COMPUTING OPTIMAL PATH FOR ROUTING IN WIRELESS MESH NETWORK

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بسم الله الرحمن الرحيم

In the Name of

ALLAH,

The most merciful and compassionate, the most gracious and beneficent Whose help and guidance we always solicit at every step and every moment.

Dedicated To
My Parents, Teachers
and
Muslim Ummah

Department of Computer Science,
International Islamic University Islamabad, Pakistan

Date: 29/07/2011

Final Approval

This is to certify that we have read and evaluated the thesis entitled **Computing Optimal Path for Routing in Wireless Mesh Network** submitted by **Khalid Mahmood** under **Reg No. 365-FBAS/MSCS/F07** and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Computer Science.

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ABSTRACT

Wireless technology is emerging as a key technology for the future networks. Wireless mesh networks (WMNs) have emerged as a key technology for deployments of wireless services for various applications in personal, enterprise and metropolitan areas. Researchers have been working actively in different fields of WMNs for providing better services. Routing protocols play a vital role in wireless mesh networks to provide reliable configuration and maintenance of topology of the network. Designing a suitable cost metric for routing protocols to provide quality links for data transmission is the backbone of wireless mesh networks. Many cost metrics have been proposed for wireless mesh networks and is still an active research topic as new performance metrics need to be discovered due to the dynamics of this field. This thesis addresses the routing technique in wireless mesh network.

We have studied the existing routing protocols and cost metrics and proposed a genetic algorithm technique for routing in wireless mesh network. To evaluate the genetic algorithm, and to determine the relative performance of the genetic algorithm in the context of routing in wireless mesh network, we carry out experiments on two test systems. We evaluate the quality of the results produced by our algorithm with the traditional hop count metric results. Our results show that routing in wireless mesh network using genetic algorithm produces better results as compared to traditional hop count metric results. Finally we carry out a detailed analysis of results, which helps us in gaining an insight into the suitability of genetic algorithm for routing in wireless mesh network.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1. INTRODUCTION

Wireless technology is emerging as new replacement of existing wired networking, but at the same time many challenges which need to be addressed for the implementation of wireless technology come into view. Wireless mesh networks provide self-organized and self-configured network infrastructure which authenticate mesh connectivity dynamically [1]. These networks impart spacious connectivity with lower cost, easy deployment and reliable service coverage than their counterpart wired networks [1]. In the next section we will explain the WMN along with its architecture and applications.

1.1 Wireless Mesh Networks

Wireless mesh networks are consisting of two types of nodes mesh clients and mesh routers. Mesh clients connect to internet backbone through mesh routers, which are connected to gateway routers. Mesh routers perform the routing to the internet gateway on the behalf of mesh clients [9]. Mesh clients are also capable of performing routing to the mesh routers but mesh clients cannot perform the functionality of gateway and bridge [1]. Usually Mesh routers are stationary and have least mobility.

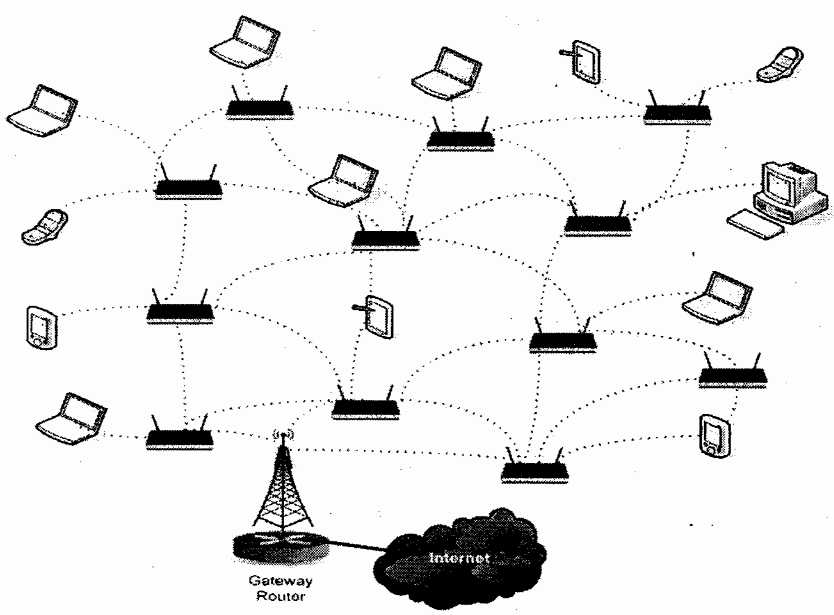

Figure 1.1: Wireless Mesh Network

1.1.1 Wireless Mesh Network Architecture

WMNs can be categorized into three major types [1] [2]: infrastructure, Client and Hybrid WMNs.

1.1.1.1 Infrastructural Wireless Mesh Networks

The backbone of infrastructural WMNs is the mesh routers which form an infrastructure for mesh clients. The communication among mesh clients and mesh clients to backhaul network take place through mesh routers. Mesh routers are actively involved in communication process while it is not necessary for mesh clients to become the part of routing and forwarding of packets [1] [2] [9]. Commonly used IEEE 802.11 and a variety of other types of radio technologies can be used to build the WMN backbone. The links among mesh routers are self-configured and self-healing. The gateway and bridging functionality embedded in mesh routers enable them to communicate with internet and other available wired and wireless networks.

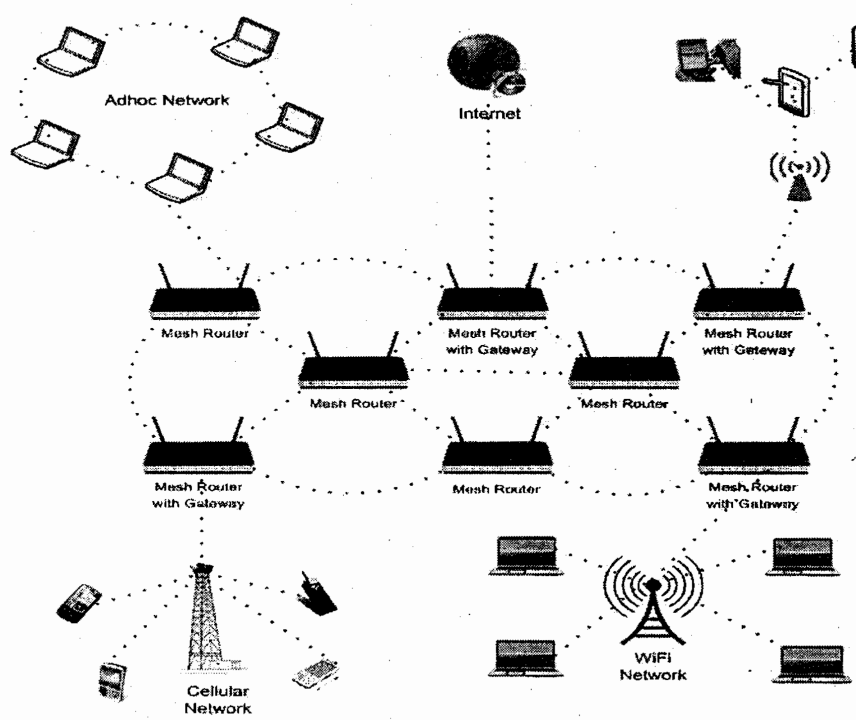

Figure 1.2: Infrastructural Wireless Mesh Networks

Mesh gateways in infrastructural WMNs are the special type of mesh routers which have a direct high speed wired link to the internet. Mesh routers and gateways have predetermined positions and have less mobility. They form a wireless multi-hop network [3]. Conventional clients having Ethernet interface can communicate with mesh routers through Ethernet links and if they have identical radio as mesh router, they will communicate directly on it. In case of different radios, client will first communicate to the base station that has an Ethernet connection to mesh routers [1].

1.1.1.2 Client Wireless Mesh Networks

Mesh clients in Client WMNs communicate with one another without the inclusion of mesh routers. The network in Client WMNs is established through client devices and all the routing and configuration is performed by them. Generally a client device in Client WMNs uses single type of radio technology. These networks are likely to be the Adhoc Networks [1] [2] [9].

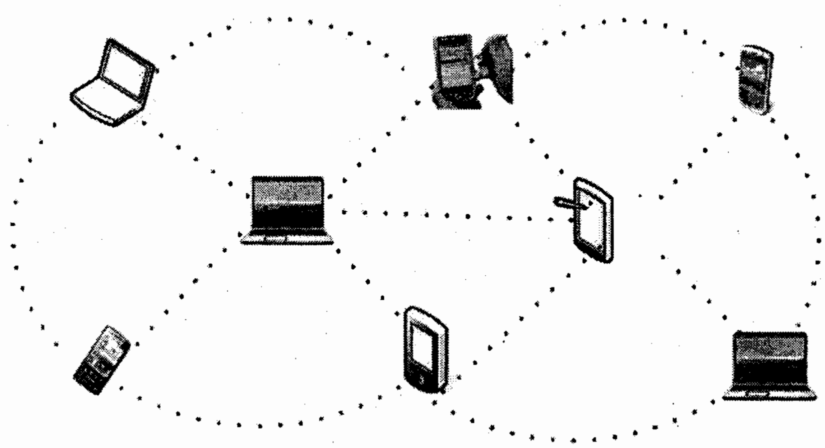

Figure 1.3: Client Wireless Mesh Networks

1.1.1.3 Hybrid Wireless Mesh Networks

Hybrid WMNs are the combination of infrastructural and client WMNs, where both infrastructure (Mesh Routers) and client (Client Nodes) provide the connectivity to the gateways and other networks. Clients can also perform routing and forwarding and access the backbone through multi-hop client network [2] [9].

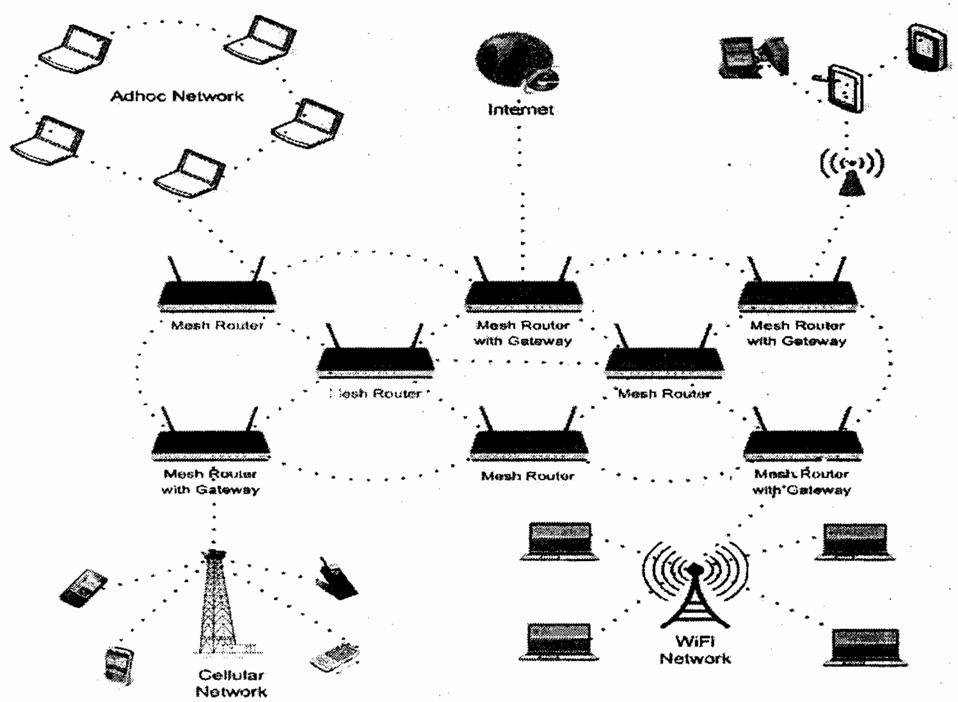

Figure 1.4: Hybrid Wireless Mesh Networks

1.2 Motivation

Our vision is to bring new innovation in the field of routing in wireless mesh networks for consideration. Routing plays an important role in both wired and wireless networks. One can easily improve the performance and quality of the network by introducing the better routing approach. Wireless mesh networks are the preeminent broadband communication systems and require an end to end QoS to its users. To achieve best performance in wireless mesh networks, the traffic should be routed on optimal path.

Many problems in the field of routing in wireless mesh networks exist and need attention. Routing in wireless mesh network is an optimization problem [22] and different search approaches have been introduced to solve these problems. We have investigated evolutionary optimization techniques to solve the routing problem in wireless mesh network as they are population based approaches. These techniques can find global optimum solution to a given problem. We have applied genetic algorithm on our routing problem in this research and proposed it for AODV protocol.

1.3 Problem Statement

Wireless mesh networks are more difficult to deal with as compared to wired networks due to the dynamic behavior of wireless networks. The conventional wireless routing protocols are developed for Adhoc networks. These protocols are designed for mobility and energy constraints, which are not the issues in wireless mesh networks. The routing issues of WMNs are different than Adhoc networks. Therefore the Adhoc routing protocols need to be enhanced for WMNs. The traditional hop count metric of AODV does not take into account; the link bandwidth and packet loss ratio. We have used an evolutionary optimization technique named as genetic algorithm for routing in wireless mesh network which will consider the link bandwidth and packet loss ratio into account and optimal path will be selected among all the available paths from source to destination on the basis of aggregated cost of all the links of the path.

1.4 Objectives of Study

Objectives of this research work are as follows:

- Implementation of evolutionary technique i-e Genetic Algorithm for finding an optimal path for routing within wireless mesh network.
- Comparison of AODV's traditional cost metric results with the results obtained from implementation of genetic algorithm.

1.5 Scope of Study

The simulation program of optimal path for routing in wireless mesh network has been developed using C#.NET. The simulation program uses aggregated Expected Transmission Time (ETT) cost metric for all the available paths from source to destination within wireless mesh network. The optimal path is selected by using the genetic algorithm technique.

1.6 Thesis Organization

Chapter 2 provides a background of the research area. It briefly discusses wireless mesh network, routing protocols and routing metrics for WMN.

Chapter 3 gives an overview of genetic algorithm, its components and working. It also gives details of our routing problem formulation on genetic algorithm.

Chapter 4 provides detailed description of wireless mesh network test systems and their statistics. These test systems are designed and implemented in C#.NET.

Chapter 5 presents details of the results obtained by applying genetic algorithm technique on WMN test systems. Conclusion drawn from the results is also presented.

Chapter 6 gives a brief overview of the research contributions during this study. It also gives some points about future work.

CHAPTER 2: BACKGROUND AND RELATED WORK

2. BACKGROUND AND RELATED WORK

In this chapter we will first have an overview to wireless mesh network and its features. We then will give a brief introduction to routing in wireless mesh network, routing protocols and routing metrics. The related work establishes where our proposal stands in comparison to the existing work.

2.1 Wireless Mesh Networks Overview

Wireless mesh networks (WMNs) are developing as a potential solution for growing wireless applications. WMNs are self configrring and self healing networks. They are typically implemented by using IEEE 802.11 hardware platform. But the difference between conventional and mesh networks lie in the connectivity of access point. In conventional networks, the access point has wired connectivity to the backbone network, while in WMNs, access points follow a multi-hop paradigm resulting in a mesh. The backbone of WMNs is composed of mesh routers which have limited or no mobility and they offer network access to both mesh and conventional clients. Gateway routers are connected to internet with a wired link [8].

2.2 Features of Wireless Mesh Networks

Wireless mesh networks hold the following features.

- Wireless mesh networks provide multi-hop wireless connectivity which helps to deploy large networks in less time and with optimal cost.
- Mesh routers in WMNs have no or least mobility, therefore, route breaking due to mobility is not an issue.
- Mesh routers in WMNs are provided with continuous power supply; therefore, energy constraint is not a limitation like Adhoc networks.
- WMNs are self configuring and self healing networks.
- WMNs provide support for Adhoc networks and P2P networks.

- WMNs can be integrated with multiple types of networks like wired, WiMax, Wi-Fi, sensor networks etc.
- Nodes in WMN are fixed therefore, topology changes occasionally due to failure or addition of node in the network.

2.3 Routing in Wireless Mesh Networks

The routing in WMNs is performed not only by the mesh routers but also by the clients. Clients can do routing and forward on behalf of the other nodes which are not directly connected to mesh router. Existing routing protocols do not fit well in WMN environment [1] [2] [8] and are still required to be modified or new protocols need to be developed. Research in this direction is carried out by many researchers but many issues are still pending [1] [2] [8] and await the development of an efficient routing protocol.

2.4 Existing Routing Protocols

Routing in WMNs has been an active research area. As there is a correspondence of some common features of WMNs with Adhoc networks, the routing protocols designed for Adhoc networks can be employed to WMNs with some extensions [1] [2]. Adhoc network protocols are designed in the light of high mobility and efficient power consumption while WMNs have no constraints on power consumption and mobility. These variations argue that the conventional Adhoc routing protocols may not be suitable for WMNs and need some improvements.

Routing protocols are divided into two categories. One is traditional table driven routing protocols for wired networks like RIP and OSPF. The protocols in this category are not designed for mobile and dynamic networks. Second category consists of Adhoc routing protocols for Adhoc networks [8].

Adhoc routing protocols can be classified into two main categories i-e Proactive and Reactive routing protocols [13].

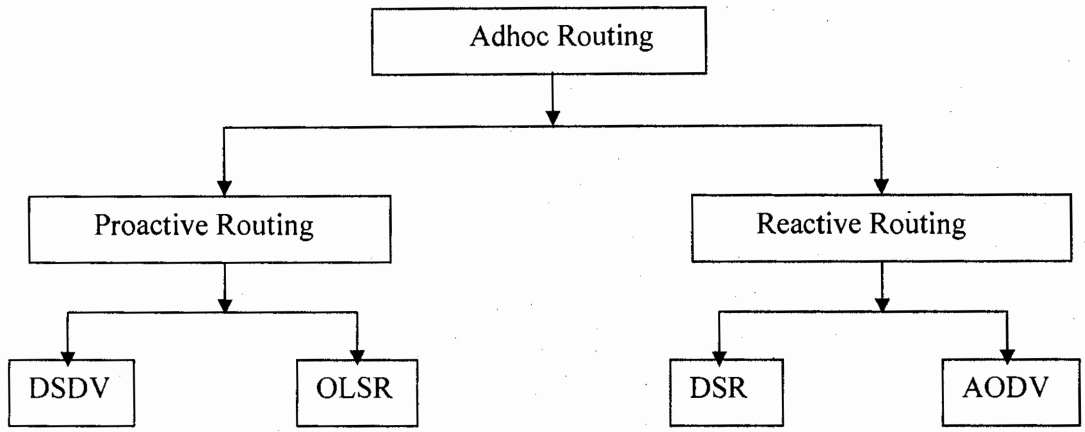

Figure 2.1: Classification of Adhoc Routing Protocols

2.4.1 Proactive Routing Protocols

Proactive routing protocols act like traditional table driven routing protocols for wired networks. In proactive routing a routing table is maintained in which up-to-date information about available route to destination is stored [4]. The routing table is periodically updated and is event driven. Protocols used in wired networks cannot directly apply in wireless networks. Wireless environment is different from wired networks therefore, routing requirements for wireless networks are also varies. Destination Sequenced Distance Vector (DSDV) [11] [12] and OLSR [55] [56] are proactive routing protocols designed for Wireless Adhoc networks.

2.4.1.1 Destination Sequenced Distance Vector (DSDV)

DSDV (Destination Sequence Distance Vector) [11] [12] is table driven Adhoc routing protocol based on well known bellmen ford algorithm. DSDV is derived from another routing protocol RIP [36], commonly used for wired networks. RIP was not applicable in Adhoc networks due to dynamic topology changes and causes looping problem due to mobility of nodes. Therefore, in DSDV a sequence number is added to identify the updates, if the sequence number is newer than previously received then routing table will be updated otherwise it will discard.

DSDV maintains a complete topology at the nodes. Each node maintains a routing table in which it maintains path to all destinations. This routing table contains all destinations, routing metric, next hope and sequence number. This routing table is exchanged periodically or when there is a change in network topology. Whenever a node receives an update message, it updates its routing table. If a node receives, multiple update messages it updates routing table with the latest sequence number, if all the packets have same sequence number, then node will update with the minimum hop count packet and discard others.

WMNs are used to deploy large networks and implementation of DSDV in WMNs is not feasible due to its topology maintaining at nodes, and periodic exchange of routing tables. In large WMN a node have to maintain quite a large routing table to list all the nodes for which extra memory and processing is required. Periodic and triggered update of routing table by all the nodes with their neighbor causes overhead for the bandwidth. Therefore, DSDV is not suitable choice for wireless mesh networks due to its overheads in terms of bandwidth, processing and memory.

2.4.1.2 Optimized Link State Routing (OLSR)

The Optimized Link State Routing Protocol (OLSR) [55] [56] is designed for mobile ad-hoc networks. It is the enhancement of classical link state algorithm to meet the requirements of mobile ad-hoc networks. The nature of the protocol is proactive i-e table driven therefore nodes exchange topology information regularly with neighbor nodes. Each node selects "multipoint relays"(MPR) as set of forwarders. MPR is the one hop neighbor of any node selected by that node to forward the packet as received if it is not duplicate. Only MPR are responsible of forwarding packets which helps reducing forwarding overheads by limiting the number of transmissions.

OLSR provides shortest path routing to the destination using MPR. It works well in large and dense networks. OLSR also suitable for the networks where topologies changes frequently. In this context routes are automatically maintained while the nodes exchange their tables frequently so changes in routes automatically adjusted and route to all known destinations are available immediately when needed. OLSR also minimizes the flooding overhead by selecting MPRs. Only MPR are responsible of participating in forwarding process. OLSR is designed to perform in distributed environment and no central control is used to control the OLSR routing. Each node communicates with its own neighbors only and multi-hop communication is used. OLSR does not require sequenced delivery of messages; each packet contains a sequence number upon receiving packet they can be arranged in order.

OLSR is divided into two modules. One is its core function and second is auxiliary function. Core provides the basic functionality of OLSR routing. The core defines the behaviors of the nodes. Main functionalities provided by the core are:

- Packet format and forwarding
- Link sensing
- Neighbor detection
- MPR selection and MPR signaling
- Topology control message diffusion
- Route calculation

Similarly auxiliary function provides the facility where additional functionality is required like in the situation where nodes have multiple interfaces and working in different routing domains. Using the link layer information nodes need to provide redundant links using its multiple interfaces.

Using OLSR in mesh networks may not be suitable as in mesh networks topology changes very less and periodic control messages are overheads in the network. Similarly nodes have to maintain the routing table.

2.4.2 Reactive Routing Protocols

Reactive or on-demand routing protocols [53] were originally proposed for MANETs. These protocols initiate the route discovery process only when source node really wants to send data to destination node. These protocols are purely on-demand. AODV [5] and DSR [7] fall in this category.

2.4.2.1 Dynamic Source Routing (DSR)

Dynamic Source Routing (DSR) [7] protocol is specifically designed for multi-hop wireless Adhoc networks. With the use of DSR, prior network administration and infrastructure is not needed and the network is self-organizing and self-configuring. The communication among nodes which are not within wireless transmission range of one another take place by forwarding packets to each other over multiple hops. As in multi-hop wireless Adhoc networks, the nodes can freely move or join or leave the network and sources of interference can also change due to the mobility of nodes, DSR automatically determine and retain all the routing information. In DSR protocol path from source to destination (source route) is discovered dynamically along multiple hops of wireless Adhoc network. As the packet propagates through multiple hops to a destination, it includes the information of traversed nodes in its header.

Route discovery and route maintenance mechanisms are the key features in DSR protocol to discover and maintain the source routes in Adhoc networks. The process of route discovery is initiated whenever a source node "S" wants to send a packet to a destination node "D", acquires a source route to "D". This process is initiated only if "S" does not already know a route to "D". If the source route from "S" to "D" is broken due to the topology change, route maintenance process detects it and now "S" can use any alternate route to "D" which it know or can again find a new route by initiating route discovery process.

Route discovery and route maintenance, both processes are functioning on demand. Periodic routing advertisements are not used in DSR thus minimizing the overhead. Using DSR a node can find out multiple routes to any destination in response to a single route discovery. As multiple routes are cached at nodes in DSR, so we do not need to perform a new route discovery process each time a route is breached.

Whenever a source node "S" propagates a packet to a destination node "D", it records the sequence of all the traversed nodes during propagation in the header of the packet and thus the source route is obtained. When "S" will send a data packet it usually find route to destination from its route cache where previously learned routes are stored, but if it does not find any route in its route cache, it will now call the route discovery process and will find out the route dynamically. Figure 2.2 illustrates the route discovery example in DSR, in which node "S" wants to communicate with node "D". Node "S" will send a RREQ (Route Request) message as a single local broadcast packet to initiate the route discovery. This RREQ message will be received by all the nodes that are currently within wireless transmission range of "S". A unique request id is determined by the initiator of the RREQ. Each RREQ message contains the unique request id (determined by the initiator of the RREQ), the initiator and target of the route discovery. Information of all the nodes through which RREQ message traversed is included into RREQ packet.

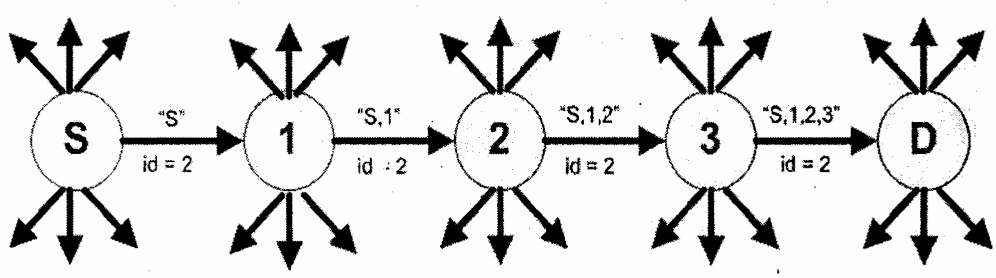

Figure 2.2: Route Discovery in DSR

When another node receives the RREQ, it will send a RREP message (accumulated route record from source to destination) to the source node if it is the destination node; initiator will cache this route for subsequent data transmission after receiving the RREP message. Otherwise, if this node has already received another RREQ message with same request id from this initiator or if it observed that its own address is already present in RREQ message, it will discard the RREQ. Otherwise, this node will add its own address in RREQ message and will broadcast it as a local broadcast.

A node sends a Route Error message to the original sender of the packet if it does not receive receipt confirmation of sent packet after retransmitting it to a maximum number of times. This will identify that the link on which data is retransmitted is broken.

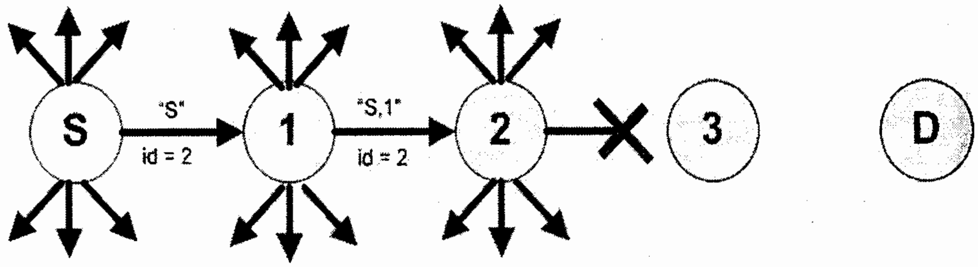

Figure 2.3: Route Maintenance in DSR

For example in figure 2.3, node 2 is unable to send the data packets to next hop 3, then node 3 will send a Route Error message to node S, identifying that route from node 2 to node 3 is currently broken. Node S then will remove this broken link from its cache and for subsequent transmissions to same destination node D, node S will send on any other route if it has already cached, otherwise, it will perform a new route discovery process for this target.

2.4.2.2 Adhoc On-demand Distance Vector (AODV)

AODV [5] is designed for Adhoc networks. Routes are obtained on demand with little or no reliance on periodic advertisements. As global advertisements for routing are not required in AODV, so the bandwidth that is available for mobile users is significantly less than in those protocols that relies on global periodic advertisements. AODV dynamically set up its route table entries at intermediate nodes. The initial path discovery progression between source and destination makes the first move whenever source node needs to correspond with another node for which it has no routing information in its routing table. During this process two separate counters: a node sequence number and a broadcast-id are preserved at each node. The source node broadcasts a Route Request (RREQ) packet to its neighbors to establish the route discovery process. Following are the parameters of RREQ packet.

- Source address.
- Source Sequence Number.

- Broadcast-id.
- Destination Address.
- Destination Sequence Number.
- Hop-count.

The pair <Source Address, Broadcast-id> distinctively classifies the RREQ. Every new RREQ by the source causes the increment in broadcast-id. Route Reply (RREP) is used to ensure RREQ. If the immediate neighbor is destination node it sends back RREP to the source otherwise rebroadcasts the RREQ to its own neighbors after incrementing the hop count. Multiple copies of same RREQ from different neighbors might be received at intermediate node but it drops the RREQ if it is already received by another node after checking <Source Address, Broadcast-id>, if it is already received from <Source Address, Broadcast-id> it drops the packet otherwise process it further. The receiving node then checks that if it is the destination node, if yes then it sends a RREP for corresponding RREQ, if no then it increments the hop count and rebroadcast the RREQ, and maintains reverse path to previous node from which it received RREQ.

For reverse path two sequence numbers are incorporated in RREQ: the source sequence number which is used to preserve latest information about the reverse route to the source and the last destination sequence number acknowledged to the source that indicates how fresh a route to the destination must be before the acceptance by the source. Reverse path from different nodes back to the source are automatically established as RREQ propagate from source to various destinations.

When RREQ reaches its destination, the node finds itself as destination in RREQ. It sends a RREP along the reverse path maintained during the propagation of RREQ and sets a forward path to itself. RREP contains the information about source address, destination address, destination sequence#, hop-count and lifetime. While the RREP came back to the source node, each node along the path maintains forward route entries in its route table to the node from which RREP came. Meanwhile these nodes also update their timeout information for route entries to the source and destination and the most up-to-date destination sequence number for the requested destination is also recorded.

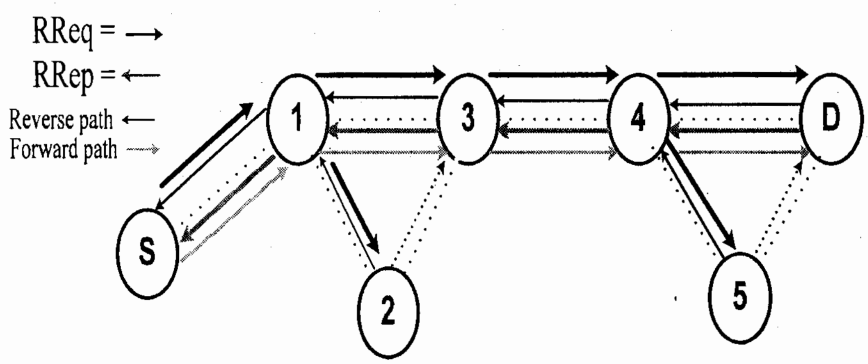

Figure 2.4: Path establishing in AODV

2.5 Existing Routing Metrics

Routing protocols play an important role in finding best path and forwarding the data along the path. Cost metric is the foundation of a routing protocol. Better the cost metric of a protocol; better will be the result of routing protocol. In any network the cost of forwarding packet along the link is known as the cost metric of a link. Defining a cost metric for wireless networks is a great deal as compared to traditional wired networks because of unevenness of link characteristics between nodes. There are many factors which directly influence the communication quality within wireless networks such as background noise, channel fading, obstacles and interference [10]. Researchers are working actively in this area and have proposed different cost metrics for wireless networks. These are Hop Count, Per-hop Round Trip Time (RTT), Per-hop Packet Pair Delay (PktPair), Quantized Loss Rate, Expected Transmission Count (ETX), modified ETX (mETX), Effective Number of Transmission (ENT), Expected Transmission Time (ETT), Weighted Cumulative Expected Transmission Time (WCETT) and Metric of Interference and channel switching (MIC).

2.5.1 Hop Count

Hop count is mostly suitable for wireless mobile Adhoc networks where mobility ratio is high. The simplicity of this metric is that no additional computations are performed as compared to other cost metrics; where link level estimations are computed depending upon certain parameters and this course of action takes time which is not preferable for Adhoc networks [10]. As in [26] the key advantage of this metric is its simplicity and we can easily compute the hop count in networks where the topology is known. The shortcoming of this metric is that it does not capture packet loss and bandwidth into account. The experiments performed in [13] using optimized link state routing (OLSR) protocol to estimate the performance of different cost metrics show that hop count metric consequences in increasingly high packet-loss rates because it does not consider the quality of the links and have a tendency to forward packets through long noisy wireless links.

2.5.2 Per-hop Round Trip Time (RTT)

[10] and [26] discussed Per-hop Round Trip Time (RTT) cost metric which is well known as delay based link cost metric that employs the measured average round trip time (RTT) observed by unicast probes between neighboring nodes. To estimate the RTT, after every 500 milliseconds a node sends probe packet carrying timestamp to each of its neighbors. After receiving the probe packet each neighbor immediately reply with probe-acknowledgement echoing the timestamp. In this way the sending node computes RTT and maintains an exponentially weighted moving average of the RTT samples to each of its neighbors

$$\boldsymbol{RTT\ estimate\,[n+1] = 0.1\ \times RTT[n] + 0.9 \times RTT\ estimate[n]} \quad \mathbf{(2.1)}$$

which is a low pass filter with a bandwidth of a few packets.

The delay at link through RTT cost metric is caused by numerous components which are: Queuing Delay, Channel Quality and Channel Contention. If a node sends probe packet to its neighbors it may be possible that there are existing jobs to be processed at neighboring nodes, so before sending probe-acknowledgment RTT will include the time it acquires for the existing jobs to be processed at neighboring nodes. This will cause a queuing delay resulting in high RTT. The communication in wireless networks occurs on different channels. There are many issues such as channel fading or interference by other nodes not directly contending with our node which directly affects the channel quality. The RTT calculation is influenced by retransmission of packets several times due to the above mentioned factors that impact on channel quality and also if there are other nodes in the neighborhood of one of the neighbors, the probe packet or the probe-acknowledgment can get delayed due to direct contention resulting in high RTT [10].

The simulation results for 12 node network with a real world web traffic model in [43] show that, the RTT metric is a realistically well representative of the actual load at the nodes. Another set of simulations were run for a relatively lightly loaded network of 35 nodes, a small subset of which generates web traffic. When the RTT metric is used for channel assignment to select the cleaner frequency for each hop, the network throughput increases by up to 70% and the average delay reduces by 50%. Nevertheless, there is a primary problem linked with using RTT. If the load is reduced at certain node then all the traffic will pass through this node yields the augmented delay resulting high RTT value. The experimental results of 23 node network in which every node pair commence a long TCP session investigated for RTT metric in [26], show that the median of the average throughputs of all the sessions may be 75% lower when RTT is used instead of the simple hop count (which achieves around 1100 Kbps). The authors also point up that this reduction is certainly due to self interference, since the optimal path assignments change about 20 times more frequently with RTT, compared to the hop count. The overhead coupled with determining the RTT may be high. RTT metric doesn't explicitly take link data rate into consideration and also it is not feasible for dense networks and does not react to the channel unpredictability.

2.5.3 Per-hop Packet Pair Delay (PktPair)

Per-hop Packet Pair Delay (PktPair) metric is designed to overcome the problem of distortion of RTT measurements caused by queuing in RTT metric. To estimate this metric, a node sends two probe packets one after the other to each neighbor every 2 seconds. The first probe packet is small having size 137 bytes, and the next one is large having size 1000 bytes. The neighbor calculates the delay between the receipts of the first and the second packet. It then reports this delay back to the sending node. The sender maintains an exponentially weighted moving average of these delays for each of its neighbors. The delay produced by retransmission of probes due to channel issues caused by fading and communication of other nodes in the neighborhood is also included in the calculated difference between the times of reception of two consecutive packets. If the network has low bandwidth paths then the second probe packet will take more time to pass through the link resulting in increased delay. The primary advantage of using PktPair cost metric over RTT is that it is not influenced by queuing delay at sending node because both the packets are sent successively and if delayed both will be delayed uniformly. As the second probe packet is larger, this metric takes link bandwidth into account which is not the case in RTT cost metric. This metric has numerous shortcomings. First, the overheads are even greater than those of the RTT metric, due to the large size of second packet. Second, this metric is not completely resistant to the phenomenon of self interference [10] [26].

2.5.4 Quantized Loss Rate

According to [10], this metric approximates the per-link frame delivery ratios and uses the continuous path loss probability as the cost of routing over a path. Each node keeps track of the number of correctly received packets from each of its neighbors to measure the link quality. A window of the most recent 32 packets is considered for each downlink and an average number of correctly decoded packets are calculated. This value is then quantized depending on the region it lies: Q0: 53-100% loss, Q1: 21-53% loss, Q2: 10-21% loss and Q3: 0-10% loss. The midpoint of each region is assigned as the representative of the region. Each node keeps track of its uplink to every neighbor as well and records the higher one of the two quantized loss rates as the (bi-directional) cost of the link. The implementation of this metric is done for the sensor network platform and tested over DSDV in sensor network. The performance is compared with that of the plain DSDV, for which the hop count is the cost metric. For 28 nodes, the quantized loss rate metric reduced the network wide loss rate by a percentage between 24-32%. For increased number of nodes, the amount of improvement decreases (e.g., for a 48 node network, percent improvement is between 6-20% and for a 91 node network it is between 2-4%). Increased number of nodes may be leading to an overflow in the neighbor lists, causing them to become ineffective. An additional issue about this metric is that it does not account for the total bandwidth consumed, because it gives preference to two links of low loss rate over a single link with higher loss-rate.

2.5.5 Expected Transmission Count (ETX)

Expected Transmission Count (ETX) is proposed by [31] to find high throughput routes in multi-hop wireless networks. The foundation of ETX cost metric is the loss ratio of each link within a route and it also take into account the number of links in a route. ETX for the complete route is the sum of ETX calculated for each link in the route. The ETX of a link is computed both in forward and reverse delivery ratios. When a packet is successfully received at recipient, the measured probability is d_f and d_r is the measured probability that the ACK packet is successfully received by the data sender [13][31]. The probability of successful data transmission and acknowledgment is $d_f \times d_r$. If the acknowledgment of any data packet is not successful, sender will retransmit it. The expected number of transmissions for a link is formulated as:

$$\boldsymbol{ETX = \frac{1}{d_f \times d_r}} \qquad (2.2)$$

In [14], ETX is calculated as:

$$\boldsymbol{\frac{1}{(1-p_f)(1-p_r)}} \qquad (2.3)$$

Where $1 - p_f = d_f$ and $1 - p_r = d_r$

In [21], ETX is calculated as:

$$\boldsymbol{p = 1 - (1 - p_f) \times (1 - p_r)} \qquad (2.4)$$

where p is the probability of unsuccessful packet transmission from x to y. The probability of successful packet delivery from x to y in k attempts is:

$$s(k) = p^{k-1} \times (1-p) \qquad (2.5)$$

Finally, the expected transmission count (ETX) is calculated as:

$$ETX = \sum_{k=1}^{\infty} k \times s(k) = \frac{1}{1-p} \qquad (2.6)$$

To calculate ETX, each node transmits a probe packet every second. The probe is enclosed with the count of probes received from each neighboring node in the previous 10 seconds. The adverse aspect of ETX is that it cannot distinguish the loss rates between low and high data rates because of the small size of probe packet [26]. ETX is designed to find the high throughput path but still it is not able to select the best path on the basis of successful transmission counts because the smaller size of probe packet does not represent the accurate results for actual data packet which are greater in size [8]. According to [18] the main constraint of ETX is that it does not consider the irregularity of the traffic on the wireless link. Forward and reverse delivery ratios are treated in the same way whereas the forward link has traffic with much larger data packets while reverse link has smaller ACK packets which are more resistant to link losses. For example consider the figure 2.5 in which node S has two possible paths to node D, S → 1 → D or S → 2 → D. Since ETX treats both forward and reverse links in the same way, the following will be true:

$$ETX_{(S,1)} = \frac{1}{0.7 \times 0.3} = ETX_{(S,2)} = \frac{1}{0.3 \times 0.7} = 4.76$$

Therefore, paths S → 1 → D and S → 2 → D are considered equal and the option for selection of path will be random but we can say that the path S → 1 → D would perform better than S → 2 → D because of asymmetry in the size of data packets and ACKs.

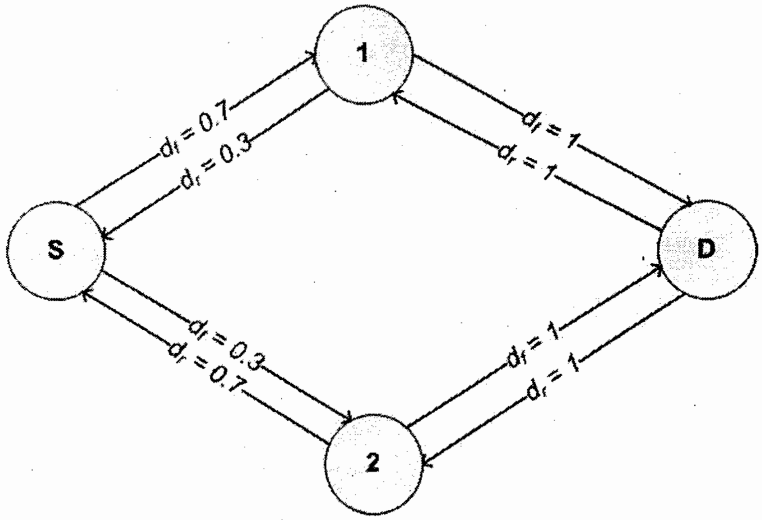

Figure 2.5: Problem of packet asymmetry in ETX

2.5.6 Modified ETX (mETX)

This metric is built to overcome the limitations of ETX in the presence of channel unpredictability. The mETX metric is a function of the mean, $\mu\sum$ and the variance, $\sigma^2\sum$ of $\sum$, the bit error probability summed over packet duration:

$$mETX = exp\left(\mu \sum + \frac{1}{2}\sigma 2_{\Sigma}\right) \qquad (2.7)$$

The $\mu\sum$ term represents the impact of gradually unreliable and static component channel e.g., shadowing, slow fading), while the $\sigma^2\sum$ represents the impact of relatively rapid channel variations, e.g. flat fading interference [8][10]. The mETX metric performs at bit level and by using the position of corrupted bit in the probe; it can calculate the bit error probability [13][37].

2.5.7 Effective Number of Transmission (ENT)

According to [10], ENT metric is designed to meet the requirements of certain higher layer protocols for finding routes. The main purpose of ENT is to find a high throughput path whereas the end-to-end packet loss rate should not go beyond a specified value that is visible to higher layers such as TCP. Choosing a high throughput path by considering only the loss constraint is not enough because links having high loss rates may also involve in this process.

So ENT is designed to overcome this issue. ENT takes into account the number of consecutive retransmissions per link [13][37]. According to [51], ENT is defined as:

$$ENT = exp(\mu + 2\delta\sigma^2) \qquad (2.8)$$

where μ is the estimated average packet loss ratio of a link, σ^2 is the variance of this value and δ is the additional degree of freedom with respect to mETX.

2.5.8 Expected Transmission Time (ETT)

The ETT routing metric was proposed by Draves et al. [21] which improve the ETX by taking into account the throughput of links into its computation [29]. If congested links have smaller link layer loss rate than un-congested links, ETX will prefer the congested links in this case [51]. To overcome this problem the bandwidth of each link is incorporated in ETT [21].

The time spent in transmission of a packet along a link l i-e ETT_l is obtained by multiplying the expected transmission count (ETX_l) by the link bandwidth. Mathematically it can be formulated as:

$$ETT_l = ETX_l \times \frac{S}{B_l} \qquad (2.9),$$

where B_l is the transmission rate of link l and S is the size of the packet. By incorporating the link bandwidth into the computation of ETT, the performance of the obtained path becomes better than the path obtained by ETX. The limitation of ETT is that it does not take into account the inter-flow and intra-flow interference in the network [29]. As an example, ETT may select a path which uses only one channel whereas a high throughput path with diverse channels having less intra-flow interference may be available.

2.5.9 Weighted Cumulative Expected Transmission Time (WCETT)

WCETT [21] was designed to overcome the issue of intra-flow interference in the network. By using WCETT, the nodes which transmit data on same channel are reduced on the path of a flow. Mathematically WCETT for a path p is formulated as:

$$WCETT(p) = (1-\beta) \sum_{link\ l\varepsilon p} ETT_l + \beta \max_{1\leq j\leq k} X_j, \tag{2.10}$$

where $0 \leq \beta \leq 1$, a tunable parameter. X_j is the number of times channel j is used along path p which helps to capture the intra-flow interference. The section $\max_{1\leq j\leq k} X_j$ is used to count the maximum number of times that the same channel appears along a path. The paths which have more diversified channel assignments on their links have lower intra-flow interference thus WCETT gives low weights to such type of paths and captures the intra-flow interference [29].

WCETT takes into account the channel diversity and end-to-end delay [13][21]. In [29] two limitations of WCETT have been discussed. First, it does not clearly reflect on the effects of inter-flow interference. Therefore, WCETT may use the flow path to more congested areas resulting in starvation of some nodes. Secondly, no efficient algorithm is designed yet to compute the minimum weight path that is based on WCETT because it is not isotonic [29].

2.5.10 Metric of Interference and Channel Switching (MIC)

The MIC metric is designed to overcome the problems of non-isotonicity and lack of ability to capture the inter-flow interference faced in WCETT [29]. The MIC metric of a path p can be formulated as:

$$MIC(p) = \frac{1}{N \times min\,(ETT)} \sum_{link\ l\varepsilon p} IRU_l + \sum_{node\ i\varepsilon p} CSC_i, \tag{2.11}$$

where N is the total number of nodes in the network and min(ETT) is the minimum expected transmission time in the network. IRU (Interference-aware Resource Usage) and CSU (Channel Switching Cost) are formulated as:

$$IRU_l = ETT_l \times N_l, \tag{2.12}$$

$$CSC_i = \begin{cases} w_1 \; if \; CH(prev(i)) \neq CH(i) \\ w_2 \; if \; CH(prev(i)) = CH(i) \\ 0 \leq w_1 < w_2, \end{cases} \qquad (2.13)$$

where N_l represents the set of neighbors that the transmission on link l interferes with, *CH(i)* is the channel assignment for node *i's* transmission and *prev(i)* corresponds to the previous hop of node *i* along the path *p*.

After studying the wireless mesh network, routing protocols and routing metrics, we finally concluded that there is a gap in finding optimal path for routing in wireless mesh network. We have used expected transmission time (ETT) cost metric in our routing problem and formulated a fitness function based on hop count and ETT. We have used our fitness function in genetic algorithm technique [47] [48] [49] for finding optimal path for routing in wireless mesh network.

We have compared our results with traditional hop count metric results. The strength and limitation of both techniques are as follows:

Hop Count

- **Strengths**
  - No additional computations except hop count are performed.
  - Selects the path which has minimal number of hops as compared to other paths.
- **Limitations**
  - This technique does not consider the link quality. It does not capture packet loss and bandwidth into account.

GA Technique

- **Strengths**
  - GA is based on fitness function computation, so fitness function can be defined in such a way that it should consider all factors contributing in quality of path.
  - GA computes a set of solutions so that we have multiple sub optimal solutions.
- **Limitations**
  - GA has greater computational cost.

CHAPTER 3: PROBLEM FORMULATION

3. PROBLEM FORMULATION

In this chapter we present our formulation for the routing in wireless mesh network. The problem is formulated as an optimization problem.

3.1 Optimization

Optimization is a method of the application of succeeding iterations with application of variations on initial idea [47], i-e. Optimization is fine-tuning of variables of system to get preferred output. The focal point of optimization techniques is an optimal point, while intervening performance is disregarded [48]. In [47] six categories of optimization are discussed. First is the trial and error approach, which binds different options without knowing the process of generating output which is more or less a random search. Second category indicates that optimization can be one dimensional or many dimensional. Third discriminates between static and dynamic optimization (If output is a function of time then optimization is dynamic). Fourth sort outs the variables of optimization as discrete or continuous. Discrete variables select a set of variable values from finite set of variable values whereas in case of continuous variables, available pool of variable values has infinite possible values. Fifth, constrained optimization integrates valid variable values into fitness function (a function which gives an output value based on variable values, the output value decides level of goodness of optimization) while unconstrained optimization lets all possible values for their variables in fitness function. Sixth, some optimization methods are deterministic while others are random based on some probabilistic methods. Deterministic methods normally get stuck local optima while random probabilistic based approaches give better results and try to achieve global optima [47].

3.2 Search Based Problems and Search Based Routing

In real life, there are a large number of problems where search space (i-e. all possible solution to problems including good solutions which fulfill desired constraints and bad solutions which do not fulfill desired constraints) is very large as compared to solution space. A solution is considered as the best solution if we check all possible options for solution. In-depth search fails if search space is too large as compared to solution space. Such types of problems are not solvable in polynomial time. Since best solution may be difficult to achieve, so an effort is made to find a sub-optimal solution. According to [48] there are three important types of search methods: first is calculus based which usually searches for the local optima. Second type is enumerative type which recommends checking every point in search space. This type of the search is simply not practical because most of the times search spaces are so large that it is impossible to check them in polynomial time. Third is random search which emphasizes random walks while keeping best solution intact.

Routing in wireless mesh networks is an optimization problem where optimal path needs to be selected from a large number of possible paths. The main purpose of optimization is to search values for a number of parameters whose aim is to maximize or minimize the objective function [45] [46]. In order to formulate the routing problem in wireless mesh network as a search based problem, three tasks need to be carried out: first is the representation of problem which is agreeable to symbolic manipulation, second is a fitness function specifying integrity of available options and third is the set of manipulation operators.

3.3 Genetic Algorithm Based Solution to Search Based Problems

Genetic Algorithms are optimization methods that make use of a search process reproduced from the mechanism of biological selection and biological genetics [48]. Genetic Algorithms follow the natural search and selection processes as described in genetics for biological processes which lead them to find the fittest individuals [48].

GA belongs to the class of evolutionary algorithm. The aim of GA is to find accurate or approximate solution for a given problem in meaningful way. Some advantages of GA are listed in [47] which are as follows:

- Genetic Algorithms can be used with continuous or discrete variables.
- Genetic Algorithms can easily deal with large number of variables.
- Genetic Algorithms provide a list of optimum solutions instead of a single solution.

- Encoding of variables can be done through GA so that optimization is done with the encoded variables.

GA gives much better results when exhaustive search techniques fail [47].

3.3.1 Components of a Simple Genetic Algorithm

It is normally observed in many optimization methods that we start finding the optimal solution from search space using some transition rules by starting from a single point and moving to the next point in search space. The transition rules are normally deterministic. Genetic algorithm initiates with a set of solutions which are encoded with some suitable GA encoding scheme. Successive sets of solutions are generated depending upon previously generated sets. These sets of solutions are generated with the help of an objective function known as fitness function. The integrity of solution depends upon this objective function [48]. Following are the components of genetic algorithm.

3.3.1.1 Variable Selection

Every problem normally is influenced by some factors which provide basis for the resolution of that problem. Variable selection is the process of finding all such variables which effect problem resolution. For example in case of routing in wireless mesh network, congestion avoidance at mesh nodes, high throughput, minimum interference, minimum cost , expected transmission time and optimal channel assignment; all these play a significant role in finding best routing solution.

3.3.1.2 Fitness Function

The resolution of a problem primarily depends upon fitness function. A fitness function discriminates the good solution from bad. It is based upon those variables which affect the problem. Appropriate weights are assigned to variables through fitness function. The outcome of fitness function is normally one value which indicates the level of goodness for solution. In our routing problem we will define a mechanism to compute the path cost (Sum of expected transmission time among all nodes within a path) which will define a criterion for optimal or non optimal path within wireless mesh network.

3.3.1.3 Encoding Scheme

GA is normally operated on coded variable values rather than actual ones. The literature survey shows that there exists many encoding schemes but two of them are commonly used. These are binary encoding and real encoding [48]. The performance of GA is highly dependent on these encoding schemes which play a vital role in determining the reliability of GA [49]. An inadequately coded GA may not deliver the results in expected time [48].

The routing problem can be encoded as a string of integers generated by sequence of integer number ID's of connected nodes. For example in figure 3.1 we assign ID's 0,1,2,3,4,5,6,7,8,9 to each node in the network and a possible path between source node 0 to destination node 9 can be 0 → 1 → 3 → 7 → 9. This sequence specifies a solution as a routing path where node 0 is connected to node 1, node 1 is connected to node 3, node 3 is connected to node 7 and node 7 is connected to node 9. The solution generated in this way in which all adjacent nodes are connected is valid. The sequence 0 → 1 → 4 → 9 is an invalid sequence because node 4 is not directly connected to node 9, hence this routing path from node 0 to node 9 is an invalid path.

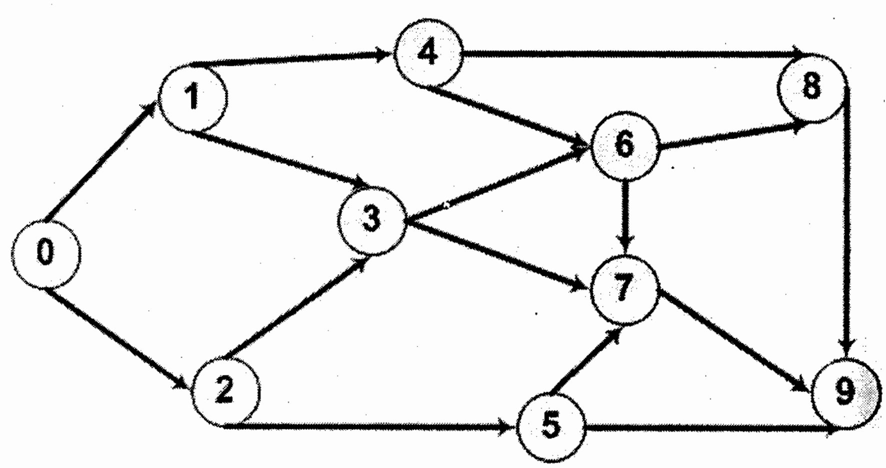

Figure 3.1: A simple network

3.3.1.4 Initial Population

The set of solutions in GA is known as a population. Each solution in solution set is known as a chromosome while each element in the chromosome is called a gene. Each time GA runs, give a population and all succeeding populations depend upon preceding populations. The selection of initial population in GA is normally random. Initial population having high fitness values can quickly direct to acceptable solution. Encoding depicted in previous section 3.2.1.3 i-e [0 → 1 → 3 → 7 → 9] represents a chromosome, while one of the hop can be regarded as a gene. Working of GA requires a set of solutions; therefore more than one solution can be generated at one time. A population of four solutions (chromosomes) can be represented as [0 → 1 → 3 → 7 → 9], [0 → 1 → 4 → 8 → 9], [0 → 2 → 5 → 9] and [0 → 1 → 3 → 6 → 8 → 9].

3.3.1.5 Selection

Selection is the process for creation of new population. In this process we select two members from a population. These members are used for crossover and mutation operations to create new population. Commonly used selection methods in GA are roulette wheel and tournament [49]. The comprehensive discussion of different selection methods can be seen in [48].Two solutions (chromosomes) are selected from a population with the application of suitable selection method for generating new solutions (chromosomes). The selection methods assure the selection of best solutions.

3.3.1.6 GA Operators

GA operators bring into play the generation of new populations from existing ones. These operators use best features of current population and produce better population as compared to previous one. Reproduction, crossover and mutation are the GA operators. In reproduction new population is generated based on fitness values of current population. High fitness solutions are used from current population to generate new population [48]. Newly generated and previous populations are combined in crossover step to generate new population according to a predefined scheme. Normally new population is generated with best features as compared to previous one from reproduction and crossover steps, but some time the entire reproduction and crossover process may result in loss of some information so mutation operator is applied. The process of mutation reduces the chance of trapping in local optima [48]. These operators have many variations and usually depend upon encoding schemes. The design of GA operators should be as much as necessary so that only feasible solutions should be created [49]. So if we select [0 → 1 → 3 → 7 → 9] and [0 → 2 → 3 → 6 → 8 → 9] chromosomes (two solutions from source 0 to destination 9) from figure 3.1, then applying one point crossover operator with crossover point being 3 result two new solutions [0 → 2 → 3 → 7 → 9] and [0 → 1 → 3 → 6 → 8 → 9]. Other common crossover operators are two point and uniform crossover which can be viewed in [48].

Mutation operator randomly changes one or more genes of a selected chromosome in order to increase the structural variability of the population. In GA, the role of mutation operator is to restore the lost or unexplored genetic material into the population to prevent the premature convergence of GA to suboptimal solutions.

3.3.1.7 Convergence

The convergence state in GA produces the desirable results and inquires the algorithm to stop [47] [50]. Stopping criteria based upon fitness value of solutions should be defined with an acceptance factor in convergence state of GA. The processing of algorithm should be stopped after fixed number of iterations if the convergence is not achieved.

3.3.1.8 Eliticism

A chromosome with highest fitness value is known as elite chromosome. Eliticism in GA is used to retain the elite chromosome in next generation for achieving best solutions. In this way we have a best solution in each population during the processing of GA.

3.4 Genetic Algorithm Steps

A simple genetic algorithm has following steps.

1) Generate the initial population (Initial population in GA is normally random).

2) Create a new population by applying the selection and reproduction operator to select pairs of strings. The number of pairs will be half of the population size, so the population size will remain constant between generations.

3) Apply the crossover operator to the pairs of strings of the new population.

4) Apply the mutation operator to each string in the new population.

5) Replace the old population with the newly created population.

6) If the number of iterations is equal to the maximum or desired acceptance level i-e convergence is achieved, stop the process and display the best answer found, else go to step 2.

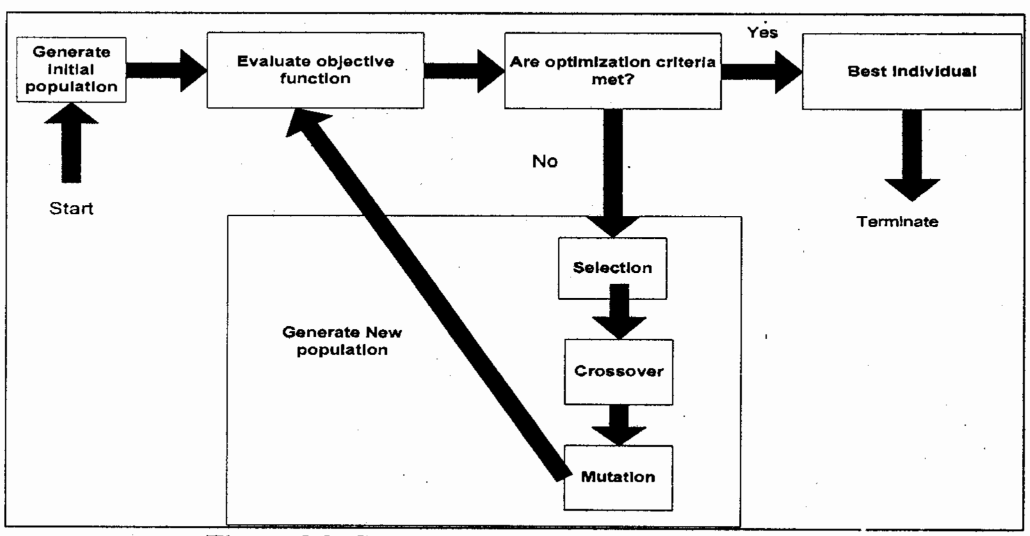

Figure 3.2: Steps in simple genetic algorithm

3.5 Types of Genetic Algorithms Based on Coding Schemes

Coding schemes play an important role in the processing of GA. In next section we will discuss the common types of coding schemes.

3.5.1 Binary Coded Genetic Algorithms

Binary coded is commonly used coding scheme [48]. In this scheme variable values are converted into binary number strings and again these binary strings are converted back into variable values. Considerable time and space is required for processing of those problems having large number of variables and their possible values. In binary encoding scheme new chromosomes are generated through crossover operator by exchanging bits among chromosomes. For example the encoding [0 1 0 0 2] can be represented in binary form by representing each gene with its corresponding binary number. The size of each gene should be kept in consideration. Therefore in this case each gene can be represented by two bits so the said encoding will be represented in binary strings as [00 01 00 00 10].

3.5.2 Real Coded Genetic Algorithms

Real coded genetic algorithms (RCGAs) are commonly applied for numerical optimization on continuous domains. This coding scheme directly codes the genes in real values, so in an n-dimensional problem a chromosome will consist of n real numbers. To represent a practical scenario, the value of the gene is kept within limits. In this type of GA, coding and search space have closed formulation which helps to avoid encoding and decoding process. In continuous variables actual values of variables are not to be quantized, so RCGAs are very useful for continuous variables. The crossover operators used in binary coded GA can also be used in RCGAs. Many other crossover operators are also defined for RCGAs. These include flat crossover, simple crossover and arithmetical crossover [48]. The mutation operators for RCGAs like random mutation and non-uniform mutation are explained in [47].

3.6 Application of Genetic Algorithm in Wireless Mesh Routing

Application of genetic algorithm for wireless mesh routing requires performing all steps listed in section 3.2. We will describe all those steps for the application of genetic algorithm.

3.6.1 Variable Selection

In our proposed solution for routing in wireless mesh network, we have three types of variables which affect the resolution of problem. First, the expected transmission count (ETX) between each pair of nodes along the complete path from source to destination. Second variable is the expected transmission time (ETT) between each pair of nodes along the complete path from source to destination. Third variable is the hop-count.

3.6.2 Fitness Function

Fitness function is based on variables involved in the system. Fitness function in our study is based on hop-count and aggregated expected transmission time (ETT) along the path from source to destination.

$$\textit{Path Cost} = \textit{Hop Count} \times \sum_{l=1}^{n} ETT_l \qquad (3.1)$$

where l is the link between two nodes.

3.6.3 Encoding Scheme

We have applied real encoding on our routing problem. The routing problem can be encoded as a string of integers generated by sequence of integer number ID's of connected nodes. For example in figure 3.1 we assign ID's 0,1,2,3,4,5,6,7,8,9 to each node in the network and a possible path between source node 0 to destination node 9 can be 0 → 1 → 3 → 7 → 9. This sequence specifies a solution as a routing path where node 0 is connected to node 1, node 1 is connected to node 3, node 3 is connected to node 7 and node 7 is connected to node 9. The solution generated in this way in which all adjacent nodes are connected is valid. The sequence 0 → 1 → 4 → 9 is an invalid sequence because node 4 is not directly connected to node 9, hence this routing path from node 0 to node 9 is an invalid path.

3.6.4 Initial Population

Initial population plays very important role for finding optimal solution as this initial population is used to generate new populations through crossover operator. GA starts by selecting an initial population of chromosomes which represent a subset of the large set of all possible solutions. Each chromosome in solution set is evaluated using the fitness function.

3.6.5 Selection for Crossover

We have applied Roulette wheel and tournament selection mechanisms for selection [48]. Roulette wheel selection mechanism [39] has the similar selecting principle as roulette wheel. In GA each sector of the roulette wheel corresponds to an individual from the population. The probability of the individual to be selected into the next generation depends upon the proportion of the individual's fitness value to the total fitness values of the whole population.

Tournament approach [47] selects individuals based on their fitness values. This method selects a subset of two or three chromosomes from the mating pool and the parent will be the chromosomes with the lowest cost in the subset. This method is suitable for large population sizes because the population never needs to be sorted.

3.6.6 Crossover

We have applied one point crossover [48]. A crossover point is chosen in the solution string to perform one point crossover and contents of solutions are exchanged before or after the crossover point.

3.6.7 Eliticism

We have used Eliticism for preserving solutions with best fitness for next generation. Eliticism is applied by retaining the best solution of current generation. After applying the crossover and mutation, new population is generated and the worst solution of new population is replaced with the preserved best solution. In this way this mechanism ensures that the best solution is retained in any generation.

3.6.8 Convergence

The convergence criterion is not well defined for routing in wireless mesh networks using genetic algorithm. We used to calculate Path Cost for each solution in population which enables us to determine the goodness of solution. If the value of the path cost of some solution is minimum than the other set of solutions, this solution will be considered to be better. We cannot give a final verdict that some value for Path Cost is best and we stop the iterations. However we can stop our solution after some specified number of iterations and by applying Eliticism we can ensure that we have a best solution at current state of computation.

4. TEST SYSTEMS AND STATISTICS

This chapter explains the test systems and their specifications. To evaluate our routing approach using genetic algorithm in wireless mesh network, we conducted experiments using test systems. We selected fifty (50) nodes WMN and one hundred (100) nodes WMN as our test systems. These systems are designed and implemented in C#.NET. We have applied genetic algorithm on these test systems for finding optimal path. The path which is selected as an optimal path will have an optimal cost as compared to other available paths. As an example suppose our system contains twenty available paths from source to destination, the optimal path will be the one which has minimal cost.

4.1 Description of 50 Nodes Wireless Mesh Network Test System

Table 4.1 depicts the fifty (50) nodes wireless mesh network test system specifications. The link between the nodes is bidirectional. Expected transmission count (ETX) between nodes is calculated depending upon loss ratio in forward direction (d_f) and in reverse direction (d_r). The probability of successful data transmission and acknowledgment is $d_f \times d_r$. ETX for the complete route is the sum of ETX calculated for each link in the route. The time spent in transmission of a packet along a link l i-e ETT_l is obtained by multiplying the expected transmission count (ETX_l) by the link bandwidth (S/B). ETT for the complete route is the sum of ETT calculated for each link in the route.

50 Nodes Wireless Mesh Network Test System Specifications

Links	d_f	d_r	ETX = $(1/d_f*d_r)$	Bandwidth (B)	Size of Packet (S)	S/B	ETT = ETX * S/B
0—1	1	1	1	48	1	0.0000203451	0.000020345
0—2	0.9	0.9	1.234567901	36	1	0.0000271267	0.000033490
0—3	0.8	0.8	1.5625	24	1	0.0000406901	0.000063578
1—2	0.7	0.7	2.040816327	54	1	0.0000180845	0.000036907
1—4	0.6	0.6	2.777777778	15	1	0.0000651042	0.000180845
1—5	0.4	0.4	6.25	24	1	0.0000406901	0.000254313
2—3	0.9	0.9	1.234567901	52	1	0.0000187800	0.000023185
2—8	0.9	0.8	1.388888889	36	1	0.0000271267	0.000037676
2—10	0.1	0.1	100	5	1	0.0001953125	0.019531250
3—6	0.9	0.7	1.587301587	11	1	0.0000887784	0.000140918
4—5	0.8	0.6	2.083333333	24	1	0.0000406901	0.000084771

4—9	0.7	0.4	3.571428571	2	1	0.0004882813	0.001743862
5—10	0.6	0.3	5.555555556	5	1	0.0001953125	0.001085069
5—11	0.9	0.8	1.388888889	54	1	0.0000180845	0.000025117
6—7	1	1	1	36	1	0.0000271267	0.000027127
7—8	0.9	0.8	1.388888889	20	1	0.0000488281	0.000067817
7—12	0.7	0.7	2.040816327	11	1	0.0000887784	0.000181180
7—13	0.6	0.5	3.333333333	5	1	0.0001953125	0.000651042
8—10	1	0.9	1.111111111	54	1	0.0000180845	0.000020094
8—13	0.9	0.9	1.234567901	48	1	0.0000203451	0.000025117
9—11	0.8	0.8	1.5625	36	1	0.0000271267	0.000042386
9—15	0.5	0.5	4	8	1	0.0001220703	0.000488281
10—14	0.6	0.6	2.777777778	15	1	0.0000651042	0.000180845
11—15	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
11—16	1	1	1	48	1	0.0000203451	0.000020345
11—18	0.7	0.6	2.380952381	5	1	0.0001953125	0.000465030
12—13	0.6	0.6	2.777777778	11	1	0.0000887784	0.000246607
12—19	0.6	0.5	3.333333333	2	1	0.0004882813	0.001627604
12—20	0.5	0.5	4	3	1	0.0003255208	0.001302083
13—14	0.7	0.7	2.040816327	36	1	0.0000271267	0.000055361
13—20	1	1	1	52	1	0.0000187800	0.000018780
13—21	1	1	1	24	1	0.0000406901	0.000040690
14—17	0.9	0.9	1.234567901	11	1	0.0000887784	0.000109603
14—21	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
15—18	0.7	0.6	2.380952381	3	1	0.0003255208	0.000775050
15—22	0.6	0.5	3.333333333	2	1	0.0004882813	0.001627604
16—17	0.5	0.4	5	1	1	0.0009765625	0.004882813
16—18	0.8	0.8	1.5625	24	1	0.0000406901	0.000063578
16—26	1	0.9	1.111111111	54	1	0.0000180845	0.000020094
17—26	0.9	0.8	1.388888889	48	1	0.0000203451	0.000028257
17—29	0.7	0.7	2.040816327	15	1	0.0000651042	0.000132866
17—31	0.9	0.9	1.234567901	11	1	0.0000887784	0.000109603
18—25	0.8	0.7	1.785714286	24	1	0.0000406901	0.000072661
18—26	0.9	0.7	1.587301587	36	1	0.0000271267	0.000043058
19—20	1	1	1	48	1	0.0000203451	0.000020345
19—23	0.7	0.6	2.380952381	5	1	0.0001953125	0.000465030
19—24	0.8	0.6	2.083333333	3	1	0.0003255208	0.000678168
20—21	0.9	0.9	1.234567901	54	1	0.0000180845	0.000022327
20—24	1	1	1	48	1	0.0000203451	0.000020345
20—27	0.8	0.8	1.5625	36	1	0.0000271267	0.000042386
21—27	0.8	0.8	1.5625	54	1	0.0000180845	0.000028257
21—29	0.7	0.6	2.380952381	15	1	0.0000651042	0.000155010
22—25	0.6	0.5	3.333333333	24	1	0.0000406901	0.000135634
22—28	0.5	0.4	5	52	1	0.0000187800	0.000093900
23—24	0.8	0.8	1.5625	36	1	0.0000271267	0.000042386
23—35	1	0.9	1.111111111	5	1	0.0001953125	0.000217014
24—27	0.9	0.8	1.388888889	11	1	0.0000887784	0.000123303
24—34	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
25—26	0.9	0.9	1.234567901	2	1	0.0004882813	0.000602816

25—28	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
25—30	1	1	1	54	1	0.0000180845	0.000018084
26—30	0.7	0.6	2.380952381	11	1	0.0000887784	0.000211377
26—31	0.6	0.6	2.777777778	5	1	0.0001953125	0.000542535
27—32	0.6	0.5	3.333333333	3	1	0.0003255208	0.001085069
27—33	0.5	0.5	4	2	1	0.0004882813	0.001953125
27—34	0.7	0.7	2.040816327	1	1	0.0009765625	0.001992985
28—38	1	1	1	48	1	0.0000203451	0.000020345
29—31	1	1	1	36	1	0.0000271267	0.000027127
29—32	0.9	0.9	1.234567901	54	1	0.0000180845	0.000022327
29—40	0.8	0.8	1.5625	15	1	0.0000651042	0.000101725
30—38	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
30—39	0.6	0.6	2.777777778	52	1	0.0000187800	0.000052167
30—44	0.4	0.4	6.25	36	1	0.0000271267	0.000169542
31—39	0.8	0.8	1.5625	54	1	0.0000180845	0.000028257
31—40	1	0.9	1.111111111	48	1	0.0000203451	0.000022606
32—33	0.9	0.8	1.388888889	36	1	0.0000271267	0.000037676
32—37	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
32—40	0.6	0.6	2.777777778	2	1	0.0004882813	0.001356337
33—37	0.4	0.4	6.25	24	1	0.0000406901	0.000254313
34—36	0.8	0.8	1.5625	52	1	0.0000187800	0.000029344
34—37	0.9	0.8	1.388888889	36	1	0.0000271267	0.000037676
34—42	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
35—36	0.9	0.9	1.234567901	11	1	0.0000887784	0.000109603
36—42	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
37—42	1	1	1	2	1	0.0004882813	0.000488281
37—47	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
38—44	0.7	0.6	2.380952381	54	1	0.0000180845	0.000043058
38—45	0.6	0.5	3.333333333	36	1	0.0000271267	0.000090422
39—40	0.5	0.4	5	20	1	0.0000488281	0.000244141
39—41	0.8	0.8	1.5625	11	1	0.0000887784	0.000138716
39—44	1	0.9	1.111111111	5	1	0.0001953125	0.000217014
39—48	0.9	0.8	1.388888889	54	1	0.0000180845	0.000025117
40—41	0.7	0.7	2.040816327	52	1	0.0000187800	0.000038327
41—47	0.9	0.9	1.234567901	36	1	0.0000271267	0.000033490
41—48	0.8	0.7	1.785714286	5	1	0.0001953125	0.000348772
42—47	0.9	0.7	1.587301587	11	1	0.0000887784	0.000140918
43—45	0.6	0.6	2.777777778	24	1	0.0000406901	0.000113028
43—46	0.4	0.4	6.25	2	1	0.0004882813	0.003051758
44—45	0.9	0.9	1.234567901	5	1	0.0001953125	0.000241127
44—46	0.9	0.8	1.388888889	54	1	0.0000180845	0.000025117
44—48	0.1	0.1	100	11	1	0.0000887784	0.008877841
46—49	0.9	0.7	1.587301587	5	1	0.0001953125	0.000310020
47—49	0.8	0.6	2.083333333	3	1	0.0003255208	0.000678168
48—49	0.7	0.4	3.571428571	2	1	0.0004882813	0.001743862

Table 4.1: Fifty (50) nodes wireless mesh network test system specifications

4.2 Description of 100 Nodes Wireless Mesh Network Test System

Table 4.2 depicts the hundred (100) nodes wireless mesh network test system specifications.

100 Nodes Wireless Mesh Network Test System Specifications

Links	df	dr	ETX = $(1/d_f * d_r)$	Bandwidth (B)	Size of Packet (S)	S/B	ETT = ETX x S/B
0—1	1	1	1	48	1	0.0000203451	0.000020345
0—2	0.9	0.9	1.234567901	36	1	0.0000271267	0.000033490
0—9	0.8	0.8	1.5625	24	1	0.0000406901	0.000063578
1—3	0.7	0.7	2.040816327	54	1	0.0000180845	0.000036907
1—9	0.6	0.6	2.777777778	15	1	0.0000651042	0.000180845
2—6	0.4	0.4	6.25	24	1	0.0000406901	0.000254313
2—9	0.9	0.9	1.234567901	52	1	0.0000187800	0.000023185
2—15	0.9	0.8	1.388888889	36	1	0.0000271267	0.000037676
3—4	0.1	0.1	100	5	1	0.0001953125	0.019531250
3—10	0.9	0.7	1.587301587	11	1	0.0000887784	0.000140918
4—5	0.8	0.6	2.083333333	24	1	0.0000406901	0.000084771
4—11	0.7	0.4	3.571428571	2	1	0.0004882813	0.001743862
5—12	0.6	0.3	5.555555556	5	1	0.0001953125	0.001085069
5—20	0.9	0.8	1.388888889	54	1	0.0000180845	0.000025117
6—7	1	1	1	36	1	0.0000271267	0.000027127
6—16	0.9	0.8	1.388888889	20	1	0.0000488281	0.000067817
7—8	0.7	0.7	2.040816327	11	1	0.0000887784	0.000181180
7—16	0.6	0.5	3.333333333	5	1	0.0001953125	0.000651042
8—13	1	0.9	1.111111111	54	1	0.0000180845	0.000020094
8—17	0.9	0.9	1.234567901	48	1	0.0000203451	0.000025117
9—10	0.8	0.8	1.5625	36	1	0.0000271267	0.000042386
9—15	0.5	0.5	4	8	1	0.0001220703	0.000488281
10—11	0.6	0.6	2.777777778	15	1	0.0000651042	0.000180845
10—23	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
11—12	1	1	1	48	1	0.0000203451	0.000020345
11—30	0.7	0.6	2.380952381	5	1	0.0001953125	0.000465030
12—22	0.6	0.6	2.777777778	11	1	0.0000887784	0.000246607
12—31	0.6	0.5	3.333333333	2	1	0.0004882813	0.001627604
13—14	0.5	0.5	4	3	1	0.0003255208	0.001302083
13—18	0.7	0.7	2.040816327	36	1	0.0000271267	0.000055361
14—19	1	1	1	52	1	0.0000187800	0.000018780
14—27	1	1	1	24	1	0.0000406901	0.000040690
15—16	0.9	0.9	1.234567901	11	1	0.0000887784	0.000109603
15—23	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
15—24	0.7	0.6	2.380952381	3	1	0.0003255208	0.000775050
16—17	0.6	0.5	3.333333333	2	1	0.0004882813	0.001627604
16—24	0.5	0.4	5	1	1	0.0009765625	0.004882813
17—18	0.8	0.8	1.5625	24	1	0.0000406901	0.000063578
17—25	1	0.9	1.111111111	54	1	0.0000180845	0.000020094

18—19	0.9	0.8	1.388888889	48	1	0.0000203451	0.000028257
18—25	0.7	0.7	2.040816327	15	1	0.0000651042	0.000132866
19—26	0.9	0.9	1.234567901	11	1	0.0000887784	0.000109603
19—27	0.8	0.7	1.785714286	24	1	0.0000406901	0.000072661
19—40	0.9	0.7	1.587301587	36	1	0.0000271267	0.000043058
20—21	1	1	1	48	1	0.0000203451	0.000020345
20—22	0.7	0.6	2.380952381	5	1	0.0001953125	0.000465030
21—29	0.8	0.6	2.083333333	3	1	0.0003255208	0.000678168
21—43	0.9	0.9	1.234567901	54	1	0.0000180845	0.000022327
22—29	1	1	1	48	1	0.0000203451	0.000020345
22—32	0.8	0.8	1.5625	36	1	0.0000271267	0.000042386
23—24	0.8	0.8	1.5625	54	1	0.0000180845	0.000028257
23—30	0.7	0.6	2.380952381	15	1	0.0000651042	0.000155010
23—34	0.6	0.5	3.333333333	24	1	0.0000406901	0.000135634
24—25	0.5	0.4	5	52	1	0.0000187800	0.000093900
24—34	0.8	0.8	1.5625	36	1	0.0000271267	0.000042386
25—26	1	0.9	1.111111111	5	1	0.0001953125	0.000217014
25—35	0.9	0.8	1.388888889	11	1	0.0000887784	0.000123303
26—39	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
26—42	0.9	0.9	1.234567901	2	1	0.0004882813	0.000602816
27—28	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
27—40	1	1	1	54	1	0.0000180845	0.000018084
28—40	0.7	0.6	2.380952381	11	1	0.0000887784	0.000211377
28—41	0.6	0.6	2.777777778	5	1	0.0001953125	0.000542535
28—53	0.6	0.5	3.333333333	3	1	0.0003255208	0.001085069
29—33	0.5	0.5	4	2	1	0.0004882813	0.001953125
29—43	0.7	0.7	2.040816327	1	1	0.0009765625	0.001992985
30—31	1	1	1	48	1	0.0000203451	0.000020345
30—34	1	1	1	36	1	0.0000271267	0.000027127
31—32	0.9	0.9	1.234567901	54	1	0.0000180845	0.000022327
31—36	0.8	0.8	1.5625	15	1	0.0000651042	0.000101725
32—33	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
32—37	0.6	0.6	2.777777778	52	1	0.0000187800	0.000052167
33—45	0.4	0.4	6.25	36	1	0.0000271267	0.000169542
33—46	0.8	0.8	1.5625	54	1	0.0000180845	0.000028257
34—35	1	0.9	1.111111111	48	1	0.0000203451	0.000022606
34—36	0.9	0.8	1.388888889	36	1	0.0000271267	0.000037676
35—38	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
35—39	0.6	0.6	2.777777778	2	1	0.0004882813	0.001356337
36—37	0.4	0.4	6.25	24	1	0.0000406901	0.000254313
36—38	0.8	0.8	1.5625	52	1	0.0000187800	0.000029344
37—46	0.9	0.8	1.388888889	36	1	0.0000271267	0.000037676
37—47	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
38—48	0.9	0.9	1.234567901	11	1	0.0000887784	0.000109603
39—42	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
39—49	1	1	1	2	1	0.0004882813	0.000488281
40—41	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
40—42	0.7	0.6	2.380952381	54	1	0.0000180845	0.000043058

41—42	0.6	0.5	3.333333333	36	1	0.0000271267	0.000090422
41—52	0.5	0.4	5	20	1	0.0000488281	0.000244141
41—53	0.8	0.8	1.5625	11	1	0.0000887784	0.000138716
42—50	1	0.9	1.111111111	5	1	0.0001953125	0.000217014
42—51	0.9	0.8	1.388888889	54	1	0.0000180845	0.000025117
43—44	0.7	0.7	2.040816327	52	1	0.0000187800	0.000038327
43—45	0.9	0.9	1.234567901	36	1	0.0000271267	0.000033490
44—54	0.8	0.7	1.785714286	5	1	0.0001953125	0.000348772
44—55	0.9	0.7	1.587301587	11	1	0.0000887784	0.000140918
45—55	0.6	0.6	2.777777778	24	1	0.0000406901	0.000113028
45—56	0.4	0.4	6.25	2	1	0.0004882813	0.003051758
46—56	0.9	0.9	1.234567901	5	1	0.0001953125	0.000241127
46—57	0.9	0.8	1.388888889	54	1	0.0000180845	0.000025117
47—48	0.1	0.1	100	11	1	0.0000887784	0.008877841
47—57	0.9	0.7	1.587301587	5	1	0.0001953125	0.000310020
47—58	0.8	0.6	2.083333333	3	1	0.0003255208	0.000678168
48—49	0.7	0.4	3.571428571	2	1	0.0004882813	0.001743862
49—50	0.8	0.8	1.5625	48	1	0.0000203451	0.000031789
49—59	1	0.9	1.111111111	15	1	0.0000651042	0.000072338
50—62	0.9	0.8	1.388888889	11	1	0.0000887784	0.000123303
50—63	0.7	0.7	2.040816327	24	1	0.0000406901	0.000083041
51—52	0.6	0.6	2.777777778	36	1	0.0000271267	0.000075352
51—62	0.4	0.4	6.25	48	1	0.0000203451	0.000127157
52—53	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
52—60	0.9	0.8	1.388888889	3	1	0.0003255208	0.000452112
52—61	0.7	0.7	2.040816327	54	1	0.0000180845	0.000036907
53—60	0.9	0.9	1.234567901	48	1	0.0000203451	0.000025117
54—55	0.7	0.7	2.040816327	36	1	0.0000271267	0.000055361
54—64	1	1	1	54	1	0.0000180845	0.000018084
55—56	0.8	0.8	1.5625	15	1	0.0000651042	0.000101725
55—65	0.7	0.6	2.380952381	24	1	0.0000406901	0.000096881
56—57	0.6	0.5	3.333333333	52	1	0.0000187800	0.000062600
56—66	0.5	0.4	5	36	1	0.0000271267	0.000135634
57—66	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
57—67	1	0.9	1.111111111	11	1	0.0000887784	0.000098643
58—59	1	0.9	1.111111111	24	1	0.0000406901	0.000045211
58—68	0.9	0.8	1.388888889	2	1	0.0004882813	0.000678168
59—63	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
59—68	0.9	0.9	1.234567901	54	1	0.0000180845	0.000022327
60—73	0.7	0.7	2.040816327	11	1	0.0000887784	0.000181180
60—74	1	1	1	11	1	0.0000887784	0.000088778
61—62	0.7	0.6	2.380952381	5	1	0.0001953125	0.000465030
61—72	0.6	0.6	2.777777778	54	1	0.0000180845	0.000050235
61—73	0.6	0.5	3.333333333	52	1	0.0000187800	0.000062600
62—63	0.5	0.5	4	36	1	0.0000271267	0.000108507
62—71	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
63—69	1	1	1	11	1	0.0000887784	0.000088778
63—70	1	1	1	24	1	0.0000406901	0.000040690

64—65	0.9	0.9	1.234567901	2	1	0.0004882813	0.000602816
64—75	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
64—76	0.7	0.7	2.040816327	54	1	0.0000180845	0.000036907
65—66	0.6	0.6	2.777777778	11	1	0.0000887784	0.000246607
65—76	0.4	0.4	6.25	5	1	0.0001953125	0.001220703
65—77	0.8	0.8	1.5625	3	1	0.0003255208	0.000508626
66—78	1	0.9	1.111111111	2	1	0.0004882813	0.000542535
67—68	0.9	0.8	1.388888889	48	1	0.0000203451	0.000028257
67—78	0.7	0.7	2.040816327	36	1	0.0000271267	0.000055361
67—79	0.6	0.6	2.777777778	24	1	0.0000406901	0.000113028
68—69	0.4	0.4	6.25	54	1	0.0000180845	0.000113028
68—79	0.8	0.8	1.5625	15	1	0.0000651042	0.000101725
69—70	0.9	0.8	1.388888889	24	1	0.0000406901	0.000056514
69—80	0.7	0.7	2.040816327	52	1	0.0000187800	0.000038327
70—71	0.9	0.9	1.234567901	36	1	0.0000271267	0.000033490
70—81	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
71—72	1	1	1	11	1	0.0000887784	0.000088778
71—82	0.8	0.8	1.5625	24	1	0.0000406901	0.000063578
72—73	0.7	0.6	2.380952381	2	1	0.0004882813	0.001162574
72—83	0.6	0.5	3.333333333	5	1	0.0001953125	0.000651042
73—74	0.5	0.4	5	54	1	0.0000180845	0.000090422
73—84	0.7	0.7	2.040816327	36	1	0.0000271267	0.000055361
74—85	0.6	0.6	2.777777778	20	1	0.0000488281	0.000135634
75—76	0.4	0.4	6.25	11	1	0.0000887784	0.000554865
75—94	0.9	0.9	1.234567901	5	1	0.0001953125	0.000241127
76—93	0.9	0.8	1.388888889	54	1	0.0000180845	0.000025117
77—78	0.6	0.5	3.333333333	36	1	0.0000271267	0.000090422
77—92	0.1	0.1	100	48	1	0.0000203451	0.002034505
77—93	0.9	0.7	1.587301587	36	1	0.0000271267	0.000043058
78—79	0.8	0.6	2.083333333	8	1	0.0001220703	0.000254313
78—91	0.7	0.4	3.571428571	15	1	0.0000651042	0.000232515
78—92	0.6	0.3	5.555555556	24	1	0.0000406901	0.000226056
79—80	0.9	0.8	1.388888889	48	1	0.0000203451	0.000028257
79—91	1	1	1	5	1	0.0001953125	0.000195313
80—81	0.9	0.8	1.388888889	11	1	0.0000887784	0.000123303
80—90	0.7	0.7	2.040816327	5	1	0.0001953125	0.000398597
81—82	0.6	0.5	3.333333333	11	1	0.0000887784	0.000295928
81—89	1	0.9	1.111111111	24	1	0.0000406901	0.000045211
82—83	0.9	0.9	1.234567901	2	1	0.0004882813	0.000602816
82—88	0.8	0.8	1.5625	5	1	0.0001953125	0.000305176
83—84	0.5	0.5	4	54	1	0.0000180845	0.000072338
83—87	0.6	0.6	2.777777778	11	1	0.0000887784	0.000246607
84—85	0.7	0.7	2.040816327	11	1	0.0000887784	0.000181180
84—86	1	1	1	5	1	0.0001953125	0.000195313
84—87	0.7	0.6	2.380952381	54	1	0.0000180845	0.000043058
85—86	0.6	0.6	2.777777778	52	1	0.0000187800	0.000052167
86—99	0.6	0.5	3.333333333	36	1	0.0000271267	0.000090422
87—88	0.5	0.5	4	5	1	0.0001953125	0.000781250

CHAPTER 5: EXPERIMENTAL RESULTS AND ANALYSIS

5. EXPERIMENTAL RESULTS AND ANALYSIS

This chapter provides the results and analysis obtained from the application of genetic algorithm and minimum hop count metric onto test systems described in Chapter 3 and Chapter 4 respectively.

Table 5.1 depicts the experimental parameters for finding optimal path for routing in wireless mesh network.

Variables	**Values**
MAC Type	802.11
Packet Size	1 KB
Bandwidth of links	Actual Bandwidth of a link
Radio Type	Half Duplex
Cross Over Rate	0.1 to 0.9
Mutation Rate	0.01 to 0.09
Generations	1000
Eliticism	True/False
Population Size	500 and 1000
Network Nodes	50 and 100
Selection Methods	Roulette Wheel and Tournament

Table 5.1: Experimental Parameters

5.1 GA and minimum hop count results on fifty (50) nodes Wireless Mesh Network

Results taken on fifty (50) nodes wireless mesh network test system are shown in Table 5.1.

Results

Network Nodes	Population Size	Generations
50	500	1000

Hops	Cost	GA Cost * 1000	Cross Over	Mutation	Selection Method	Elitisim	MinHops	MinHops Cost	MinHops Cost * 1000
18	0.043	43	0.9	0.09	Roulette wheel	Yes	12	0.251	251
12	0.011	11	0.9	0.08	Roulette wheel	Yes	11	0.04	40
13	0.06	60	0.9	0.07	Roulette wheel	Yes	13	0.06	60
14	0.021	21	0.9	0.06	Roulette wheel	Yes	12	0.048	48
20	0.053	53	0.9	0.05	Roulette wheel	Yes	11	0.23	230
11	0.027	27	0.9	0.04	Roulette wheel	Yes	11	0.027	27
26	0.117	117	0.9	0.03	Roulette wheel	Yes	18	0.166	166
17	0.044	44	0.9	0.02	Roulette wheel	Yes	14	0.058	58
12	0.023	23	0.9	0.01	Roulette wheel	Yes	10	0.024	24
11	0.023	23	0.8	0.09	Roulette wheel	Yes	11	0.023	23
12	0.027	27	0.8	0.08	Roulette wheel	Yes	10	0.187	187
15	0.027	27	0.8	0.07	Roulette wheel	Yes	13	0.062	62
13	0.032	32	0.8	0.06	Roulette wheel	Yes	12	0.071	71
14	0.026	26	0.8	0.05	Roulette wheel	Yes	12	0.05	50
15	0.022	22	0.8	0.04	Roulette wheel	Yes	14	0.035	35
15	0.051	51	0.8	0.03	Roulette wheel	Yes	13	0.26	260
14	0.035	35	0.8	0.02	Roulette wheel	Yes	14	0.035	35
15	0.028	28	0.8	0.01	Roulette wheel	Yes	15	0.028	28
13	0.025	25	0.7	0.09	Roulette wheel	Yes	12	0.041	41
14	0.026	26	0.7	0.08	Roulette wheel	Yes	11	0.234	234
15	0.038	38	0.7	0.07	Roulette wheel	Yes	13	0.062	62
13	0.04	40	0.7	0.06	Roulette wheel	Yes	13	0.04	40
14	0.053	53	0.7	0.05	Roulette wheel	Yes	11	0.213	213
13	0.025	25	0.7	0.04	Roulette wheel	Yes	13	0.025	25
14	0.037	37	0.7	0.03	Roulette wheel	Yes	14	0.037	37
12	0.02	20	0.7	0.02	Roulette wheel	Yes	12	0.02	20
12	0.019	19	0.7	0.01	Roulette wheel	Yes	12	0.042	42
13	0.037	37	0.6	0.09	Roulette wheel	Yes	12	0.044	44

18	0.03	30	0.6	0.08	Roulette wheel	Yes	11	0.045	45
11	0.015	15	0.6	0.07	Roulette wheel	Yes	11	0.015	15
12	0.022	22	0.6	0.06	Roulette wheel	Yes	12	0.022	22
13	0.022	22	0.6	0.05	Roulette wheel	Yes	12	0.034	34
14	0.032	32	0.6	0.04	Roulette wheel	Yes	12	0.269	269
14	0.044	44	0.6	0.03	Roulette wheel	Yes	13	0.28	280
21	0.108	108	0.6	0.02	Roulette wheel	Yes	11	0.308	308
11	0.049	49	0.6	0.01	Roulette wheel	Yes	11	0.049	49
14	0.024	24	0.5	0.09	Roulette wheel	Yes	12	0.047	47
14	0.019	19	0.5	0.08	Roulette wheel	Yes	11	0.03	30
12	0.021	21	0.5	0.07	Roulette wheel	Yes	12	0.051	51
15	0.04	40	0.5	0.06	Roulette wheel	Yes	12	0.042	42
13	0.038	38	0.5	0.05	Roulette wheel	Yes	12	0.066	66
14	0.023	23	0.5	0.04	Roulette wheel	Yes	12	0.066	66
14	0.055	55	0.5	0.03	Roulette wheel	Yes	14	0.055	55
20	0.112	112	0.5	0.02	Roulette wheel	Yes	13	0.153	153
23	0.164	164	0.5	0.01	Roulette wheel	Yes	14	0.312	312
12	0.029	29	0.4	0.09	Roulette wheel	Yes	12	0.029	29
15	0.026	26	0.4	0.08	Roulette wheel	Yes	12	0.041	41
18	0.067	67	0.4	0.07	Roulette wheel	Yes	13	0.527	527
12	0.031	31	0.4	0.06	Roulette wheel	Yes	11	0.127	127
15	0.035	35	0.4	0.05	Roulette wheel	Yes	11	0.041	41
14	0.03	30	0.4	0.04	Roulette wheel	Yes	12	0.041	41
13	0.055	55	0.4	0.03	Roulette wheel	Yes	13	0.055	55
12	0.041	41	0.4	0.02	Roulette wheel	Yes	11	0.112	112
11	0.026	26	0.4	0.01	Roulette wheel	Yes	11	0.026	26
16	0.036	36	0.3	0.09	Roulette wheel	Yes	12	0.06	60
17	0.045	45	0.3	0.08	Roulette wheel	Yes	14	0.046	46
12	0.039	39	0.3	0.07	Roulette wheel	Yes	12	0.039	39
13	0.037	37	0.3	0.06	Roulette wheel	Yes	13	0.037	37
17	0.034	34	0.3	0.05	Roulette wheel	Yes	12	0.263	263
19	0.054	54	0.3	0.04	Roulette wheel	Yes	14	0.065	65
17	0.074	74	0.3	0.03	Roulette wheel	Yes	17	0.074	74
13	0.032	32	0.3	0.02	Roulette wheel	Yes	13	0.032	32
15	0.047	47	0.3	0.01	Roulette wheel	Yes	15	0.047	47
12	0.026	26	0.2	0.09	Roulette wheel	Yes	12	0.038	38
16	0.031	31	0.2	0.08	Roulette wheel	Yes	10	0.277	277
17	0.051	51	0.2	0.07	Roulette wheel	Yes	12	0.252	252
13	0.042	42	0.2	0.06	Roulette wheel	Yes	13	0.042	42
12	0.014	14	0.2	0.05	Roulette wheel	Yes	12	0.014	14
15	0.037	37	0.2	0.04	Roulette wheel	Yes	13	0.176	176

13	0.048	48	0.2	0.03	Roulette wheel	Yes	13	0.048	48
13	0.066	66	0.2	0.02	Roulette wheel	Yes	13	0.066	66
15	0.062	62	0.2	0.01	Roulette wheel	Yes	11	0.113	113
13	0.027	27	0.1	0.09	Roulette wheel	Yes	12	0.034	34
12	0.039	39	0.1	0.08	Roulette wheel	Yes	12	0.039	39
16	0.044	44	0.1	0.07	Roulette wheel	Yes	14	0.051	51
13	0.058	58	0.1	0.06	Roulette wheel	Yes	13	0.058	58
13	0.044	44	0.1	0.05	Roulette wheel	Yes	12	0.344	344
14	0.045	45	0.1	0.04	Roulette wheel	Yes	14	0.045	45
13	0.046	46	0.1	0.03	Roulette wheel	Yes	13	0.046	46
14	0.032	32	0.1	0.02	Roulette wheel	Yes	12	0.042	42
15	0.069	69	0.1	0.01	Roulette wheel	Yes	15	0.069	69
14	0.029	29	0.9	0.09	Tournament	Yes	11	0.221	221
14	0.03	30	0.9	0.08	Tournament	Yes	13	0.032	32
13	0.031	31	0.9	0.07	Tournament	Yes	12	0.052	52
14	0.04	40	0.9	0.06	Tournament	Yes	13	0.049	49
13	0.057	57	0.9	0.05	Tournament	Yes	11	0.218	218
15	0.04	40	0.9	0.04	Tournament	Yes	13	0.041	41
11	0.049	49	0.9	0.03	Tournament	Yes	11	0.049	49
16	0.031	31	0.9	0.02	Tournament	Yes	13	0.152	152
18	0.107	107	0.9	0.01	Tournament	Yes	18	0.107	107
12	0.02	20	0.8	0.09	Tournament	Yes	12	0.02	20
12	0.036	36	0.8	0.08	Tournament	Yes	12	0.046	46
13	0.037	37	0.8	0.07	Tournament	Yes	12	0.24	240
15	0.042	42	0.8	0.06	Tournament	Yes	13	0.052	52
12	0.033	33	0.8	0.05	Tournament	Yes	12	0.033	33
11	0.019	19	0.8	0.04	Tournament	Yes	11	0.019	19
13	0.02	20	0.8	0.03	Tournament	Yes	13	0.02	20
18	0.036	36	0.8	0.02	Tournament	Yes	13	0.055	55
24	0.111	111	0.8	0.01	Tournament	Yes	16	0.183	183
12	0.015	15	0.7	0.09	Tournament	Yes	11	0.036	36
13	0.023	23	0.7	0.08	Tournament	Yes	12	0.028	28
13	0.027	27	0.7	0.07	Tournament	Yes	11	0.034	34
11	0.012	12	0.7	0.06	Tournament	Yes	11	0.012	12
15	0.038	38	0.7	0.05	Tournament	Yes	14	0.313	313
10	0.022	22	0.7	0.04	Tournament	Yes	10	0.03	30
13	0.019	19	0.7	0.03	Tournament	Yes	13	0.019	19
13	0.022	22	0.7	0.02	Tournament	Yes	13	0.022	22
21	0.074	74	0.7	0.01	Tournament	Yes	16	0.088	88
15	0.026	26	0.6	0.09	Tournament	Yes	12	0.155	155
11	0.026	26	0.6	0.08	Tournament	Yes	11	0.026	26

14	0.026	26	0.6	0.07	Tournament	Yes	11	0.032	32
12	0.028	28	0.6	0.06	Tournament	Yes	10	0.2	200
16	0.042	42	0.6	0.05	Tournament	Yes	13	0.048	48
14	0.041	41	0.6	0.04	Tournament	Yes	13	0.053	53
13	0.027	27	0.6	0.03	Tournament	Yes	12	0.038	38
17	0.062	62	0.6	0.02	Tournament	Yes	14	0.071	71
15	0.057	57	0.6	0.01	Tournament	Yes	13	0.07	70
15	0.024	24	0.5	0.09	Tournament	Yes	12	0.037	37
11	0.045	45	0.5	0.08	Tournament	Yes	11	0.045	45
13	0.046	46	0.5	0.07	Tournament	Yes	12	0.049	49
14	0.039	39	0.5	0.06	Tournament	Yes	13	0.274	274
14	0.038	38	0.5	0.05	Tournament	Yes	12	0.243	243
14	0.041	41	0.5	0.04	Tournament	Yes	12	0.307	307
18	0.098	98	0.5	0.03	Tournament	Yes	15	0.17	170
13	0.014	14	0.5	0.02	Tournament	Yes	12	0.017	17
9	0.174	174	0.5	0.01	Tournament	Yes	9	0.174	174
12	0.028	28	0.4	0.09	Tournament	Yes	12	0.034	34
14	0.02	20	0.4	0.08	Tournament	Yes	11	0.045	45
12	0.014	14	0.4	0.07	Tournament	Yes	12	0.014	14
13	0.05	50	0.4	0.06	Tournament	Yes	11	0.051	51
19	0.036	36	0.4	0.05	Tournament	Yes	11	0.075	75
15	0.052	52	0.4	0.04	Tournament	Yes	15	0.094	94
14	0.079	79	0.4	0.03	Tournament	Yes	14	0.079	79
14	0.025	25	0.4	0.02	Tournament	Yes	14	0.025	25
13	0.043	43	0.4	0.01	Tournament	Yes	13	0.043	43
12	0.041	41	0.3	0.09	Tournament	Yes	12	0.041	41
13	0.017	17	0.3	0.08	Tournament	Yes	10	0.198	198
14	0.026	26	0.3	0.07	Tournament	Yes	11	0.045	45
15	0.028	28	0.3	0.06	Tournament	Yes	11	0.037	37
13	0.038	38	0.3	0.05	Tournament	Yes	13	0.038	38
12	0.021	21	0.3	0.04	Tournament	Yes	12	0.035	35
19	0.089	89	0.3	0.03	Tournament	Yes	14	0.301	301
14	0.042	42	0.3	0.02	Tournament	Yes	11	0.045	45
22	0.139	139	0.3	0.01	Tournament	Yes	22	0.139	139
13	0.032	32	0.2	0.09	Tournament	Yes	12	0.034	34
13	0.025	25	0.2	0.08	Tournament	Yes	12	0.036	36
18	0.036	36	0.2	0.07	Tournament	Yes	13	0.061	61
13	0.037	37	0.2	0.06	Tournament	Yes	13	0.037	37
13	0.029	29	0.2	0.05	Tournament	Yes	12	0.053	53
12	0.026	26	0.2	0.04	Tournament	Yes	12	0.026	26
12	0.019	19	0.2	0.03	Tournament	Yes	10	0.2	200

14	0.016	16	0.2	0.02	Tournament	Yes	14	0.016	16
18	0.104	104	0.2	0.01	Tournament	Yes	18	0.104	104
13	0.046	46	0.1	0.09	Tournament	Yes	13	0.046	46
15	0.025	25	0.1	0.08	Tournament	Yes	11	0.222	222
13	0.02	20	0.1	0.07	Tournament	Yes	11	0.148	148
16	0.036	36	0.1	0.06	Tournament	Yes	13	0.166	166
12	0.02	20	0.1	0.05	Tournament	Yes	12	0.02	20
13	0.022	22	0.1	0.04	Tournament	Yes	13	0.03	30
16	0.081	81	0.1	0.03	Tournament	Yes	15	0.092	92
19	0.512	512	0.1	0.02	Tournament	Yes	19	0.512	512
14	0.032	32	0.1	0.01	Tournament	Yes	12	0.035	35
16	0.038	38	0.9	0.09	Roulette wheel	No	13	0.073	73
13	0.018	18	0.9	0.08	Roulette wheel	No	11	0.048	48
11	0.029	29	0.9	0.07	Roulette wheel	No	11	0.029	29
16	0.056	56	0.9	0.06	Roulette wheel	No	13	0.06	60
14	0.028	28	0.9	0.05	Roulette wheel	No	11	0.221	221
14	0.03	30	0.9	0.04	Roulette wheel	No	13	0.083	83
14	0.038	38	0.9	0.03	Roulette wheel	No	14	0.038	38
15	0.076	76	0.9	0.02	Roulette wheel	No	15	0.076	76
20	0.138	138	0.9	0.01	Roulette wheel	No	20	0.138	138
12	0.023	23	0.8	0.09	Roulette wheel	No	12	0.023	23
11	0.022	22	0.8	0.08	Roulette wheel	No	11	0.022	22
11	0.04	40	0.8	0.07	Roulette wheel	No	11	0.074	74
14	0.035	35	0.8	0.06	Roulette wheel	No	13	0.179	179
14	0.041	41	0.8	0.05	Roulette wheel	No	12	0.126	126
14	0.041	41	0.8	0.04	Roulette wheel	No	14	0.041	41
12	0.038	38	0.8	0.03	Roulette wheel	No	12	0.038	38
19	0.055	55	0.8	0.02	Roulette wheel	No	14	0.07	70
18	0.075	75	0.8	0.01	Roulette wheel	No	16	0.079	79
16	0.035	35	0.7	0.09	Roulette wheel	No	15	0.081	81
13	0.023	23	0.7	0.08	Roulette wheel	No	12	0.041	41
12	0.03	30	0.7	0.07	Roulette wheel	No	12	0.03	30
12	0.026	26	0.7	0.06	Roulette wheel	No	10	0.032	32
14	0.035	35	0.7	0.05	Roulette wheel	No	12	0.234	234
16	0.042	42	0.7	0.04	Roulette wheel	No	12	0.247	247
13	0.044	44	0.7	0.03	Roulette wheel	No	13	0.044	44
18	0.052	52	0.7	0.02	Roulette wheel	No	11	0.231	231
21	0.114	114	0.7	0.01	Roulette wheel	No	12	0.159	159
13	0.03	30	0.6	0.09	Roulette wheel	No	11	0.223	223
14	0.021	21	0.6	0.08	Roulette wheel	No	13	0.041	41
15	0.048	48	0.6	0.07	Roulette wheel	No	13	0.183	183

13	0.035	35	0.6	0.06	Roulette wheel	No	13	0.035	35
13	0.029	29	0.6	0.05	Roulette wheel	No	11	0.032	32
12	0.014	14	0.6	0.04	Roulette wheel	No	11	0.06	60
12	0.045	45	0.6	0.03	Roulette wheel	No	12	0.045	45
15	0.019	19	0.6	0.02	Roulette wheel	No	12	0.034	34
17	0.072	72	0.6	0.01	Roulette wheel	No	14	0.324	324
12	0.03	30	0.5	0.09	Roulette wheel	No	11	0.222	222
13	0.018	18	0.5	0.08	Roulette wheel	No	11	0.03	30
13	0.022	22	0.5	0.07	Roulette wheel	No	12	0.037	37
12	0.029	29	0.5	0.06	Roulette wheel	No	12	0.029	29
13	0.044	44	0.5	0.05	Roulette wheel	No	12	0.166	166
15	0.046	46	0.5	0.04	Roulette wheel	No	12	0.244	244
12	0.03	30	0.5	0.03	Roulette wheel	No	12	0.03	30
11	0.034	34	0.5	0.02	Roulette wheel	No	11	0.034	34
14	0.076	76	0.5	0.01	Roulette wheel	No	14	0.076	76
15	0.027	27	0.4	0.09	Roulette wheel	No	12	0.03	30
14	0.053	53	0.4	0.08	Roulette wheel	No	13	0.078	78
13	0.029	29	0.4	0.07	Roulette wheel	No	11	0.031	31
12	0.036	36	0.4	0.06	Roulette wheel	No	11	0.113	113
18	0.076	76	0.4	0.05	Roulette wheel	No	14	0.319	319
13	0.032	32	0.4	0.04	Roulette wheel	No	11	0.208	208
15	0.071	71	0.4	0.03	Roulette wheel	No	13	0.14	140
21	0.104	104	0.4	0.02	Roulette wheel	No	14	0.186	186
17	0.103	103	0.4	0.01	Roulette wheel	No	17	0.103	103
14	0.038	38	0.3	0.09	Roulette wheel	No	13	0.043	43
12	0.032	32	0.3	0.08	Roulette wheel	No	12	0.041	41
14	0.03	30	0.3	0.07	Roulette wheel	No	14	0.03	30
19	0.091	91	0.3	0.06	Roulette wheel	No	14	0.291	291
13	0.03	30	0.3	0.05	Roulette wheel	No	13	0.03	30
13	0.036	36	0.3	0.04	Roulette wheel	No	13	0.036	36
14	0.034	34	0.3	0.03	Roulette wheel	No	13	0.034	34
12	0.041	41	0.3	0.02	Roulette wheel	No	12	0.041	41
16	0.086	86	0.3	0.01	Roulette wheel	No	16	0.086	86
11	0.031	31	0.2	0.09	Roulette wheel	No	11	0.031	31
12	0.034	34	0.2	0.08	Roulette wheel	No	12	0.034	34
11	0.011	11	0.2	0.07	Roulette wheel	No	11	0.011	11
12	0.019	19	0.2	0.06	Roulette wheel	No	12	0.019	19
13	0.035	35	0.2	0.05	Roulette wheel	No	13	0.035	35
12	0.021	21	0.2	0.04	Roulette wheel	No	12	0.021	21
13	0.053	53	0.2	0.03	Roulette wheel	No	13	0.053	53
14	0.059	59	0.2	0.02	Roulette wheel	No	10	0.063	63

14	0.05	50	0.2	0.01	Roulette wheel	No	11	0.222	222
13	0.03	30	0.1	0.09	Roulette wheel	No	13	0.03	30
17	0.05	50	0.1	0.08	Roulette wheel	No	11	0.213	213
16	0.062	62	0.1	0.07	Roulette wheel	No	13	0.293	293
14	0.027	27	0.1	0.06	Roulette wheel	No	14	0.027	27
12	0.036	36	0.1	0.05	Roulette wheel	No	12	0.036	36
17	0.046	46	0.1	0.04	Roulette wheel	No	14	0.085	85
14	0.061	61	0.1	0.03	Roulette wheel	No	11	0.231	231
13	0.018	18	0.1	0.02	Roulette wheel	No	13	0.018	18
13	0.041	41	0.1	0.01	Roulette wheel	No	13	0.041	41
17	0.046	46	0.9	0.09	Tournament	No	11	0.15	150
14	0.029	29	0.9	0.08	Tournament	No	11	0.148	148
15	0.06	60	0.9	0.07	Tournament	No	12	0.124	124
12	0.029	29	0.9	0.06	Tournament	No	11	0.208	208
14	0.043	43	0.9	0.05	Tournament	No	14	0.043	43
13	0.058	58	0.9	0.04	Tournament	No	13	0.058	58
12	0.044	44	0.9	0.03	Tournament	No	12	0.125	125
15	0.054	54	0.9	0.02	Tournament	No	13	0.059	59
17	0.038	38	0.9	0.01	Tournament	No	11	0.148	148
13	0.032	32	0.8	0.09	Tournament	No	11	0.048	48
12	0.02	20	0.8	0.08	Tournament	No	11	0.148	148
11	0.015	15	0.8	0.07	Tournament	No	11	0.015	15
12	0.041	41	0.8	0.06	Tournament	No	12	0.041	41
12	0.038	38	0.8	0.05	Tournament	No	11	0.207	207
14	0.028	28	0.8	0.04	Tournament	No	13	0.054	54
15	0.027	27	0.8	0.03	Tournament	No	14	0.052	52
12	0.029	29	0.8	0.02	Tournament	No	12	0.029	29
11	0.032	32	0.8	0.01	Tournament	No	11	0.032	32
13	0.02	20	0.7	0.09	Tournament	No	12	0.034	34
12	0.012	12	0.7	0.08	Tournament	No	11	0.04	40
12	0.038	38	0.7	0.07	Tournament	No	12	0.038	38
16	0.038	38	0.7	0.06	Tournament	No	13	0.076	76
13	0.038	38	0.7	0.05	Tournament	No	13	0.038	38
13	0.044	44	0.7	0.04	Tournament	No	13	0.044	44
12	0.028	28	0.7	0.03	Tournament	No	12	0.028	28
15	0.034	34	0.7	0.02	Tournament	No	11	0.045	45
12	0.045	45	0.7	0.01	Tournament	No	12	0.045	45
10	0.03	30	0.6	0.09	Tournament	No	10	0.03	30
14	0.024	24	0.6	0.08	Tournament	No	12	0.041	41
12	0.021	21	0.6	0.07	Tournament	No	11	0.223	223
18	0.04	40	0.6	0.06	Tournament	No	11	0.04	40

13	0.031	31	0.6	0.05	Tournament	No	12	0.033	33
12	0.025	25	0.6	0.04	Tournament	No	11	0.23	230
12	0.048	48	0.6	0.03	Tournament	No	12	0.048	48
19	0.037	37	0.6	0.02	Tournament	No	14	0.059	59
11	0.013	13	0.6	0.01	Tournament	No	11	0.013	13
12	0.018	18	0.5	0.09	Tournament	No	11	0.075	75
12	0.016	16	0.5	0.08	Tournament	No	12	0.016	16
12	0.024	24	0.5	0.07	Tournament	No	11	0.041	41
11	0.013	13	0.5	0.06	Tournament	No	11	0.013	13
12	0.023	23	0.5	0.05	Tournament	No	12	0.023	23
15	0.034	34	0.5	0.04	Tournament	No	13	0.047	47
12	0.016	16	0.5	0.03	Tournament	No	12	0.016	16
24	0.196	196	0.5	0.02	Tournament	No	16	0.511	511
16	0.067	67	0.5	0.01	Tournament	No	14	0.085	85
15	0.03	30	0.4	0.09	Tournament	No	11	0.039	39
12	0.021	21	0.4	0.08	Tournament	No	12	0.021	21
16	0.04	40	0.4	0.07	Tournament	No	10	0.2	200
12	0.041	41	0.4	0.06	Tournament	No	11	0.049	49
13	0.028	28	0.4	0.05	Tournament	No	12	0.054	54
13	0.023	23	0.4	0.04	Tournament	No	12	0.03	30
15	0.049	49	0.4	0.03	Tournament	No	12	0.052	52
12	0.02	20	0.4	0.02	Tournament	No	12	0.02	20
14	0.059	59	0.4	0.01	Tournament	No	12	0.243	243
13	0.033	33	0.3	0.09	Tournament	No	11	0.222	222
13	0.016	16	0.3	0.08	Tournament	No	11	0.019	19
12	0.019	19	0.3	0.07	Tournament	No	12	0.019	19
17	0.041	41	0.3	0.06	Tournament	No	12	0.042	42
11	0.043	43	0.3	0.05	Tournament	No	11	0.043	43
14	0.039	39	0.3	0.04	Tournament	No	14	0.056	56
19	0.058	58	0.3	0.03	Tournament	No	18	0.126	126
14	0.075	75	0.3	0.02	Tournament	No	14	0.075	75
13	0.059	59	0.3	0.01	Tournament	No	13	0.059	59
14	0.031	31	0.2	0.09	Tournament	No	12	0.164	164
14	0.021	21	0.2	0.08	Tournament	No	12	0.164	164
11	0.024	24	0.2	0.07	Tournament	No	11	0.024	24
11	0.027	27	0.2	0.06	Tournament	No	10	0.199	199
15	0.045	45	0.2	0.05	Tournament	No	12	0.163	163
19	0.035	35	0.2	0.04	Tournament	No	14	0.06	60
14	0.032	32	0.2	0.03	Tournament	No	13	0.034	34
25	0.211	211	0.2	0.02	Tournament	No	25	0.211	211
16	0.051	51	0.2	0.01	Tournament	No	15	0.065	65

13	0.031	31	0.1	0.09	Tournament	No	12	0.042	42
16	0.039	39	0.1	0.08	Tournament	No	13	0.055	55
12	0.041	41	0.1	0.07	Tournament	No	12	0.041	41
13	0.023	23	0.1	0.06	Tournament	No	13	0.023	23
12	0.041	41	0.1	0.05	Tournament	No	11	0.222	222
12	0.015	15	0.1	0.04	Tournament	No	12	0.015	15
12	0.085	85	0.1	0.03	Tournament	No	12	0.085	85
12	0.028	28	0.1	0.02	Tournament	No	12	0.028	28
11	0.036	36	0.1	0.01	Tournament	No	11	0.036	36

Table 5.2: GA and minimum hop count results on 50 nodes WMN

5.2 Application of GA Model 1

GA model 1 (depicted in Table 5.2) is applied on fifty (50) nodes wireless mesh network. The selection method Roulette Wheel with elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 1, the population size is 500 with 1000 generations. Table 5.2 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 1 Parameters

Selection Method	Elitism	Nodes	Population	Generations
Roulette Wheel	Yes	50	500	1000

Optimal Path and minimum hop count Results of GA Model 1

(Cross Over, Mutation)	GA Hop Count	GA Optimal Cost * 1000	Minimum Hop Count	Minimum Hop Count Cost * 1000
(0.9, 0.08)	12	11	11	40
(0.8, 0.04)	15	22	14	35
(0.7,0.01)	12	19	12	42
(0.6, 0.07)	11	15	11	15
(0.5, 0.08)	14	19	11	30
(0.4, 0.08)	15	26	12	41
(0.3, 0.02)	13	32	13	32
(0.2, 0.05)	12	14	12	14
(0.1, 0.09)	13	27	12	34

Table 5.3: Application of GA Model 1

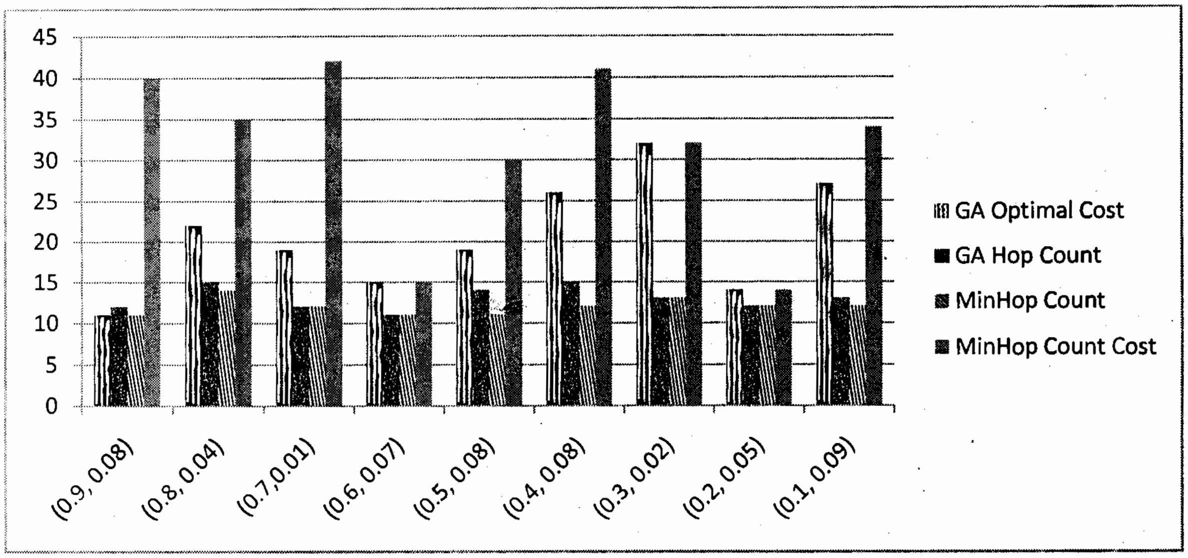

Figure 5.1: Graph of Application of GA Model 1

The graph in figure 5.1 shows that on fifty (50) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.9, 0.08) respectively. Keeping the same cross over and mutation rate, the cost of minimum hop count path is more than that of GA cost and thus the path selected through minimum hop count metric is not optimal.

5.3 Application of GA Model 2

GA model 2 (depicted in Table 5.3) is applied on fifty (50) nodes wireless mesh network. The selection method Tournament with elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 2, the population size is 500 with 1000 generations. Table 5.3 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 2 Parameters				
Selection Method	Elitism	Nodes	Population	Generations
Tournament	Yes	50	500	1000

Optimal Path and minimum hop count Results of GA Model 2				
(Cross Over, Mutation)	**GA Hop Count**	**GA Optimal Cost * 1000**	**Minimum Hop Count**	**Minimum Hop Count Cost * 1000**
(0.9, 0.09)	14	29	11	221
(0.8, 0.04)	11	19	11	19
(0.7, 0.06)	11	12	11	12
(0.6, 0.08)	11	26	11	26
(0.5, 0.02)	13	14	12	17
(0.4, 0.07)	12	14	12	14
(0.3, 0.08)	13	17	10	198
(0.2, 0.02)	14	16	14	16
(0.1, 0.07)	13	20	11	148

Table 5.4: Application of GA Model 2

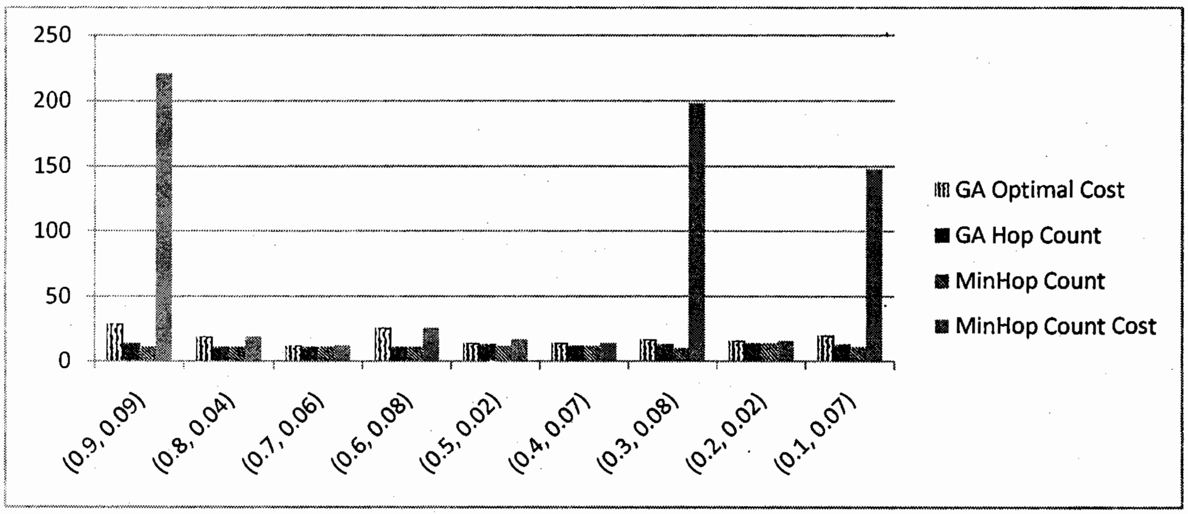

Figure 5.2: Graph of Application of GA Model 2

The graph in figure 5.2 shows that on fifty (50) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.7, 0.06) respectively. Keeping the same cross over and mutation rate, the cost of minimum hop count path is same as of GA cost and thus the path selected through minimum hop count metric is also an optimal path.

5.4 Application of GA Model 3

GA model 3 (depicted in Table 5.4) is applied on fifty (50) nodes wireless mesh network. The selection method Roulette Wheel without elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 3, the population size is 500 with 1000 generations. Table 5.4 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 3 Parameters				
Selection Method	**Elitism**	**Nodes**	**Population**	**Generations**
Roulette Wheel	No	50	500	1000
Optimal Path and minimum hop count Results of GA Model 3				
(Cross Over, Mutation)	**GA Hop Count**	**GA Optimal Cost * 1000**	**Minimum Hop Count**	**Minimum Hop Count Cost * 1000**
(0.9, 0.08)	13	18	11	48
(0.8, 0.08)	11	22	11	22
(0.7, 0.08)	13	23	12	41
(0.6, 0.04)	12	14	11	60
(0.5, 0.08)	13	18	11	30
(0.4, 0.09)	15	27	12	30
(0.3, 0.05)	13	30	13	30
(0.2, 0.07)	11	11	11	11
(0.1, 0.02)	13	18	13	18

Table 5.5: Application of GA Model 3

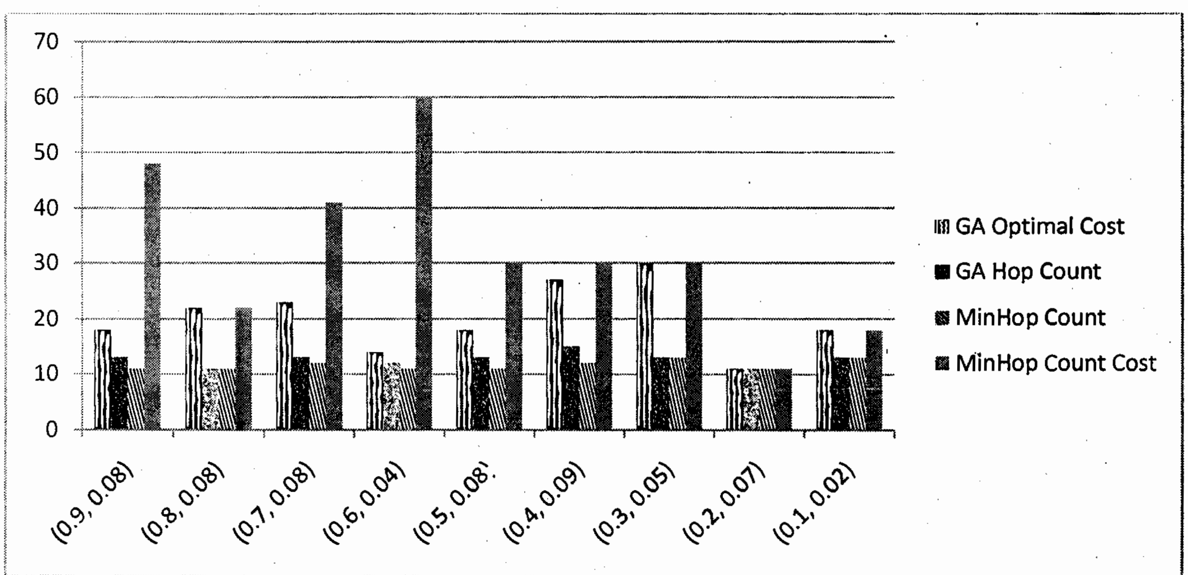

Figure 5.3: Graph of Application of GA Model 3

The graph in figure 5.3 shows that on fifty (50) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.2, 0.07) respectively. Keeping the same cross over and mutation rate, the cost of minimum hop count path is same as of GA cost and thus the path selected through minimum hop count metric is also an optimal path.

5.5 Application of GA Model 4

GA model 4 (depicted in Table 5.5) is applied on fifty (50) nodes wireless mesh network. The selection method Tournament without elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 4, the population size is 500 with 1000 generations. Table 5.5 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 4 Parameters				
Selection Method	**Elitism**	**Nodes**	**Population**	**Generations**
Tournament	No	50	500	1000

Optimal Path and minimum hop count Results of GA Model 4				
(Cross Over, Mutation)	**GA Hop Count**	**GA Optimal Cost * 1000**	**Minimum Hop Count**	**Minimum Hop Count Cost * 1000**
(0.9, 0.06)	12	29	11	208
(0.8, 0.07)	11	15	11	15
(0.7, 0.08)	12	12	11	40
(0.6, 0.01)	11	13	11	13
(0.5, 0.06)	11	13	11	13
(0.4, 0.02)	12	20	12	20
(0.3, 0.08)	13	16	11	19
(0.2, 0.08)	14	21	12	164
(0.1, 0.04)	12	15	12	15

Table 5.6: Application of GA Model 4

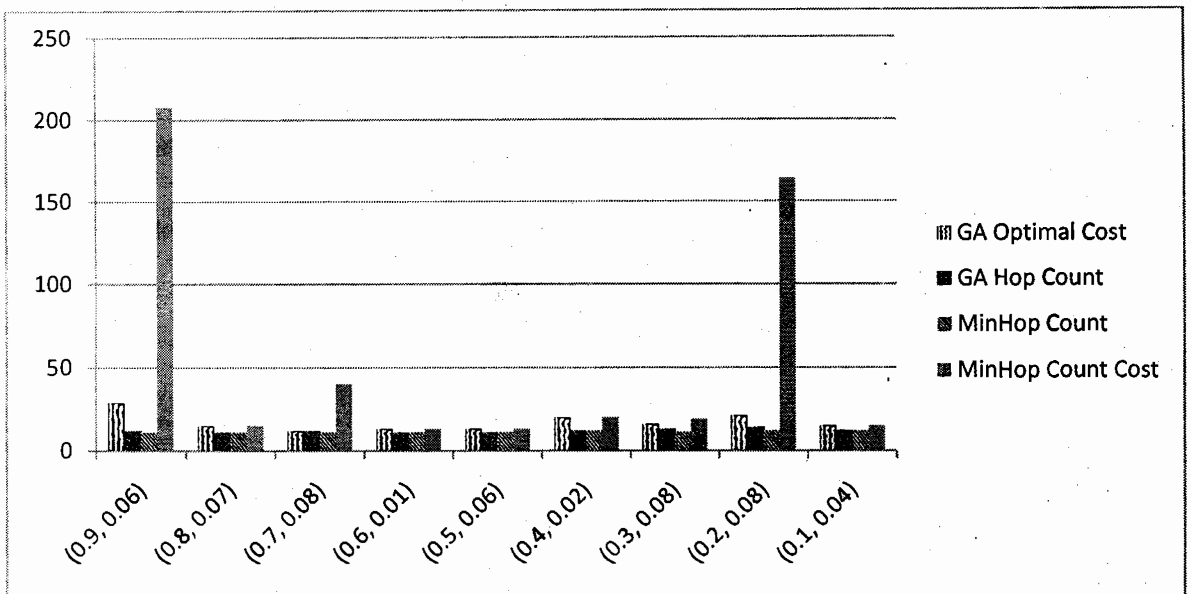

Figure 5.4: Graph of Application of GA Model 4

The graph in figure 5.4 shows that on fifty (50) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.7, 0.08) respectively. Keeping the same cross over and mutation rate, the cost of minimum hop count path is more than that of GA cost and thus the path selected through minimum hop count metric is not optimal.

5.6 Overall Optimal Path Results on 50 Nodes WMN

Table 5.6 shows the overall optimal path results on fifty (50) nodes WMN. The results are taken by applying selection methods roulette wheel and tournament with and without elitism.

Nodes	Population	Generations
50	500	1000

Optimal Path and minimum hop count Results

Selection Method-Elitism	GA Hop Count	GA Optimal Cost * 1000	Minimum Hop Count	Minimum Hop Count Cost * 1000
(0.9, 0.08) RW-Elitism-Yes	12	11	11	40
(0.7, 0.06) TR-Elitism-Yes	11	12	11	12
(0.2, 0.07) RW-Elitism-No	11	11	11	11
(0.7, 0.08) TR-Elitism-No	12	12	11	40

Table 5.7: Overall Optimal Path Results on 50 Nodes WMN

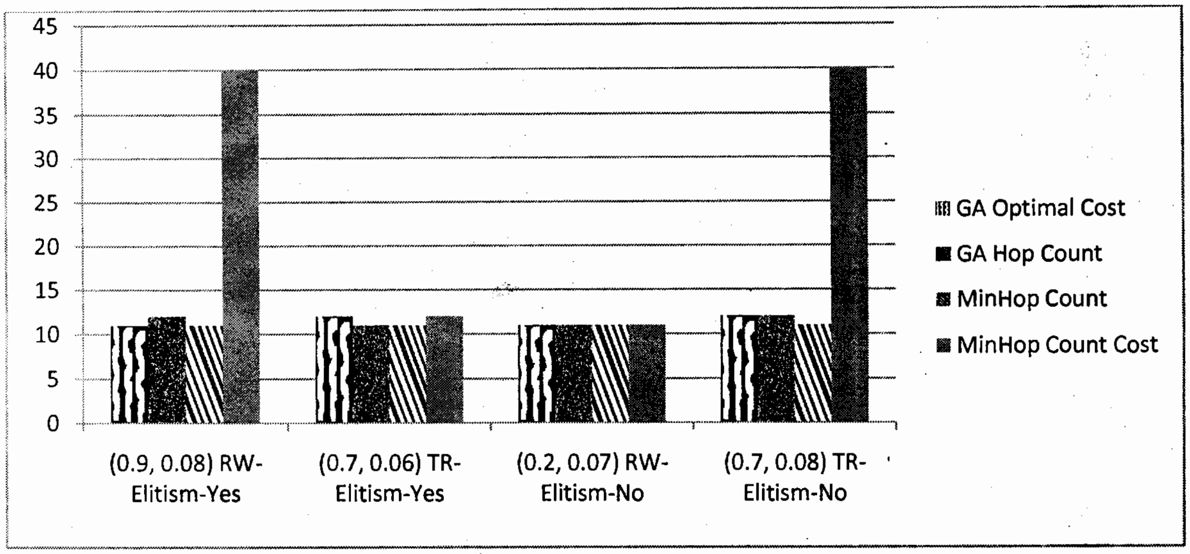

Figure 5.5: Graph of Overall Optimal Path Results on 50 Nodes WMN

The graph in Figure 5.5 shows that on fifty (50) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.9, 0.08) respectively on selection method Roulette Wheel with elitism. Keeping the same parameters, minimum hop count path cost is more than that of GA cost and thus the path selected through minimum hop count metric is not optimal. The optimal path cost obtained through selection method Roulette Wheel without elitism on cross over and mutation rate (0.2, 0.07) is same for both GA and minimum hop count. The optimal path cost obtained through selection method tournament with elitism on cross over and mutation rate (0.7, 0.06) is same for both GA and minimum hop count. By applying selection method tournament without elitism, the optimal path is selected on cross over and mutation rate (0.7, 0.08). Keeping the same parameters, minimum hop count path cost is more than that of GA cost and thus the path selected through minimum hop count metric is not optimal.

5.7 GA and minimum hop count results on hundred (100) nodes Wireless Mesh Network

Results taken on hundred (100) nodes wireless mesh network test system are shown in Table 5.7.

Results

Network Nodes	Population Size	Generations
100	1000	1000

GA Hops	GA Cost	GA Cost * 1000	Cross Over	Mutation	Selection Method	Elitism	MinHops	MinHops Cost	MinHops Cost * 1000
20	0.054	54	0.9	0.09	Roulette wheel	Yes	17	0.062	62
18	0.045	45	0.9	0.08	Roulette wheel	Yes	17	0.144	144
22	0.083	83	0.9	0.07	Roulette wheel	Yes	22	0.11	110
18	0.045	45	0.9	0.06	Roulette wheel	Yes	18	0.045	45
22	0.083	83	0.9	0.05	Roulette wheel	Yes	22	0.083	83
23	0.066	66	0.9	0.04	Roulette wheel	Yes	21	0.08	80
22	0.089	89	0.9	0.03	Roulette wheel	Yes	20	0.149	149
21	0.166	166	0.9	0.02	Roulette wheel	Yes	21	0.166	166
22	0.104	104	0.9	0.01	Roulette wheel	Yes	22	0.104	104
17	0.071	71	0.8	0.09	Roulette wheel	Yes	17	0.083	83
22	0.053	53	0.8	0.08	Roulette wheel	Yes	18	0.063	63
20	0.058	58	0.8	0.07	Roulette wheel	Yes	17	0.385	385
17	0.065	65	0.8	0.06	Roulette wheel	Yes	17	0.065	65
24	0.09	90	0.8	0.05	Roulette wheel	Yes	19	0.115	115
20	0.076	76	0.8	0.04	Roulette wheel	Yes	20	0.076	76
21	0.043	43	0.8	0.03	Roulette wheel	Yes	17	0.062	62
18	0.053	53	0.8	0.02	Roulette wheel	Yes	18	0.053	53
30	0.328	328	0.8	0.01	Roulette wheel	Yes	28	0.521	521
22	0.061	61	0.7	0.09	Roulette wheel	Yes	20	0.146	146
24	0.092	92	0.7	0.08	Roulette wheel	Yes	21	0.136	136
22	0.063	63	0.7	0.07	Roulette wheel	Yes	20	0.095	95
19	0.088	88	0.7	0.06	Roulette wheel	Yes	19	0.088	88
17	0.062	62	0.7	0.05	Roulette wheel	Yes	17	0.062	62
25	0.094	94	0.7	0.04	Roulette wheel	Yes	20	0.117	117
20	0.057	57	0.7	0.03	Roulette wheel	Yes	20	0.057	57
26	0.143	143	0.7	0.02	Roulette wheel	Yes	24	0.176	176
19	0.063	63	0.7	0.01	Roulette wheel	Yes	19	0.063	63
21	0.061	61	0.6	0.09	Roulette wheel	Yes	19	0.174	174

26	0.153	153	0.6	0.08	Roulette wheel	Yes	19	0.452	452
22	0.125	125	0.6	0.07	Roulette wheel	Yes	21	0.515	515
24	0.113	113	0.6	0.06	Roulette wheel	Yes	18	0.121	121
18	0.04	40	0.6	0.05	Roulette wheel	Yes	18	0.04	40
28	0.08	80	0.6	0.04	Roulette wheel	Yes	20	0.102	102
21	0.09	90	0.6	0.03	Roulette wheel	Yes	21	0.09	90
20	0.055	55	0.6	0.02	Roulette wheel	Yes	20	0.055	55
25	0.103	103	0.6	0.01	Roulette wheel	Yes	25	0.103	103
20	0.054	54	0.5	0.09	Roulette wheel	Yes	19	0.111	111
18	0.071	71	0.5	0.08	Roulette wheel	Yes	18	0.071	71
22	0.11	110	0.5	0.07	Roulette wheel	Yes	21	0.166	166
18	0.058	58	0.5	0.06	Roulette wheel	Yes	18	0.058	58
20	0.049	49	0.5	0.05	Roulette wheel	Yes	20	0.087	87
20	0.077	77	0.5	0.04	Roulette wheel	Yes	20	0.077	77
21	0.057	57	0.5	0.03	Roulette wheel	Yes	19	0.067	67
35	0.167	167	0.5	0.02	Roulette wheel	Yes	23	0.187	187
21	0.098	98	0.5	0.01	Roulette wheel	Yes	21	0.098	98
18	0.067	67	0.4	0.09	Roulette wheel	Yes	18	0.067	67
19	0.057	57	0.4	0.08	Roulette wheel	Yes	18	0.091	91
18	0.06	60	0.4	0.07	Roulette wheel	Yes	18	0.06	60
17	0.036	36	0.4	0.06	Roulette wheel	Yes	17	0.039	39
17	0.068	68	0.4	0.05	Roulette wheel	Yes	17	0.068	68
20	0.11	110	0.4	0.04	Roulette wheel	Yes	19	0.463	463
28	0.137	137	0.4	0.03	Roulette wheel	Yes	21	0.196	196
23	0.102	102	0.4	0.02	Roulette wheel	Yes	23	0.102	102
26	0.164	164	0.4	0.01	Roulette wheel	Yes	26	0.164	164
16	0.024	24	0.3	0.09	Roulette wheel	Yes	16	0.024	24
23	0.094	94	0.3	0.08	Roulette wheel	Yes	20	0.14	140
18	0.039	39	0.3	0.07	Roulette wheel	Yes	18	0.039	39
20	0.039	39	0.3	0.06	Roulette wheel	Yes	20	0.039	39
28	0.162	162	0.3	0.05	Roulette wheel	Yes	21	0.575	575
21	0.06	60	0.3	0.04	Roulette wheel	Yes	21	0.06	60
29	0.363	363	0.3	0.03	Roulette wheel	Yes	27	0.706	706
30	0.125	125	0.3	0.02	Roulette wheel	Yes	25	0.157	157
22	0.088	88	0.3	0.01	Roulette wheel	Yes	22	0.088	88
26	0.066	66	0.2	0.09	Roulette wheel	Yes	20	0.108	108
22	0.077	77	0.2	0.08	Roulette wheel	Yes	19	0.085	85
21	0.055	55	0.2	0.07	Roulette wheel	Yes	19	0.058	58
17	0.033	33	0.2	0.06	Roulette wheel	Yes	17	0.033	33
20	0.036	36	0.2	0.05	Roulette wheel	Yes	18	0.068	68
22	0.077	77	0.2	0.04	Roulette wheel	Yes	22	0.077	77

27	0.151	151	0.2	0.03	Roulette wheel	Yes	23	0.201	201
31	0.162	162	0.2	0.02	Roulette wheel	Yes	20	0.473	473
26	0.075	75	0.2	0.01	Roulette wheel	Yes	24	0.091	91
20	0.07	70	0.1	0.09	Roulette wheel	Yes	20	0.07	70
23	0.069	69	0.1	0.08	Roulette wheel	Yes	19	0.071	71
18	0.05	50	0.1	0.07	Roulette wheel	Yes	18	0.05	50
25	0.086	86	0.1	0.06	Roulette wheel	Yes	21	0.516	516
23	0.12	120	0.1	0.05	Roulette wheel	Yes	22	0.217	217
19	0.053	53	0.1	0.04	Roulette wheel	Yes	19	0.053	53
21	0.099	99	0.1	0.03	Roulette wheel	Yes	21	0.099	99
22	0.071	71	0.1	0.02	Roulette wheel	Yes	22	0.071	71
19	0.085	85	0.1	0.01	Roulette wheel	Yes	19	0.085	85
21	0.093	93	0.9	0.09	Tournament	Yes	20	0.445	445
21	0.076	76	0.9	0.08	Tournament	Yes	18	0.078	78
19	0.037	37	0.9	0.07	Tournament	Yes	17	0.044	44
17	0.088	88	0.9	0.06	Tournament	Yes	17	0.088	88
18	0.046	46	0.9	0.05	Tournament	Yes	17	0.107	107
19	0.059	59	0.9	0.04	Tournament	Yes	19	0.059	59
22	0.071	71	0.9	0.03	Tournament	Yes	19	0.112	112
19	0.079	79	0.9	0.02	Tournament	Yes	19	0.079	79
20	0.092	92	0.9	0.01	Tournament	Yes	20	0.092	92
23	0.066	66	0.8	0.09	Tournament	Yes	18	0.124	124
18	0.04	40	0.8	0.08	Tournament	Yes	17	0.053	53
21	0.077	77	0.8	0.07	Tournament	Yes	19	0.083	83
19	0.04	40	0.8	0.06	Tournament	Yes	19	0.04	40
17	0.066	66	0.8	0.05	Tournament	Yes	17	0.066	66
20	0.061	61	0.8	0.04	Tournament	Yes	18	0.079	79
19	0.069	69	0.8	0.03	Tournament	Yes	19	0.069	69
23	0.061	61	0.8	0.02	Tournament	Yes	20	0.088	88
21	0.119	119	0.8	0.01	Tournament	Yes	21	0.119	119
18	0.055	55	0.7	0.09	Tournament	Yes	17	0.067	67
20	0.059	59	0.7	0.08	Tournament	Yes	17	0.062	62
19	0.065	65	0.7	0.07	Tournament	Yes	18	0.241	241
17	0.068	68	0.7	0.06	Tournament	Yes	17	0.068	68
17	0.053	53	0.7	0.05	Tournament	Yes	17	0.053	53
18	0.053	53	0.7	0.04	Tournament	Yes	18	0.053	53
19	0.07	70	0.7	0.03	Tournament	Yes	19	0.07	70
24	0.065	65	0.7	0.02	Tournament	Yes	20	0.077	77
24	0.112	112	0.7	0.01	Tournament	Yes	21	0.192	192
19	0.057	57	0.6	0.09	Tournament	Yes	17	0.068	68
21	0.03	30	0.6	0.08	Tournament	Yes	16	0.057	57

20	0.065	65	0.6	0.07	Tournament	Yes	19	0.094	94
24	0.057	57	0.6	0.06	Tournament	Yes	19	0.078	78
21	0.051	51	0.6	0.05	Tournament	Yes	18	0.087	87
20	0.053	53	0.6	0.04	Tournament	Yes	19	0.087	87
17	0.043	43	0.6	0.03	Tournament	Yes	17	0.043	43
24	0.248	248	0.6	0.02	Tournament	Yes	22	0.575	575
25	0.147	147	0.6	0.01	Tournament	Yes	24	0.446	446
19	0.039	39	0.5	0.09	Tournament	Yes	15	0.061	61
19	0.043	43	0.5	0.08	Tournament	Yes	18	0.06	60
18	0.072	72	0.5	0.07	Tournament	Yes	18	0.072	72
22	0.055	55	0.5	0.06	Tournament	Yes	18	0.447	447
23	0.046	46	0.5	0.05	Tournament	Yes	19	0.083	83
22	0.085	85	0.5	0.04	Tournament	Yes	18	0.096	96
20	0.047	47	0.5	0.03	Tournament	Yes	15	0.073	73
22	0.102	102	0.5	0.02	Tournament	Yes	20	0.103	103
25	0.275	275	0.5	0.01	Tournament	Yes	25	0.275	275
18	0.04	40	0.4	0.09	Tournament	Yes	16	0.051	51
26	0.054	54	0.4	0.08	Tournament	Yes	18	0.076	76
19	0.047	47	0.4	0.07	Tournament	Yes	19	0.047	47
20	0.059	59	0.4	0.06	Tournament	Yes	19	0.08	80
26	0.062	62	0.4	0.05	Tournament	Yes	20	0.095	95
17	0.034	34	0.4	0.04	Tournament	Yes	17	0.034	34
20	0.045	45	0.4	0.03	Tournament	Yes	17	0.118	118
20	0.055	55	0.4	0.02	Tournament	Yes	19	0.059	59
21	0.179	179	0.4	0.01	Tournament	Yes	21	0.179	179
18	0.057	57	0.3	0.09	Tournament	Yes	16	0.058	58
19	0.056	56	0.3	0.08	Tournament	Yes	19	0.056	56
19	0.037	37	0.3	0.07	Tournament	Yes	18	0.084	84
19	0.051	51	0.3	0.06	Tournament	Yes	18	0.112	112
18	0.069	69	0.3	0.05	Tournament	Yes	17	0.071	71
19	0.041	41	0.3	0.04	Tournament	Yes	18	0.074	74
25	0.103	103	0.3	0.03	Tournament	Yes	24	0.108	108
18	0.056	56	0.3	0.02	Tournament	Yes	18	0.056	56
26	0.183	183	0.3	0.01	Tournament	Yes	23	0.28	280
18	0.044	44	0.2	0.09	Tournament	Yes	18	0.044	44
22	0.04	40	0.2	0.08	Tournament	Yes	17	0.073	73
18	0.041	41	0.2	0.07	Tournament	Yes	17	0.079	79
22	0.054	54	0.2	0.06	Tournament	Yes	17	0.071	71
23	0.055	55	0.2	0.05	Tournament	Yes	18	0.106	106
18	0.042	42	0.2	0.04	Tournament	Yes	18	0.042	42
17	0.046	46	0.2	0.03	Tournament	Yes	16	0.055	55

19	0.068	68	0.2	0.02	Tournament	Yes	19	0.068	68
25	0.165	165	0.2	0.01	Tournament	Yes	25	0.165	165
19	0.04	40	0.1	0.09	Tournament	Yes	17	0.066	66
22	0.056	56	0.1	0.08	Tournament	Yes	17	0.058	58
25	0.082	82	0.1	0.07	Tournament	Yes	18	0.478	478
18	0.039	39	0.1	0.06	Tournament	Yes	18	0.039	39
27	0.091	91	0.1	0.05	Tournament	Yes	20	0.423	423
18	0.067	67	0.1	0.04	Tournament	Yes	18	0.067	67
23	0.072	72	0.1	0.03	Tournament	Yes	21	0.12	120
21	0.085	85	0.1	0.02	Tournament	Yes	18	0.122	122
19	0.057	57	0.1	0.01	Tournament	Yes	19	0.057	57
19	0.054	54	0.9	0.09	Roulette wheel	No	16	0.055	55
17	0.059	59	0.9	0.08	Roulette wheel	No	17	0.059	59
19	0.058	58	0.9	0.07	Roulette wheel	No	19	0.058	58
19	0.064	64	0.9	0.06	Roulette wheel	No	19	0.064	64
26	0.098	98	0.9	0.05	Roulette wheel	No	22	0.133	133
23	0.089	89	0.9	0.04	Roulette wheel	No	21	0.101	101
25	0.155	155	0.9	0.03	Roulette wheel	No	24	0.277	277
20	0.049	49	0.9	0.02	Roulette wheel	No	20	0.049	49
26	0.141	141	0.9	0.01	Roulette wheel	No	21	0.542	542
15	0.045	45	0.8	0.09	Roulette wheel	No	15	0.045	45
18	0.069	69	0.8	0.08	Roulette wheel	No	18	0.069	69
23	0.078	78	0.8	0.07	Roulette wheel	No	19	0.085	85
18	0.038	38	0.8	0.06	Roulette wheel	No	18	0.038	38
20	0.087	87	0.8	0.05	Roulette wheel	No	20	0.087	87
23	0.081	81	0.8	0.04	Roulette wheel	No	20	0.093	93
18	0.051	51	0.8	0.03	Roulette wheel	No	18	0.051	51
26	0.112	112	0.8	0.02	Roulette wheel	No	23	0.62	620
26	0.169	169	0.8	0.01	Roulette wheel	No	22	0.46	460
18	0.036	36	0.7	0.09	Roulette wheel	No	18	0.036	36
25	0.078	78	0.7	0.08	Roulette wheel	No	18	0.078	78
22	0.054	54	0.7	0.07	Roulette wheel	No	19	0.459	459
25	0.078	78	0.7	0.06	Roulette wheel	No	20	0.118	118
21	0.048	48	0.7	0.05	Roulette wheel	No	17	0.077	77
25	0.07	70	0.7	0.04	Roulette wheel	No	19	0.086	86
23	0.166	166	0.7	0.03	Roulette wheel	No	23	0.166	166
17	0.056	56	0.7	0.02	Roulette wheel	No	17	0.056	56
26	0.126	126	0.7	0.01	Roulette wheel	No	24	0.282	282
18	0.059	59	0.6	0.09	Roulette wheel	No	17	0.13	130
21	0.098	98	0.6	0.08	Roulette wheel	No	21	0.098	98
23	0.085	85	0.6	0.07	Roulette wheel	No	17	0.103	103

19	0.074	74	0.6	0.06	Roulette wheel	No	19	0.074	74
24	0.073	73	0.6	0.05	Roulette wheel	No	20	0.187	187
16	0.063	63	0.6	0.04	Roulette wheel	No	16	0.063	63
21	0.093	93	0.6	0.03	Roulette wheel	No	21	0.093	93
30	0.124	124	0.6	0.02	Roulette wheel	No	22	0.128	128
18	0.093	93	0.6	0.01	Roulette wheel	No	18	0.093	93
19	0.048	48	0.5	0.09	Roulette wheel	No	19	0.048	48
21	0.085	85	0.5	0.08	Roulette wheel	No	19	0.452	452
25	0.106	106	0.5	0.07	Roulette wheel	No	24	0.183	183
20	0.059	59	0.5	0.06	Roulette wheel	No	19	0.078	78
19	0.086	86	0.5	0.05	Roulette wheel	No	18	0.425	425
17	0.077	77	0.5	0.04	Roulette wheel	No	17	0.077	77
24	0.138	138	0.5	0.03	Roulette wheel	No	20	0.16	160
18	0.075	75	0.5	0.02	Roulette wheel	No	18	0.075	75
18	0.074	74	0.5	0.01	Roulette wheel	No	16	0.121	121
21	0.065	65	0.4	0.09	Roulette wheel	No	18	0.069	69
17	0.06	60	0.4	0.08	Roulette wheel	No	17	0.06	60
27	0.109	109	0.4	0.07	Roulette wheel	No	19	0.142	142
20	0.07	70	0.4	0.06	Roulette wheel	No	19	0.107	107
18	0.049	49	0.4	0.05	Roulette wheel	No	18	0.049	49
23	0.087	87	0.4	0.04	Roulette wheel	No	20	0.205	205
20	0.1	100	0.4	0.03	Roulette wheel	No	20	0.1	100
20	0.074	74	0.4	0.02	Roulette wheel	No	20	0.074	74
21	0.105	105	0.4	0.01	Roulette wheel	No	21	0.105	105
20	0.053	53	0.3	0.09	Roulette wheel	No	17	0.068	68
19	0.064	64	0.3	0.08	Roulette wheel	No	18	0.064	64
23	0.057	57	0.3	0.07	Roulette wheel	No	20	0.071	71
25	0.15	150	0.3	0.06	Roulette wheel	No	25	0.15	150
20	0.06	60	0.3	0.05	Roulette wheel	No	20	0.06	60
23	0.081	81	0.3	0.04	Roulette wheel	No	21	0.087	87
21	0.095	95	0.3	0.03	Roulette wheel	No	21	0.095	95
23	0.135	135	0.3	0.02	Roulette wheel	No	22	0.23	230
23	0.097	97	0.3	0.01	Roulette wheel	No	23	0.097	97
17	0.054	54	0.2	0.09	Roulette wheel	No	17	0.054	54
19	0.079	79	0.2	0.08	Roulette wheel	No	19	0.079	79
21	0.07	70	0.2	0.07	Roulette wheel	No	20	0.085	85
25	0.123	123	0.2	0.06	Roulette wheel	No	20	0.158	158
22	0.085	85	0.2	0.05	Roulette wheel	No	21	0.233	233
19	0.083	83	0.2	0.04	Roulette wheel	No	19	0.083	83
22	0.102	102	0.2	0.03	Roulette wheel	No	20	0.229	229
25	0.104	104	0.2	0.02	Roulette wheel	No	25	0.104	104

22	0.091	91	0.2	0.01	Roulette wheel	No	22	0.091	91
21	0.092	92	0.1	0.09	Roulette wheel	No	21	0.092	92
19	0.101	101	0.1	0.08	Roulette wheel	No	19	0.101	101
19	0.036	36	0.1	0.07	Roulette wheel	No	19	0.036	36
22	0.097	97	0.1	0.06	Roulette wheel	No	22	0.097	97
18	0.053	53	0.1	0.05	Roulette wheel	No	18	0.053	53
21	0.057	57	0.1	0.04	Roulette wheel	No	19	0.082	82
18	0.064	64	0.1	0.03	Roulette wheel	No	18	0.064	64
32	0.185	185	0.1	0.02	Roulette wheel	No	31	0.239	239
20	0.097	97	0.1	0.01	Roulette wheel	No	20	0.097	97
18	0.046	46	0.9	0.09	Tournament	No	17	0.076	76
24	0.065	65	0.9	0.08	Tournament	No	19	0.151	151
21	0.086	86	0.9	0.07	Tournament	No	21	0.086	86
22	0.056	56	0.9	0.06	Tournament	No	20	0.067	67
20	0.071	71	0.9	0.05	Tournament	No	20	0.071	71
21	0.091	91	0.9	0.04	Tournament	No	20	0.173	173
23	0.15	150	0.9	0.03	Tournament	No	17	0.184	184
20	0.11	110	0.9	0.02	Tournament	No	20	0.11	110
25	0.208	208	0.9	0.01	Tournament	No	25	0.208	208
20	0.042	42	0.8	0.09	Tournament	No	19	0.054	54
16	0.045	45	0.8	0.08	Tournament	No	16	0.045	45
27	0.079	79	0.8	0.07	Tournament	No	21	0.09	90
16	0.036	36	0.8	0.06	Tournament	No	15	0.043	43
22	0.101	101	0.8	0.05	Tournament	No	18	0.15	150
19	0.057	57	0.8	0.04	Tournament	No	18	0.074	74
24	0.081	81	0.8	0.03	Tournament	No	20	0.125	125
24	0.079	79	0.8	0.02	Tournament	No	20	0.083	83
21	0.192	192	0.8	0.01	Tournament	No	21	0.192	192
19	0.036	36	0.7	0.09	Tournament	No	16	0.055	55
18	0.04	40	0.7	0.08	Tournament	No	18	0.04	40
17	0.039	39	0.7	0.07	Tournament	No	16	0.043	43
21	0.106	106	0.7	0.06	Tournament	No	19	0.115	115
21	0.078	78	0.7	0.05	Tournament	No	17	0.087	87
25	0.081	81	0.7	0.04	Tournament	No	19	0.429	429
17	0.056	56	0.7	0.03	Tournament	No	17	0.056	56
20	0.169	169	0.7	0.02	Tournament	No	20	0.169	169
25	0.128	128	0.7	0.01	Tournament	No	23	0.37	370
23	0.062	62	0.6	0.09	Tournament	No	20	0.108	108
19	0.035	35	0.6	0.08	Tournament	No	17	0.079	79
19	0.051	51	0.6	0.07	Tournament	No	19	0.051	51
22	0.087	87	0.6	0.06	Tournament	No	21	0.497	497

20	0.081	81	0.6	0.05	Tournament	No	19	0.091	91
19	0.041	41	0.6	0.04	Tournament	No	19	0.041	41
19	0.05	50	0.6	0.03	Tournament	No	19	0.05	50
19	0.063	63	0.6	0.02	Tournament	No	19	0.063	63
25	0.107	107	0.6	0.01	Tournament	No	25	0.107	107
19	0.051	51	0.5	0.09	Tournament	No	17	0.087	87
21	0.077	77	0.5	0.08	Tournament	No	18	0.113	113
18	0.041	41	0.5	0.07	Tournament	No	17	0.071	71
22	0.033	33	0.5	0.06	Tournament	No	17	0.124	124
20	0.057	57	0.5	0.05	Tournament	No	19	0.066	66
17	0.055	55	0.5	0.04	Tournament	No	17	0.055	55
20	0.062	62	0.5	0.03	Tournament	No	17	0.092	92
19	0.071	71	0.5	0.02	Tournament	No	19	0.071	71
30	0.153	153	0.5	0.01	Tournament	No	21	0.571	571
20	0.064	64	0.4	0.09	Tournament	No	19	0.081	81
18	0.038	38	0.4	0.08	Tournament	No	18	0.038	38
21	0.047	47	0.4	0.07	Tournament	No	19	0.065	65
20	0.054	54	0.4	0.06	Tournament	No	18	0.073	73
20	0.056	56	0.4	0.05	Tournament	No	20	0.056	56
21	0.058	58	0.4	0.04	Tournament	No	17	0.063	63
26	0.075	75	0.4	0.03	Tournament	No	18	0.244	244
19	0.073	73	0.4	0.02	Tournament	No	19	0.073	73
23	0.077	77	0.4	0.01	Tournament	No	23	0.077	77
20	0.043	43	0.3	0.09	Tournament	No	18	0.063	63
16	0.054	54	0.3	0.08	Tournament	No	16	0.054	54
20	0.042	42	0.3	0.07	Tournament	No	17	0.058	58
18	0.038	38	0.3	0.06	Tournament	No	17	0.052	52
21	0.059	59	0.3	0.05	Tournament	No	16	0.077	77
19	0.04	40	0.3	0.04	Tournament	No	17	0.079	79
19	0.068	68	0.3	0.03	Tournament	No	19	0.068	68
23	0.084	84	0.3	0.02	Tournament	No	21	0.117	117
22	0.076	76	0.3	0.01	Tournament	No	20	0.092	92
22	0.053	53	0.2	0.09	Tournament	No	17	0.133	133
16	0.039	39	0.2	0.08	Tournament	No	16	0.039	39
16	0.036	36	0.2	0.07	Tournament	No	16	0.036	36
21	0.071	71	0.2	0.06	Tournament	No	18	0.073	73
21	0.05	50	0.2	0.05	Tournament	No	21	0.05	50
19	0.051	51	0.2	0.04	Tournament	No	18	0.061	61
20	0.046	46	0.2	0.03	Tournament	No	19	0.426	426
21	0.09	90	0.2	0.02	Tournament	No	21	0.09	90
22	0.047	47	0.2	0.01	Tournament	No	22	0.047	47

17	0.054	54	0.1	0.09	Tournament	No	17	0.054	54
21	0.07	70	0.1	0.08	Tournament	No	20	0.092	92
20	0.081	81	0.1	0.07	Tournament	No	20	0.081	81
19	0.056	56	0.1	0.06	Tournament	No	18	0.121	121
20	0.033	33	0.1	0.05	Tournament	No	17	0.163	163
21	0.04	40	0.1	0.04	Tournament	No	19	0.128	128
21	0.07	70	0.1	0.03	Tournament	No	21	0.07	70
25	0.15	150	0.1	0.02	Tournament	No	21	0.305	305
24	0.133	133	0.1	0.01	Tournament	No	24	0.133	133

Table 5.8: GA and minimum hop count results on 100 nodes WMN

5.8 Application of GA Model 5

GA model 5 (depicted in Table 5.8) is applied on hundred (100) nodes wireless mesh network. The selection method Roulette Wheel with elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 5, the population size is 1000 with 1000 generations. Table 5.8 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 5 Parameters

Selection Method	Elitism	Nodes	Population	Generations
Roulette Wheel	Yes	100	1000	1000

Optimal Path and minimum hop count Results of GA Model 5

(Cross Over, Mutation)	GA Hop Count	GA Optimal Cost * 1000	Minimum Hop Count	Minimum Hop Count Cost * 1000
(0.9, 0.08)	18	45	17	144
(0.8, 0.03)	21	43	17	62
(0.7, 0.03)	20	57	20	57
(0.6, 0.05)	18	40	18	40
(0.5, 0.05)	20	49	20	87
(0.4, 0.06)	17	36	17	39
(0.3, 0.09)	16	24	16	24
(0.2, 0.06)	17	33	17	33
(0.1, 0.07)	18	50	18	50

Table 5.9: Application of GA Model 5

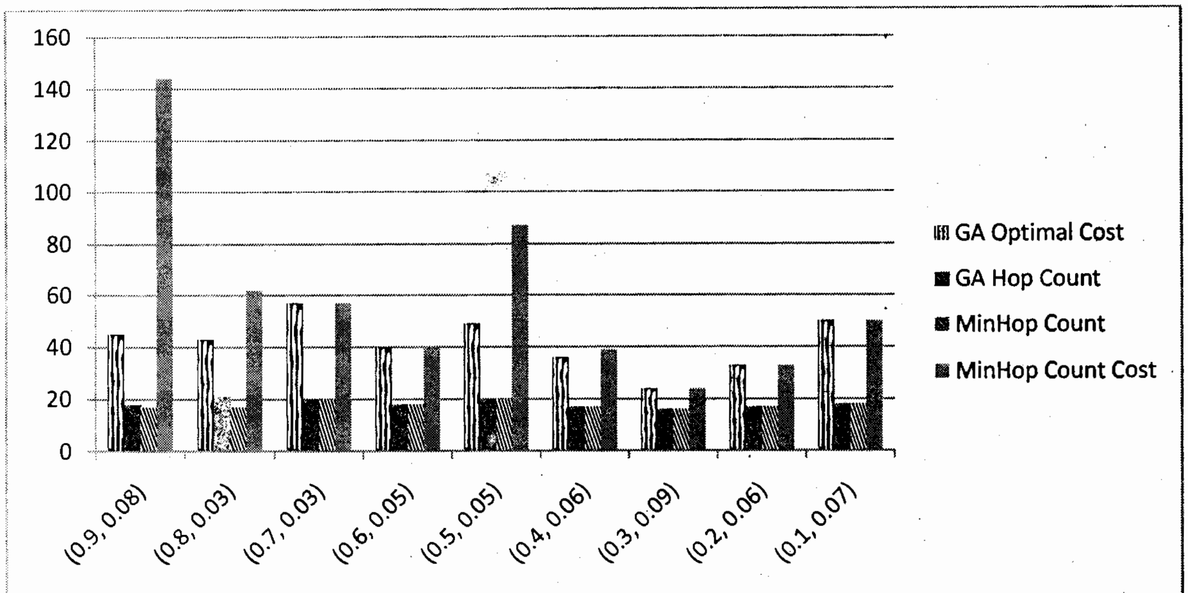

Figure 5.6: Graph of Application of GA Model 5

The graph in figure 5.6 shows that on hundred (100) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.3, 0.09) respectively. Keeping the same cross over and mutation rate, the cost of minimum hop count path is also same as of GA cost and thus the optimal path is same for GA and minimum hop count metric.

5.9 Application of GA Model 6

GA model 6 (depicted in Table 5.9) is applied on hundred (100) nodes wireless mesh network. The selection method Tournament with elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 6, the population size is 1000 with 1000 generations. Table 5.9 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 6 parameters				
Selection Method	Elitism	Nodes	Population	Generations
Tournament	Yes	100	1000	1000

Optimal Path and minimum hop count Results of GA Model 6				
(Cross Over, Mutation)	GA Hop Count	GA Optimal Cost * 1000	Minimum Hop Count	Minimum Hop Count Cost * 1000
(0.9, 0.07)	19	37	17	44
(0.8, 0.08)	18	40	17	53
(0.7, 0.05)	17	53	17	53
(0.6, 0.08)	21	30	16	57
(0.5, 0.09)	19	39	15	61
(0.4, 0.04)	17	34	17	34
(0.3, 0.07)	19	37	18	84
(0.2, 0.08)	22	40	17	73
(0.1, 0.06)	18	39	18	39

Table 5.10: Application of GA Model 6

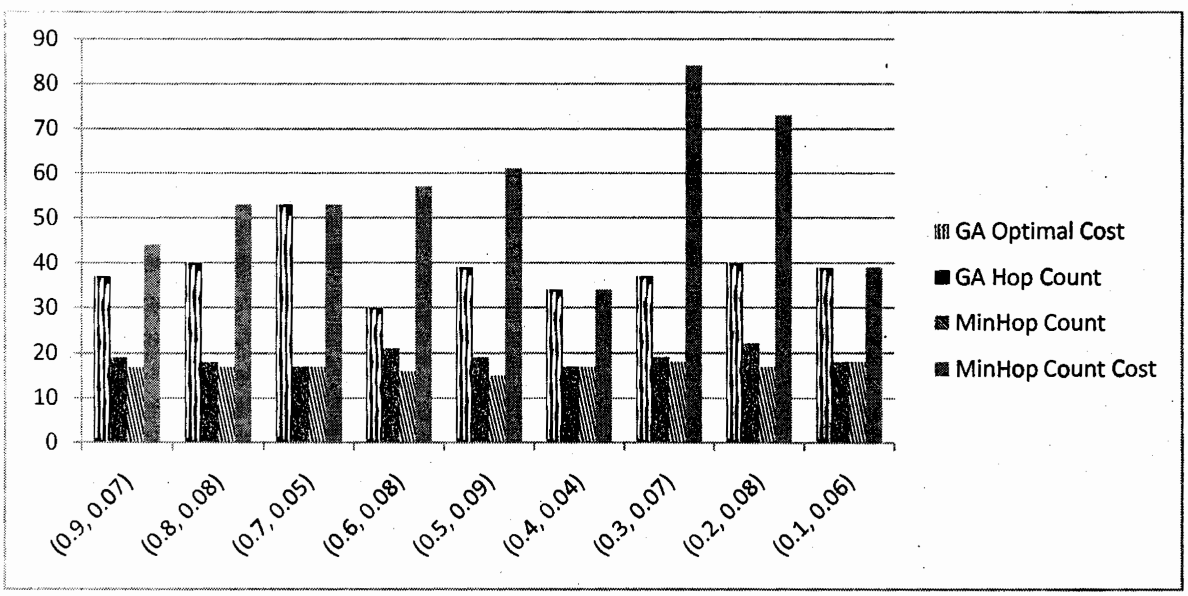

Figure 5.7: Graph of Application of GA Model 6

The graph in figure 5.7 shows that on hundred (100) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.6, 0.08) respectively. Keeping the same cross over and mutation rate, the cost of minimum hop count path is more than that of GA cost and thus the path selected through minimum hop count metric is not optimal.

5.10 Application of GA Model 7

GA model 7 (depicted in Table 5.10) is applied on hundred (100) nodes wireless mesh network. The selection method Roulette Wheel without elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 7, the population size is 1000 with 1000 generations. Table 5.10 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 7 parameters				
Selection Method	**Elitism**	**Nodes**	**Population**	**Generations**
Roulette Wheel	No	100	1000	1000

Optimal Path and minimum hop count Results of GA Model 7				
(Cross Over, Mutation)	**GA Hop Count**	**GA Optimal Cost * 1000**	**Minimum Hop Count**	**Minimum Hop Count Cost * 1000**
(0.9, 0.02)	20	49	20	49
(0.8, 0.06)	18	38	18	38
(0.7, 0.09)	18	36	18	36
(0.6, 0.09)	18	59	17	130
(0.5, 0.09)	19	48	19	48
(0.4, 0.05)	18	49	18	49
(0.3, 0.09)	20	53	17	68
(0.2, 0.09)	17	54	17	54
(0.1, 0.07)	19	36	19	36

Table 5.11: Application of GA Model 7

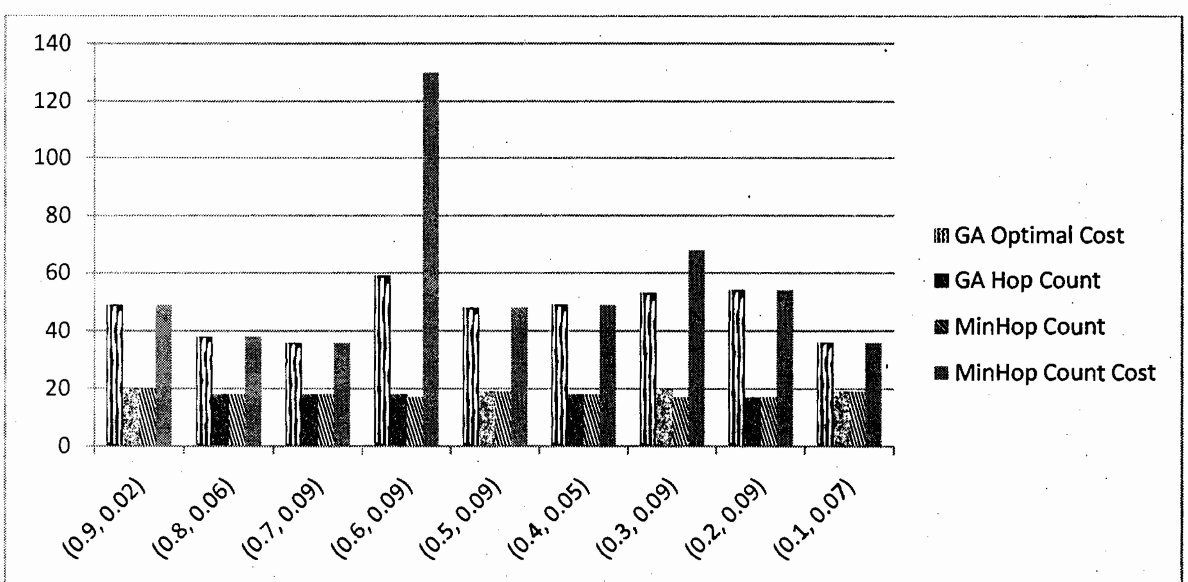

Figure 5.8: Graph of Application of GA Model 7

The graph in figure 5.8 shows that on hundred (100) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.7, 0.09) and (0.1, 0.07). Keeping the same cross over and mutation rates, the cost of minimum hop count path is also same as of GA cost and thus the path selected through minimum hop count metric is also an optimal path.

5.11 Application of GA Model 8

GA model 8 (depicted in Table 5.11) is applied on hundred (100) nodes wireless mesh network. The selection method Tournament without elitism is employed for finding the optimal path for routing in wireless mesh network. In GA Model 8, the population size is 1000 with 1000 generations. Table 5.11 shows the optimal path and minimum hop count results on different cross over and mutation rates.

GA Model 8 parameters

Selection Method	Elitism	Nodes	Population	Generations
Tournament	No	100	1000	1000

Optimal Path and minimum hop count Results of GA Model 8

(Cross Over, Mutation)	GA Hop Count	GA Optimal Cost * 1000	Minimum Hop Count	Minimum Hop Count Cost * 1000
(0.9, 0.09)	18	46	17	76
(0.8, 0.06)	16	36	15	43
(0.7, 0.09)	19	36	16	55
(0.6, 0.08)	19	35	17	79
(0.5, 0.06)	22	33	17	124
(0.4, 0.08)	18	38	18	38
(0.3, 0.06)	18	38	17	52
(0.2, 0.07)	16	36	16	36
(0.1, 0.05)	20	33	17	163

Table 5.12: Application of GA Model 8

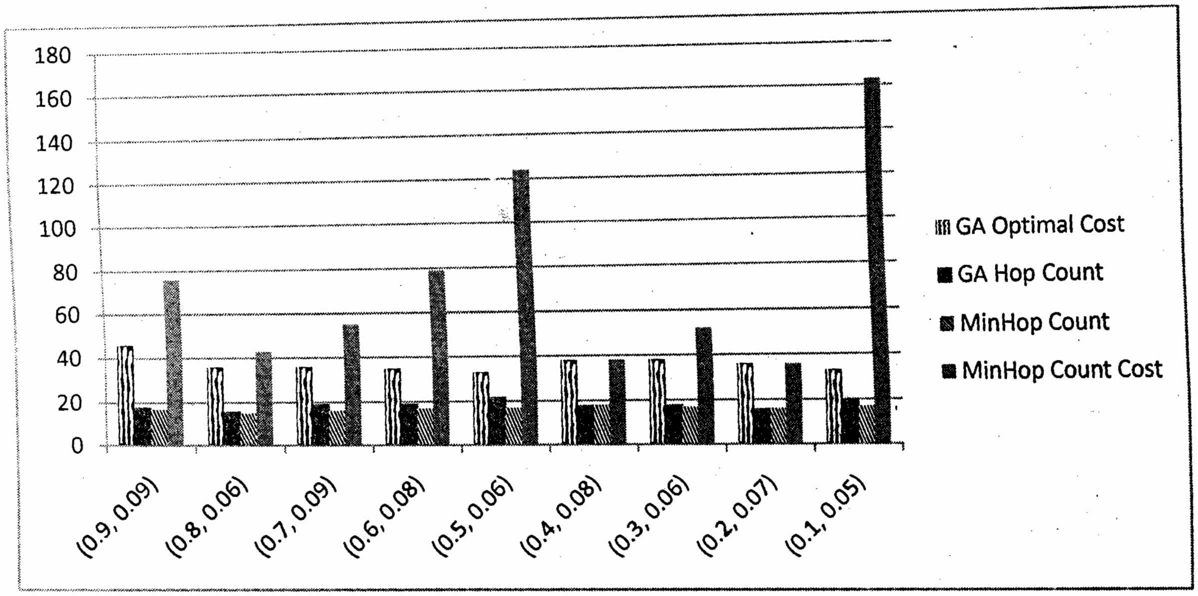

Figure 5.9: Graph of Application of GA Model 8

The graph in figure 5.9 shows that on hundred (100) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.5, 0.06) and (0.1, 0.05). Keeping the same cross over and mutation rates, the cost of minimum hop count path is more than that of GA cost and thus the path selected through minimum hop count metric is not an optimal path.

5.12 Overall Optimal Path Results on 100 Nodes WMN

Table 5.12 shows the overall optimal path results on hundred (100) nodes WMN. The results are taken by applying selection methods roulette wheel and tournament with and without elitism.

Selection Method-Elitism	GA Hop Count	GA Optimal Cost * 1000	Minimum Hop Count	Minimum Hop Count Cost * 1000
(0.3, 0.09) RW-Elitism-Yes	16	24	16	24
(0.6, 0.08) TR-Elitism-Yes	21	30	16	57
(0.7, 0.09) RW-Elitism-No	18	36	18	36
(0.1, 0.07) RW-Elitism-No	19	36	19	36
(0.1, 0.05) TR-Elitism-No	20	33	17	163
(0.5, 0.06) TR-Elitism-No	22	33	17	124

Table 5.13: Overall optimal path results on 100 nodes WMN

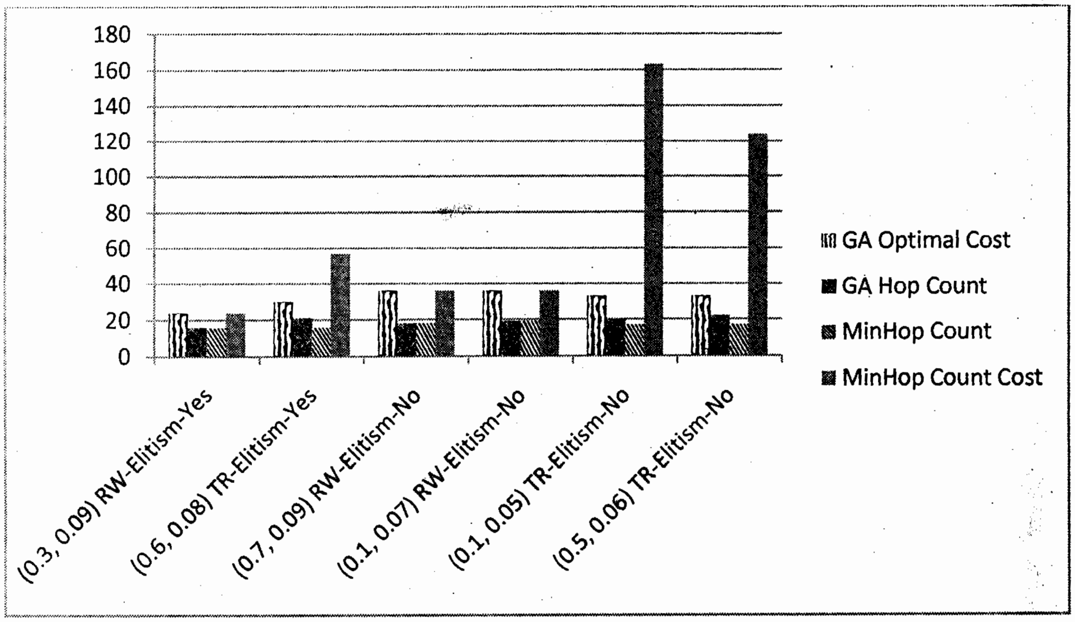

Figure 5.10: Graph of Overall optimal path results on 100 nodes WMN

The graph in Figure 5.10 shows that on hundred (100) nodes wireless mesh network, optimal path is selected on cross over and mutation rate (0.3, 0.09) respectively on selection method Roulette Wheel with elitism. Keeping the same parameters, minimum hop count path cost is also same as of GA cost and thus the path selected through minimum hop count metric is also an optimal path. The optimal path cost obtained through selection method Roulette Wheel without elitism on cross over and mutation rate (0.7, 0.09) and (0.1, 0.07) is same for both GA and minimum hop count. By applying selection method tournament with elitism, the optimal path is selected on cross over and mutation rate (0.6, 0.08). Keeping the same parameters, minimum hop count path cost is more than that of GA cost and thus the path selected through minimum hop count metric is not an optimal path. By applying selection method tournament without elitism, the optimal path is selected on cross over and mutation rate (0.1, 0.05) and (0.5, 0.06). Keeping the same parameters, minimum hop count path cost is more than that of GA cost and thus the path selected through minimum hop count metric is not optimal.

5.13 Analysis and Conclusion

The study and analysis of routing in WMN using genetic algorithm guide us to conclude that using GA technique instead of traditional hop count in AODV for finding optimal path gives better results. The experimental results taken on fifty (50) nodes and hundred (100) nodes wireless mesh network test systems show that the cost of optimal paths obtained through GA is minimum than the cost of traditional hop count metric in most of the cases. Although GA takes more time than hop count metric for finding the optimal path, but GA returns high throughput path for routing. We have applied two selection methods roulette wheel and tournament on our two test systems. We have also investigated the role of cross over rate and mutation rate by taking different values. The range of cross over rate is 0.1 to 0.9 while the range of mutation rate is 0.01 to 0.09. We collected best results from these combinations and used them in analysis. The best result for roulette wheel method on fifty (50) nodes WMN test system is on (0.9, 0.08) cross over and mutation respectively while the best result for tournament method is on (0.7, 0.06) cross over and mutation respectively. Similarly on hundred (100) nodes WMN test system, the best result for roulette wheel method is on (0.3, 0.09) cross over and mutation respectively while the best result for tournament method is on (0.6, 0.08) cross over and mutation respectively.

CHAPTER 6: RESEARCH CONTRIBUTIONS AND FUTURE WORK

RESEARCH CONTRIBUTIONS AND FUTURE WORK

Routing in wireless mesh network is an active research area with increasing contributions from research community. This work is done in the spirit to highlight some hidden areas of this diverse and multidimensional field of study. In the following section we describe our research contributions.

6.1 Research Contributions

Research contributions of this study are based on following categories:

6.1.1 Analysis of Wireless Mesh Network Test Systems and their Characteristics

We have selected a set of two test systems developed in C#.NET. We have studied useful characteristics of these test systems and presented our observations which may help researchers to find a suitable direction in the field of routing in wireless mesh network.

6.1.2 Implementation of Genetic Algorithm

We have designed and implemented genetic algorithm for routing in wireless mesh network. We have provided a mechanism for mapping routing problem to genetic algorithm and also provided a fitness computation function based on wireless mesh network routing metric i-e Expected Transmission Time (ETT). We have applied genetic algorithm on two WMN test systems which helped us to evaluate relative performance of the genetic algorithm.

6.1.3 A Framework for Routing in Wireless Mesh Network

A framework for the implementation of routing in wireless mesh network is proposed. Detailed features and implementation strategies along with guidelines for reuse are presented. The framework provides the researchers with a useful set of features and their possible and successful implementation.

6.2 Future Work

Currently the research work is done on only two test systems due to time constraints. In future it is possible to perform all this analysis on a large set of test systems so that the performance trend of GA with different set of parameters can be concluded and also the best parameters of GA for WMN can be proposed. In experimentation simple GA is used, if we use parallel GA with more suitable parameters, results can be achieved much faster and accurate. Author and his research group are currently working on similar issues. We have used expected transmission time (ETT) cost metric for our routing problem and one can use other cost metrics as well.

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APPENDIX A: GLOSSARY OF ABBREVIATIONS USED IN THESIS

Term	**Description**
WMNs	Wireless Mesh Networks
AODV	Adhoc On Demand Distance Vector
RREQ	Route Request
RREP	Route Reply
RERR	Route Error
RTT	Round Trip Time
PktPair	Per-hop Packet Pair Delay
ETX	Expected Transmission Count
mETX	modified ETX
ENT	Effective Number of Transmission
ETT	Expected Transmission Time
WCETT	Weighted Cumulative Expected Transmission Time
MIC	Metric of Interference and channel switching
DSDV	Destination Sequenced Distance Vector
GA	Genetic Algorithm
DSR	Dynamic Source Routing
OLSR	Optimized Link State Routing
RCGAs	Real coded genetic algorithms