Topology Planning Model for Rural Wireless Mesh Networks

Dissertation

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LETTER OF RECOMMENDATION

Mr. ***Bishnu Subedi*** has carried out this thesis work in title "**Topology Planning Model for Rural Wireless Mesh Networks"** under my supervision and guidance. In my best knowledge this dissertation/thesis successfully completed with fulfills the requirements for the aware of the Degree of Master's in computer science and information technology, therefore I recommended for further evaluation.

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We certify that we have read this dissertation work and in our opinion it is satisfactory in the scope and quality as a dissertation as the partial fulfillment of the requirement of Master in Computer Science and Information Technology from Tribhuvan University, Nepal.

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Abstract

The use of communication network is a major component of development to improve living standard of people. Deployment of wireless networks in the developed and developing countries differs in terms of its growth. The digital division has created a gap between developed and developing places, countries and regions.

Wireless mesh networks are the emerging area of wireless communication networks. Recent use of wireless mesh networks in the deployment of communication networks shows, it has great potential to be used in the rural areas as a cost effective solution. Remote and rural areas of developing countries like Nepal have difficult geographical and economical condition. So, cost effective solution with proper planning before deployment is required.

This study, focused on the planning of wireless mesh network as a cost effective solution for the rural areas, especially to find connectivity pattern (the topology) of each locations in the rural areas. The major findings showed that tree based topologies with point to multipoint links are suitable for minimizing the cost and effort to deploy networks in rural areas. Tree based topologies are also suitable to give flexibility to the advancement of deployed networks on these topologies.

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List of Abbreviations

CSMA/CA	Carrier Sense Multiple Access/Contention Avoidance
EMST	Euclidean Minimum Spanning Tree
ICT	Information Communication Technology
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
LOS	Line Of Sight
MAC	Medium Access Control
MST	Minimum Spanning Tree
NLOS	Non Line Of Sight
RNT	Rural Wireless Mesh Network Topology
STDMA	Spatial Time Division Multiple Access
TDMA	Time Division Multiple Access
VoIP	Voice over Internet Protocol
Wi-Fi	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave Access
WMN	Wireless Mesh Network
2D	Two Dimensional
3G	Third Generations
$802.11_{a/b/c/d/e/s}$/15/16	Families of IEEE Wireless Technology Standards

Chapter 1

Introduction

1.1. Introduction

Communication Network is a collection of computers and other communication devices connected via communication media that allows sharing of data, information and other resources. Network can be of any size and of varying complexity. Communication networks have become part of life in modern society. Recent progress in use of communication networks has changed the environment in which people’s requirements are fulfilled. Now a day’s people are dependent in communication network to perform every task to fulfill their requirements.

There has been a huge development of internet and other communication based services in the last two decades. However, this development is confined to only developed countries and metropolitan areas of developing countries. This is really unfortunate for the developing county like Nepal, where the majority of population is still living in rural areas and is out of the reach of communication based services and technologies. In other term there is a digital divide between people in rural areas and urban areas.

The use of communication based services and technologies could have improved the different aspects of life of the people in the rural areas. But there is s lack of communication networks in the rural areas. The lack has created a gap between rural and urban people in using communication based services and technologies.

One way of bridging this gap between people is to provide internet connectivity. This can be achieved cost effectively by establishing network with nearest developed part in the region. Connecting rural areas with wired network needs a lot of investment and time, so wireless system could serve as good alternative option. Deployment of wireless networking in some rural areas has shown significant improvement in the life style of people [1].

Even though, there is a encouraging sign of wireless networks deployments in rural and remote parts, they lacks systematic way of planning wireless networks before the deployments.

In urban areas the wireless network has moved one step ahead. There has been a trend to deploy wireless mesh network instead of wireless networks for the reliability and quality of service. This trend to deploy wireless mesh networks can be passed into the rural and remote areas for the connectivity with low cost and in less time and can be modified in future for the advancement of the networks.

The deployment wireless mesh network requires a systematic planning of the network. Formation of topology of networks is a major part of the systematic planning, since it defines the connectivity pattern of communication devices or the location in the rural areas.

This work contributes to ongoing research process in the area of planning process for wireless mesh network deployments. It focuses on how locations in the rural areas are connected to form a network, defining the topology of network.

1.2. Motivation

The motivation behind this study is the recent trend in the deployment in the wireless mesh networks. These deployments have shown the significant impact on improving the different aspects of life of people. These deployments are used to bridge the digital divide between the developed and developing areas. Development in the information and communication technology is concentrated mainly in the developed country and the urban part of the developing countries like Nepal. Deploying the wireless networks in the remote parts will allows the peoples to get the resources or the essential services through the networks. Connected topology pattern is the important part to plan the deployment of wireless mesh network in the rural areas.

1.3. Objective of the Study

The specific objective of this study was to describe and to analyze a rural wireless mesh topology planning model for the wireless networks planning process based on modifying the existing topologies to the date.

The general objectives of this study were stated as:

- To study the wireless mesh network architecture.
- To find out the necessity of topology planning model for the deployments of rural wireless networks.
- To describe the topology planning model for rural wireless mesh networks.
- To assess the topology planning model in the context of wireless networks deployments in rural areas.

1.4. Significance and Limitations of the Study

This study focuses on the physical topology planning of the rural wireless mesh networks. This also introduces the basic concepts associated with the wireless mesh and its architecture. This presents a topology planning model and assesses it in the network scenario. Hence, this study will serve as a building block for the topology planning for rural wireless mesh networks.

Every research work has to face some limitations. The main problem with this work is unavailability of the test-beds and the physical resources. So, this study uses the simulation environment. This study was completed within a confined time with limited resources. However, we had tried to make every possibility to carry out the study works more accurately as far as possible rather than just being perfunctory.

1.5. Report Structure

This section introduced some idea about the communication networks and their impact on the life of people. In this section the brief aspect of this study is also presented.

The rest of material in this study is organized into subsequent seven chapters.

Chapter 2 provides background study required for the dissertation. In this chapter, a brief overview of the various wireless mesh networking architectures and the conditions under which they can be applied are presented.

Chapter 3 presents the review of the literature related with the study. This chapter has presented various literatures and discussion on them.

Chapter 4 provides the description of related terminologies used for the problem solution approach of the topology planning model for the rural wireless mesh networks.

Chapter 5 presents overall solution approach for the topology planning for rural wireless mesh networks**.** The algorithmic view of rural topology planning model and algorithmic assessment also presented.

Chapter 6 incorporates the implementation details of topology planning models mentioned in Chapter 5

Chapter 7 includes the testing and evaluation with various test cases and their results obtained by using the designated implementation. The study includes comparing performance of implemented topology planning model.

Chapter 8 concludes our study with some remarks and future recommendation for the study on the planning for the wireless mesh network deployments.

Chapter 2

Background and Problem Definition

2.1 Wireless Networks

Wireless network refers to any type of computer network that is wireless, and is commonly associated with a telecommunication networks whose interconnections between nodes[1] is implemented without the use of wires [2]. Wireless telecommunication networks are generally implemented with some types of remote information transmission system that uses electromagnetic waves, such as radio waves.

2.2 Wireless Mesh Networks

Wireless mesh network (WMN) is a wireless network made up of radio nodes[2] organized in mesh topology [3]. In WMN, information data packets can be transmitted from one node to other nodes even though they may not be within direct communication range. Information data packets are routed from source to destinations over multiple nodes relaying the information for other nodes which is called as multiple hopping. This has a potential advantage in terms of network connectivity and reliability.

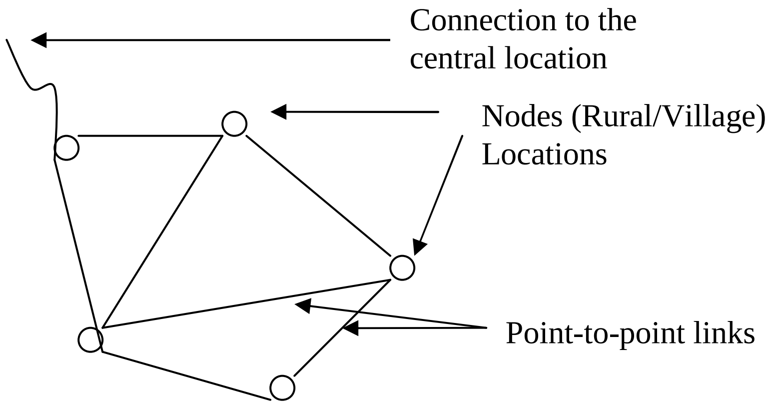

Fig 2.1. A Typical Wireless Mesh Network

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[1] Nodes are communication devices located at different geographic locations.
[2] A radio node is a communication device that uses radio signal for communication.

2.3 Network Topology

Network topology is the arrangement of mapping of nodes and links between nodes of network, especially the physical (real) and logical (virtual) interconnections between nodes [4].The mapping of links and nodes onto a graph results in a geometrical shape that determines the physical topology of the network. Likewise the mapping of flow of data between nodes in the network determines the logical topology of the network. The physical and logical topology might be identical in any particular network but also may different.

2.3.1 Mesh Topology

1. **Fully Connected Mesh**

The type of network topology in which each of nodes of the network is connected to each other nodes in the network with a point-to-point link. This makes it possible for data to be simultaneously transmitted from any single node to all of other nodes.

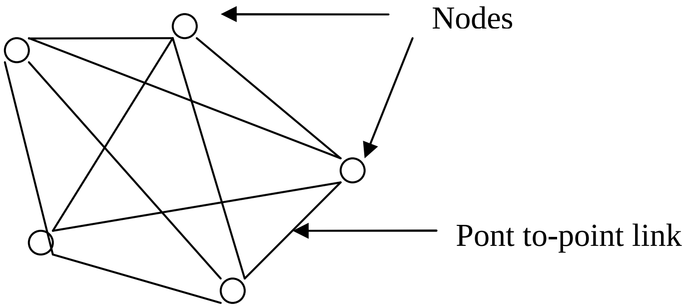

Fig 2.2. A fully connected mesh network of 5 nodes

2. Partially Connected Mesh

Network topology in which some of nodes of the network are connected to more than other node in the network with point-to-point link is called as partially connected mesh.

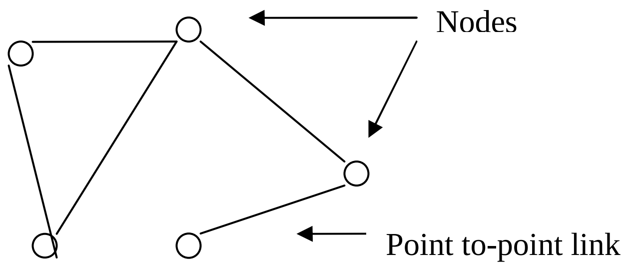

Fig 2.3. A partially connected mesh network of 5 nodes

2.4 Wireless Mesh Network Architecture

A wireless mesh network (WMN) is self-configuring network of wireless mesh nodes. WMNs use multi hopping to transmit data packets from the end user nodes to the internet gateways and vice versa. They are characterized by self organization and self healing capabilities; a key factor for a rapid, effective and low-cost network deployment [5].

Nodes in wireless mesh networks (WMNs) can play two different logical roles.

1. **Mesh Clients (Wireless Mesh Nodes)**

   Mesh clients are used by end user usage and either be the source or destination of network connection.

2. **Mesh Routers (Wireless Mesh Access Points)**

   Mesh routers are incharge of forwarding packets to and from the internet or other network. A single node in the network can play both roles at a same time with mesh router providing multi-hop backhaul connectivity to the internet while mesh client act as just source/destination of network connections.

This architecture provides more flexibility to system designers in deciding the powerful dedicated device with specific features like multi-radio interfaces to perform packet forwarding thus enhancing network performance. WMNs have to be thought as access network architecture to connect unconnected areas not as s tand alone network.

2.4.1 Architecture

Depending on the hierarchy by the differentiation of nodes functionality WMN architecture can be classified as following [5].

1. **Infrastructure/Backbone Wireless Mesh Networks**

This type of network can be built using various types of radio technologies in additions to the mostly used IEEE 802.11 based wireless technologies. This approach, also called infrastructure meshing, provides a backbone for conventional clients and enables integration of WMNs with existing wireless networks through Gateway/Bridge functionalities in mesh routers. Clients can directly connect to router using Ethernet ports (Ports for wired cabling).

As depicted in fig 2.4, wireless mesh routers realizes a self configuring and self healing mesh backbone, providing the mesh clients with opportunities to connect internet gateways.

Typical applications of this architecture are community/Village networking and in the wireless internet service providers. The deployment of Locust World [6] and MIT Roof Net [7] are based on this type of architecture.

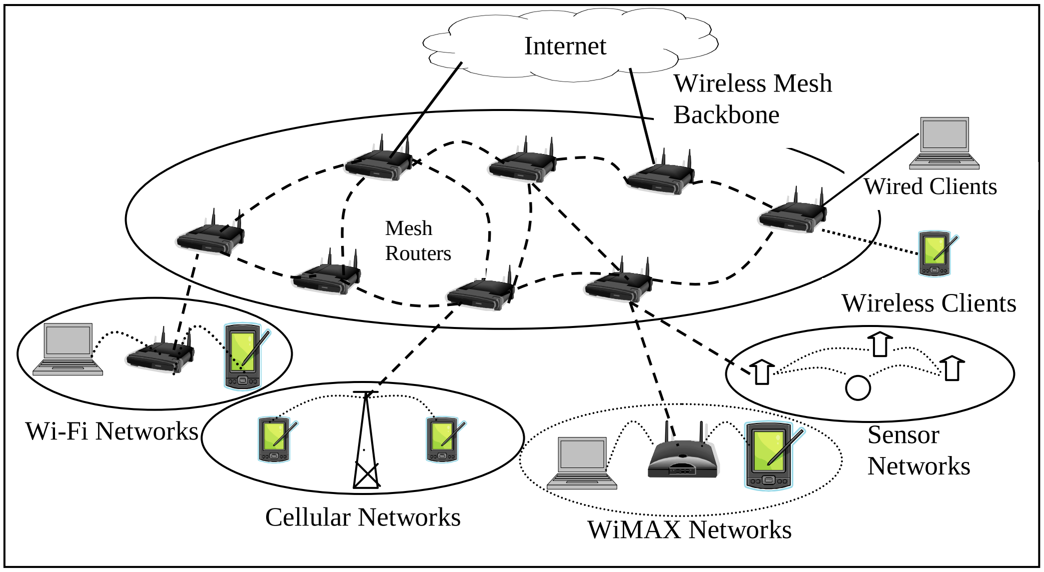

Fig2.4. Infrastructure/Backbone Wireless Mesh Networks (Source: [5])

2. Client Wireless Mesh Networks

In client WMNs, client nodes organize themselves into a flat architecture as depicted in fig 2.5. Client nodes constitute the actual network and are responsible for performing routing and configuration functionalities as well as providing end user applications like internet connectivity. Hence, mesh router is not required for these types of networks. Client WMNs are usually formed by using similar types of radio technologies used on communication devices.

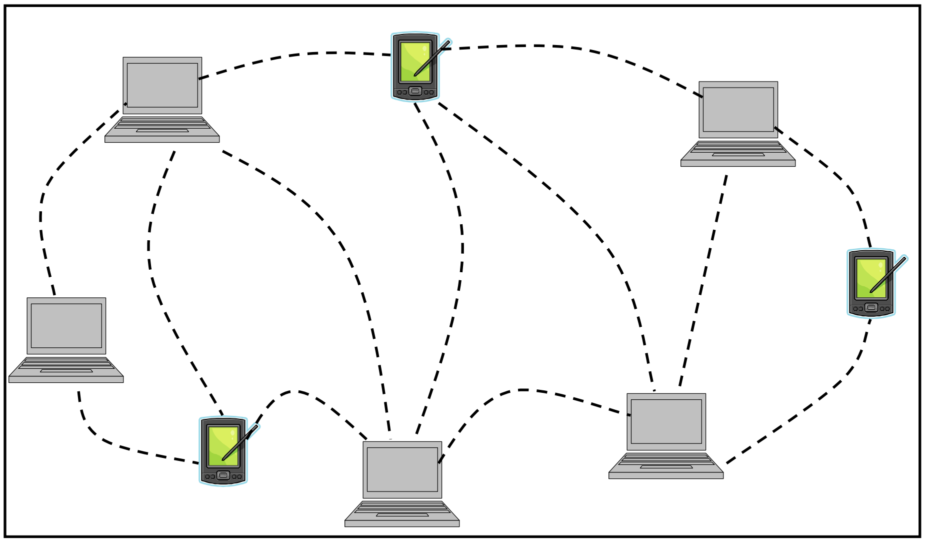

Fig 2.5. Client Wireless Mesh Networks (Source: [5])

3. Hybrid Wireless Mesh Networks

This architecture is the combination of infrastructure and client mesh networking as shown in fig 2.6. In hybrid wireless mesh networks, a hierarchy with dedicated mesh routers is present but at the same time client to client communications are enabled in order to extend coverage and robustness of the networks.

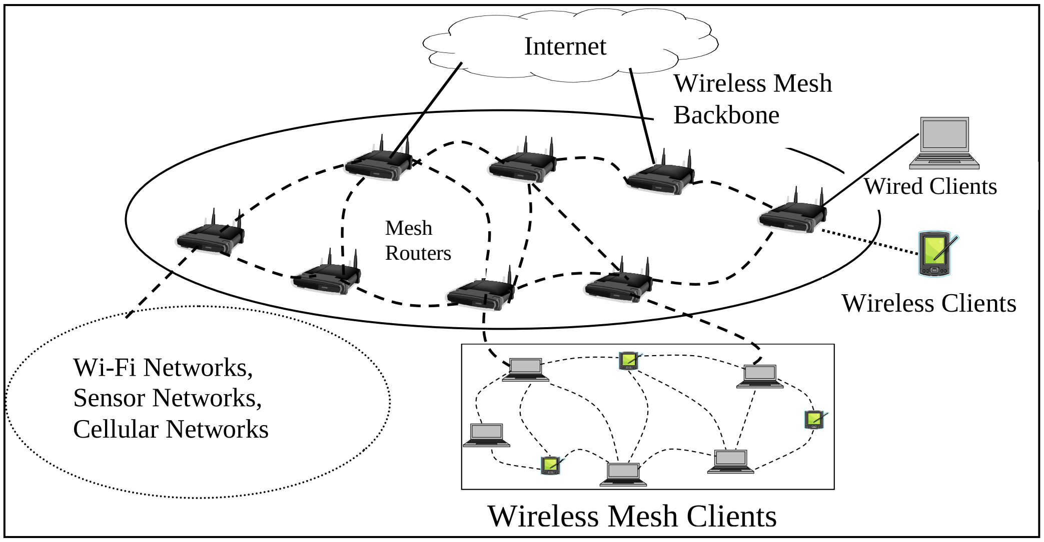

Fig 2.6. Hybrid Wireless Mesh Networks (Source: [5])

In principle WMN could interface, through suitable gateway nodes, networks based on different radio technologies 3G, Wi-Fi, IEEE, 802.15, WiMax etc. However in both academic and business environments, solutions heavily rely on family of IEEE 802.11 standards.

This comes from the large availability of low cost equipment on the market as well as “Ad- hoc” (ability to communicate with each other without central mechanism) features already present. In such family of standards, it is possible to obtain a mesh configuration with some minor changes.

2.5 Characterizing Features of WMNs

The WMNs are different than the conventional wireless networks or simple networks, since they have following characterizing features according to authors in [5].

1. Multi-hop wireless networks

An objective to develop WMNs is to extend the coverage range of current wireless networks without compromising the channel capacity. Another objective is to provide Non-line-of-sight (NLOS) connectivity among the nodes. To meet up these requirements, the mesh style multi hopping is needed [6].

2. Support for Ad-hoc networking, capability of self-forming, self-healing and self-organization

WMNs enhance network performance; because of flexible architecture, ease of deployment and configuration, and mesh connectivity i.e. multipoint-to-multipoint communications [7].

3. Mobility dependence on the type of mesh nodes

Mesh routers usually have minimal mobility, while mesh clients can be either stationary or have mobility within certain region.

4. Multiple types of network access

In WMNs both backhaul[3] access to the internet and peer-to-peer communications are supported [8]. In addition it can be integrated with other wireless networks.

5. Dependence of power consumption constraints on the type of mesh nodes

Mesh routers usually do not have constraints on power consumptions.

6. Compatibility and interoperability with existing wireless networks

WMNs are compatible and can operate with other existing wireless networks. For example, WMNs built based on IEEE 802.11 technologies must be compatible with IEEE 802.11 standards in the sense that both mesh capability and conventional Wi-Fi

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[3] Wireless backhaul is the use of wireless communications systems to get data from an end user to a node in a major network such as the Internet or the proprietary network of a large business, academic institution or government agency.

clients are supported. Such WMNs also need to be interoperable with other wireless networks such as WiMax and other networks [5].

2.6 Advantages of WMNs

Based on their characteristics, WMNs have following advantages according to the authors in [5].

1. Infrastructure/Backbone WMNs provide large coverage, connectivity and robustness.
2. Integration of conventional wireless clients can be done in WMNs. WMN also enables integration of other wireless networks.
3. Dedicated routing and configuration functionalities for all other clients are done by mesh routers. So client do not need to do additional configurations to connect network.
4. Mesh routers can be equipped with multiple radios to perform access functionalities. This enables the enhancement in traffic of data packets.

2.7 Application Scenarios of WMNs

Research and development of WMNs is motivated by several applications. All those applications are not supported by current wireless networks like cellular networks etc.

So, application scenarios where WMNs are the suitable, as presented by authors in [5] are described below.

1. **Broadband home networking**

   If access of broadband network in home is available, and there are many places in home where network is not accessible then mesh style structure of every device in home would allow broadband connectivity at any place in home.

2. **Community and Neighbourhood networking**

   Neighbours in the community are in a WMN and finally connected to gateways to provide applications as well as peer-to-peer network in the community. In this situation the whole community can be served through high bandwidth requiring applications like video applications.

3. **Enterprise networking**

   WMNs in the small office to all offices in entire building or a large scale networks among offices in the multiple buildings can be done. Expanding the network in such cases is easy in comparison to wire and other wireless networks.

4. **Metropolitan Area networking**

   WMNs in metropolitan area have several advantages. The transmission rate of node in WMNs is much higher than that of cellular networks. WMNs can be cost effective solution for the metropolitan area networking.

5. **Building automation**

   In building, various types of electrical devices including power, light, air conditioner etc, need to be controlled and monitored. Currently this task is done by conventional wiring. WMNs can be the solutions for controlling and monitoring the devices in the building.

6. **Heath and medical system**

   In hospital and medical centre, monitoring and diagnosis data need to be processed and transmitted from one location to other locations for various purposes or from remotely held clinic. In such cases data transmission rate needs to be higher. So WMNs can be deployed to achieve this goal.

7. **Security and surveillance system**

   Security is turning out to be very high concern. Security surveillance system becomes a necessity for enterprise buildings, shopping malls, other public areas, road traffic surveillance etc. WMNs can be better alternatives in those places.

8. **Rural area network coverage extension and telephony system**

   Various rural areas are still not connected to mainstream information and communication technologies (ICT). Hybrid structure of WMNs can be deployed as cost effective solution to connect rural areas.

9. **Disaster management system**

   When disaster strikes, disaster management team should have a communication system to coordinate work. In this situation, temporary communication system enabled by WMN can be served to the disaster management team.

   In the situation of disaster, the disaster management team can be served form temporary communication system enabled by WMNs.

2.8 Planning the Deployment of WMNs

Deployment of WMNs in the real field by setting up device and then modifying positions and other parameters can be done. For remote areas and difficult terrain this is hard and exhaustive process, so planning before the deployment should be done carefully.

Authors in [9] categorically listed the different aspects of deployments in such areas. They are as follows:

1. Applications and services that network provide

Before the deployment of WMNs in rural areas it should be clear that, what applications and services it is going to provide. For example: Internet service, Voice over Internet Protocol (VoIP) for internet phone, Tele-Teaching, Tele-Medicine, Hearth training, Agricultural information etc. By knowing this target applications and services it would simplify the deployment planning process.

2. MAC protocols of devices

MAC (Medium Access Control) protocols are the underlying hardware technique to forward data packets from one device to another. It should be clear and need knowledge of such MAC protocols, so that it is easier to decide which MAC protocol is suitable for the type of network that is being deployed. For example TDMA (Time Division Multiple Access), CSMA/CA (Carrier Sense Multiple Access/ Contention Avoidance) are the popular protocols used for IEEE 802.11 standards devices [9]

3. Network management

Network management consists of performance management, fault diagnosis and repair. Such management is more complicated in rural WMNs because nodes located in different geographic location are not easily accessible and there may not be other means of communication. Remote diagnosis and repair of problems is very important to address WMNs deployed in rural areas. To handle this problem there should be a central management system.

4. Power saving in devices

Another important concern in the system for developing countries, especially rural areas is the electric power problems. So devices used for deployment of WMNs need to have minimal power consumptions. The technique for power saving has been studied in [10].

5. Network planning

Network planning has the significant importance in the WMNs deployment. It is a determining factor for all aforementioned aspects. According to authors in [9] network planning for the rural areas have following aspects.

1. Connected links of nodes (The topology of network).
2. Antenna assignment for the links.
3. Channel of operation for links (channel are the frequency of transmission form one node to another).
4. Transmit power of nodes (Transmit power are the strength of frequency transmitted from nodes).

2.9 Problem Definition

There are many deployments of wireless networks in the developed countries and some urban part of developing countries. Deployment of WMNs in the developing country is still minimal. Some wireless network deployment has been done in rural areas [1, 9**,** 10], but these deployment has been achieved with setting up devices in real field with test and adjustment method. From these deployments, we came to know that the planning in the real field with setting up devices is hard, exhaustive, time consuming and costly process. So it is necessary to plan the network before deployment. Planning process needs to have certain model that decides what type of network is going to be deployed.

There are many aspects of WMN planning in rural areas such as topology formation, antenna assignment, channel of operations and transmit power of nodes [9]. The topology planning is a process of finding cost effective connectivity pattern of nodes. In rural areas how the nodes in wireless mesh network are going to be connected has significant part to plan the network.

In this scenario this study focused to, finding the connected topology planning of nodes and antenna assignment to that topology. Here, the question of this research was how to develop the WMN topology planning model that gives the suitable network connectivity of nodes placed in rural areas while it should be cost effective solution. This also analyses the suitability of topology planning model for rural.

Chapter 3

Literature Review

3. Literature

Multi-hop wireless mesh network has been a topic of significant research. Some of the literatures present the general overview of the WMNs and its architecture only. Some researchers have presented the detailed topology control model for WMNs, which is determining the connectivity pattern while minimizing the energy strength in the network. All these research are focused mainly for WMNs for urban area.

This study however, focused on finding the connected topology of given set of nodes for network planning process in the rural area.

3.1 Overview of the Literature

The early researches on WMNs were concentrated to the wireless mesh architecture. Later on, researchers on this area get diverse with issues regarding topology control, power efficient and reliable deployments of WMNs.

3.2 Detailed Survey

In this subsection, we present some of the literatures which closely resemble with this study.

Topology control approach using directional antenna approach:

Authors in [11] presented a topology control approach using directional antenna in wireless multi-hop networks. The goal was to design a system using simple directional antenna and legacy MAC protocols (such as 802.11 based MAC protocols) and find orientations of the antenna so that network remains connected. This goal was achieved by assuming that a reasonable number of directional antennas are available on each node that can be oriented (statically) at will and then using a known approximation algorithm to create minimum degree spanning tree. Authors compared their solution with the network having omni directional antennas for the evaluation. Their evaluation shows that the resultant topology of network has low interference and network remains connected. They conclude this as a one way to achieve maximum network throughput.

WMN Planning in terms of positioning mesh routers:

Study on [12] is focused on WMNs planning problems in terms of deciding mesh routers position and configuration of network devices to be deployed. It proposed a set of optimization models based on the mathematical programming whose objective is minimization of overall installation cost while taking account the coverage to end user nodes, the wireless connectivity in the wireless distribution system, management of traffic flows. Technology dependent issues such as adoptions and interference effect are also considered. Three resulting models: basic, interference aware and multi-channel described in their work. Basic model considers fixed transmission rates for both wireless interference and wireless distribution system and they named this model as Fixed Rate Model. Interference aware model considers the impact of interference on both access capacity and the wireless distribution system capacity. Multiple channel model accounts channel assignment to multi-radio devices. Results are quite similar to basic and interference aware models in terms of installed mesh access points and mesh routers and links from the presented evaluation.

Topology control with two hop forest construction in multi-hop ad hoc network

The deciding parameter of multi-hop networks; Throughput, latency and quality of service has been studied in [13]. In this, author proposed a two hop forest construction of nodes. Nodes are connected in tree structure constituting the forest. The evaluation of their result shows it works with good result in ad hoc scenarios. The approach presented in this work, constructs the forest of by choosing a preferred neighbours having highest number of neighbours with in communication range. As a result of this work a framework for the evaluation of routing in ad-hoc network was developed. Two modified forest constructions approach are proposed and studied. The proposed forest constructions approaches are compared with the standard forest and with the plain scheme. The comparison with the plain scheme reveals a substantial reduction of end to end latency for significant number of nodes. This is interpreted in terms of reduced variability of the traffic through the nodes. On the contrary, the plain scheme increases the risk of the occurrence of hot spots when using shortest paths.

Decentralized minimum spanning tree (MST) based topology control approach

Authors in [14] described a decentralized minimum spanning tree (MST) based topology control algorithm for wireless multi-hop networks with limited mobility. This study proposed an algorithm that; each node builds its local minimum spanning tree independently using collected information, the algorithm incurs less message overloading in constructing the topology. This algorithm can perform local repair in the case of mobility. The algorithm proposed in this work has following phases: information collection, topology construction and determination of transmission power. In information collection each node shares the information. After obtaining information topology used to be constructed with Prim's MST. For constructed topology if distance between nodes is greater than transmission range then transmission power required to cover that distance is calculated.

Channel assignment problem for given topology

Channel assignment for a given topology, the solution proposed in [15] uses graph colouring technique to overcome the interference produced by adjacent nodes in multi-hop networks. The proper allocation of channel to the nodes in the network minimizes the network interference, which is shown in their evaluation result. In this work, the author assumed the situation that: given set of mesh routers and gateways, the goal was to construct a mesh network that meets the requirement of the telephony and every router must have a connection to a gateway with fixed available bandwidth to and from gateway. For solution the problem was divided in two sub problems: topology construction and channel allocation. The main focus is on the channel allocation. Graph colouring technique was used by the author for this problem and the good results are shown in evaluation. 802.16 mesh networks were considered in the problem solution.

Power allocation in the Mesh networks

[16] did the work on power allocation issues in wireless mesh networks. Spatial Reuse Time Division Multiple Access (STDMA) is MAC technique that allows simultaneous reception and transmission of signals in the wireless networks. Simultaneous transmission and receptions between different antennas that are geographically very close impose various constraints on power transmitted by these antennas and proper power values for the radios placed at various nodes given by the nodes they are going to form links with has been studied in [16]. The authors assumed the power allocation problem only for the topology that is bipartite. All nodes in same partition will simultaneously receive or send at the same time. For a given topology, nodes will alternate between their transmitting and phases.

State of art analysis of wireless mesh networks

State of art analysis of wireless mesh networks is done in [22], both from point of view of standardization and academic research activities. In the standardization, the authors' focus is on the recent developments on the defining new physical layer and MAC layer standard for the wireless mesh networks in the IEEE 802.11 and 802.16 working groups. At the IP layer, in additions to routing, mobility point of recent IETF activities in the field has been studied. In academic research, the emphasis has been on identifying feasible mechanism that can be used to mitigate spatial multiplexing through several orthogonal channels and multiple radio interfaces. Review of some commercial products is also given.

Detailed study of recent advances in WMNs

[5] presents a detailed study on recent advances and open research issues in WMNs. System architecture and application of WMNs are described followed by discussing the critical factors influencing protocol design. Theoretical network capacity and state of art protocol for WMNs are explored with an objective to point out a number of open research issues. And it also explorers test-beds, industrial practice and current activities related to WMNs are highlighted.

Topological analysis tree based WMN

Topological analysis of tree based WMNs is presented in [23]. In this study authors provided an analytical evaluation of network performance in terms of average and worst case end to end transmission delay and validated it through simulations. This analysis of network performance in WMN with tree architecture can be very useful for the network deployments. The architecture of network in which this analysis was carried out consists: gateway, access points and mobile nodes. Gateway and router constructs a backbone for the network and the mobile devices are the clients to use communication services.

Gateway placement in WMNs

Authors in [24] addressed gateway placement, fair routing and scheduling problems for WMNs where their major concern is optimal placement of gateways and throughput guarantee. If multiple gateways are available then their solution would give near to optimal solution in terms of gateways placement and fairness throughput. In study, each node transmits on a common isotropic channel and the same power and omni directional antennas. Communications between nodes create interference such that no two interfering links can be activated simultaneously. The network is synchronous with slotted Time Division Multiplexing (TDM). This model is considered as simplified version of 802.16 WiMax or as a very opportunistic approximation of 802.11 Wi-Fi. Three models: optimal gateways placement, fair gateway placement problem, and fair routing and scheduling are presented in the solution. In evaluation three models, they showed that even for small networks gateway placement has major impact on networks

Shortest path based topology control

Shortest path based topology control algorithm that computes a topology preserving minimal energy paths presented in [25]**.** In this work the authors shown with theoretical analysis that this algorithm can be instantiated with different energy models. Their algorithm works by link weight calculation, link weight information exchange, and topology construction and transmission power assignment. In link weight calculation, each node locally collects the information needed in the weight calculation for all links associated with it and calculates the link weights. After calculating link weights, each node exchanges the information with 1-hop neighbours. Topology construction is done after having the knowledge of neighbours with shortest paths. If the communication link is not sufficient for error free transmission then transmission power is adjusted for each node.

Geometric family based mesh topologies

Two geometric family of mesh based topologies “GPeternet”, a graph theoretic framework and “FraNtiC”, a fractal geometric architecture has been proposed in [21] for arbitrary access network deployments. In order to evaluate the performance of the generated mesh topologies with existing networks in real life access network scenario, they had developed a generic framework. In this work, authors identified the principle characteristic of the next generation access networks and presented multi-hop mesh architectures as promising candidate for future backhaul.

3.3 Discussion and Future Trends

Out of above discussed literatures, most of them focused on topology control approach. In topology control approach literatures found efficient approach which fulfill the needs for the certain conditions, and some can be generalized in all conditions. All the work certainly focused in reliability, fault tolerant system design and fulfilling the needs of urban areas.

Various issues and deployments of wireless mesh network are studied in [17]. The Digital Gagnetic Plains (DGP) project [18], in and around kanpur India, wireless mesh deployment in Africa and Nepal Wireless Networking Project, in Myagdi district and Makawanpur district of Nepal [1] are the operational examples of rural wireless networks that motivates this study on wireless mesh network. Communication between nodes in these projects is accomplished by long distance point to point links using directional antennas.

Also there has been some recent work and study on constructing low cost WMNs authors in [19,20], both focused on low cost network formations for rural areas and they shown on their work that the cost of network is heavily depends on tower heights and they provided the solutions to minimize cost by proper tower height management.

There have been nominal studies in the rural topology planning formulations, where the connectivity of network does not need to have every location. In rural areas, connectivity needs only where communities are living and more areas are unoccupied. This leads a different planning scenario and this study is focused on this situation.

Chapter 4

Related Terminologies and Problem Formulation

4.1. Graph theory related Terminologies

As every network can be represented as graphical mapping of entities, we are no different and use the same for the topology planning model on rural wireless mesh networks. Graph theory related terminologies related in the process of problem solution approach are covered next.

4.1.1. Graph

A graph is an unordered pair G= (V, E) comprising a set of vertices or nodes V together with set E of distinct edges or links. This type of graph may be described as undirected graph or simple graph. [26]

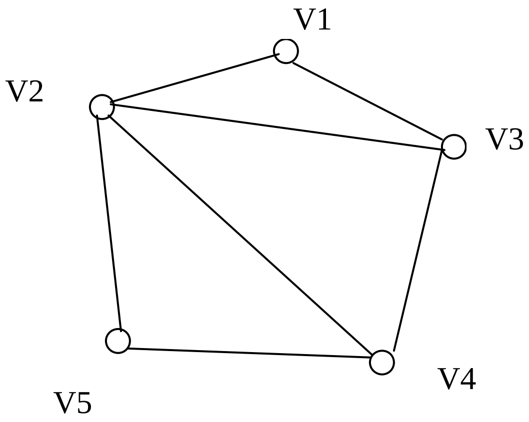


Fig 4.1. An undirected or simple graph

In figure 4.1 , set of vertices (V)= $\{v_1,v_2,v_3,v_4,v_5\}$ and set of edges (E)= $\{\{v_1,v_2\},\{v_1,v_3\},\{v_2,v_3\},\{v_2,v_5\},\{v_2,v_4\},\{v_3,v_4\},\{v_4,v_5\}\}$.

4.1.2. Complete graphs:

The complete graph of n vertices is simple graph that contains exactly one edge between each pair of distinct vertices. The complete graph of 5 vertices in fig 4.2, and every pair of vertices in this graph has one edge.

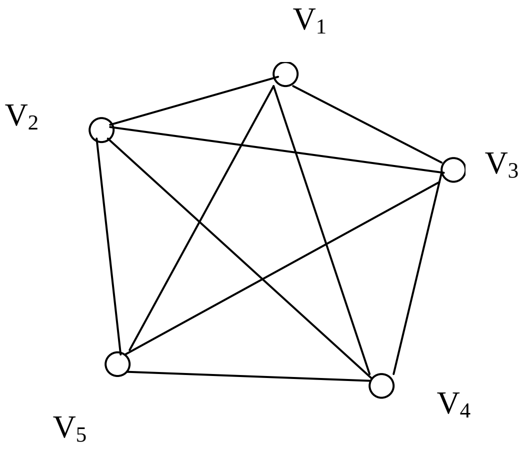


Fig 4.2. A complete graph of 5 vertices

4.1.3. Cycle

The cycle is a graph of n >=3, consists n vertices v_1, v_2……v_n and edges {v_1, v_2}, {v_2, v_3}…. {v_{n-1}, v_n}, {v_n, v_1}.

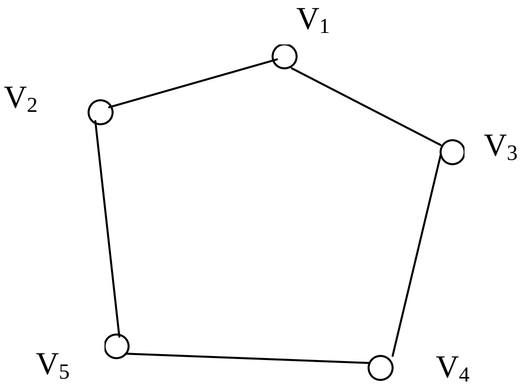


Fig 4.3. A cycle of 5 vertices

4.1.4. Bipartite graph

A simple graph G is called bipartite graph if its vertices can be partitioned into two disjoint sets V1 and V2 such that every edge in the graph connects a vertex in V1 and vertex in V2 (no edge in G connects either two vertices in V1 or two vertices in V2) [26].

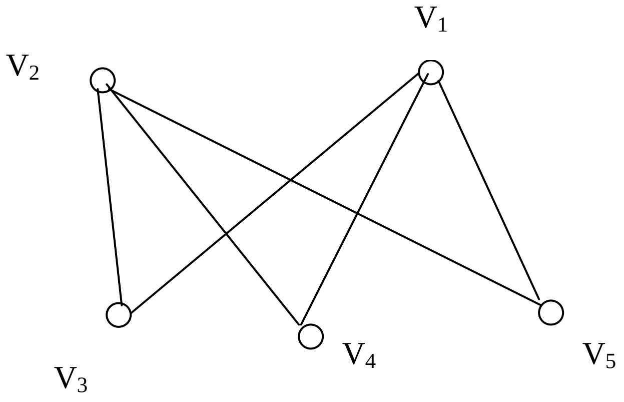


Fig 4.4. A Bipartite graph of 5 vertices

Figure 4.4 is bipartite graph since vertices can be divided into two sets V1= $\{v_1, v_2\}$ and V2= $\{v_3, v_4, v_5\}$ so that there is edge from vertices in V1 to vertices in V2

4.1.5. Sub-Graph

A Sub-Graph of G = (V, E) is a graph H= (W, F) where $W \subseteq V$ and $F \subseteq E$ [26]. That is sub-graph is a subset of graph. Graph constructed by removing some edges and vertices from original graph is called sub-graph.

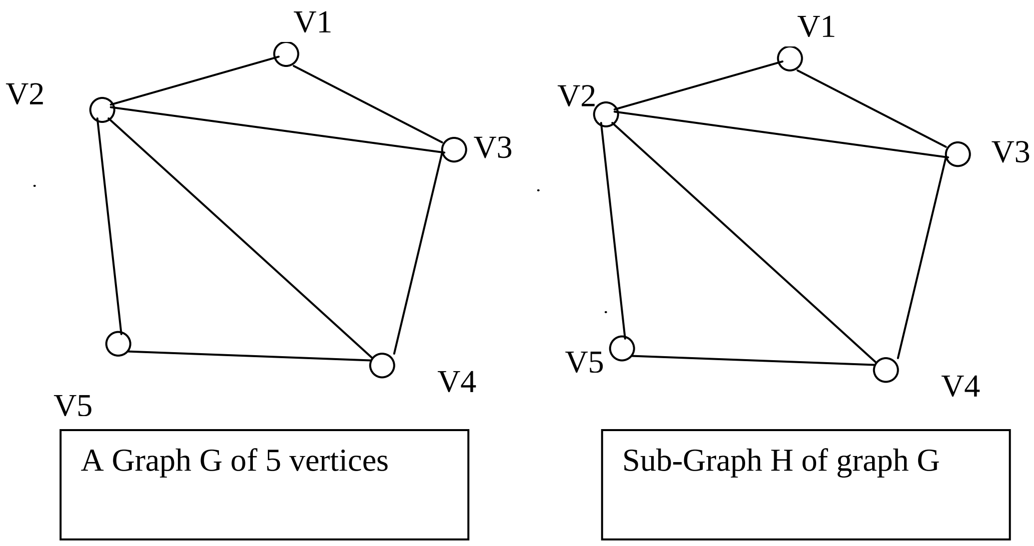


Fig 4.5. A Graph and Sub-Graph

4.1.6. Connectivity

A graph is connected if every pair of distinct vertices in graph can be connected through some path [26].

4.1.7. Weighted graph

A graph is weighted if a number (weight) is assigned to each edge such weight represent, for example costs, lengths, capacities etc depending on the problem [26].

4.1.8. Tree

Tree is a connected undirected graph with no cycles or an undirected graph is tree if and only if there is unique simple path between any two of its vertices. A tree which one vertex has been assigned as root is called rooted tree. A tree is a bipartite graph [26].

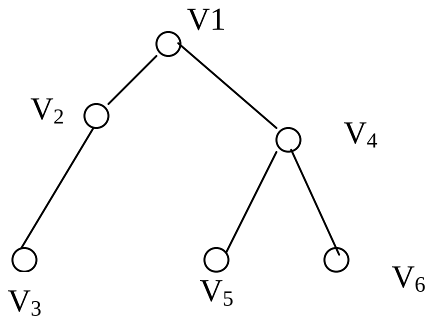


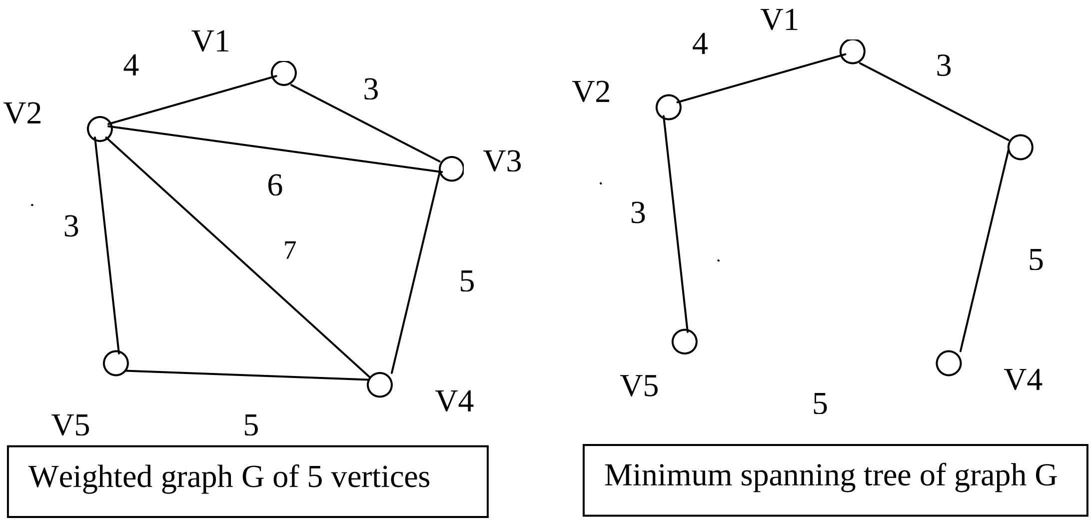
Fig 4.6. A tree of 6 nodes (vertices)

4.1.9. Spanning Tree

Given a connected, undirected graph, a spanning tree of that graph is a sub-graph which is a tree and connects all the vertices together. A simple graph can have many different spanning trees. Weight can be assigned to each edge [26].

4.1.10. Minimum Spanning Tree (MST)

Minimum spanning tree of a weighted graph is a spanning tree with sum of edges weight less than or equal to that of every other spanning tree. Minimum spanning tree is generated by connecting minimal weight edge from the graph [26]. The total edge weight of minimum spanning tree is less or equal to any other spanning tree of that graph. In figure 4.7, numbers in the edges represent weight of the edges.



Weighted graph G of 5 vertices

Minimum spanning tree of graph G

Fig 4.7. A Weighted graph and Minimum Spanning Tree

4.1.11. Euclidean Minimum Spanning Tree (EMST)

The Euclidean Minimum Spanning Tree or EMST is a spanning tree of a set of points in the plane, where the weight of the edge between each pair of points is the Euclidean distance[4] between those two points.In other terms, EMST is the minimum spanning tree of Graph that is represented in 2 dimensional planes, where weight is Euclidean distance between two points.

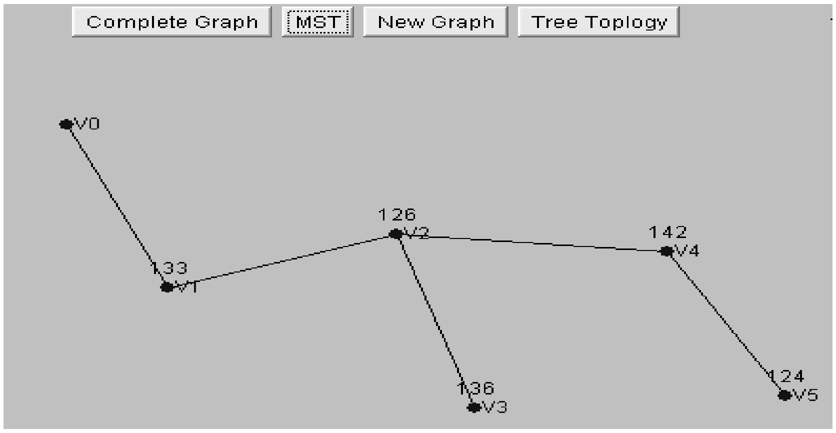


Fig 4.8. A Euclidean minimum spanning tree in 2d plane

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[4] Euclidean distance is the distance between two points in the two dimensional coordinate space. If (x1, y1) and (x2, y2) are two points then Euclidean distance between them (d) =sqrt((x2-x1)^2+(y2-y1)^2).

4.2. Wireless network related Terminologies

The graphical representation of network uses the graph structure. Parameters or entities in wireless network that determine the graph structure are overviewed in this section.

4.2.1. Nodes and links

Nodes in the wireless mesh networks are wireless mesh router and clients. These wireless routers and clients communicate with other to form link. These nodes and links are represented as vertices and the edges.

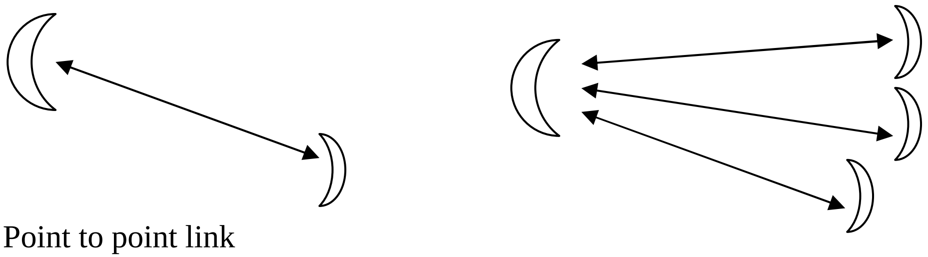
4.2.2. Link Types

1. **Point to point links**

   A point to point (p-to-p) link is a link that connects exactly two nodes; these types of links are generally having high gain directional antennas.

2. **Point to multipoint links**

   A point to multipoint (p-to-mp) link set involves communication of one node with multiple nodes so that in communication system, one node is common and multiple nodes communicate with common node.



Point to point link

Point to multipoint link

Fig 4.9. Point to point and point to multipoint links

4.2.3. Transmit power of nodes

Transmit power is the power or strength of radio signals that is being transmitted from the radio devices used in the nodes.

The signals transmitted are degraded as it is attenuated when link distance is increased due to environmental condition. So the value of transmit power of radios should be carefully calculated and this work has been done in [16]. The transmit power should only high enough to be receive signal at the receiver end

There is a constraint on power transmitted that it should not cross the maximum 36 dbm[5] for any single link. [27].

4.2.4. Received Power

The strength or power of radio signal received at receiving end is called received power. The equation of received power in dbm scale is given below [27].

$P(R) = P(T) + G(T) + G(R) - PL$ --- (1).

Where $P(R)$ = Received power at the receiving node.

$P(T)$ = Power of transmission at transmitting node.

$G(T)$ = Antenna gain of transmitting node’s antenna

$G(R)$ = Antenna gain of receiving node’s antenna

PL = Loss of signal at path and popular model for path loss is

$PL = \mathrm{Log}(c/4\Pi fd)^2$-- (2).

Where, c = speed of light ($3\text{x}10^8$ m/s^2)

f = frequency of radio waves in MHz.

d = distance between two nodes.

---

[5] dbm is a unit to determine strength of radio waves.

There is bound to minimum expected strength of signal at receiver for 802.11b standard radio equipments is -85dbm [16].

The distance (d) mentioned in the above formula is used to calculate the link possibility. If the distance is with in the communication range of the nodes then there a link is established between nodes. These links are represented as the edges in the graphical representation of network.

4.2.5. Medium Access Control (MAC)

The 802.11 MAC is originally designed for short distance, however authors of [27] have demonstrated by using high gain directional antennas, ensuring line of sight and by appropriately setting certain device MAC parameters, a long distance (>25 kilometres.) link can be achieved.

4.2.6. Line of Sight (LOS)

In wireless mesh networks, to form link there needs to have clear sight from one node to another node without obstructions. To calculate whether there is line of sight or not the below formula is used [27].

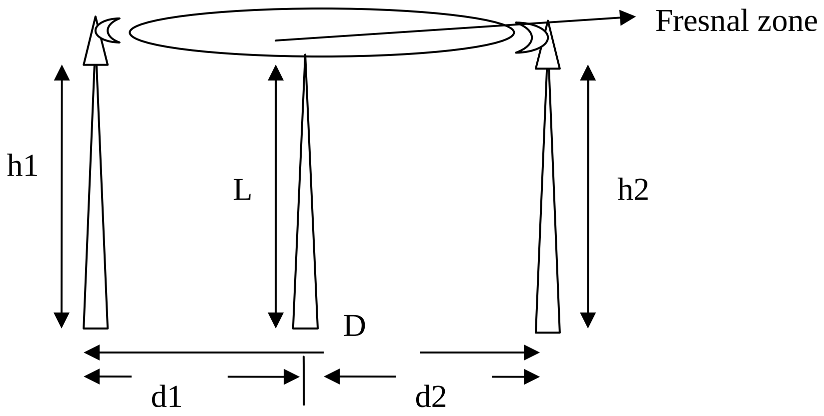


Fig 4.10. A Line of sight link

In figure 4.7, h1 = height of node1

h2 = height of node2

L = height of obstruction between two nodes

D= distance between two nodes.

d1= distance from node1 to obstruction

d2= distance from node2 to obstruction

Condition for the line of sight is:

$$h1xd1+h2xd2 >= LxD \quad \text{---} \ (3)$$

For line of sight between node1 and node2, the condition (3) must be true. The D in the condition is also used to find the power equation presented in equation (1). For the power equation calculation, there must be line of sight between two nodes.

Fresnal zone is the elliptical area made by two antennas radiation pattern located in two different places facing each other. For line of sight in 2.5GHz frequency of transmission the 60 % of this zone must be clear [28].

4.2.7. Antenna Systems

An antenna is a passive device which does not offer any added power to the signal. Instead, an antenna simply redirects the energy it receives from the transmitter. The redirection of this energy has the effect of providing more energy in one direction, and less energy in all other directions [29].

Beamwidths are defined in both horizontal and vertical plains. Beamwidth is the angular separation between the half power points (3dB points) in the radiation pattern of the antenna in any plane. Therefore, for an antenna you have horizontal beamwidth and vertical beamwidth [29].

Antennas can be broadly classified as omni directional and directional antennas, which depends on the directionality. Direction is the shape of the transmission pattern.

The omni directional antennas radiate radio signals in all directions. These antennas provide a 360 degree horizontal radiation pattern. These are used when coverage is required in all directions (horizontally) from the antenna with varying degrees of vertical coverage

As the gain of a directional antenna increases, the angle of radiation usually decreases. This provides a greater coverage distance, but with a reduced coverage angle. The coverage area or radiation pattern is measured in degrees. These angles are measured in degrees and are called beamwidths.

Directional antennas focus the radio frequency energy in a particular direction. For directional antennas, the lobes[6] are pushed in a certain direction and little energy is there on the back side of the antenna. Directional antennas have less interference to other signals because they focus on certain directions called beam widths [26].

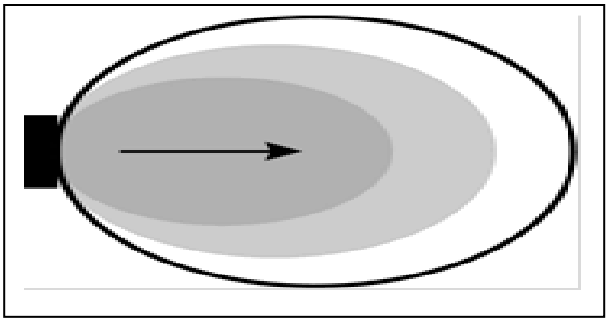


Fig 4.11. Radiation Pattern of a Directional Antenna

In order to optimize the overall performance of a wireless network, it is important to understand how to maximize radio coverage with the appropriate antenna selection and placement.

---

[6] An identifiable segment of an antenna radiation pattern.

Chapter-5

Problem Solution Approach

5.1. Topology planning model for rural wireless mesh networks

Topology planning model constructs connected topology of given nodes and assign the required number of antennas required to cover each nodes in the topology, for the deployment of wireless mesh networks in rural areas.

Topology is determined by graphical representation. So, we use graphical representation of nodes while determining the topology for the planning of rural wireless mesh.

For the solution of the topology planning model we have following assumptions.

1. The network planning scenario is that the placement of nodes i.e. villages are fixed. One node works as gateway for the connection to internet or other networks and is considered as root node.
2. Tree topology generated i.e. the connectivity pattern of nodes is a tree.
3. There is maximum link length in which each node can transmit, we assumed this link length as threshold distance for the link formation
4. Each node can communicate with multiple numbers of other nodes which are adjacent to that node.
5. Directional antennas are used for the communication in each link.
6. There is clear line of sight to form links.

We intended to make systematic way of planning the real world WMNs, especially for the developing countries like Nepal. We further describe a topology planning model, considering the cost of deployment we sacrifice reliability but maintaining the connectivity. Because there needs the connectivity before the reliability.

Topology planning model is described into two sections: topology formation and assigning antennas to that topology.

5.1.1 Topology Formation

We consider the network nodes as vertices in a 2 dimensional plane (coordinate space) and we have to find the connected graph of vertices in the plane.

For a given no of nodes, what is the optimal connectivity pattern of the nodes so that there is minimal distance to cover and is a cost effective solution? The answer of this question is Minimum Spanning Tree (MST) of given nodes [26]. If the nodes are mapped into a two dimensional coordinate space then the minimum spanning tree is called Euclidean Minimum Spanning Tree.

Regardless of the topology of network, at the time of data packets routing, network constructs a MST or shortest path from source to destination of the nodes, So that data packets will forwarded efficiently.

Generally nodes in a WMN are connected with more than one nodes and it needs more resources to construct WMNs. So the assumption of tree topology generation from given nodes is to minimize the overlaying cost to construct WMNs. Tree is bipartite graph and if there is a MAC protocols to support simultaneous transmission then this MAC protocol can be easily used in devices used for constructing tree topology. If tree topology is constructed and the network is deployed, then routing path will be the same as tree topology. So, fault detection and management is easier.

The optimal tree topology from graph theory is MST. There are several algorithms to find MST of given nodes like Prim’s algorithm, Kruskal’s algorithm etc. Since we assume the network mapping in a two dimensional coordinate space, so finding the minimum spanning tree in this case is Euclidean minimum spanning tree

The Prim’s algorithm to find EMST of given nodes in a two dimensional coordinate space is described below [26].

Algorithm for computing EMST in 2d plane

Input: *n number of nodes.*

Step1: *Compute complete graph of n number of generated nodes.*

Step2: *Assign Euclidean distance as weights to all edges.*

Step3: *Use Prim's algorithm to find MST.*

Output: *EMST.*

Prim's Algorithm to find MST

Input: *G weighted connected graph of n nodes (vertices)*

Step1: *Start with a tree T which contains only one node.*

Step2: *Identify a node (outside the tree) which is closest to the tree and add the minimum weight edge from that node to some node in the tree and incorporate the additional node as a part of the tree.*

Step3: *If there are less then* n - 1 *edges in the tree, go to* ***2***

Output: *T is minimum spanning tree of graph G.*

Algorithm 1: Prim's Algorithm to find Minimum Spanning Tree.

The running time complexity of the algorithm is O (E) or O (n^2), where E is number of edges and n is number of nodes in the tree.

Tree topology construction

The tree generation of given nodes for the tree topology formation for our model based on graph theory with assumptions mentioned earlier is presented as.

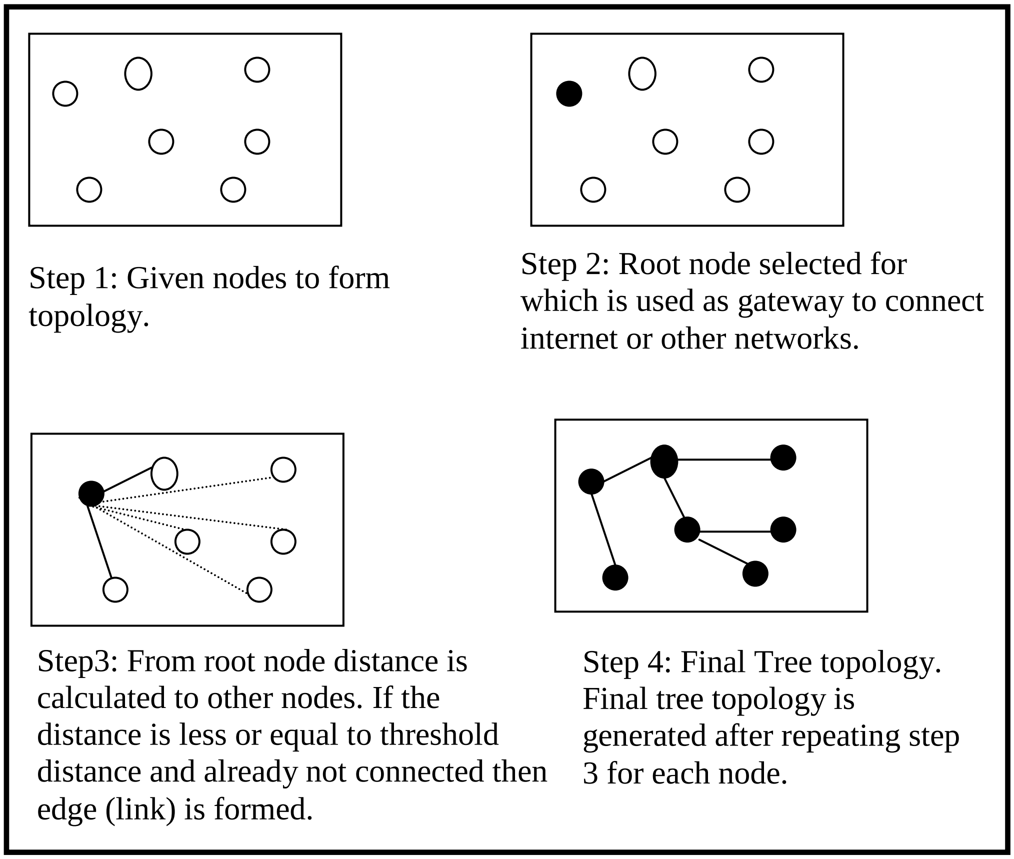
Algorithm for graph theory based tree topology construction

```
Input: Generate n number of nodes in bounded 2D coordinate space. So that every node $v_i (x_i, y_i)$ is situated in bounded 2D plane.

    Step1: Node having smallest x and y coordinate value, let $v_1(x_1, y_1)$ is selected as root.

    Step2: Initialize

    T= tree containing $v_1(x_1, y_1)$ i.e. root only.

    L=Empty list (for unprocessed vertices)

    Put $v_1$ in L

    Step3:

     While L is not empty

        Remove first vertex v from L

        For each vertex w if Euclidean distance from v to w (d) <= $d_t$ (threshold distance)

            If w is not in the L and not in T then

            Add w to the end of the list L

            Add w and edge {v,w} to T

        End of for loop

    End of while loop

Output: T tree (is connected topology pattern of nodes)
```

Algorithm 2: Tree topology construction algorithm in 2D plane

This algorithm uses breadth first search to determine tree topology but it uses a threshold distance to determine adjacent nodes. Nodes with in threshold distance are considered as neighbour nodes.

Illustration of topology formation algorithm



Step 1: Given nodes to form topology.

Step 2: Root node selected for which is used as gateway to connect internet or other networks.

Step3: From root node distance is calculated to other nodes. If the distance is less or equal to threshold distance and already not connected then edge (link) is formed.

Step 4: Final Tree topology. Final tree topology is generated after repeating step 3 for each node.

Fig 5.1. Step wise illustration of tree topology construction

This algorithm returns a tree that is connected topology pattern of given nodes. And this algorithm has O (n^2) time complexity, where n is number of nodes in the tree.

Aspects of tree construction algorithm

Minimum spanning tree generated by Prim's algorithm uses greedy approach and is an optimal solution. Tree generated by tree topology construction algorithm is a breadth first search with constraint of threshold distance to find neighbour of each node.

Though this approach has a constraint of threshold distance to connect nodes, it starts by taking edges having length less than or equal to threshold distance from any node, if that edge is already not in the tree. This solution minimizes the depth of tree that is minimum number hops to visit all nodes from root node.

The reason for putting constraint of threshold distance is valid since every devices used in the node has hardware limitation of maximum length capacity to transmit or gain the radio signal.

5.1.2. Antenna Assignment

For the given topology we have to find the number of antennas required to cover each nodes in that topology.

Authors in [11] used a topology control approach to using directional antenna in wireless mesh networks. In their work they provided a solution for topology control approach during transmission of data packets and that approach can use the directional antennas. But our work is to provide a solution that uses directional antenna for the topology planning before the deployment of the WMNs. Authors in [11] provided a solution for topology control works by generating spanning tree T and iteratively improves on it. When the suitable spanning tree is generated the algorithm terminates. In the generated tree the algorithm calculates k arcs of angle θ and radius R_d to cover the all edges in the tree. These k arcs represent the number of directional antennas to be used. This approach fails as k and θ are fixed in advanced and some edges can not be covered [11]. But in the large no of simulation they did not found such case.

We accommodate this solution in our topology planning model for the antenna assignment as follows since we have already a tree.

Antenna assignment algorithm

Input: *Tree generated from tree topology generation algorithm*

Step1: *for every node n_i in the tree (except leaf nodes)*

Angularly sort the adjacent nodes

Find the angle between leftmost node and rightmost node adjacent to parent node

If angle is >30 degree then break them in two set until the each set has maximum angle of separation (i.e. angle between leftmost node and rightmost node adjacent to parent node) <30 degree.

Count no of set of nodes adjacent to that parent node return that the no of set is equal to no of antenna to be assigned to that node to connect adjacent node

Step2: *repeat step 1 for each node to find how many antenna to be needed to connect adjacent nodes.*

Step3*: terminate if no. of antenna needed to each node is calculated*

Output: *No. of antenna required in each node*

Algorithm 3: Antenna assignment algorithm.

Minimum antenna used for any node except root and leaf node is 2; one to connect with parent node and another to cover adjacent nodes. This algorithm returns only the number of antenna needed in each node and total number of antenna required to cover all nodes in the topology.

Aspect of antenna assignment algorithm

Optimal solution of this problem is to find the minimum number of antennas with minimum angular separation. Antenna with minimum angular separation produces less interference in the network and also they have higher cost than that of antenna having more angular separation.

In rural scenario achieving optimal solution will increase cost of network deployment since it increase number of antenna to be used. There is less chance of existence of such other networks so interference is nominal. In our model, we have used the directional antenna having maximum angular separation so that the cost will decrease and the property of less interference with more distance coverage of directional antenna is also achieved.

Chapter-6

Implementation and Testing

6.1 Implementation

As the implementation part of this study, a simulation environment has been developed. This environment simulates the Topology planning model. The program has been developed using Java programming language (JDK 1.6.0) under the system consisting Windows XP 2000, with 3 GHZ processor and 2 GB of memory.

6.2 Program structure

The simulation we named it RNT, consists of node generation, topology tree generation antenna assignment and final topology out put with number of antenna required to cover generated topology. For simplicity, Topology generation has been carried out in the square region having fixed side of 45km. Node generation is random so that the program covers all types of node placement scenarios. Threshold distance in which the node can form link is assumed 10km. The following figure depicts the simple structure of the program.

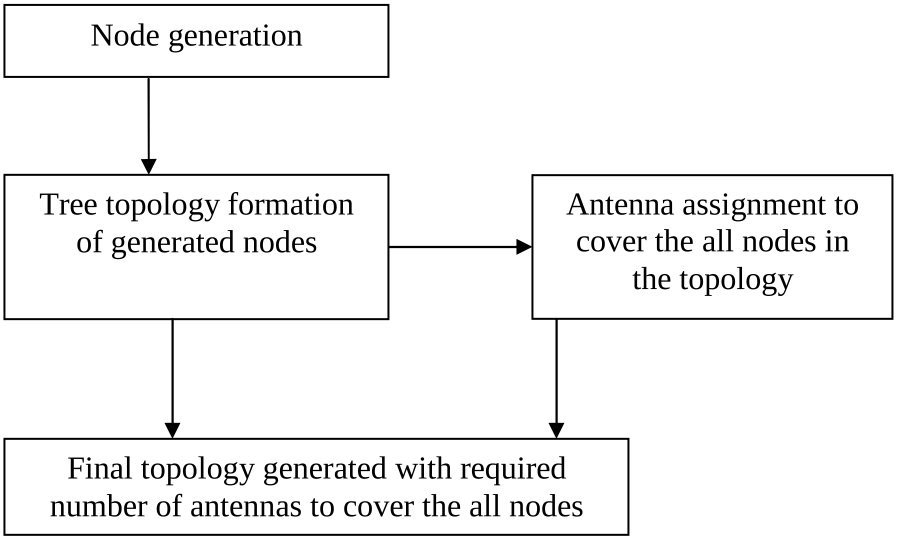


Fig 6.1. Simple Program Structure of topology planning model

As the main part of the implementation, the tree topology formation algorithm (presented in previous chapter) has been implemented. The topology planning model then executes the antenna assignment algorithm to find out he required number of antenna to cover all the nodes in the topology.

6.3 Implementation Classes

In the implementation of the program, topology formation algorithm and antenna assignment to that topology is implemented as *Rnt.java* class. The detail implementation source code is presented in APPENDIX A.

6.4 Testing and Evaluation

For the testing and evaluation of our model, we simulate the random node placement and nodes placement pattern similar to some deployed wireless network in rural areas of Nepal.

6.4.1 Evaluation of topologies for deployed networks in rural areas

We have run our algorithm for the set of nodes having similar node placement as of some wireless networks deployed in rural and remote parts of Nepal. We have also made comparative evaluation between topologies generated from our topology formation algorithm and current topologies of deployed wireless networks, and presented in following evaluations.

Evaluation 1:

Wireless network deployed in Myagdi, a district of Nepal, has topology as in figure 6.2. Topology generated from our topology formation algorithm for the same node placement as in figure 6.2 is shown in figure 6.3.

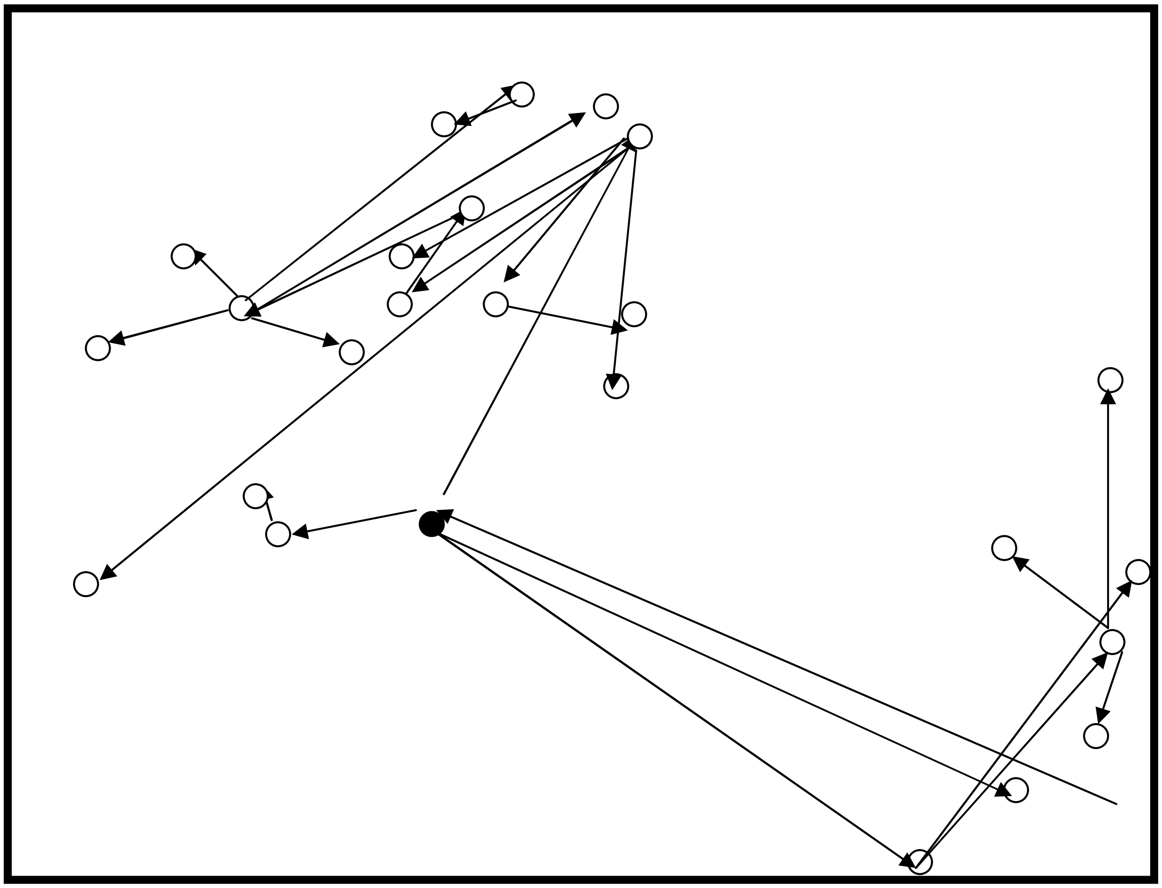
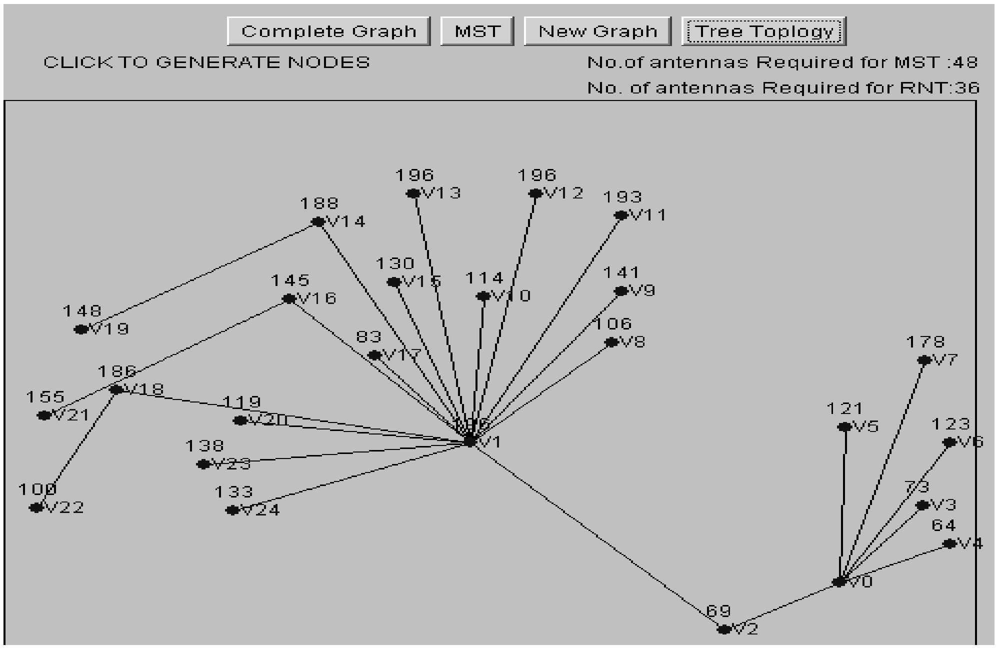


Fig 6.2. Topology of Rural Wireless Network in Myagdi district of Nepal (source [1])



CLICK TO GENERATE NODES

No.of antennas Required for MST :48

No. of antennas Required for RNT:36

Fig 6.3. Topology generated form tree topology formation algorithm for similar node placement as in figure 6.2.

Topology of network presented in figure 6.2 has more long links than that of topology generated from topology formation algorithm. Even though, several nodes are closer to root nodes, it uses farthest nodes from root as intermediate nodes to reach nodes even located between root node and intermediate nodes. This is not the case of topology presented in figure 6.3. It has used nodes closer to root node as intermediate node.

Number of hops in topology presented in figure 6.2 has greater than that of topology presented in figure 6.3.

There is a less no of antenna required to cover the all nodes unless there is point-to point link for each node in topology presented in figure 6.3. But the general structure of both topologies is tree and can be easily modified to mesh network for the reliability where multiple links to one node is created to provide connectivity in case one links fails.

Another key difference of topology generated from topology formation algorithm presented in figure 6.3 to topology deployed as in figure 6.2 is; root node and intermediate nodes are heavily populated with links. This fact leads deployment process to be concentrated heavily only on some nodes, which is beneficiary for the rural areas in several aspects.

Evaluation 2:

Wireless network deployed in Makawanpur, has topology as in figure 6.4. Topology generated from our topology formation algorithm for the same node placement as in figure 6.4 is shown in figure 6.5.

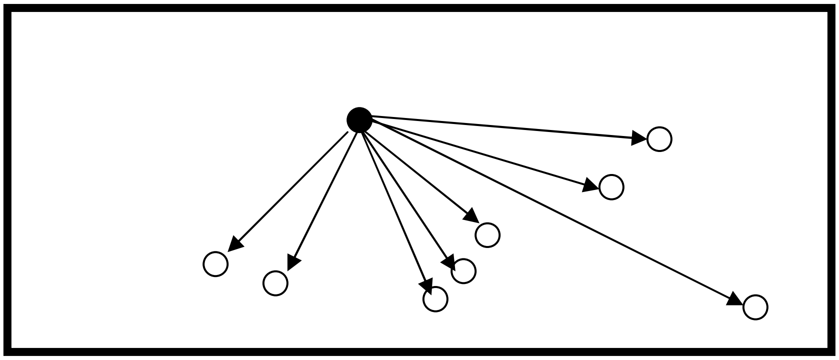
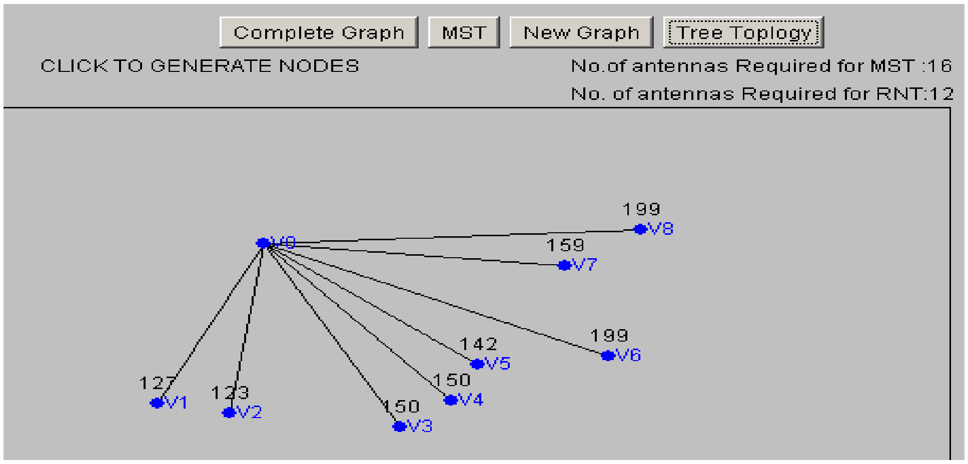


Fig 6.4. Topology of Rural Wireless Network in Makawanpur district (source[1])



CLICK TO GENERATE NODES

No.of antennas Required for MST :16

No. of antennas Required for RNT:12

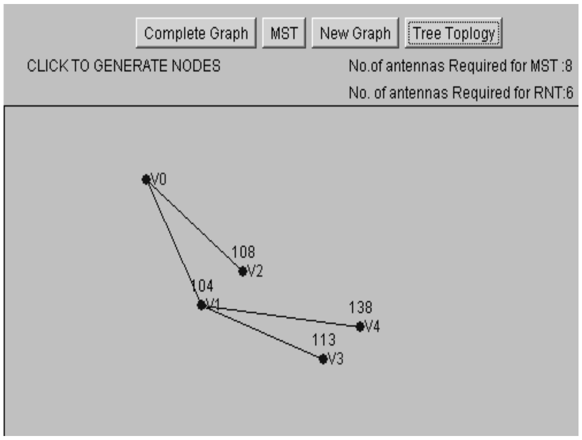
Fig 6.5. Topology generated form tree topology formation algorithm for similar node placement as in figure 6.4.

Topology of wireless network deployed in Makawanpur district of Nepal and topology generated from topology formation algorithm are same. Both are tree topologies and can be easily converted into mesh network for the reliability.

6.4.2 Evaluation of Random Topologies

In this section we present the evaluation of randomly generated topologies from topology formation algorithm. At first we present screenshot of some final topologies generated by our model.

Topology generated from random node placements

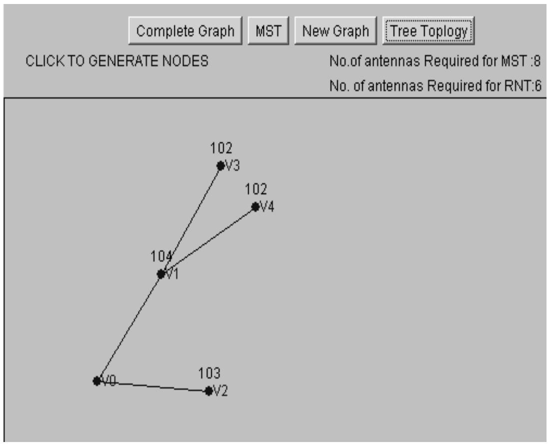


CLICK TO GENERATE NODES

No.of antennas Required for MST :8

No. of antennas Required for RNT:6

(a). Topology for randomly generated point set 1

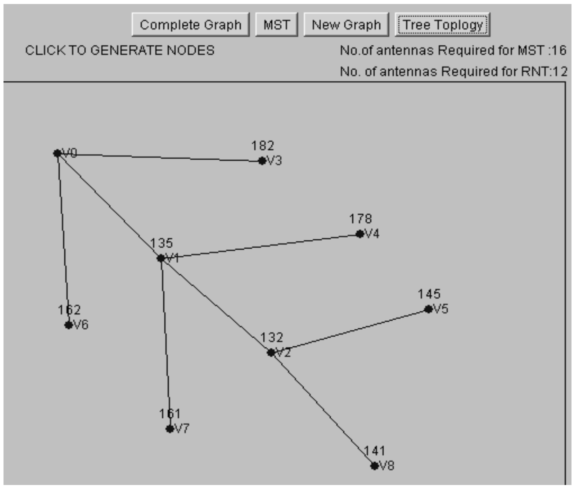


CLICK TO GENERATE NODES

No.of antennas Required for MST :8

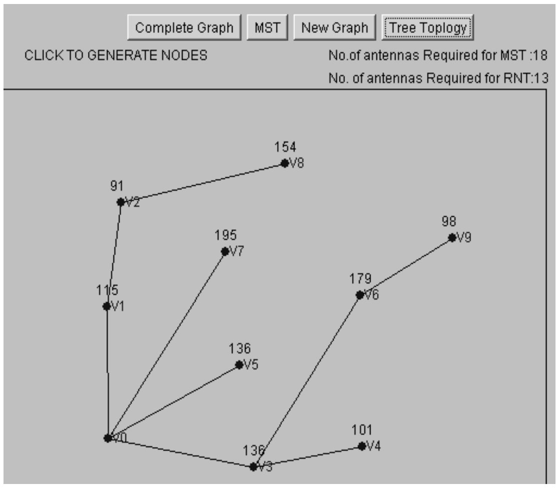
No. of antennas Required for RNT:6

(b). Topology for randomly generated point set 2



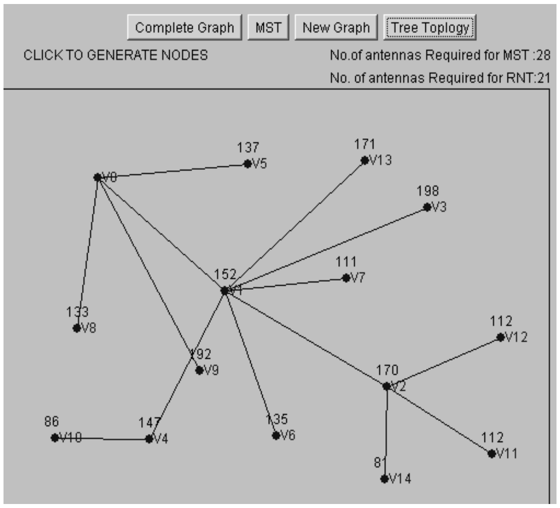
No.of antennas Required for MST :16
No. of antennas Required for RNT:12

(c). Topology for randomly generated point set 3



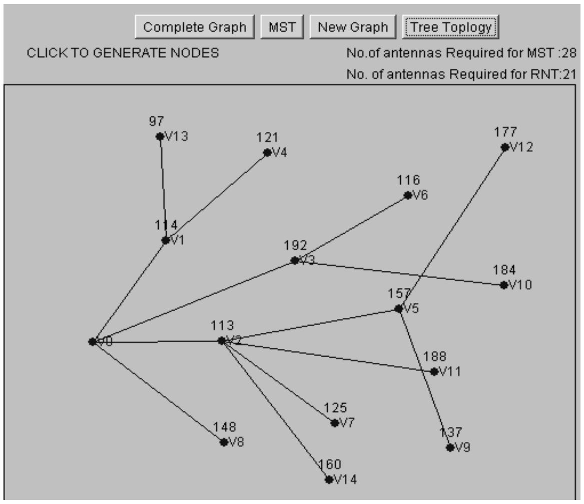
No.of antennas Required for MST :18
No. of antennas Required for RNT:13

(d). Topology for randomly generated point set 4



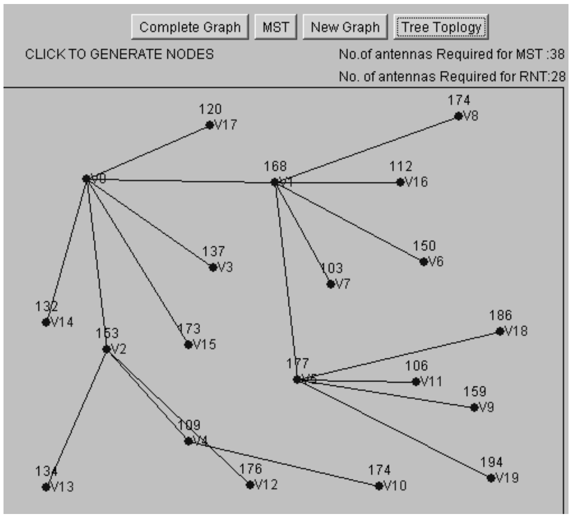
No.of antennas Required for MST :28
No. of antennas Required for RNT:21

(e). Topology for randomly generated point set 5

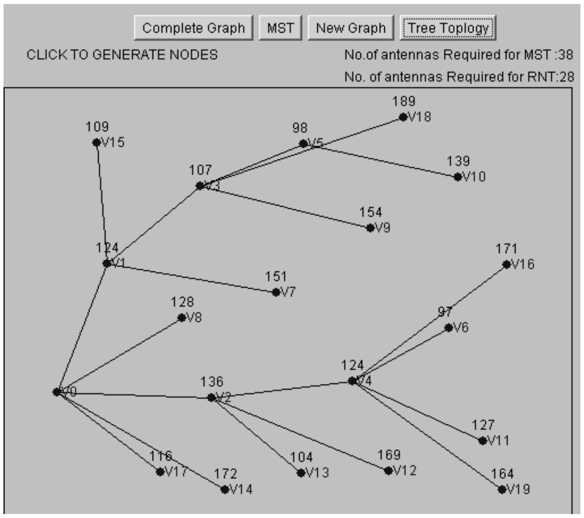


No.of antennas Required for MST :28
No. of antennas Required for RNT:21

(f). Topology for randomly generated point set 6



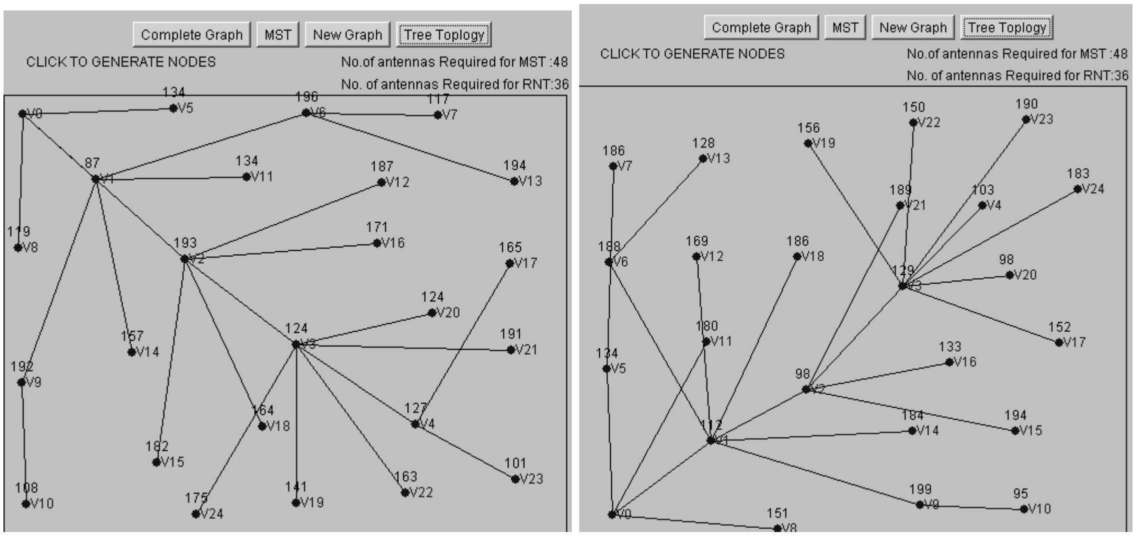
No.of antennas Required for MST :38
No. of antennas Required for RNT:28



No.of antennas Required for MST :38
No. of antennas Required for RNT:28

(g). Topology for randomly generated point set 7

(h). Topology for randomly generated point set 8



No.of antennas Required for MST :48
No. of antennas Required for RNT:36

No.of antennas Required for MST :48
No. of antennas Required for RNT:36

(i). Topology for randomly generated point set 9 **(j).** Topology for randomly generated point set 10

Fig 6.6. Topologies generated form topology formation algorithm for random node placement.

Topologies for randomly generated nodes placements from topology planning model, illustrated in figure 6.6, shown that nodes are bushy in nature; links are heavily populated in some nodes.

6.5 Analysis and results

Topologies for node placement with random and as in wireless network deployed in rural areas are generated from topology planning model and this topology planning model produces realistic topologies for the deployment of wireless mesh networks for rural areas.

Evaluation of the results produced by our topology planning model named as RNT (Rural Wireless Mesh Network Topology) for point to point and point to multipoint links has been presented below

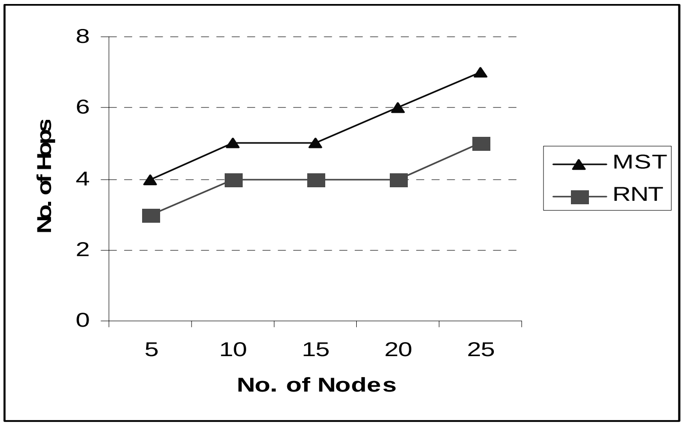


Fig 6.7. No. of hops in MST and RNT for randomly generated topologies

1. **For point to point links.**

In case of point to point links, each link required a pair of antenna, which will be placed at nodes in either side of a link. So, total number of antenna required to both MST and RNT topologies is 2(n-1), where n is number of nodes. Since, both MST and RNT are spanning trees with n number of nodes and all spanning trees with n number of nodes have n-1 edges. But in terms of hop count (number of nodes to be visited to reach any node from a node); MST has greater as compared to RNT. Hop count has significant impact on response time and throughput. As no of hop count increases, throughput is minimised and processing time in each node increases response time. So MST is not suitable for network deployment of networks, but is the cost effective solution. Comparison of RNT with MST is due to cost effectiveness of MST but for operational feasibility a spanning tree which minimizes number of hops and maintains the cost effectiveness is suitable. RNT produces the spanning tree topology which maintains this criterion. So, it is better for the deployments. From evaluation of the model, we can conclude that RNT produces more realistic topology which can be used for the cost effective solutions for the deployment of networks in rural areas.

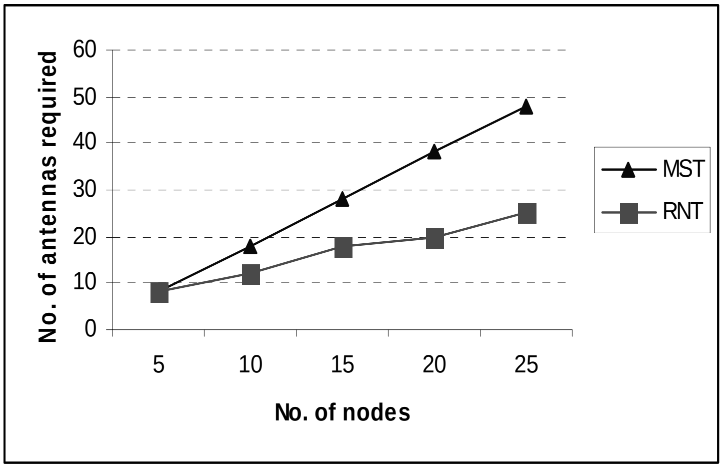


Fig 6.8. No. of antennas required in MST and RNT for randomly generated topologies.

2. For point to multipoint links.

Number of antenna required to cover all nodes in the topology can be minimised by using point to multipoint links. In case points to multipoint links are used, any node can use single directional antenna to cover multiple nodes on other side of links if nodes in other sides of links are within beamwidth of that directional antenna. This approach minimises the number of antennas required in the deployment of network ultimately cost of the network deployment in the rural areas.

In numerous simulations we did not found, antenna having beamwidth 30^o can cover two or more nodes in MST, where as in RNT we found such case virtually in all simulations. So RNT requires less number of antennas in comparison to MST when points to multipoint links are to be used for the network deployment.

Chapter-7

Conclusion and Further Recommendation

7.1. Conclusion

The study was mainly focused on the problem of topology planning for the deployments of wireless mesh networks in the rural areas. Due to recent developments in the communication based services and technologies, there is a need of wireless mesh networks in the rural areas. There are various unoccupied places and many inhabitants are grouped in some location forming the villages. The need of communication networks in rural areas is different and connectivity is required in occupied location only where as in urban areas, places are heavily populated and the demand of connectivity is everywhere. This fact leads the different network deployment scenario for the rural areas and there has been less work for the planning the wireless mesh network for the rural areas. So, there is a need for the wireless mesh network planning model for the rural areas.

This study has presented an overview of the wireless mesh networks with its distinguished features and also justifies the need for the wireless mesh network in rural areas.

The study has presented a topology planning model which has major part in defining the connectivity of each location in the network. The presented model in the study focused on the connectivity of location which takes less time, effort and cost, rather than reliability. The topology planning model used the tree topology for the topology construction. Evaluation and results showed that this topology maintains the cost effectiveness and constructs deployable topologies for the rural wireless mesh networks. This model had also calculates the number of antenna required to cover generated tree topology. This model also maintains the flexibility to advancement of the network. In addition the model minimizes the number of antenna required to cover whole network when point to multipoint links are going to be used. So that cost of deploying the network in rural area becomes less.

7.2. Further Recommendation

In this study, the topology planning model for the rural wireless mesh networks based on the tree architecture with some assumptions has been discussed.

The future work in the planning of rural wireless mesh networks should incorporate all the conditions with out assumptions and goal should be overall network planning model for the deployments of networks. The terrain condition in remote areas differs significantly and the other parameter should be considered.

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APPENDIX A

Complete source code of Topology Construction with antenna assignment Program

```
/**
 * @(#)RntApplet.java
 *
 *
 * @Bishnu Subedi
 * @version 2.0  2009/3/14
 */

import java.awt.*;
import java.awt.event.*;
import java.util.*;
import java.applet.*;
import java.math.*;
import java.util.*;


public class RntApplet extends java.applet.Applet implements ActionListener, MouseListener {

   /** Initialization method that will be called after the applet is loaded
    *  into the browser.
    */
          Button allEdges, showTree,restartApplet,nextStep,treeTopology;
          Panel drawingArea;

          int num = 10;
          int td              = 15;
          int maxX            = 50;
          int maxY            = 50;
          int TDISTANCE = 100 ; /* Threshold distance equivalent to 10km*/
          int MAXIMUMANGLE = 30;
          //public Random randObj ;

          // for animation
   int globalCount=0;

   boolean paintMSTree = false;
   boolean paintAllEdges = true;
   boolean paintTopology = false;

   Vector nodes = new Vector();
   Vector edges = new Vector();
   Vector alledges = new Vector();
```

```
   Vector allNodes = new Vector();
   Vector toAdd     = new Vector();
//          Random randObj            = new Random();
   Vector nodesConsidered, nodesNotConsidered;
   int x=0,y=0;

   // get the point with minimum X and Y coordinate
   public Node getFirstNode()
   {
        Node n = null;
        if(allNodes.size()>0)
        {
                n = (Node)allNodes.firstElement();
                for(int i =0;i<allNodes.size();i++)
                {
                        Node node = (Node)allNodes.elementAt(i);
                        if( n.x > node.x)
                                n = node;
                        else if( n.x == node.x ) // taking care of y-coordinate in case of equal x
cooardinate
                                n = (n.y <= n.y) ? n : node;
                }
        }
        return n;
   }

   public void makeTree(Node startNode)
   {
        startNode.makeConnected(true);
        toAdd.add(startNode);
        while(toAdd.size()>=1)
                {
                        Node firstNode = (Node) toAdd.elementAt(0);
                        addNodesFrom(firstNode);
                        toAdd.removeElementAt(0);
                }
   }

        public void addNodesFrom(Node startNode)
        {
          for (int i = 0; i<allNodes.size(); i++)
          {
                        Node node = (Node)allNodes.elementAt(i) ;
                        if(! node.isConnected && (node!= startNode))
                        {
                                int d = startNode.distanceTo(node); // distance from startNode to
node of consideration
```

```
                if( d <= TDISTANCE )
                {
                    edges.addElement(new Edge(startNode, node)); //create
and edge from startNode to node of consideration
                    node.makeConnected(true);
                    toAdd.add(node);
                }
            }
        }
    }
    //returns all child nodes of the rootNode
    //finds the nodes adjacent to the rootNode and returns the vector of such nodes
    public Vector childNodesOf(Node rootNode)
    {
        Vector adjacent = new Vector();
        for (int i = 0; i<edges.size(); i++)
        {
            Edge edge = (Edge)edges.elementAt(i);
            if(rootNode == edge.n1)
                adjacent.addElement(edge.n2);
        }

        return adjacent ;
    }
    //
    public int angleBetween(Node vertex,Node first, Node second)
 {
    double wf = vertex.angleWith(first) ;
        double ws = vertex.angleWith(second) ;
        int angle = 0 ;
        if((vertex.y <= first.y && vertex.y <= second.y) || (vertex.y >= first.y && vertex.y
>=second.y) )
            angle = (int)Math.abs(wf - ws) ;
    else
        angle = (int)Math.abs(wf + ws) ;
    System.out.println("Angle Between: " + vertex.toString() + " AND " +first.toString() + " : "+
wf);
    System.out.println("Angle Between: " + vertex.toString() + " AND " + second.toString()
+":"+  ws);
    System.out.println("Angle Between: " + angle);
    return angle;
 }
 //
 public void assignAntena()
    {
        for (int i = 0; i<allNodes.size(); i++) {
            Node processNode = (Node)allNodes.elementAt(i) ;
```

```
            if(!processNode.considered)
            {
                Vector adjacents                      = childNodesOf(processNode) ;

                processNode.numOfAntena = processNode.numOfAntena +
getAntenaNumber(processNode,adjacents) ;
                processNode.considered                = true;
            }
        }
    }
    //
    public int getAntenaNumber(Node processNode,Vector nodes)
    {
        int count ;
        if(nodes.isEmpty() || nodes.size() == 1)
            count = 0;
        else
        {
            int angleSeparation = maxAngularSeparation(processNode, nodes) ;
            if(angleSeparation <= MAXIMUMANGLE)
                count = 0;
            else
            {
                count           = 0 ;
                int angle       = 0;
                for (int i = 0; i<nodes.size()-1; i++) {
                    Node firstNode  = (Node)nodes.elementAt(i) ;
                    Node secondNode = (Node)nodes.elementAt(i+1) ;
                    angle = angle +
angleBetween(processNode,firstNode,secondNode);

                    System.out.println("Checking " + firstNode.toString() + "
and " + secondNode.toString() + " Angle: " + angle);
                    if(angle > MAXIMUMANGLE )
                    {
                        count = count + 1 ;
                        angle = 0 ;
                    }
                }
            }
        }
        return count ;
    }
    //
 public int maxAngularSeparation(Node processNode,Vector nodes)
 {
    int separation;
```

```
        if(nodes.size() <=1 )
                separation = 0;
        else
        {
                Node up = (Node)nodes.firstElement();
                Node down = (Node)nodes.firstElement();

                for (int i = 0; i<nodes.size(); i++)
                {
                        Node n  = (Node) nodes.elementAt(i);
                        up      = up.y > n.y ? n : up ;
                        down    = down.y < n.y ? n : down ;
                        }
                        separation = angleBetween(processNode,up,down) ;
        }
        return separation;
    }

    public void init() {
       // TODO start asynchronous download of heavy resources

       Panel buttonBox = new Panel();
       showTree = new Button("Show Tree");
       restartApplet = new Button("Restart");
       treeTopology = new Button("Toplogy");

                buttonBox.setLayout(new FlowLayout());
       buttonBox.add(showTree);
       buttonBox.add(restartApplet);
                buttonBox.add(treeTopology);

       add(buttonBox);

                restartApplet.addActionListener(this);
       showTree.addActionListener(this);
       treeTopology.addActionListener(this);
       addMouseListener(this);

       this.setBackground(Color.white);
       buttonBox.setBackground(Color.lightGray);
       setVisible(true);
    }

    public void paint(Graphics g) {
       super.paint(g);

       Edge tmpE;
```

```
        Node tmpN;
        g.drawString("Click somewhere to add the nodes. Number of Nodes : " + allNodes.size() + "
Edges: " + edges.size() ,100,50) ;

                    g.setColor(Color.blue);
        for (int i = 0 ; i < edges.size(); i++)
        {
           tmpE = (Edge)edges.elementAt(i);
           g.drawLine(tmpE.n1.x,tmpE.n1.y,tmpE.n2.x,tmpE.n2.y);
        }

        g.setColor(Color.red);
        for (int i = 0; i<allNodes.size(); i++) {
            tmpN = (Node)allNodes.elementAt(i);
            g.drawOval(tmpN.x,tmpN.y,5,5);
            if(paintTopology)
                    g.drawString(" "+
(getAntenaNumber(tmpN,childNodesOf(tmpN)))+tmpN.toString(),tmpN.x,tmpN.y-5);
        }
        g.setColor(Color.black);
    }

            public void mouseReleased(MouseEvent e) {
        x = e.getX();
        y = e.getY();
                    Node newNode = new Node(x,y);
                    allNodes.addElement(newNode);
                    paintTopology = false;
                    repaint();
    }

    /** dummy mouse methods to keep compiler happy */
    public void mousePressed(MouseEvent e)
            {
            }
    public void mouseClicked(MouseEvent e)
            {
            }
    public void mouseEntered(MouseEvent e)
            {
            }
    public void mouseExited(MouseEvent e)
            {
            }
    public void actionPerformed(ActionEvent e)
    {
        if (e.getSource() == showTree) {
```

```
            globalCount=nodes.size();
            makeTree(getFirstNode());
            paintMSTree = true;
                          paintTopology = false;
            paintAllEdges = false;
            globalCount=0; // to make the "Step" button more logical
            showTree.disable();
        }

        if (e.getSource() == restartApplet) {

            nodes = new Vector();
            edges = new Vector();
            allNodes.clear();
            paintMSTree = false;
                          paintTopology = false;
            globalCount=0;
            repaint();
            showTree.enable();

        }
        if (e.getSource() == treeTopology) {

            globalCount              = nodes.size();
            assignAntena();
            paintMSTree       = false;
                          paintTopology    = true;
            paintAllEdges     = false;
            globalCount              = 0; // to make the "Step" button more logical

        }
        repaint();
    }
}

//
class Node{
    public int x,y,numOfAntena;
    public boolean isConnected = false;     // this status shows if the node is connected by any edge
    public boolean considered = false;
    public boolean added = false;
    public boolean discarded = false;

    public Node(int xP,int yP) {
        x=xP; y=yP;
        numOfAntena = 2;       // default is 2
```

```
    }
            // gives the angle with respect to the node
            public double angleWith(Node node)
            {
                        return Math.atan2(Math.abs(this.y-node.y),Math.abs(this.x-node.x))*180/Math.PI ;
            }

    public String toString() {
        return "("+ (new Integer(x)).toString()+":"+(new Integer(y)).toString() + " )";
    }

    public int distanceTo(Node n2){
                        double dx = n2.x - x, dy = n2.y - y;
        return (int)java.lang.Math.sqrt(dx*dx + dy*dy);
    }
    public void makeConnected(boolean connectedOrNot)
    {
            isConnected = connectedOrNot ; //make the node as connected to other or not
    }
    public void makeConsidered(boolean consideredOrNot)
    {
            considered = consideredOrNot ;
    }
}
//
class Edge implements Comparable {
    Node n1, n2;
            int distance ;
    public Edge(Node n1P, Node n2P) {
        n1 = n1P;
        n2 = n2P;
        distance = this.getLength();
    }

    public int getLength() {
        double dx = n2.x - n1.x, dy = n2.y - n1.y;
        return (int)java.lang.Math.sqrt(dx*dx + dy*dy);
    }

    public String toString() {
        return n1.toString()
            + "-->"
            + n2.toString()
            + "(Length: "+getLength()+")";
    }
    public Node getOtherNode(Node node)
    {
```

```
        if(n1 == node)
            return n2;
        else
            return null;
    }

    public Node getChildNodeOf(Node node)
    {
        if(n1 == node)
            return n2;
        else
            return null;
    }

    public int compareTo(Object o)
    {
        Edge e = (Edge) o;
        return this.distance - e.distance ;
    }
}
```