: Network End-to-end Delay when Two MPP's are deployed

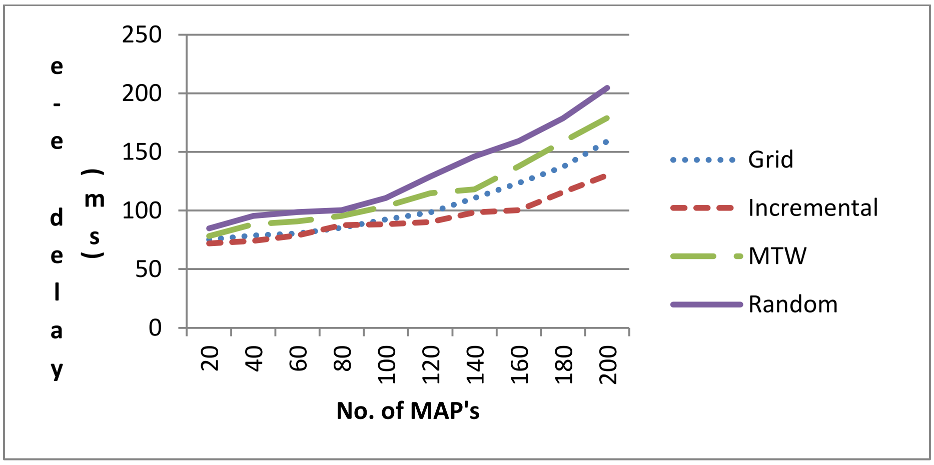

Figure 5.33 :Network End-to-end Delay when Three MPP's are deployed

Experiment 12: The Network Packet Delivery Ratio in Isolated Settlement Pattern

Table 5.35, Table 5.36 and Table 5.37 illustrate the packet delivery ratio obtained by the by novel Grid Based, Incremental Clustering, MTW and Random MPP's placement schemes as the number of MPP's was varied. It can be observed on figure 5.30 that when using a single MPP, the packet delivery rate decreased quite rapidly as the number of MAP's deployed increased. This is due to the fact that many MAP's being connected to the same MPP led to heavily congested paths particularly in proximity of the MPP.

It can also be observed from figure 5.31 and figure 5.32 that, when more than one MPPs is deployed, the decrease in the packet delivery ratio is less than when only one MPP is deployed. This is mainly because the average distance between MAP's and MPP's decreases as the number of MPPs increases in the same area. Therefore, the average paths are smaller and the network is less prone to link failures

The other important fact which can be noted is that even though packet delivery decreases as MAP's vary from 20 to 200 nodes, even at 200 nodes the ratio is still above 50%. This can be attributed to the TCP assisting in the re-transmission of lost packet or dropped packet which thus maintain the packet delivery ratio.

Table 5.35 :Network Packet Delivery Ratio when One MPP is deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	81.2%	84.5%	82.1%	80.9%
40	81.1%	83.9%	80.6%	80.5%
60	78.5%	83.9%	75.6%	76.8%
80	78%	82.5%	73.4%	68.5%
100	68.3%	80.7%	65.7%	62.3%
120	58.6%	78.8%	56.4%	54.5%
140	58.4%	68.4%	55.8%	50.9%
160	55.2%	58.8%	47.9%	46.9%
180	50.8%	52.3%	49.8%	45.8%
200	49.9%	55.3%	49.9%	44.9%

Table 5.36 :Network Packet Delivery Ratio when Two MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	84.9%	85.9%	83.1%	82.9%
40	84.8%	85.7%	83%	82.8%
60	83.8%	85.6%	82.6%	81.8%
80	82.8%	84.5%	80.5%	78.7%
100	82.3%	84.3%	78.2%	70.3%
120	75.8%	82.8%	73%	65.8%
140	72.4%	82.6%	65.9%	55.9%
160	70.2%	78.8%	63.9%	52.6%
180	68.5%	75.3%	55.9%	50.9%
200	60.9%	68.5%	50.9%	49.9%

Table 5.37: Network Packet Delivery Ratio when Three MPP's are deployed

No. Of Mesh Points	Grid	Incremental	MTW	Random
20	89.1%	89.9%	88.9%	88.3%
40	88.8%	89.8%	87%	84.7%
60	87.8%	88.8%	86.9%	83.8%
80	86.7%	87.5%	86.8%	80.8%
100	86.5%	87.2%	85.5%	78.8%
120	85.3%	86.9%	78.9%	73.7%
140	78.8%	86.9%	75.3%	68.8%
160	75.2%	85.8%	72.3%	65.8%
180	70.8%	84.5%	65.9%	55.9%
200	68.9%	82.5%	60.8%	52.6%

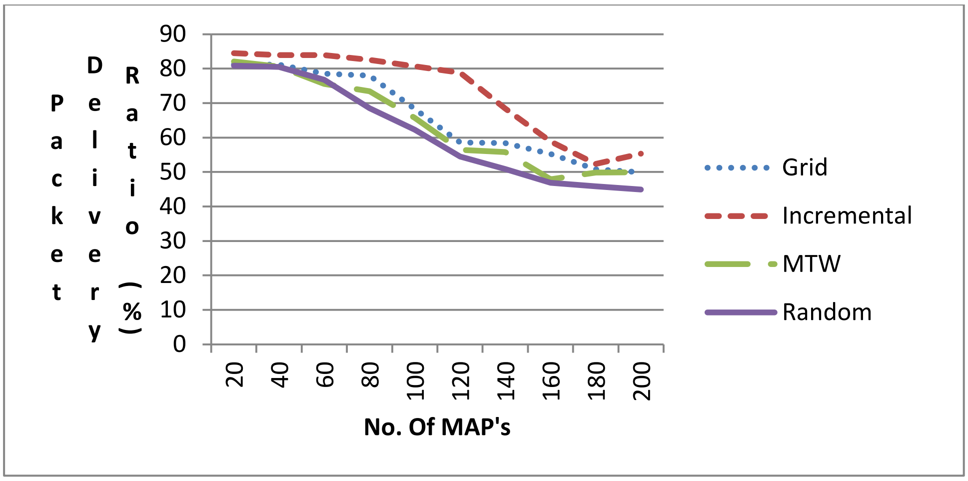

Figure 5.34: Network Packet Delivery Ratio when One MPP is deployed

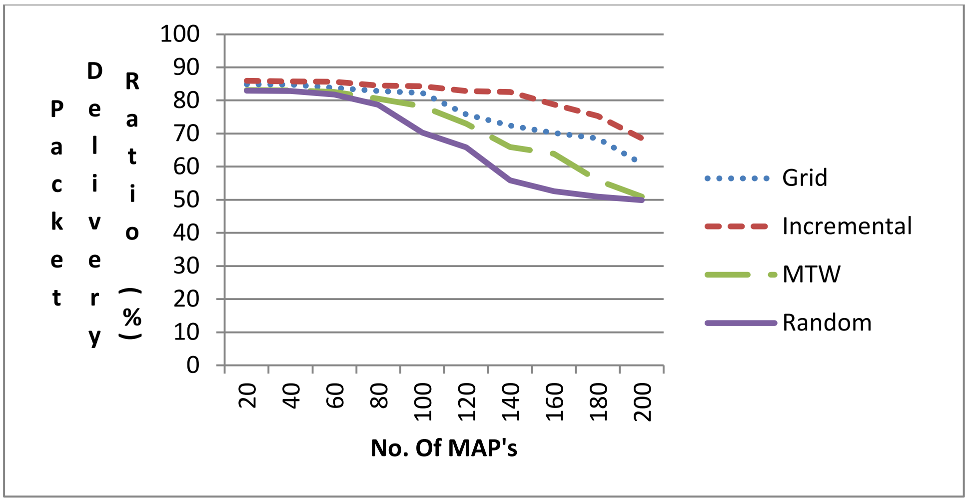

Figure 5.35 :Network Packet Delivery Ratio when Two MPP's are deployed

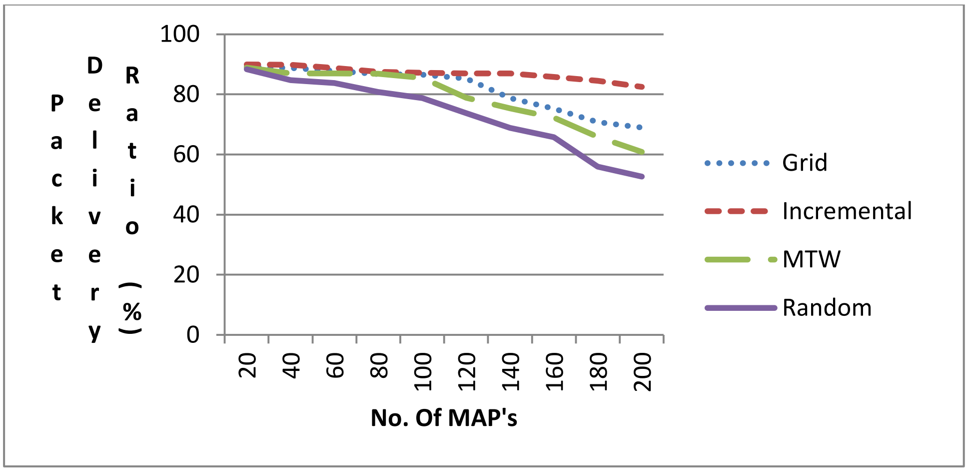

Figure 5.36 :Network Packet Delivery Ratio when Three MPP's are deployed

5.4 Simulation Summary and Recommendations

In this chapter, the problem of MPP's placement scheme is tackled by evaluating and comparing four placement schemes namely Grid Based, Incremental, MTW and random MPPs placement schemes. The main goal was to evaluate the effectiveness of MPP's placement schemes in the nucleated, dispersed, isolated and linear settlement pattern in order to find the best scheme to be adopted for rural deployment. The goal was further expanded into comparing the effect of the placement schemes when the number of deployed MPP's is varied from one to three. Network throughput, packet delivery ratio and end-to-end delay were the three performance metrics used to evaluate and compare the schemes. MAP's placement schemes that were recommended for each settlement patterns from the previous chapter were used to select the MPP's for conducting the experiments in this chapter.

The Tables 5.38 to 5.41 represents the summary of the results obtained when experiments were conducted. The placement schemes are rated in the ascending order number 1 up to 4, where 1 represents the best scheme and number 4 represents the worst scheme in the settlement. The experiments revealed that, in the nucleated settlement pattern, the MTW outperforms the Grid Based, Incremental and Random placement schemes in terms of obtaining minimum end-to-end delay, higher packet delivery ratio and increased network throughput results is represented in table 5.38.

In the nucleated settlement pattern, MAP's cluster towards the center and this feature makes it easier for the MTW to select optimal positions for placing MPP's by selecting MAP's with the highest weight of hops.

Table 5.38: Performance of MPP's placement schemes in Nucleated Settlement Pattern

Performance Metrics	Grid	Incremental	MTW	Random
Throughput	2	3	1	4
End-to-end Delay	2	3	1	4
Packet Delivery Ratio	2	3	1	4

Table 5.39: Performance of MPP's placement schemes in Linear Settlement Pattern

Performance Metrics	Grid	Incremental	MTW	Random
Throughput	3	2	1	4
End-to-end Delay	3	2	1	4
Packet Delivery Ratio	3	2	1	4

Table 5.40 : Performance of MPP's placement schemes in Dispersed Settlement Pattern

Performance Metrics	Grid	Incremental	MTW	Random
Throughput	1	2	3	4
End-to-end Delay	1	2	3	4
Packet Delivery Ratio	1	2	3	4

Table 5.41 : Performance of MPP's placement schemes in Isolated Settlement Pattern

Performance Metrics	Grid	Incremental	MTW	Random
Throughput	2	1	3	4
End-to-end Delay	2	1	3	4
Packet Delivery Ratio	2	1	3	4

It is also important to consider the fact that as more MAPs cluster towards the center the possibility of the interfering MPP's is very high since there would not be enough distance between them, interestingly the MTW caters for this effect by constructing a table of interfering MPP's whereby the conflicting MPP's are separated giving them enough distance between, in this case the interference is minimized. Simulation results summary for the linear settlement pattern in table 5.38 revealed that the MTW outperformed the other placement schemes by obtaining higher network throughput and successfully delivered packets while ensuring minimum end-to-end delay.

In the linear scenario the MAP's are closely arranged in a sort of lineal topology and MPP's should be deployed where enough MAP's will be able to access it. Again, the MTW ensure that there is enough distance between the deployed MPP's. Table 5.39 represents the simulation results of MPP's placement schemes in the dispersed settlement pattern, it can be observed that the Grid based placement scheme is the best scheme for this settlement because it experiences less end-to-end delay, higher network throughput and packet delivery ratio then the other placement schemes. The distribution of MAP's is uneven in the dispersed settlement pattern which complicates the deployment of MPP's and the physical distractions affect transmission of the packet.

The Grid based placement scheme managed to achieve best performance by ensuring that the selected MPP's candidate position would guarantee schedulable links which are interference free. To guarantee fair consideration for all the MAP's the terrain is divided into equal grids and at each grid MPP is deployed at the center giving enough concentration for MAP's from all directions. Table 5.41depict the simulation results of all four placement schemes in an isolated settlement pattern. It can be noted that Incremental clustering placement scheme outperformed the other three placement schemes by achieving higher packet delivery ratio, throughput and reduced end-to-end delay. This is due to the fact that Incremental clustering caters for the uncovered MAP’s (isolated MAP’s) by ensuring that for every uncovered MAP’s cluster the MPP’s are deployed.

In a general overview, MPP’s placement schemes revealed the same behavior in all the scenarios at the beginning of the simulation. When few MAP’s were deployed, the network throughput and packet delivery ratio was very high while the end-to-end delay was low. However, increase in the number of MAP’s decreased the packet delivery ratio and network throughput while increasing the end-to-end delay. This is due to the fact that when there are few MAP’s there is enough bandwidth capacity to be shared among few MAP’s at the MPP. Increase in the number of MAP’s causes a bottleneck on the MPP, degrading the network performance. On the other hand, deploying more than one MPP helps to improve the network performance although the behavior of the placement schemes is still the same as previously explained. The increase in the network throughput and packet delivery ratio is better than when only one MPP is deployed and even when more MAP’s are used the decrease in the network performance in the throughput and packet delivery ratio is less than when only one MPP is deployed. The same apply to the end-to-end delay variant. The reason behind such behavior is due the fact that now each MPP would receive less traffic when traffic from MAP’s is shared among the existing MPP’s.

Another fact is that the number of hops a packets needs to travel is reduced in this way, thus network performance improves since the network would be less prone to errors, like packet loss/ packet drop, network speed. In the nucleated settlement pattern all placement (including the least performing Random placement) schemes provided an outstanding network performance, this is because there are short distances between the MP’s and packet would not have to travel long distances to and from MP’s hence chances of transmission disturbances are small. However, as more MPP’s are being deployed the network performance degrades due to interference among the MPP’s.

-CHAPTER SIX-

CONCLUSION AND FUTURE WORK

6.1 Conclusion

This work aimed to investigate the effects of existing Mesh Points Placement schemes on rural settlement patterns in order to improve the performance for future rural Wireless Mesh Network (WMN) deployments. The good behavior and operability of a WMN mainly depends on the placement of MP's in a geographical deployment area. Hence common settlement patterns in the rural Africa were identified and used for evaluation of MP's. The objective is to find the optimal positions where MP's could be deployed. This is a two way problem, the first task is to find optimal positions for placing Mesh Access Points (MAP's) and the second task is to select the optimal position for deploying Mesh Portal Points (MPP's). The last task involves selecting possible MAP's to connect to the internet by wires and act as a gateway for the entire WMN.

The goal of this work was to compare the existing MP's placement schemes and to recommend the best scheme to be used for rural wireless mesh network deployment. In the process of achieving the research goal the first question to answer is how MP's placement addressed in the literature. In order to study the existing MP's placement schemes a classification framework was developed taking into account the type of Mesh Clients (MC's), distribution of MC's, type of MAP's, distribution of MAP's, purpose, approach used to solve placement problem and the type of evaluation.

Using the developed classification framework, work on MAP's placement schemes was analyzed and categorized into three groups, however due to time constraints only one scheme was selected for simulation purposes from each group. In the first group, Movement Based MAP's placement scheme, the Hill Climbing placement scheme was selected; in the second group, Measure and Place MAP's placement, the Time-efficient Local Search placement scheme was selected and in the third group, Relay Based MAPs placement, the Virtual Force Based was selected.

The literature review was furthered by analyzing MPP's placement schemes and as a deliverable MPP's placement schemes were categorized into three groups, namely Greedy-Based MPP's placement, Clustering-Based MPP's placement schemes and Weighted-Based MPP's placement schemes. Again only one scheme was selected from each group. On the Clustering-based, the Incremental clustering MPP placement scheme was selected; on the Greedy Based, the novel Grid MPP placement scheme was selected and on the Weighted-Based, the MTW/ MPP placement scheme was selected. The classification framework assisted to accomplish the first objective of this study which is a prerequisite for the other objectives.

The selected MP's placement schemes were implemented using java Netbeans IDE 6.9.1 and simulated using NS2. The second objective considered finding optimal positions for deploying MAPs given a number of MC's distributed in isolated, dispersed, nucleated and linear settlement patterns. This objective involved simulating the selected placement schemes using the same network environment/parameters. The third objective involved evaluating and comparing Time-efficient Local Search, Hill Climbing and VFPlace placement methods in the four rural settlement patterns in order to judge on their suitability of solving the MAP's placement problem in a rural scenario. The main objective was to study the performance of the schemes and to recommend the best scheme among the three families that improves the network performance altogether. Different from the existing work, this work not only concentrates on optimizing coverage and connectivity but also on improving the packet delivery ratio, throughput while reducing network end-to-end delay. From the study, it was observed that no scheme was best in all rural scenarios; schemes reacted differently due to their characteristics and limitations imposed by the particular settlement pattern. The study revealed that Hill Climbing is a better fit for solving MAP's placement problems than the other placement methods in nucleated and dispersed settlement patterns (refer to table 4.22 and table 4.23).

This could be explained by the fact that Hill Climbing exchanges local movements during the search, applies a radius movement for better search in a dense area and swap movement in the area with the diversity of MC's distribution. Thus viewing this behavior with respect to the nucleated pattern where MCs are located closely toward the center and dispersed pattern where MCs are sparsely distributed in no particular order, it can be concluded that Hill Climbing has an advantage for better search due to local movements.

The VFPlace was found to be more suitable for deployment in the linear settlement pattern than the Time-efficient Local Search and Hill Climbing MAPs placement schemes (refer to table 4.24). MC's in this settlement form a line like pattern and the VFPlace is more privileged to choose optimal MAPs positions with ease by applying attractive force to pull MAP's closely to each other placing MAP's only in the preferential areas and by applying the repulsive force, pushing MAP's away from the prohibitive areas, thus reducing potential interference. In the isolated settlement pattern the Time-efficient Local Search outperformed the Hill Climbing and VFPlace MAPs placement schemes. This attribute can be explained by the fact that in the Time-efficient Local Search before a position is selected, all the possible positions are measured to ensure that the MAP's that can give maximum required signal strength which can cover large areas selected. The Random MAP's placement scheme performed poorly in all the settlement patterns, this behavior was caused by the fact that the random placement in most scenarios chooses the obsolete MAP's positions which is not in communication range with the other MAPs thus degrading the entire network performance. In the experimental study it was also observed that all the placement schemes achieved outstanding performance in terms of achieving high coverage and connectivity which contributed in increasing the network throughput, packet delivery ratio and decreased the end-to-end in a nucleated pattern than in the other patterns.

The performance of the placement schemes was very hard to distinguish and very low when only few MAP's were deployed, however, as the number of deployed MAPs increased the coverage, connectivity, packet delivery ratio and throughput increased, while the network-end-to-end delay decreased. Recommended MAP's placement schemes were then used as a basis for achieving the fourth objective which involves simulating the selected MPPs placement schemes in rural settlement patterns. Packet delivery ratio, throughput and end-to-end delay were the three metrics used to evaluate and judge the performance of MPP's placement schemes and this was the last objective of this study.

The experimental study revealed that the MTW outperformed the Incremental, Grid and Random MPP's placement schemes by improving the network performance in the nucleated and dispersed settlement patterns. The MTW achieved this performance by selecting the positions with the highest weight of hops as MPP's and by ensuring that the MPP's do not interfere with each other bearing in mind that the nucleated and linear settlement patterns have a short distance between the MP's. The experimental evaluation showed that the Grid based MPP's placement scheme should be applied as a first choice for solving placement problem in a dispersed settlement pattern due to it better performance outperforming the other placement schemes. On the other hand, the Incremental Clustering was recommended for solving deployment in isolated settlement pattern. The Random placement performs poorly in all settlement patterns and is found to be the least of the other placement schemes. A single MPP gives high packet delivery ratio and high throughput while obtaining minimal end-to-end delay however as the number of MAP’s that a MPP will have to serve increases, the performance of the network also decreases. Experimental study also shows that deploying more MPP’s enhances the network performance; this behavior is due to the fact that the bottleneck problem at the MPP will now be resolved since traffic from MAP’s will now be shared among the existing MPP’s. Having successfully achieved the goal of this research, the following section gives an insight to possible future directions.

6.2 Limitations and Future work

This section presents the limitations together with the possible future work directions. Due to time constraints, only one placement scheme was selected from each MP placement group for simulation, even though the goal of this work is achieved, selecting more than one MP placement scheme would help to verify the accuracy of the result obtained from each group. Even though settlements patterns represented the picture of the real world scenario, however simulation had limitations of radio propagation models most importantly in presenting all the physical medium present in a real world scenario which highly affect signal transmission such as hills and trees. For future work we intend to further the study by now performing an outdoor test bed in order to test the effectiveness of the recommended placement schemes in a realistic environment which would be affected by distances between nodes, environmental effects on signal propagation and realistic application traffic load on the network and to confirm if the simulation findings are valid. Another important area that can be investigated is the effect the recommended placement schemes on power control and rate adaptations in order to further form the sustainable network performance, more especially since the power control is still a challenging factor in most rural Africa.

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APPENDIX A

Simulation Script

```
#
======================================================================
====
# Define options
#
======================================================================
====
set opt(chan)           Channel/WirelessChannel          ;# channel type
set opt(prop)           Propagation/TwoRayGround  ;# radio-propagation model
set opt(netif)          Phy/WirelessPhy                  ;# network interface type
set opt(mac)            Mac/802_11                ;# MAC type
set opt(ifq)            Queue/DropTail/PriQueue          ;# interface queue type
set opt(ll)             LL                        ;# link layer type
set opt(ant)          Antenna/OmniAntenna         ;# antenna model
set opt(ifqlen)         50                        ;# max packet in interface queue
set opt(rp)           DSDV;                       ;# routing protocol script
set opt(nn)             20                        ;# number of mobile nodes
set opt(x)              722                  ;# X dimension of the topography
set opt(y)              580                       ;# Y dimension of the topography
set opt(sc)             "ScenarioGridBaseddis20"  ;# scenario file.
set opt(cp)             "20MNTraffic"                    ;# connection pattern file
set opt(seed)           0.0                       ;# seed for random number gen.
set opt(stop)           120.0                     ;# simulation time
set opt(tr)             zama.tr                   ;# trace file
#set opt(lm)          "off"          ;# log movement
#set opt(agent)        Agent/DSDV
#set opt(energymodel)   EnergyModel      ;
#set opt(initialenergy)  1.0           ;# Initial energy in Joules
#set opt(logenergy)      "on"          ;# log energy every 150 seconds

#
======================================================================
====
```

```
# needs to be fixed later
#set AgentTrace                    ON
#set RouterTrace              ON
#set MacTrace                 OFF

#NZY
set num_wired_nodes       1

#Number of MPPs
set num_bs_nodes          2


LL set mindelay_              50us
LL set delay_                 25us
LL set bandwidth_             0

Agent/Null set sport_         0
Agent/Null set dport_         0

Agent/CBR set sport_          0
Agent/CBR set dport_          0

Agent/TCPSink set sport_      0
Agent/TCPSink set dport_      0

Agent/TCP set sport_          0
Agent/TCP set dport_          0
Agent/TCP set packetSize_     1460

Queue/DropTail/PriQueue set Prefer_Routing_Protocols    1

# unity gain, omni-directional antennas
# set up the antennas to be centered in the node and 1.5 meters above it
Antenna/OmniAntenna set X_ 0
Antenna/OmniAntenna set Y_ 0
```

```
Antenna/OmniAntenna set Z_ 1.5
Antenna/OmniAntenna set Gt_ 1.0
Antenna/OmniAntenna set Gr_ 1.0

# Initialize the SharedMedia interface with parameters to make
# it work like the 914MHz Lucent WaveLAN DSSS radio interface
Phy/WirelessPhy set CPThresh_ 10.0
Phy/WirelessPhy set CSThresh_ 1.559e-11
Phy/WirelessPhy set RXThresh_ 3.652e-10
Phy/WirelessPhy set Rb_ 2*1e6
#Phy/WirelessPhy set Pt_ 0.2818
Phy/WirelessPhy set freq_ 914e+6
Phy/WirelessPhy set L_ 1.0

#
=================================================================
====

proc usage { argv0 }  {
	puts "Usage: $argv0"
	puts "\tmandatory arguments:"
	puts "\t\t\[-x MAXX\] \[-y MAXY\]"
	puts "\toptional arguments:"
	puts "\t\t\[-cp conn pattern\] \[-sc scenario\] \[-nn nodes\]"
	puts "\t\t\[-seed seed\] \[-stop sec\] \[-tr tracefile\]\n"
}


proc getopt {argc argv} {
	global opt
	lappend optlist cp nn seed sc stop tr x y

	for {set i 0} {$i < $argc} {incr i} {
	set arg [lindex $argv $i]
	if {[string range $arg 0 0] != "-"} continue
```

```
        set name [string range $arg 1 end]
        set opt($name) [lindex $argv [expr $i+1]]
        }
}

#
=====================================================================
====
# Main Program
#
=====================================================================
====
getopt $argc $argv

#source ../lib/ns-bsnode.tcl
# do the get opt again incase the routing protocol file added some more
# options to look for
getopt $argc $argv

#
=====================================================================
==========
# check for boundary parameters and random seed
if { $opt(x) == 0 || $opt(y) == 0 } {
        usage $argv0
        exit 1
}

if {$opt(seed) > 0} {
        puts "Seeding Random number generator with $opt(seed)\n"
        ns-random $opt(seed)
}

# create simulator instance
set ns_ [new Simulator]

#Sets number of nodes per cluster
```

```
set nodes_per_cluster [expr $opt(nn) / $num_bs_nodes]
puts "Nodes per cluster: $nodes_per_cluster\n"

#Calculates the number of remaining nodes for distribution
set remaining_nodes [expr $opt(nn) % $num_bs_nodes]
puts "Remaining nodes: $remaining_nodes\n"

#Set up for hierarchical routing
$ns_ node-config -addressType hierarchical

#Set up number of domains( "1" wired domain plus "N" wireless domains)
AddrParams set domain_num_ [expr $num_bs_nodes + 1] ;# number of domains
#puts "Number of domains: $domain_num_\n"

if {$num_bs_nodes == 1} {
   lappend cluster_num 1 1 ;# number of clusters in each domain
   lappend eilastlevel  1 $nodes_per_cluster ;# number of nodes in each cluster
} elseif {$num_bs_nodes == 2} {
   lappend cluster_num 1 1 1 ;# number of clusters in each domain
   lappend eilastlevel  1 $nodes_per_cluster $nodes_per_cluster ;# number of nodes in each
cluster
} elseif {$num_bs_nodes == 3} {
   lappend cluster_num 1 1 1 1 ;# number of clusters in each domain
   lappend eilastlevel  1 $nodes_per_cluster $nodes_per_cluster [expr
$nodes_per_cluster+$remaining_nodes] ;# number of nodes in each cluster
}
AddrParams set cluster_num_ $cluster_num
AddrParams set nodes_num_ $eilastlevel

set tracefd       [open $opt(tr) w]
$ns_ trace-all $tracefd

# Create topography object
set topo          [new Topography]

# define topology
```

```
$topo load_flatgrid $opt(x) $opt(y)

# Create God
create-god [expr $opt(nn) + $num_bs_nodes]



#create wired nodes
set WN [$ns_ node 0.0.0]

#
#  Create the specified number of nodes $opt(nn) and "attach" them
#  the channel.
#  Each routing protocol script is expected to have defined a proc
#  create-mobile-node that builds a mobile node and inserts it into the
#  array global $node_($i)
#
#global node setting
$ns_ node-config -adhocRouting $opt(rp) \
        -llType $opt(ll) \
            -macType $opt(mac) \
            -ifqType $opt(ifq) \
            -ifqLen $opt(ifqlen) \
        -antType $opt(ant) \
        -propType $opt(prop) \
        -phyType $opt(netif) \
        -channelType $opt(chan) \
        -topoInstance $topo \
          -wiredRouting ON \
        -agentTrace ON \
          -routerTrace ON \
          -macTrace OFF
# General pseudo-random sequence generator
set genSeed [new RNG]
$genSeed seed $opt(seed)
set randomSeed [new RandomVariable/Uniform]
```

```
$randomSeed use-rng $genSeed
$randomSeed set min_ 1.0
$randomSeed set max_ 100.0

#  model: x node position [m]
set genNodeX [new RNG]
$genNodeX seed [expr [$randomSeed value]]
set randomNodeX [new RandomVariable/Uniform]
$randomNodeX use-rng $genNodeX
$randomNodeX set min_ 1.0
$randomNodeX set max_ [expr $opt(x) - 1.0]

# model: y node position [m]
set posNodeY [new RNG]
$posNodeY seed [expr [$randomSeed value]]
set randomNodeY [new RandomVariable/Uniform]
$randomNodeY use-rng $posNodeY
$randomNodeY set min_ 1.0
$randomNodeY set max_ [expr $opt(y) - 1.0]

# create base-station node
# Base stations are created with wired routing flag turned on since
# they are a gateway to the wired network
set temp {1.0.0 2.0.0 3.0.0}   ;# hierarchical address to be used for base stations

puts "Creating \$num_bs_nodes base station nodes..\n"
for {set i 0} {$i < $num_bs_nodes } {incr i} {

  set bs_($i) [$ns_ node [lindex $temp $i]]
  $bs_($i) random-motion 0  ;# disable random motion

  #provide some random co-ord (fixed) to base station node
  $bs_($i) set X_ [expr [$randomNodeX value] ]
  $bs_($i) set Y_ [expr [$randomNodeY value] ]
  $bs_($i) set Z_ 0.0
```

```
   puts "BS [$bs_($i) node-addr] created..\n"
}

#Turn off wired routing
$ns_ node-config -wiredRouting OFF


puts "total nodes $opt(nn)\n"

for {set i 1} {$i <= $opt(nn) } {incr i} {


  set index [expr $i - 1]
  if {$num_bs_nodes == 1 } {

       set node_($index) [$ns_ node 1.0.$i]
           $node_($index) base-station [AddrParams addr2id [$bs_(0) node-addr]]
  } elseif { $num_bs_nodes == 2 } {
      if {$i < $nodes_per_cluster} {
         set node_($index) [$ns_ node 1.0.$i]
         $node_($index) base-station [AddrParams addr2id [$bs_(0) node-addr]]
      } else {
         set node_($index) [$ns_ node 2.0.$i]


         $node_($index) base-station [AddrParams addr2id [$bs_(1) node-addr]]
      }

puts "total nodes $opt(nn)\n"

for {set i 1} {$i <= $opt(nn) } {incr i} {
```

```
# Illustration of hierarhical addressing scheme
#                                WN(0.0.0)
#                                    |
#                                  / | \
#                                 /  |  \
#                                /   |   \
#                               /    |    \
#                              /     |     \
#                             /      |      \
#                            /       |       \
#                           /        |        \   1 Wired network domain
#                          /         |         \
#                         /          |          \
#                        /           |           \
#                       /            |            \
#                      /             |             \
#                     /              |              \
#                    /               |               \
#                   /                |                \
#                  /                 |                 \
#         BS(1.0.0)             BS(2.0.0)             BS(3.0.0)     3 Gateways
#              |                     |                     |
#             /|\                  / | \                 / | \
#            / | \                /  |  \               /  |  \
#           /  |  \              /   |   \             /   |   \   3 Wireless network domains
#          /   |   \            /    |    \           /    |    \
#         /    |    \          /     |     \         /     |     \
#        /     |     \        /      |      \       /      |      \
# MN(1.0.1)   MN(1.0.2)  MN(1.0.3)  MN(2.0.1)   MN(2.0.2)    MN(2.0.3)   MN(3.0.1)
MN(3.0.2)      MN(3.0.3)
```

```
  set index [expr $i - 1]
  if {$num_bs_nodes == 1 } {

        set node_($index) [$ns_ node 1.0.$i]
            $node_($index) base-station [AddrParams addr2id [$bs_(0) node-addr]]
  } elseif { $num_bs_nodes == 2 } {
       if {$i < $nodes_per_cluster} {
          set node_($index) [$ns_ node 1.0.$i]
          $node_($index) base-station [AddrParams addr2id [$bs_(0) node-addr]]
       } else {
          set node_($index) [$ns_ node 2.0.$i]
          $node_($index) base-station [AddrParams addr2id [$bs_(1) node-addr]]
       }
  } elseif {$num_bs_nodes == 3} {

  }
  $node_($index) random-motion 0 ;# disable random motion
}

#create links between wired nodes and base station nodes
if {$num_bs_nodes == 1} {
  $ns_ duplex-link $WN $bs_(0) 5Mb 2ms DropTail
} elseif {$num_bs_nodes == 2} {
  $ns_ duplex-link $WN $bs_(0) 5Mb 2ms DropTail
  $ns_ duplex-link $WN $bs_(1) 5Mb 2ms DropTail
} elseif {$num_bs_nodes == 3} {
  $ns_ duplex-link $WN $bs_(0) 5Mb 2ms DropTail
  $ns_ duplex-link $WN $bs_(1) 5Mb 2ms DropTail
  $ns_ duplex-link $WN $bs_(2) 5Mb 2ms DropTail
}


# Source the Connection and Movement scripts
#
if { $opt(cp) == "" } {
```

```
        puts "*** NOTE: no connection pattern specified."
      set opt(cp) "none"
} else {
        puts "Loading connection pattern..."
        source $opt(cp)
}


#
# Tell all the nodes when the simulation ends
#
for {set i 0} {$i < $opt(nn) } {incr i} {
   $ns_ at $opt(stop).000000001 "$node_($i) reset";
}
$ns_ at $opt(stop).00000001 "puts \"NS EXITING...\" ; $ns_ halt"


if { $opt(sc) == "" } {
        puts "*** NOTE: no scenario file specified."
      set opt(sc) "none"
} else {
        puts "Loading scenario file..."
        source $opt(sc)
        puts "Load complete..."
}

puts $tracefd "M 0.0 nn $opt(nn) x $opt(x) y $opt(y) rp $opt(rp)"
puts $tracefd "M 0.0 sc $opt(sc) cp $opt(cp) seed $opt(seed)"
puts $tracefd "M 0.0 prop $opt(prop) ant $opt(ant)"

puts "Starting Simulation..."
$ns_ run
```

CBRGEN

```
======================================================================
====
# Default Script Options
#
======================================================================
====
set opt(nn)             0               ;# Number of Nodes
set opt(seed)           0.0
set opt(mc)             0
set opt(pktsize)        512
set opt(bc)     1

set opt(rate)           0
set opt(interval)       0.0             ;# inverse of rate
set opt(type)         ""

#
======================================================================
====

proc usage {} {
   global argv0

   puts "\nusage: $argv0 \[-type cbr|tcp\] \[-nn nodes\] \[-bc bc\] \[-seed seed\] \[-mc
connections\] \[-rate rate\]\n"
}

proc getopt {argc argv} {
        global opt
        lappend optlist nn seed mc rate type bc

        for {set i 0} {$i < $argc} {incr i} {
        set arg [lindex $argv $i]
        if {[string range $arg 0 0] != "-"} continue
```

```
            set name [string range $arg 1 end]
            set opt($name) [lindex $argv [expr $i+1]]
            }
}

proc create-cbr-connection { src dst } {
           global rng cbr_cnt opt

           set stime [$rng uniform 0.0 180.0]

           #set dst 0

           puts "#\n# $src connecting to $dst at time $stime\n#"

           ##puts "set cbr_($cbr_cnt) \[\$ns_ create-connection \
           ##CBR \$node_($src) CBR \$node_($dst) 0\]";
           puts "set udp_($cbr_cnt) \[new Agent/UDP\]"
           puts "\$ns_ attach-agent \$node_($src) \$udp_($cbr_cnt)"
           puts "set null_($cbr_cnt) \[new Agent/Null\]"
           puts "\$ns_ attach-agent \$node_($dst) \$null_($cbr_cnt)"
           puts "set cbr_($cbr_cnt) \[new Application/Traffic/CBR\]"
           puts "\$cbr_($cbr_cnt) set packetSize_ $opt(pktsize)"
           puts "\$cbr_($cbr_cnt) set interval_ $opt(interval)"
           puts "\$cbr_($cbr_cnt) set random_ 1"
           puts "\$cbr_($cbr_cnt) set maxpkts_ 10000"
           puts "\$cbr_($cbr_cnt) attach-agent \$udp_($cbr_cnt)"
           puts "\$ns_ connect \$udp_($cbr_cnt) \$null_($cbr_cnt)"

           puts "\$ns_ at $stime \"\$cbr_($cbr_cnt) start\""

           incr cbr_cnt
#######################################################################
#adds a reverse traffic flow
           set stime [$rng uniform 0.0 180.0]
```

```
	puts "#\n# $dst connecting to $src at time $stime\n#"

	##puts "set cbr_($cbr_cnt) \[\$ns_ create-connection \
	##CBR \$node_($src) CBR \$node_($dst) 0\]";
	puts "set udp_($cbr_cnt) \[new Agent/UDP\]"
	puts "\$ns_ attach-agent \$node_($dst) \$udp_($cbr_cnt)"
	puts "set null_($cbr_cnt) \[new Agent/Null\]"
	puts "\$ns_ attach-agent \$node_($src) \$null_($cbr_cnt)"
	puts "set cbr_($cbr_cnt) \[new Application/Traffic/CBR\]"
	puts "\$cbr_($cbr_cnt) set packetSize_ $opt(pktsize)"
	puts "\$cbr_($cbr_cnt) set interval_ $opt(interval)"
	puts "\$cbr_($cbr_cnt) set random_ 1"
	puts "\$cbr_($cbr_cnt) set maxpkts_ 10000"
	puts "\$cbr_($cbr_cnt) attach-agent \$udp_($cbr_cnt)"
	puts "\$ns_ connect \$udp_($cbr_cnt) \$null_($cbr_cnt)"

	puts "\$ns_ at $stime \"\$cbr_($cbr_cnt) start\""

	incr cbr_cnt
}

proc create-tcp-connection { src dst } {
	global rng cbr_cnt opt

	set stime [$rng uniform 0.0 180.0]

	#set dst 0

	puts "#\n# $src connecting to $dst at time $stime\n#"

	puts "set tcp_($cbr_cnt) \[\$ns_ create-connection \
	TCP \$node_($src) TCPSink \$bs_($dst) 0\]";
	puts "\$tcp_($cbr_cnt) set window_ 32"
	puts "\$tcp_($cbr_cnt) set packetSize_ $opt(pktsize)"
```

```
        puts "set ftp_($cbr_cnt) \[\$tcp_($cbr_cnt) attach-source FTP\]"


        puts "\$ns_ at $stime \"\$ftp_($cbr_cnt) start\""

        incr cbr_cnt

####################################################################
#adds a reverse traffic flow
        set stime [$rng uniform 0.0 180.0]

        puts "#\n# $dst connecting to $src at time $stime\n#"

        puts "set tcp_($cbr_cnt) \[\$ns_ create-connection \
        TCP \$bs_($dst) TCPSink \$node_($src) 0\]";
        puts "\$tcp_($cbr_cnt) set window_ 32"
        puts "\$tcp_($cbr_cnt) set packetSize_ $opt(pktsize)"

        puts "set ftp_($cbr_cnt) \[\$tcp_($cbr_cnt) attach-source FTP\]"


        puts "\$ns_ at $stime \"\$ftp_($cbr_cnt) start\""

        incr cbr_cnt

}

#
===================================================================
====

getopt $argc $argv

if { $opt(type) == "" } {
   usage
   exit
```

```
} elseif { $opt(type) == "cbr" } {
   if { $opt(nn) == 0 || $opt(seed) == 0.0 || $opt(mc) == 0 || $opt(rate) == 0 || $opt(bc) == 0 }
{
         usage
         exit
   }

   set opt(interval) [expr 1 / $opt(rate)]
   if { $opt(interval) <= 0.0 } {
         puts "\ninvalid sending rate $opt(rate)\n"
         exit
   }
}

puts "#\n# mobile nodes: $opt(nn), bs nodes: $opt(bc),  max conn: $opt(mc), send rate:
$opt(interval), seed: $opt(seed)\n#"

set rng [new RNG]
$rng seed $opt(seed)

set u [new RandomVariable/Uniform]
$u set min_ 0
$u set max_ 100
$u use-rng $rng

set cbr_cnt 0
set src_cnt 0

#Base station addresses
if { $opt(bc) == 2 } {
  set nodes_per_bs [expr $opt(nn)/$opt(bc)]
}

for {set i 0} {$i < $opt(nn) } {incr i} {

      if { $opt(bc) == 1 } {
```

```
   set dst 0
    } elseif { $opt(bc) == 2 } {
     if { $i < $nodes_per_bs } {
         set dst 0
     } else {
         set dst 1
          }
}

    #set x [$u value]

    #if {$x < 50} {continue;}

    incr src_cnt

#set dst [expr ($i+1) % [expr $opt(nn) + 1] ]

    if { $opt(type) == "cbr" } {
    create-cbr-connection $i $dst
    } else {
    create-tcp-connection $i $dst
    }

    if { $cbr_cnt == $opt(mc) } {
    break
    }


puts "#\n#Total sources/connections: $src_cnt/$cbr_cnt\n#"
```

APPENDIX B

Average Throughput awk script

```
BEGIN {
      recvdSize = 0
      startTime = 400
      stopTime = 0
  }

  {
            event = $1
            time = $2
            node_id = $3
            pkt_size = $8
            level = $4

  # Store start time
  if (level == "AGT" && event == "s" && pkt_size >= 512) {
    if (time < startTime) {
            startTime = time
            }
      }

  # Update total received packets' size and store packets arrival time
  if (level == "AGT" && event == "r" && pkt_size >= 512) {
      if (time > stopTime) {
            stopTime = time
            }
      # Rip off the header
      hdr_size = pkt_size % 512
      pkt_size -= hdr_size
      # Store received packet's size
      recvdSize += pkt_size
      }
  }

  END {
      printf("Average Throughput[kbps] = %.2f\t\t
StartTime=%.2f\tStopTime=%.2f\n",(recvdSize/(stopTime-
startTime))*(8/1000),startTime,stopTime)
  }
```

Packet Delivery Ratio awk script

```
BEGIN {
        sendLine = 0;
        recvLine = 0;
        fowardLine = 0;
}

$0 ~/^s.* AGT/ {
        sendLine ++ ;
}

$0 ~/^r.* AGT/ {
        recvLine ++ ;
}

$0 ~/^f.* RTR/ {
        fowardLine ++ ;
}

END {
        printf "cbr s:%d r:%d, r/s Ratio:%.4f, f:%d \n", sendLine, recvLine,
(recvLine/sendLine),fowardLine;
}
```

End-to-end Delay awk script

```
#
=================================================================
=
# AWK Script for calculating:
#     => Average End-to-End Delay.
#
=================================================================
=
BEGIN {

   seqno = -1;

#    droppedPackets = 0;

#    receivedPackets = 0;

   count = 0;

}
```

```
{

   if($4 == "AGT" && $1 == "s" && seqno < $6) {

         seqno = $6;

   }


   #end-to-end delay

   if($4 == "AGT" && $1 == "s") {

         start_time[$6] = $2;

   } else if(($7 == "tcp") && ($1 == "r")) {
       end_time[$6] = $2;
   } else if($1 == "D" && $7 == "tcp") {
         end_time[$6] = -1;
   }
}

END {

   for(i=0; i<=seqno; i++) {
         if(end_time[i] > 0) {
             delay[i] = end_time[i] - start_time[i];
                 count++;
       }
           else
           {
                 delay[i] = -1;
           }
   }
   for(i=0; i<=seqno; i++) {
         if(delay[i] > 0) {
             n_to_n_delay = n_to_n_delay + delay[i];
       }
   }
  n_to_n_delay = n_to_n_delay/count;
   print "\n";
   print "Average End-to-End Delay    = " n_to_n_delay * 1000 " ms";
   print "\n";
}
```