Intelligent Mobile Ad Hoc Network Management System

Submitted in partial fulfilment of the requirement for the degree of Doctor of Philosophy

By

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October 2016

ABSTRACT

Currently wireless networks have grown significantly and contributed to several fields of technology especially communication. One of the imperative features of wireless networks is providing access to information without considering the geographical and the topological attributes of a user. One of the most popular wireless network technologies is mobile Ad Hoc network. In order to find an appropriate route between two connected nodes, several routing protocols have been suggested and created. Each routing protocol performs best under specific network conditions, such as under relatively low mobility level and highly dense network size. The main attribute to routing protocol performance degradation is connected to changes of the network context and conditions. Up to date, there is no routing protocol that can maintain its performance at high level under all possible context conditions.

In this thesis, the introduction of a management system utilizing artificial intelligence and optimisation techniques to be responsible for predicting MANET routing protocol performance behaviour and selecting the best suited one to adapted to the changes in the network conditions to solve the network performance degradation problem. MANET is modelled with the support of Artificial Intelligent (AI) techniques to help in a better understanding of the network performance under different context scenarios, the use of various packet types, and operating with different routing protocols. Thus the main addition made by this research is the use of different techniques to model our mobile Ad Hoc networks in terms of their behaviour that can be utilised for prediction purposes. An additional contribution is utilisation and comparison of different optimisation techniques based on MANET performance models that can be part of the system for choosing the best of the selected five routing protocols based on the network. The determined parameters for the context that affect the network were average mobility, number of nodes, and packet types. I_MMS manages the selection of a routing mechanism to maintain a stable performance by the network. The selected routing mechanism resulted by a minimum value in delay rate, RA, load, and higher throughput.

ACKNOWLEDGEMENTS

I would like to take the opportunity to express my gratitude to my supervisor Prof. John Cosmas who guided me and supported me throughout my PhD journey. Without his advise it would be impossible to conduct this research. Also I would like to thank Dr. Maysam Abbod who made it possible for me to accomplish the AI modelling. I really appreciate the support and advise from Dr. Nagham Saeed the author of I-MAN optimisation system.

My warmest appreciation goes to my loving parents, to whom my words cannot express their caring and endless love. This dream cannot turn to reality without the patience and understating from my wife and two children. Thank you from the bottom of my heart.

Majdi Mohammed Said Bait Ali Sulaiman

October 16, 2016, London, UK

DECLARATION

I declare that this thesis has not been submitted for a degree in any university. I declare that this thesis was written by me and all the information sources and literature used are referenced in this thesis.

Signature

ABBREVIATIONS

ABR	Associativity-based Routing
AI	Artificial Intelligence
AMRoute	Ad Hoc Multicast Routing
ANFIS	Adaptive Network Fuzzy Inference System
ANN	Artificial Neural Network
ANSI	Ad Hoc Networking with Swarm Intelligence
AODV	Ad Hoc On Demand Distance Vector
CAMP	Core-assisted Mesh Protocol
CBT	Core-based Tree
CEDAR	Core Extraction Distributed Ad Hoc Routing
CGSR	Clusterhead Gateway Switch Routing
CRDF	Cross-layer Route Discovery Framework
DARPA	Defense Advance Research Projects Agency
DREAM	Distance Routing Effect Algorithm for Mobility
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
EA	Evolutionary (computation) Algorithm
FTP	File Transfer Protocol
GA	Genetic Algorithm
GloMo	Global Mobile Information Systems
GPS	Global Positioning System
GRP	Geographic Routing Protocol
HSR	Hierarchical State Routing
HTTP	Hypertext Transfer Protocol
IETF	Internet Engineering Task Force
I-MMS	Intelligent MANET Management System
IP	Internet Protocol
LAR	Location Aided Routing

MANET	Mobile Ad Hoc NETwork
MLP	Multi-layer Perceptron
MOSPF	Multicast Open Shortest Path First
MPRs	MultiPoint Relays
MS	Mean Square
NF	Neuro-fuzzy
NTDR	Near-term Digital Radio
ODMRP	On Demand Multicast Routing Protocol
OLSR	Optimised Link State Routing
PAN	Personal Area Network
PC	Personal Computer
PCMCIA card	Personal Computer Memory Card International Association
PDA	Personal Digital Assistant
PE	Percentage Error
PIDIS	Protocol-independent (packet) Delivery Improvement Service
PRDS	Priority-based Route Discovery Strategy
PRNET	Packet Radio Networks
PSO	Particle Swarm Optimisation
RA	Retransmission Attempt
RBF	Radial Basis Function
RE	Regression Equation
RIP	Routing Information Protocol
RoSAuto	Routing Strategy Automation
SA	Simulated Annealing
SI	Swarm Intelligence
SURAN	Survivable Adaptive Radio Networks
TORA	Temporally Ordered Routing Algorithm
TSK	Takagi-Sugeno-Kang
TTL	Time To Live
UML	Unified Modeling Language

VANETs	Vehicular Ah hoc Networks
VC	VideoConferencing
WMN	Wireless Mesh Network
XML	Extensible Markup Language
ZRP	Zone Routing Protocol

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

1.1 Overview

Nowadays, the advances and wide spread use of mobile technology applications such as web browsing, online banking, online gaming and social media, has stimulated the hanger for the use of wireless network increased dramatically. Therefore, wireless networks have become almost a necessity and a vital component of contemporary daily life.

Mobile Ad Hoc Network (MANET) [1] is defined as a collection of nodes that interact with each other via wireless links in the absence of a centralized authority. In MANET, a network is considered as highly dynamic due to its flexible characteristics. Each node within the network has the ability to change its location and configure itself on the fly. Thus, the packets (supposedly reaching the destination) are heavily affected and pose vital challenging problems in MANET. Due to great quest by researchers to mitigate this effect, numerous routing protocols have been proposed to search for an appropriate route that connects between the sender and the receiver. The key aim is to provide or create a reliable path for packet exchange between network nodes. However, up to now there has not been an optimal routing protocol that produces the best network performance under all possible network conditions since every available routing protocol was designed or modified for specific network conditions.

To gain the proper knowledge about MANET routing protocols, review of different MANET routing protocol classifications is shown at the beginning of this thesis. Then, the implementation of optimisation in MANET to enhance MANET routing protocol functionality is covered to shed a light on the various efforts in optimised protocols. The novel design for the proposed intelligent management system is described afterwards. Moreover, a review of Artificial

Intelligence is presented as well. Finally, the optimisation system for MANET routing protocol based on AI is developed.

1.2 Thesis Motivations

In mobile Ad Hoc networks, each node within the network has the ability to change its location and configure itself on the fly. Due to the nature of MANET's dynamic topology, which experiences a lot of node movement, this has led to the design of various routing protocols. The aim of each protocol is to solve problems for a specific MANET topology condition; therefore, the designer or developer should have a prior knowledge of the condition or the context of the network targeted with his/her routing protocol design. Therefore, different routing protocols perform differently with different networks' conditions such as level of mobility, size of the network in terms of connected nodes number or type of packets being routed in the network. Once the network has established the connectivity, a specific routing protocol will be in use and cannot be changed, however the condition of the network may change to a scenario that the specified routing protocol might perform poorly.

There have been several attempts in performance simulation comparison and evaluation to MANET routing protocols behavior under different contexts that concluded the fact that there is no optimal routing protocol that provides better network performance within different contexts. There is an attempt to provide an optimisation system that changes the routing protocol based on the changes in the network context [3]. However, it was limited to only three routing protocols and with absence of any application such as FTP, VoIP etc.

1.3 Thesis Objectives

In this thesis, the essence of this research goal is to create, develop, and implement a novel intelligent mobile Ad Hoc network management system. In fulfilling this aim, the following objectives are considered important to be achieved:

- Review the literature and study MANET routing protocols to understand the field issues.
- Identify the various optimisation techniques utilised in the field of MANET routing protocols that is related to intelligent MANET management system.
- Designing the intelligent MANET management system architecture.
- Building 180 different simulated scenarios to collect the necessary data regarding MANET performance behaviour for five routing protocols with the support of Opnet™ 17.5 software package then MATLAB™ software package is utilized for modelling the simulation results
- Study and compare three of modelling methods through MATLAB™ software package and Essential Regression software package for modelling the MANET performance metrics then choose the most accurate method for representing MANET behaviour.
- Study and compare three of optimisation techniques through MATLAB™ software package and choose a suitable technique.
- Convert the selected modeller and optimiser from MATLAB™ code to C++ code and embedded it in Opnet™ 17.5 software package.

- I-MMS implementation in Opnet^{TM} 17.5 software package with a case study scenario.
- Finally, provide an analysis and comparisons of the simulation scenario results.

1.4 Thesis Challenges

To create the I-MMS and fulfilling the mentioned objectives are considered challenging tasks; the challenges are as follows:

- Determine the suitable networking simulation software package to support creating, developing and implementing the system.
- Determine the network performance metrics and network context to be considered by the design.
- Identifying and selecting the modelling techniques for the final design.
- Formulating the objective function to assist in selecting the optimal routing protocol.
- Converting the selected modelling and optimisation techniques to C++ language to be compatible with Opnet^{TM} 17.5 modeller.
- Embedding the modeller and the optimiser in the MANET node to create smart node in the software package.
- Creating the Topology and decision packet and the protocol changing mechanism.
- Identifying the threshold time at which the MANET nodes adopt the selected optimal routing protocol and the mechanism of implementing and using the protocol by MANET nodes.

- Finally, conducting the system implementation in the software package.

1.5 Thesis Contributions

The principal contributions can be summarised as follow:

- Creating MANET performance behaviour with three different network sizes and four mobility levels with three different packet types for five routing protocols models with the linear regression equation, ANN, and NF for prediction. Moreover, in this thesis a comparison is accomplished between the mentioned methods according to the Percentage Error (PE) to determine the best-suited method for MANET performance.
- Three optimisation techniques are searched fully in this thesis, the Simulated Annealing (SA), the Genetic Algorithm (GA) and Particle Swarm Optimisation (PSO). The selected optimiser to be utilised in the system is based on a comparison evaluation.
- This thesis presents a novel system design and implementation with the support of Opnet™ 17.5 the software package, which is considered a self-organised system to choose the best, suited among the five protocols based on the network previous performance. This is the first time a system has been developed that predicts the MANET performance for five routing protocols based on the changing network contexts with three different packet types. The optimised system commands the network nodes to change their current routing protocol and adopt the selected protocol to keep an adequate level of network performance.

1.6 Thesis Organisation

There are nine chapters in this thesis that ends with a brief conclusion. This chapter, the overview, motivation, aims and objectives, challenges, contributions and thesis organisation are included.

The second chapter presents the literature review related to mobile Ad Hoc network. The routing protocols for wired networks are defined and clarified as well. The classification of MANET routing protocols based on network characteristics are defined and explained.

The third chapter, the optimised routing protocols is surveyed. In this chapter the protocols are categorised based on the network routing cost function, modelling and prediction methods, or Artificial Intelligence technique (ANN, NF, SA, GA, PSO) utilised. Related work in regards to I-MAN optimisation system was explained and the difference between I-MAN and I-MMS was clarified. Finally, a summary section presented at the end.

The fourth chapter, the I-MMS routing protocol management system scheme and system components are identified and defined. The five routing protocols are defined and their working principle is explained with their advantages and disadvantages and a summary.

The fifth chapter, simulation environment configuration is identified and the MANET network simulated with the five routing protocols. The collected results are presented in 2D graph, and then arranged in 3D graphs. The discussion of the simulation results is presented in detail for each network performance metric utilising each of the three applications traffic. The chapter finalises with a brief summary.

In the sixth chapter, the detailed explanation in defining both empirical model and Regression Equation (RE) models are presented and then followed by an elaborate explanation of artificial neural network and neural fuzzy. The generated MANET performance models were presented in the chapter and then a quantitative comparison based on PE is performed to select the most accurate modelling technique and a brief summary of the results of this chapter is presented.

The seventh chapter presents detailed descriptions of GA, SA and PSO operations. The MANET optimiser created by GA, SA and PSO are then configured. The three optimisers selected different routing protocols as the network changes and the comparison was based on the minimum cost function value produced. Finally, a short summary is presented at the end of the chapter.

The eighth chapter presents the importance of utilising the optimisation unit then the creation of smart node and embedding the I-MMS optimisation system. The case study results were discussed and the chapter closes with a brief summary.

Finally, conclusion, achievements, limitations and future work are the sections that make up chapter 9.

Chapter 2: Routing in Mobile Ad Hoc Networks

2.1 Overview

Nowadays, the advances of wireless communication technology in terms of , low cost, powerful wireless devices are commonly used in mobile applications. Because of the reasons such as the better flexibility, low cost, and freedom of movement in mobile wireless networks, a significant interest continues to grow in the research community despite the drawbacks of wireless networks, such as network topology changes, issues with link capacity, high error rate, and bandwidth constrains and power restriction [1].

Mobile Ad Hoc networks environment in terms of mobility, dynamic nature and multi-hop topology are the main reason for such limitations. A new set of network strategies were proposed for implementation so as to deliver an efficient end-to-end communication.

Included in the current chapter, a definition and description of wireless mobile Ad Hoc network, routing network and various classifications of Ad Hoc routing protocols have been presented. In section 2.2, the introduction of mobile Ad Hoc network is presented. Then followed by an explanation of the routing protocols, both wired and wireless networks. The classification of wireless and routing issues are presented and recognized in section 2.4. Finally, a summary and conclusion of this chapter can be found in section 2.5.

2.2 Mobile Ad Hoc networks

A Mobile Ad Hoc network (MANET) is defined as an assembly of nodes that are capable of moving around and connected with each other via wireless links, as shown in figure 2.1. Such types of networks are infrastructure-less networks since they do not need any dedicated agency to manage their operation and the channel resources for the network nodes. In contrast, conventional wireless networks require as prerequisites some sort of fixed network infrastructure, such as a base station, and centralized administration for their operation [2] [3].

In mobile Ad Hoc network, nodes move randomly, thus the network may experience fast and unpredicted network topology changes as mobile nodes join or depart the network or radio links between nodes become unusable. Hence, a routing path in MANET potentially contains multiple-hops, and every node in the network has to work as a router.

Since Ad Hoc wireless network is different from the classical wireless and wired networks, a distinctive set of challenges are present when implementing such networks. The routing protocol in Ad Hoc network is considered as one of the prominent challenges.

MANET is considered to be one type of Ad Hoc networks paradigm. There are different network paradigms such as VANET (Vehicular Ad Hoc Network), networks operating under water or ground, networks operating at home, and sensor networks [5].

A wide variety of application in civilian and commercial arenas have become possible due to the recent rise in popularity of mobile wireless devices and technological developments. Indeed, this popularity has been because of the nature of mobile Ad Hoc networks, where they can be quickly deployed in parts where services are not provided due to lack of necessary infrastructure or because it cost a huge budget and no profit is foreseen. Some of conditions where infrastructure absence is possible due to disaster recovery of personnel (such as flood and earthquake) or military troops (in battlefield communications). MANET can be utilised for collaborative and distributive work such as video conferencing or transferring files in a conference or meeting without geographical constraints.

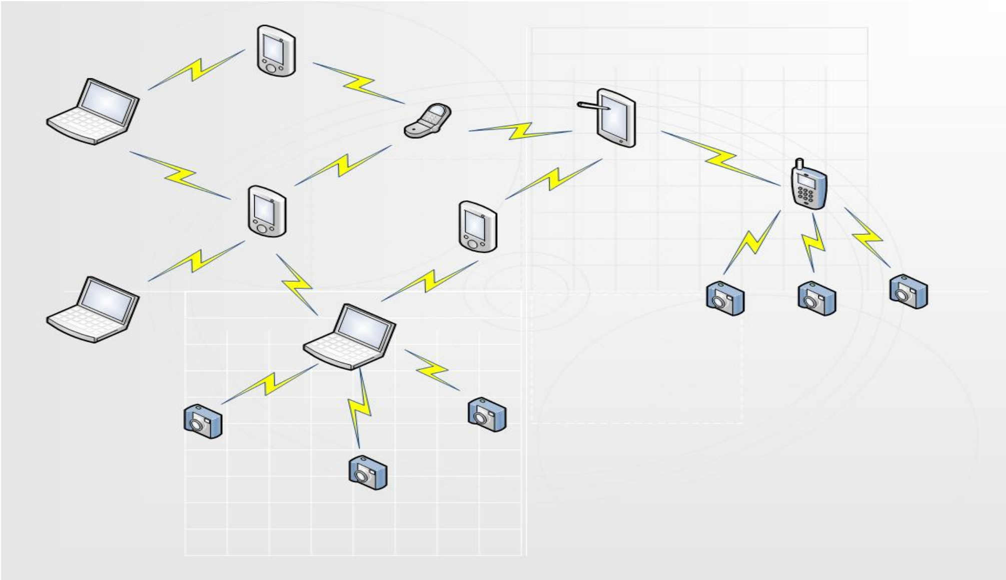


Figure 2.1: MANET network.

2.2.1 Brief History

Multi-hop relaying is the main idea behind Ad Hoc networking; its roots go back to 500 B.C [2]. The communication system used to convey messages and news between the Persian Empire's capital, in the era of Darius I king of Persia, to the various remote provinces by means of a line of shouting men located on tall structures or heights. Different ancient/tribal societies used the principle of multi-hop relaying with smoke signals, drums, trumpets, or horns as a way of communication [6].

Since the advent of packet radio networks until today's mobile Ad Hoc network, the entire life cycle of Ad Hoc networks can be characterized primarily into three categories: first generation, second generation, and third generation. Present Ad Hoc networks are considered the third-generation networks [2] [4].

The first Ad Hoc network can be traced back to 1972 when it was called Packet Radio Network (PRNET) [7]. Mainly, PRNET uses the combination of Areal Location of Hazardous Atmospheres (ALOHA) and Carrier Sense Multiple

Access (CSMA) for multiple access and distance vector routing [2]. The Defence Advanced Research Project Agency (DARPA) adopted PRNET project mainly to provide packet switched networking to mobile wireless and hostile environments where the infrastructure does not exist as in MANET in battlefield as shown in Figure 2.2.

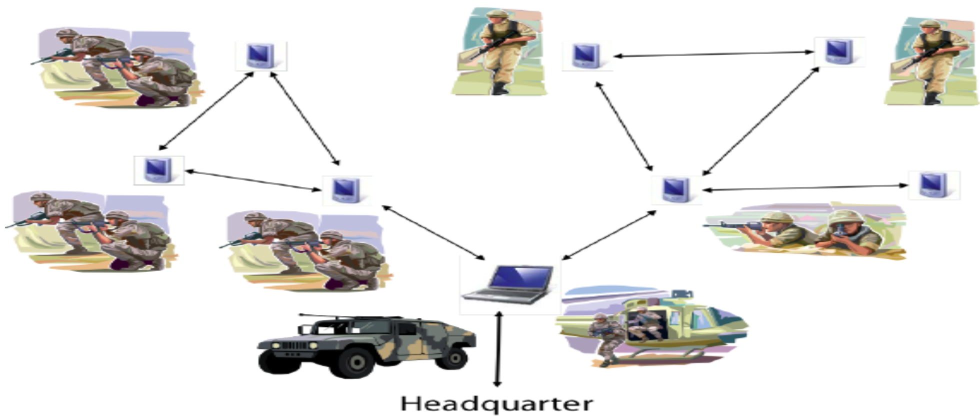


Figure 2.2: MANET in battlefield environment.

The technology that groups all transmitted data regardless of contents, types, or structure, in blocks is called packet switching. These packets are routed over the network relying on the destination address contained within each packet. Breaking down the communication into packets in which data is transmitted over shared network and each packet is routed individually from others and is allocated the transmission resources whenever required. The main objectives of such technology are to optimise link capacity usage, reduce the transmission latency and elevate the level of communication [8].

The prominence of the followed generation was in the eighties, as the Survivable Adaptive Radio Network (SURAN) program [9] adopted further enhancement and implementation of Ad Hoc systems. SURAN significantly improved upon the radios by making them smaller, cheaper, with scalability of algorithms, and more resilience to electronic attacks.

During the nineties, the concept of commercial (non-military) Ad Hoc networking had arrived due to the introduction of notebook computers and other communications equipment. During the same period, although the goal of GloMo (Global Mobile Information System) was to provide office-environment Ethernet-type multimedia connectivity anytime, anywhere, in handheld devices, the NTDR (Near-term Digital Radio) used clustering and link-state routing, and was self-organized into a two tier Ad Hoc network. Both technologies were funded programs by DoD (Department of Defence).

In the mid to late'90s, witnessed the launch of number of research on the field of Ad Hoc networks when presented in the Internet Engineering Task Force (IETF) conference [14]. Within the IETF, the Mobile Ad Hoc Network (MANET) working group was born, and sought to standardize routing protocols for Ad Hoc networks. Precise worries regarding implementing the current routing protocol with IP network in a rapid changing network conditions. The development of routing with the MANET working group and the larger community resulted into reactive (routes on-demand) and proactive (routes ready-to-use) routing protocols [10]. By providing standards for the medium access protocol through the IEEE 8.02 subcommittee, paved the way for Ad Hoc networks prototype out of notebooks to be built. Bluetooth technology is another standard that addressed and benefited Ad Hoc networking. The created network through utilising Bluetooth technology is referred to as Personal Area Network (PAN).

Nowadays, the devices equipped with wireless capabilities become less expensive, smaller in size, reduced weight and were complex. In addition to an increase in users' requests, the pursuing for cheaper means to retain device connectivity is progressing by competing telecommunication companies. Therefore, wireless technology and particularly Ad Hoc networks, in essence, have emerged as an attractive answer to such issues.

2.3 Routing

The transfer of information and communication between two parties is the main function of routing in networking world that makes it significant. Therefore, routing plays a major role in wireless networks. The main role played by routing is the same in networking whether wired or wireless, that is a set of rules that govern the flow of packets between connected devices in a network. In case a direct connection exists between node A (sender) and C (receiver) and node C lies in the vicinity of node A radio coverage or a peer to peer connection as in wired network. Then the set of rules for sending and receiving packets (routing protocol) will send the packets once it establishes the route between node A and C. However, if node A cannot reach node C directly then the routing protocol will search to identify a path to node C through a third or a number of mediators to get the packets to node C. Since Ad Hoc networks specifically MANET where the network environment is highly dynamic encouraged numerous routing protocol algorithms to be created or modified to mitigate or resolve such issues.

The different types of wired and wireless types are presented in the following sections.

2.3.1 Wired Network Routing

Routing protocols in wired networks were developed prior to their counterpart in wireless networks because the invention of wired network was before wireless network. The goal of routing a protocol is to find the shortest path or route where the data packet can be carried from the source to the desired destination. As shown in figure 2.3 there are two main and commonly used routing protocols for wired networks namely: distance vector and link state algorithms.

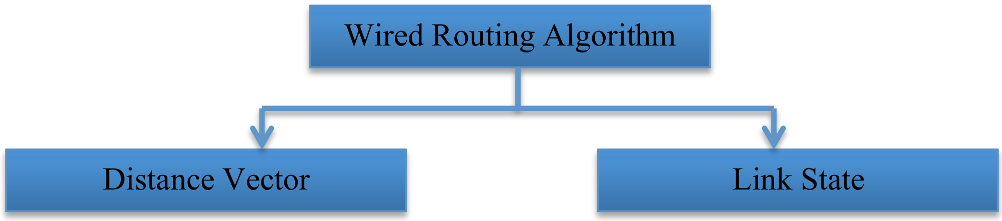


Figure 2.3: Routing protocol in wired network.

2.3.1.1 Distance Vector Routing

Distance Vector routing algorithm uses the path calculation [2]. The path calculation between the source and destination is accomplished based on different metrics. These metrics are length of queues of data waiting for transmission, the delay experienced, or the number of hops. Distance vector routing algorithm, which is commonly known as Bellman-Ford routing algorithm, after the researchers that developed it (Bellman, 1957; and Ford and Fulkerson, 1962)[11], is used.

The operation of Distance Vector routing protocol relies on every router maintaining a routing table (vector) giving the best known distance to each destination and which path to use to get there. Every neighbouring router exchanges the necessary information with each other to keep these tables updated.

Setting the routes to the best path over which packets can be carried across the network is called convergence. One of the main drawbacks of Distance Vector routing protocol is slow convergence. Therefore, it is susceptible to loops and issues with count-to-infinity. One famous routing protocol built according to distance vector algorithm is Routing Information Protocol [12], has managed to overcome the issue with count to infinity by introducing the maximum hop count of 16. However, the solution for looping problem is Time to live (TTL) on IP packets, which define the maximum amount of, time which an IP packet could remain in a network before being discarded.

2.3.1.2 Link State Routing

Too slow convergence as mentioned in the previous section after the network topology has changed, results in the count-to-infinity problem that Distance Vector routing algorithm encountered. Consequently, a new algorithm was introduced called Link State routing. OSPF and IS-IS are the most widely used Link State routing algorithms. The Dijkstra's algorithm [13] is being used to calculate the shortest path.

A periodic flooding is sent through the network to all connected routers to update the current status of links. As a result, if any changes occur in the link status a notification will be flooded throughout the entire network. Then all the routers will re-compute the routes based on the new notification and topology information will be refreshed.

Even though, the use of Link State routing to overcome the problems encountered with Distance Vector routing has created a different set of issues. The routing control overhead, which is considered a draw back in this category, is quite large due to the advertisement scheme. Moreover, since a large network advertisement consumes most of the bandwidth, the overall network performance will thus be degraded. Therefore, the attempt to reduce the routing control overhead became an important topic for routing scalability.

2.3.2 Routing in Wireless Ad Hoc Network

Since Ad Hoc networks are associated to operate in areas or part with the absence of any supporting services (infrastructure), change of network topology due to node mobility contributes to routing problems that do not exist in wired networks. Moreover, every node in Ad Hoc network has the responsibility to act as router. Therefore, the two types of routing protocols used in wired networks namely: distance vector routing protocol and link state routing protocol are not suitable for such dynamic nature of MANET. By implementing wired routing protocols MANET will suffer from increases of control overhead, slow route convergence and the algorithm performance will deteriorate resulting in overused bandwidth.

Due to all mentioned issues of implementing wired routing protocols, the need for improved or modified routing protocols is a necessity to meet MANET features. Consequently, several routing protocols were devised for MANET and the following reference (Internet Engineering Task Force) elaborates on the description of Ad Hoc routing protocols [14].

2.4 Classification of Routing Protocols

As explained at the beginning of this chapter, routing is the process of determining a suitable path between a source node and some arbitrary destination node in the network. However, the movement of mobile nodes in MANET, causes the nodes to continuously move in and out the range from one another. Hence, there is a rapid breaking of links and establishment in the network, making the network topology to dynamically change through time. This might be considered the main reason why traditional routing protocols, which are used in wired network, do not scale for MANETs. Moreover, the periodic or frequent route updates in large networks may consume significant part of the available bandwidths as mentioned in subsection 2.3.1.2 to overcome the problems associated with routing protocols in wired networks. As a result of mobility capabilities of nodes, a number of routing protocols have been proposed for MANETs.

These protocols can be classified and categorized based on different criteria, which facilitate understanding, comparing, evaluating and analysing the routing protocols.

In the following section, various routing protocols classifications are presented.

2.4.1 Communication Model

The routing protocols can be categorised according to the communication model. Protocols are designed for either single or multiple channels. In case where a single shared media is to be used, then this is called a single channel protocol. In contrast, Clustered Gateway Switched Routing (CGSR) is an example of multi-channel protocol [15].

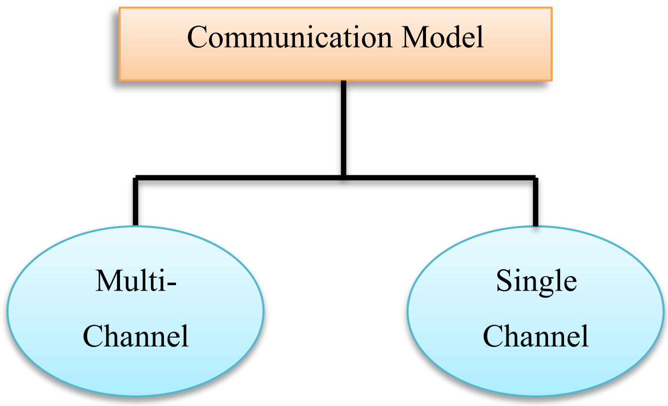


Figure 2.4: MANET routing algorithms classification based on communication model.

2.4.2 Network Structure

Node mobility and network scalability are two main factors that affect the routing algorithm that depends on network structure. As shown in figure 2.4 below, routing in Ad Hoc networks is broadly categorised into three parts: uniform routing, non-uniform routing, and geographic position information assisted routing.

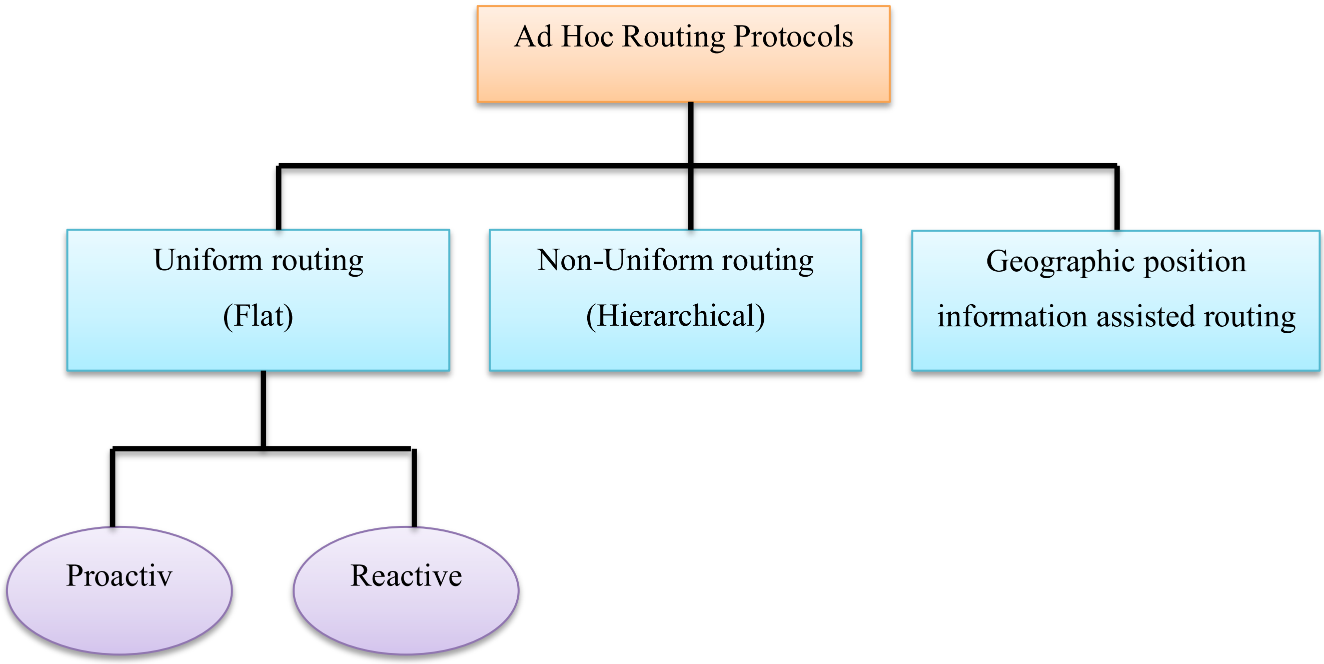


Figure 2.5: Routing protocols based on network structure.

2.4.2.1 Uniform Routing

In a uniform routing, all nodes participating in the network are at the same level and perform the same routing function [22]. It is simple and efficient for small networks. However, in large networks the amount of routing information is large and takes a long time to arrive at remote nodes. Uniform routing systems further divided into two broad groups namely; table-driven, and on demand routing protocols (more details about these two classes is given in Section 2.4.6). Uniform reactive protocols outperform proactive routing protocols in large networks. All the five routing protocols that are used in our simulation are, namely: The Optimised Link State Routing (OLSR) protocol [16], Dynamic Source Routing (DSR) protocol [17], Ad Hoc On Demand Distance Vector (AODV) protocol [18], Temporally-Ordered Routing Algorithm (TORA) protocol [19], and Geographic Routing Protocol (GRP) protocol [20] [21].

2.4.2.2 Non-uniform Routing

The use of routing hierarchy has several benefits, the most imperative ones being the reduction in the size of routing tables and better scalability. This network structure emerged because uniform routing scheme becomes inefficient when the wireless network size increases due to link and processing overhead. Moreover, hierarchy routing has been implemented in wired networks for a long time.

Unlike uniform routing, some nodes in non-uniform routing protocol for mobile Ad Hoc networks carry out distinct management and /or routing functions. Non-uniform routing protocols further can be divided according to the organization for mobile nodes and how routing functions and management are performed. Based on these criteria, non-uniform routing protocols for mobile Ad Hoc networks can be further divided into three subcategories: zone based hierarchical routing, cluster-based hierarchical routing, and core node based routing.

a. **Zone-based**

   In zone based routing protocols, different zone constructing algorithms are exploited for node organization, e.g. some zone constructing algorithms uses geographical information. Also zones may overlap or not depending on the constructing method. Mobile nodes in the same zone know how to reach each other with smaller cost compared to maintaining routing information for the all nodes in the entire network. Specific nodes may act as gateway nodes in some zone based routing protocols and perform inter-zone communication. Thus, there will be number of zones inside the network Routing protocol example is Zone Routing Protocol (ZRP)[23].

b. **Cluster-based**

   In this subcategory, network nodes are grouped as different clusters, usually a cluster-head is selected in each cluster. Only the cluster-head acts as the routers' response to the route request message and forwards the route reply message, thus the overhead in routing is reduced. However, there are some drawbacks that cluster-based routing suffers from. Such problems are the overhead in maintaining the clusters and electing the cluster-heads could consume large bandwidth in high-mobility networks. Some cluster-based MANET routing protocols such as Cluster head Gateway Switch Routing (CGSR) [15] and Hierarchical State Routing (HSR) [24].

c. **Core Node-base**

In core-node based routing protocols for mobile Ad Hoc networks, critical nodes are dynamically selected to compose a "backbone" for the network. The "backbone" nodes carry out special functions, such as routing paths construction and control/data packets propagation. Core Extraction Distributed Ad Hoc Routing (CEDAR) [25] protocols and Optimised Link State Routing (OLSR) [17] are classical main node-based Mobile Ad Hoc Network routing protocols.

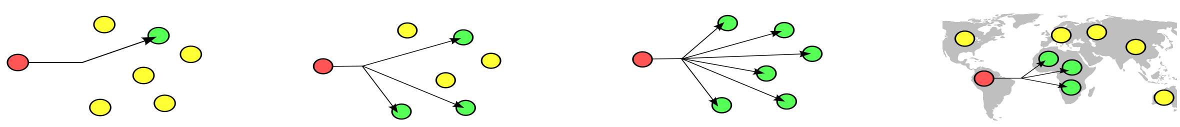
2.4.2.3 Geographic Position Information Assisted Routing

There are a number of routing protocols that are based on this category, such as Location-Aided Routing (LAR) [26], Distance Routing Effect Algorithm for Mobility (DREAM) [27], and Greedy Perimeter Stateless Routing (GPSR) [20]. Routing with the assistance from geographic location information is when a source node sends a message to the geographic location of the destination. Indeed Global Positioning System (GPS) is a realistic choice nowadays, the devices that implement GPS are cheap, sophisticated, can be updated regularly, and may deliver a suitable accuracy. The aid of information acquired from geographic location for Ad Hoc network can enhance the performance of routing [28]. Therefore, the distributed Ad Hoc schemes can utilise the information of nodes location for directional routing.. It is fair to state that in a mobile environment, location may not be accurate by the time the information is used due to different reasons such as node moving out of range, sudden change in position, or even device shutdown. All GPS protocols assume that the nodes know their positions.

2.4.3 Type of Cast

Unicast, multicast, broadcast, and geocast are considered to be types of packet casting in a network as indicated in Figure 2.

- **Unicast**: a packet (control or data) is send to a single receiver.
- **Multicast**: a specific number of receivers will receive a packet from a single sender.
- **Broadcast**: All connected nodes in a network will receive a message from a single source.
- **Geocast**: all targeted receivers situated inside a specified geographical area will receive the message form a single source



(a) Unicast **(b) Multicast** **(c) Broadcast** **(d) Geocast**

Figure 2.6: Types of casting

2.4.4 Network Routing Cost Function

In order for a router to determine the best path from the source node to the destination node in a network, certain factors should be considered by the routing protocol. These factors are being utilised as standard to classify the routing protocols in mobile Ad Hoc network, it is presented in figure 2.4.

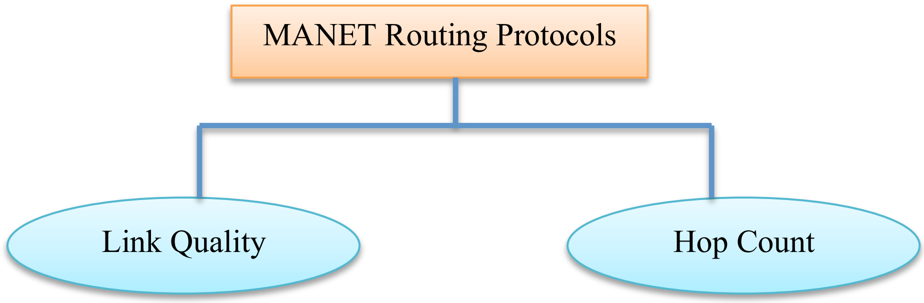


Figure 2.7: Manet routing protocol classification based on route cost function

Routing protocols for MANENT such as OLSR [16], AODV [18], DSR [17], GRP [20], and TORA [19] have focused on finding the route path according to the minimum value of a routing metric (the hop number as a cost function). The primary advantage of this metric is its simplicity. Once the topology is known, it is easy to compute and minimize the hop count between a source and a destination. Moreover, computing the hop count requires no additional measurements. In addition, in order to obtain a reduction in packet collision and a minimum traffic overhead in longer paths, the shortest routing path will be selected with the least number of hops from the multiple routing paths available.

Because of the high dynamic feature in MANET environment where nodes have the ability to move, there might be a route failure which frequently leads to route rediscovery as a result of node mobility as mentioned in previous sections. As such, link stability should be taken into account for routing path selection. Associativity-based Routing (ARB) [29] utilizes the concept of route path selection based on the stability in nodes link since such stability has a specific period that indicated and connected to individual nodes in the network. ARB is considered to an ideal for MANET such as a conference size scenario because it is a simple and bandwidth-efficient distributed routing protocol. ABR does not attempt to consistently maintain routing information in every node in contrast to the conventional approaches as can be found in both proactive and reactive routing algorithms. In this manner a higher throughput can be attained since route selections are expected to prolong; hereafter, the need for a frequent restart is not longer required. Moreover, the protocol is free from deadlock and an on demand broadcast of route requests is applied.

2.4.5 Broadcast Techniques

When a periodic message is being used by a MANET node, then this mechanism is called broadcasting. An efficient broadcasting protocols according to distributed hierarchical methodology has been suggested. The method of transmission is the main factor for sub-classification, as shown in figure 2.4. The sub-classification includes the traditional “simple flooding, probability-based methods, area-based methods, and neighbour knowledge methods”. These broadcast techniques are classification and summarised in Reference [30].

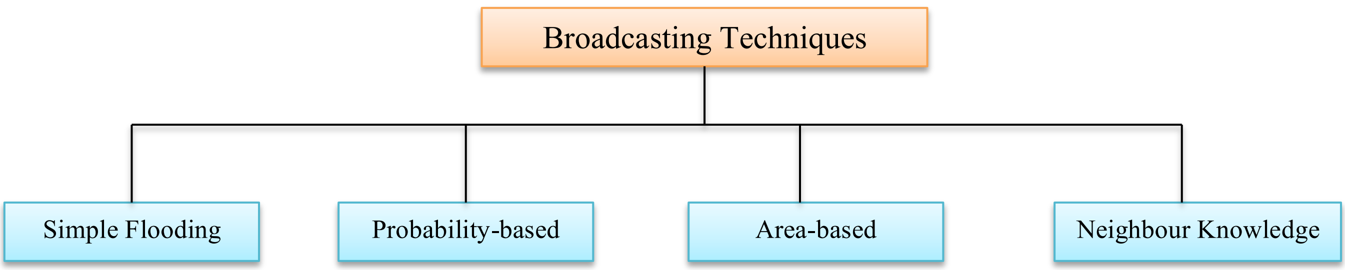


Figure 2.8: Broadcasting techniques classification

2.4.6 Scheduling

When route information is obtained in a way that can be continuous or a regular procedure or even trigged only on demand, protocols can be classified to proactive, reactive, and hybrid protocols as shown in figure2.4.

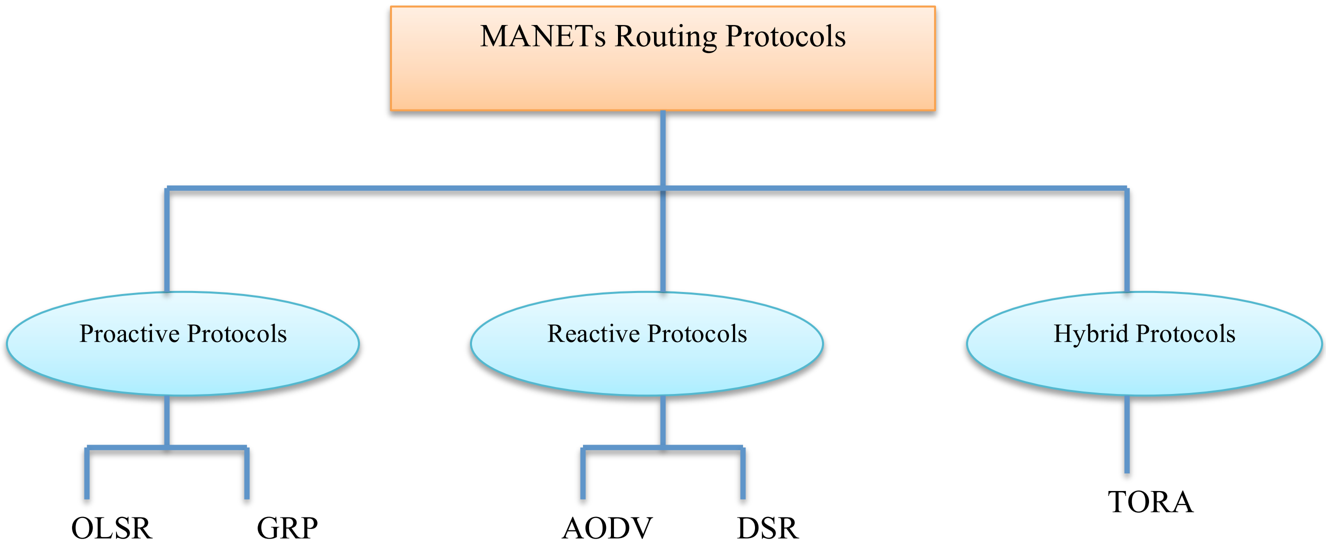


Figure 2.9: MANET routing classification based on scheduling

2.4.6.1 Proactive Routing Protocols

Proactive routing protocols are also called Table-Driven routing protocols [31]; they attempt to maintain the routing information even before it is needed. Each and every node in the network maintains routing information to every other node in the network. Route information is generally kept in the routing tables and periodically propagates an update throughout the entire network as a response to the network topology changes.

Real-time communication and QoS ensures low latency and substitute route aid and examining are considered a kind of application that takes advantage of the desirable properties that proactive routing protocols provide such as a lower latency in data delivery. However, its main drawback is the wastage of bandwidth and power used in periodically sending update packets even when they are not necessary, for example when there is no link failure, or when only a few amount of routes are required. Some proactive protocols in MANET include: GRP [20], OLSR [16] and are explained in further detail in chapter 4. Most proactive protocols are not suitable for larger networks and higher mobility, as they need to maintain node entries for each and every node in the routing table of every node.

2.4.6.2 Reactive Routing Protocols

Reactive routing protocols [32], which are known as, source-initiated on demand routing protocols, are designed to minimize routing overhead. Instead of tracking all changes in the network topology to determine the shortest path to all destinations, on-demand protocols are characterized by *Route discovery* mechanism, which is triggered when a node requires a route to particular destination. *Routing discovery* process is performed by source node (source-initiated). *Route request* and *route reply* together forms *Route discovery*; each protocol is different in this regard. When the source wishes to communicate with a destination, *route discovery* is triggered and a query flood is broadcasted to all network nodes to search for the desired destination. In case that all possible paths have been tested then *route discovery* is considered accomplished.

Secondly, *Maintenance* mechanisms; once a route is established, it is maintained by routing maintenance till one of the two cases is true; firstly, if the path between the source and destination is not required, secondly, if the destination becomes unreachable from all possible routes by the source node. There are a number of factors that attribute to unreachable destination node as follows:

- The nodes between the source and destination are switched off due to battery depletion or other reasons.
- The nodes between the source and destination are out of the radio range of one of them or both.
- One of the mentioned possibilities is applicable to the destination node.

- Due to a constant movement by the source node to keep connectivity with the destination and results in moving outside the network coverage.

Some reactive protocols in MANET include: AODV [8], and DSR [17].

2.4.6.3 Hybrid Routing Protocols

A new generation of routing protocols, which have been generated, for adoption in MANET, is called Hybrid routing protocols. These protocols combine the two previous techniques (the pro and re active routing techniques) in order to utilizes the strengths obtained from both categories and overcome their shortcomings. It increases network scalability, since this enhancement is accomplished by taking the benefits of dividing the network into zones or clusters and using different protocols in two different zones i.e. one protocol is used within are zone, and another protocol is used between them. Temporally Ordered Routing Algorithm Protocol (TORA) [19] is an example of hybrid routing protocol, which is explained, in further detail in chapter 4.

2.5 Summary

In this chapter, routing in both wired and wireless networks was reviewed and presented. The complexity exhibited in MANET is more than in their wired network counterpart. This level of complexity is attributed to node mobility, broadcasting, and interference of wireless signals, which are part of the nature of wireless communications. As such, researchers have the motivation to resolve such issues by developing different routing protocols in MANET, which has resulted in several routing protocols, which perform differently in different networking conditions based on the protocol's criterion.

Also in this chapter, a comprehensive survey of six distinctive classifications of MANET routing protocol was included, with communication model, network structure, type of cast, network routing cost function, broadcast techniques, and scheduling. Each category has its own characteristics in which protocols can be classified since they share the similar inherent characteristics.

A conclusion that can be drawn from the review in this chapter is that with a long list of different routing protocols already available, creating a new routing protocol is not considered a solution. However, equipped with the knowledge of the network conditions and requirements in which every protocol is appropriate and performs well, a system can be designed to enhance and improve the overall performance of the network, which selects the routing protocol that best meets such network conditions and requirements.

Chapter 3: Routing Protocol Optimisation in Mobile Ad Hoc Network

3.1 Overview

The growing demands of mobile applications for the study and work by researchers on MANET optimisation for better service. MANET features such as decentralization, multi-hop communication, and mobility add more layers of complexity in comparison to wired networks. Therefore, optimisation is a crucial and vital field in MANET development nowadays.

In this chapter, present optimisation techniques, which have been utilised in improving upon traditional MANET routing protocol or making a new routing protocol, are presented. The use of optimisation in this area was categorised based on context cost function, modelling, prediction, artificial intelligence, and optimisation techniques. The use of artificial intelligence and optimisation was combined to create a system to be used in MANET. Finally, the chapter identifies the relationship between the work within this thesis and the work reviewed.

3.2 Optimisation of MANET Routing Protocol

The tendency in modifying or creating an optimised version of the traditional routing protocols is widely implemented. The enhancement added upon the original MANET routing protocols, by which new features that have been included convert the classical routing protocols to an optimised one. The effort and work exerted on implementing such optimised routing protocol are for different reasons such as increased packet delivery ratio, increased throughput, increased network lifetime, reduced latency, reduced delay, reduced load. The focal point in the literature tends to the two most important performance metrics, which optimisation is trying to solve namely: throughput and delay.

3.2.1 Optimised Routing Protocols Based on Network Routing Cost Function

The following subsections discuss MANET optimisation based on different routing cost functions, which also can be called network routing metrics. As such, link metrics and various network context-aware metrics are reviewed below.

3.2.1.1 "Classical" Link Metrics

The simplest and popular metrics for multi-hop wireless networks is called Hop Count. When hop count is used the path containing the minimal possible number of links (the number of nodes involved in the packet delivery process) is selected. Thus dependence on such a metric is considered a method of optimised route selection. The selection of the optimal route depending on hop count can be manifested in various ways, for example: in You, Lei, et al [33], proposed a hop count based heuristic routing protocol by utilizing the information carried by the peripatetic packets in the network or performing the route discovery process through unicast query [33].

As stated in section 2.4.4, hop count is defined as the default metric in numerous routing protocols, e.g. AODV [18], OLSR [16] due to its simplicity. However, it is known to choose the worst paths in wireless networks, for example in reference [34]. The result of minimizing the number of nodes on the route might result in selecting the longest links with lowest signal to noise ratio, and consequently longest transmission time, lowest data rate and increase in re-transmission due to high collision probability which in turn, increases the packet service time and contributes to the end-to-end packet delivery time. Therefore, other path/route selection schemes (link metrics) were suggested such as Expected Transmission count (ETX) [34]. The link metric in such a case finds paths with the fewest expected number of re-transmissions required to deliver a packet all the way to its destination. Air Time Link (ATL metric) was introduced by IEEE 802.11s standard draft [35].

3.2.1.2 Network Context-Aware Metrics

Fast and efficient mobile Ad Hoc routing for protocols are not the only desired feature, because adaptability is also important due to the frequent changes in network topology since without it the overall network performance will suffer from a severe degradation. MANET performance can be measured based on context through optimisation. Context-aware metrics could include relay load metric, node density metric, mobility-awareness, bandwidth-awareness, power-awareness, energy-awareness, delay-awareness, contention-awareness, location-awareness, and congestion-awareness. There is an ongoing search for further context-aware metrics, which affects the routing in networking. Considering such context-aware metrics in designing a new routing protocol should assist in improving mobile Ad Hoc network performance. There are various optimised routing protocols that rely upon the mentioned context-aware metrics. The following listings are examples of such optimised routing protocols:

a) The ***bandwidth aware*** algorithm is used to determine the maximum bandwidth possible for link pairs. As wireless technology strives to ensure low end-to-end delay, low packet loss and high throughput, thus the bandwidth factor was selected as a route selection metric. The author in [36] proposed an enhanced AODV [18] where a detector packet, during route discovery process, measures the available bandwidth of each hop along the path.

   R.S. Al-Qassas, et al. [37] proposed a new routing protocol (vector routing protocol) that utilizes bandwidth awareness to reduce communication overhead to establish a route from source to destination.

   Furthermore, a different aspect emerged to address the importance of bandwidth awareness. As a result of this importance of the rising popularity of multimedia applications and potential commercial usage of

Ad Hoc networks, the authors in [38] developed a bandwidth-aware routing protocol BARP [38] based on the existing Dynamic Source Routing protocol (DSR) [17] by selecting the route of largest bandwidth.

b) ***Congestion-aware*** metric is utilized to reduce transmission delays, packet loss and minimize the wastage of time and energy due to recovery. Xiaoqin, et al. [39] proposed a congestion-aware routing protocol for MANET by utilizing data-rate, MAC overhead, and buffer delay to combat congestion.

   T.G. Basavaraju, et al. [40] utilized congestion –aware metric to develop EACARP congestion control algorithm for pro-re active routing protocols.

c) ***Mobility-aware*** metric was utilised to create Mi-Seon Kang, et al. [41] mobility-aware hybrid routing approach for MANETs, which varies its routing between a reactive and proactive approach according to the node mobility.

d) ***Contention-aware*** Admission Control Protocol (CACP) [40] which provides admission control employed contention-aware metric for flows in a single-channel Ad Hoc network is based on the knowledge of both local resources at a node and the effect of admitting the new flow on neighbouring nodes. The objective is to control bandwidth allocation, delay and jitter.

e) Since nodes in mobile Ad Hoc network are usually battery-operated, ***Energy-awareness*** was considered a vital metric for devising many routing protocols where the whole transmission power is reduced required for every connection thereby effectively minimising energy consumption of each node, thus increasing evidently the lifetime of the network. The routing scheme based on an energy-aware routing protocol TORA [19] was devised to select the path according to hop count and the residual energy of nodes. The nodes that have more energy have more possibility to be chosen [41].

Additionally, Azzedine Boukerche and Harold Owens [42] enhanced both DSR [17] and TORA [19] by implementing ***energy-aware*** scheme, which uses the relative distance between nodes for route request packets and current energy levels of both sending and receiving node.

Furthermore, the combination of two or more than one metric with a single routing protocol to accomplish improved results was devised. Reference [43] combines ***power and delay aware*** metrics on a single routing protocol for two objectives: finding a more stable path from source to destination in terms of remaining *life time of battery*, *delay*, and *bandwidth*.

Moreover, the protocol devised by the authors in [44] combined ***hop count*** metric with both ***energy usage*** and ***path congestion*** as the cost metric that states route cost when *route discovery* takes place.

Another possible combination is between ***power-aware*** and ***mobility-aware*** metrics as in the paper [45] where they proposed ***mobility-aware*** approach utilised to control packet flooding during *route discovery* and substantially reduce the network overheads caused by link breakages. Whereas, ***power-aware*** metrics helped in choosing a route based on maximising the minimum node battery power and minimising the total transmission power required to reach the destination.

Finally, ***mobility-aware***, ***energy-aware***, and ***congestion-aware*** metrics were all combined and contained in the mobile routing [46].

All these combinations and others that represent context-aware metrics can be added to a traditional or devised routing protocol to enhance the overall network performance and life cycle. Moreover, routing protocols should be equipped to meet the increasing demand on multimedia and different applications whether online or in real-time scenarios.

3.2.2 Modelling/Prediction of Network Routing Cost Function

One kind of optimisation presented in the previous section was based on network context-aware metrics. The optimised routing protocol can rely on a single metric or a combination of two or more metrics to enhance the network performance and become adaptable to different application requirements. The other kind of possible field where optimisation can be utilised is prediction and modelling. The initial knowledge of network elements' behaviour yield to prediction, however, modelling the various metric performances to enhance prediction techniques is considered as a third kind of optimisation.

In the study by A. Rhim and Z. Dziong [47] a prediction algorithm was proposed based on Global Positioning System (GPS), or the signal strength (SS), or both to predict the link expiration time; in other words, enabling a MANET node to predict the remaining connectivity time with their neighbours to avoid disconnections. However, the author in reference [48] implemented a formulated equation to predict the future trajectory of a destination node by obtaining the position information. Whereas, the authors in [51] proposed an enhanced mobility prediction for unicast and multicast routing protocols utilising GPS location information. As such, GPS position information is piggybacked on data packets during a live connection and is used to estimate the expiration time of the link between two adjacent nodes. Therefore the routes will be reconfigured before they are disconnected based on the previous prediction.

In contrast, prediction techniques may gain more accuracy when modelling is incorporated in the process of prediction. Thus, several studies present work done with such optimisation, for example reference [49] utilized an empirical model technique such as linear regression for predicting the performance of MANET. The mathematical equation characterizes a response metric (end-to-end delay, packet delivery ratio, and jitter) as a function of the independent factors (mobility, traffic load, and network size, and protocol). An autoregressive modelling was used in [50] to enable each node to predict its neighbours' mobility and position.

3.2.3 Artificial Intelligence Utilisation in Optimised Routing Protocols

Employing artificial intelligence for the prediction mechanism was used several researchers. The following subsection provides some examples of work done with the use of *neural network* and *neuro-fuzzy inference system* (ANFIS).

3.2.3.1 Artificial Neural Network

In reference [52] the authors employed *neural networks* for a proposed prediction mechanism in MANET to predict bandwidth, energy, buffer-space, and traffic to improve efficiency in resource allocation for real-time and multimedia communication support. AODV [18] benefited from neural network to solve the change of topology due to mobility. In AODV the Beacon messages (HELLO messages) are used for detection and monitoring links to neighbours. Consequently, the local network topology view is clearer due to such message, however, a fixed time interval for squeal of messages could cause unnecessary traffic. Thus the authors in [53] proposed the use of a *neural network* to make adaptive time interval of these messages. The paper in [54] a *neural network* is used as a path set selection algorithm as it produced a set of backup paths with higher reliability through link expiration time between two nodes. H. Kaaniche and F. Kamoun [57] presented a system based on the neural network for mobility prediction in Ad Hoc networks. This system consists of a multi-layer and recurrent *neural network* using back propagation through time algorithm for training. R. Nagwani and D. Singh Tomar [58] present a Hidden Markov Model (HMM) approach for predicting the mobility of nodes to reduce the overhead of routing for route discovery.

Furthermore, a combination between AI and optimisation techniques are possible as in [55], where the authors employed the concept of both *genetic* algorithm technique and *artificial neural network* to coordinate with AODV protocol for fast route rebuilding. Similarly in [56] *neural network*, *fuzzy logic* and *genetic* optimisation were used to solve the objective function in finding the path within the shortest possible time. The parameters that were used as inputs were: mobility, network size, congested and blocked routes, active nodes, and link failure history.

3.2.3.2 Adaptive Neural-Fuzzy Inference System

Elleuch, et al. [59] utilised an ANFIS for the purpose of mobility prediction. ANFIS predictor was utilised to describe location of MANET node movement based on Random Waypoint Mobility (RWM) model. In paper [60] an *adaptive neuro-fuzzy inference system* technique was used to model and simulate voice over IP (VoIP) routed MANET.

3.2.4 Optimisation Technique Utilisation in Optimised Routing Protocols

There are several optimisation techniques, which can be used in MANETs, however, some examples of three of these techniques are given below.

3.2.4.1 Simulated annealing

A routing algorithm based on *simulated annealing* is proposed [61]. This algorithm initially uses an energy function to convert multiple QoS weights into a single mixed metric and then seeks to find a viable path by simulated annealing. In contrast, R. Asokan and S. Chandrasekar [62] Simulated Annealing Dynamic Source Routing (SADSR) modifies DSR [17] with the assistance of *simulated* *annealing* optimisation to select the route with minimum possible energy to satisfy the requirement of specific multimedia traffic.

3.2.4.2 Genetic Algorithm

A Genetic Algorithm (GA) based routing method for Mobile Ad Hoc Network (GAMAN) is proposed by Barolli, et al [63]. Rather than seek for the optimal routes GAMAN pays more attention to the response time and the robustness of the algorithm itself. By using small population size, few nodes are involved in route computation. By taking a subpopulation, the nodes in this subpopulation consider only the routes in this subpopulation. The broadcast is avoided because the information is transmitted only for the nodes in a population. GA searches different routes and they are sorted by ranking them.

3.2.4.3 Swarm Intelligence

Ad Hoc Networking with Swarm Intelligence (ANSI) is a congestion-aware routing protocol, which owing to the self-configuring based on s*warm intelligence* mechanisms, is able to collect more information about local network and make more effective routing decisions than traditional MANET protocols [64].

3.3 MANET Optimisation System

Nagham Saeed [3] proposed an intelligent system for mobile Ad Hoc network where neither new or modified routing protocol were present, unlike in the previous literature, where the focus was on improving the overall network performance in terms of modifying or creating a new routing protocol.. The author created a system that made a decision which of the three routing protocol (AODV, DSR, OLSR) should be used based on MANET context, namely: network size (number of nodes in the network), and mobility. The performance evaluation metric selected was parameters namely; delay rate, load, retransmission attempt, and throughput. A brief list of the main elements of the system listed below:

- **Simulation**: different MANET scenarios were simulated depending on different network context, collecting the four parameters that represent network performance and determining the representative value for each parameter.
- **Modelling**: Empirical modelling, neural networks, and neural-fuzzy were used to produce MANET performance models for the five routing protocols and three applications depending on whole scenarios and compared.
- **Optimisation**: genetic, simulated annealing and particle swarm optimisation techniques were utilised to produce optimised MANET performance according to the created performance models to suggest the optimal routing protocol based on network contexts.
- **Changing protocol**: Protocol-changing technique among the selected five protocols in MANET was implemented.

3.4 Related Work

Based on the previous literature review in section 3.2 and its subsections, AI techniques such as neural network, neural-fuzzy, empirical modelling, and optimisation techniques such as simulated annealing, genetic, and particle swarm were all utilised to make a better mobile Ad Hoc network and incorporated in the protocol design. However, in this thesis no routing protocol needed to be created nor enhanced as in the work presented in this chapter.

However, the work in this thesis was inspired by the work done in [3]. The elements that comprise I-MAN [3] were adapted in our work. The difference between the work in this thesis and I-MAN is as follow:

1. **Simulation**:

    - *Software*: Opnet™ 14 was the software package in use whereas Opnet™ 17.5 version was used in in our work.
    - *Communication Model*: raw data packet using Poisson's Inter-Arrival time is used in I-MAN whereas application types (FTP, VoIP and VC) were used in this thesis.
    - *Mobility Model*: Random Walk Mobility Model was the mobility model in use for I-MAN, however a different mobility model was considered in our work namely Random Way Point Model.
    - *Routing Protocols*: three routing protocols (AODV, DSR, OLSR) were adopted in I-MAN whereas five routing protocols were considered for robustness of the system. The selected routing protocols are; AODV, DSR are the reactive routing protocols, the proactive routing protocols OLSR, GRP, and the hybrid routing protocol TORA.
    - *Network Context*: seven cases of network sizes and four mobility levels of user average mobility were considered whereas in I-MAN only three cases of network sizes and four mobility levels of user average mobility were considered.

- *Optimisation Techniques*: even though genetic and particle swarm were used as an optimiser and both were compared, in this thesis three optimisers were compared, namely: genetic and particle swarm and simulated annealing.

Therefore, the gathered MANET performance parameters versus network context that are presented in chapter 5 are completely different due to the added routing protocols, two different packet types, and mobility model. Thus the model that represents the MANET's context and performance is significantly different to the work in [3].

3.5 Summary

There can be one or more objectives to be fulfilled by an optimised routing protocol in mobile Ad Hoc networks. Several optimisation methods and techniques can be explored or utilised to enhance or creating a routing protocol as presented in this chapter. Link metric and context-aware metrics were used for optimised routing protocol, prediction, artificial intelligence, modelling, and optimisation methods. In some cases a combination of metrics or techniques can be used as presented in the previous sections.

Indeed, a routing protocol can achieve a single or a number of objectives, however there is no ultimate protocol than can achieve the fulfilment of all objectives and meet all applications and network requirements. Yet the process of improving and creating a new protocol to be added to a long list of available routing protocols still continues. In conclusion the need for a system that deploys the current routing protocol according to the application, network context requirements in terms of performance metrics where a routing protocol considered is an optimum is crucial.

Chapter 4: I-MMS Design

4.1 I-MMS Design Components

The Intelligent MANET Management System involves the contribution of three main areas namely: the wireless mobile Ad Hoc network, and both modelling and optimisation through artificial intelligence. The objective of the proposed system is to manage the network through choosing the optimum routing protocol in mobile Ad Hoc network based on specific network context. Thus, designing the I-MMS routing management system requires particular simulation, modelling and optimisation. There are different methods for both modelling and optimisation, which needs testing to select the best-suited technique for our system. The main components are the network context simulation unit, modelling unit, optimisation unit and routing protocol alteration unit. The same components were adopted from reference [3] as shown in figure 4.1. As shown in figure 4.1 the main function of the system is to compare the routing protocols and evaluate it and then choose the optimum routing protocol for the current network context. The context is based on node mobility and network size (based on the node numbers). The simulation unit block where all five routing protocols were evaluated on various node mobility levels and network sizes are based on specific performance metrics, which the modelling unit will model.

The modelling unit represents the models for the previous network performance recorded with two different applications or packet types namely: File Transfer Protocol (FTP) and Voice over IP (VoIP). Once the models were built for the network performance, the models will be used as a reference for the optimisation unit. It will be considered as a reference for the optimisation unit decision, when the current context is passed to the optimisation unit. The optimisation will generate all possible solutions and then pass it to the modelling unit to predict the network performance for each routing protocol. Then the optimisation unit will choose the best-suited protocol. The selection of the routing protocol decision will be sent to all nodes for tuning /changing the current protocol to the selected one.

A further elaborated discussion for each component of the system is presented in the following chapters. The setting of the simulation and performance of each routing protocol, based on various contexts, is presented in chapter 5. Chapter 6 discusses the three artificial intelligent systems that are compared and the most suitable AI for modelling MANET performance depending on the contexts. Investigation, definition, and comparison of three different optimisation techniques used can be found in chapter 7. Finally, chapter 8 is concerned with the system implementation through modification in the MANET node to process the protocol's tuning and embedding the intelligent unit.

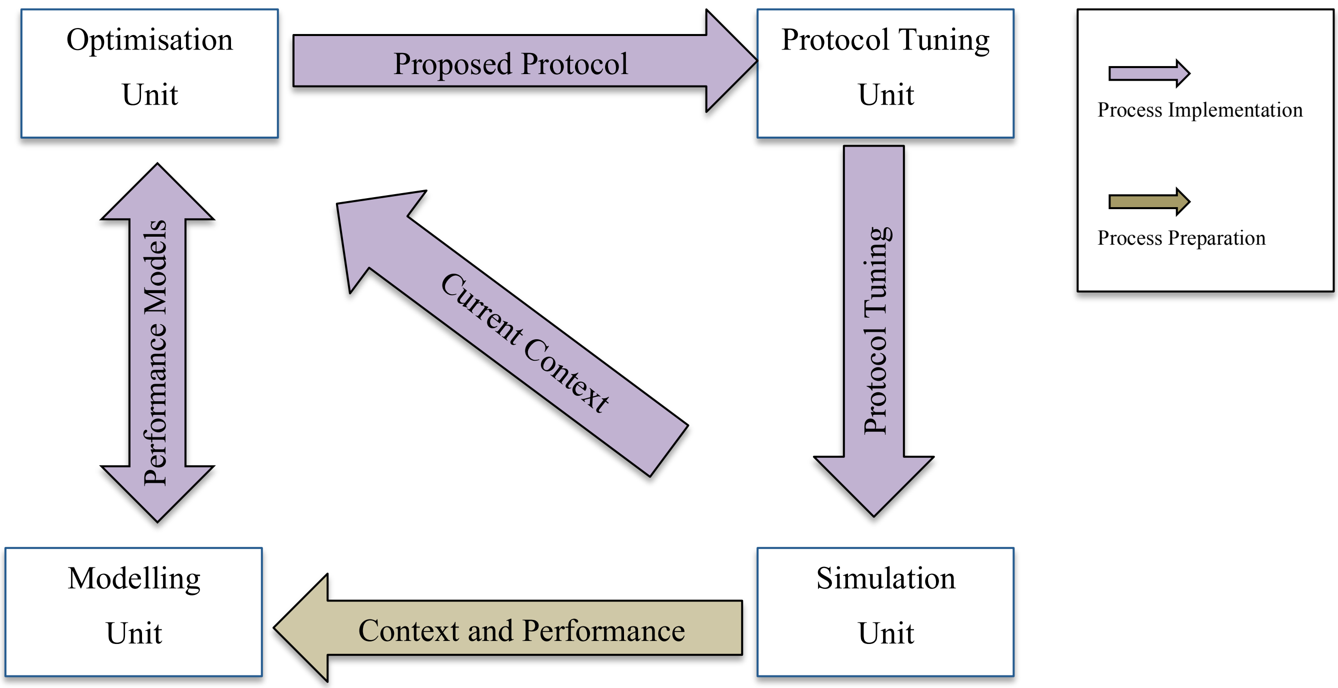


Figure 4.1: I-MMS block diagram.

4.2 Mobile Ad Hoc Routing Protocols

The description of the mobile Ad Hoc routing protocols that was implemented and evaluated in this thesis is presented in this section. Five routing protocols have been selected for review namely, Ad Hoc On-Demand Distance Vector Routing (AODV), Dynamic Source Routing (DSR), Optimised Link State Routing (OLSR), Temporally Ordered Routing Algorithm (TORA), and Geographic Routing Protocol (GRP).

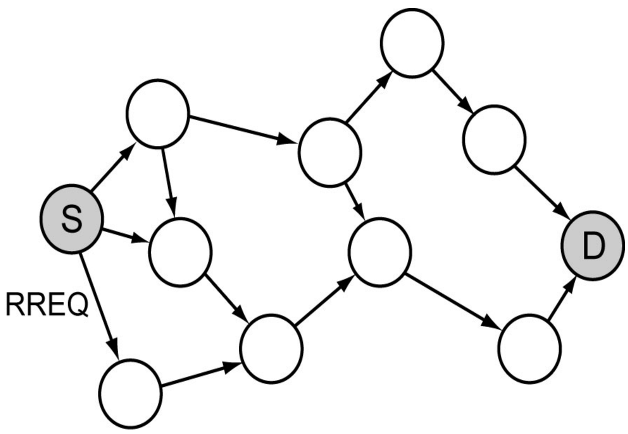
4.2.1 Ad Hoc On-Demand Distance Vector Routing

Ad Hoc on-demand distance vector (AODV) [18] routing protocol uses an on-demand approach for searching routes, that is, a path is established only when it is required by a source node for transmitting data packets, which reduces the number of broadcast packets as mentioned previously in Chapter 2. AODV employs a destination sequence number to identify the most recent path (freshness) and ensure the avoidance of loops.

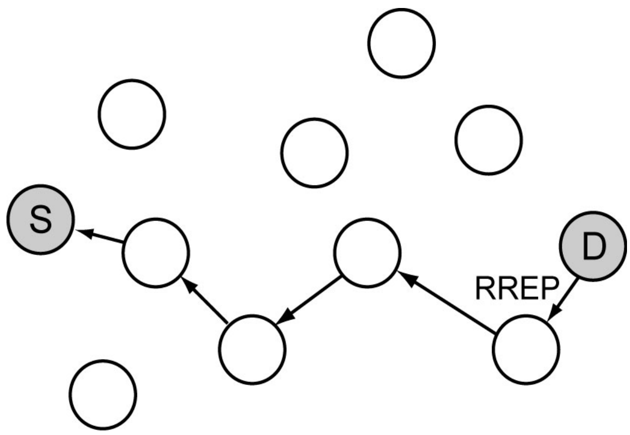
4.2.1.1 Path Discovery Process

The sending node (source) initiates a *path discovery process*, when there is an unknown active route between the source and destination node. A route request message (RREQ) is broadcast to all neighbours, as shown in Figure 4.2 (a), which in turn broadcast the message to their neighbours and so on. The forwarding process is carried out until the destination node is reached or any intermediate node has a 'fresh' route to the destination. This feature of sequence numbers, which are borrowed from DSDV [65], are used in identifying the most recent routes and to resolve the loops. The *Route Request* carries the source address, the destination address, the source sequence number, the destination sequence number (that indicates the freshness of the route that is accepted by the source), the broadcast identifier, and the number of hops to the destination.

When the intermediate node receives a RREQ, it either forwards it or prepares a unicast *Route Reply packet* (RREP) back to the node from which it received the RREQ, if it has a valid route to the destination. The validity of a path at the intermediate node is determined by comparing the sequence number at the intermediate node with the destination sequence number in the RREQ packet. While the RREQ is sent, the intermediate node increases the field 'number of hops to the destination' and, also stores in its routing table the address of the neighbour from whom they first received the message, in order to establish a '*Reverse Path'*, as shown in figure 4.2 (b). A route is considered fresh enough, if the intermediate node's route to the destination node has a destination sequence number which is equal to or greater than the one contained in the RREQ packet. As the RREP is sent back to the source, every intermediate node along this path adds a forward route entry to its routing table. The forward route is set active for some time, which is indicated by a route timer entry. The default value is 3000 milliseconds, according to the reference in AODV RFC [18]. In case the route is no longer used, it will be deleted after a specified period of time. Since the RREP packet is always sent back over the reverse path established by the routing request, AODV only supports symmetric (bidirectional) links.



(a) Source node S initiates the path



(b) A PREP packet is sent back to the

Figure 4.2: AODV path discovery process.

4.2.1.2 Maintaining Routes

The movement of the source activates restarting the discovery protocol by sending a new RREQ packet to find a new route to the destination. However, if an intermediate node along the path moves, its upstream neighbours notice the move and send a *link failure notification* message to each of their active upstream neighbours to inform them of the link breakage of that part of the route, as shown in figure 4.3. As long as the source node is not reached the link failure notification is forwarded. After the failure is known, the source node may reinitiate the route discovery protocol. A mobile node may perform local connectivity maintenance by periodically broadcasting hello messages. The AODV hello message is defined as RREP packet with a time to live (TTL) filed of 1. The node may send a unicast RREP or an ICMP echo request message to the next hop for local route maintenance.

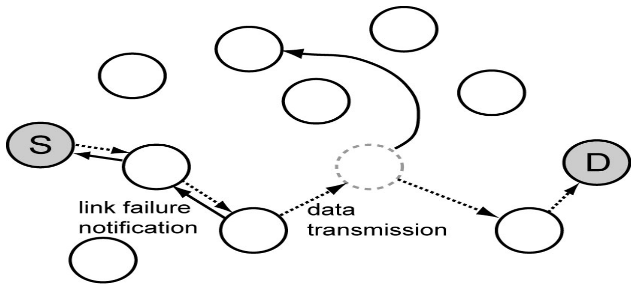


Figure 4.3: AODV route maintenance by using link failure notification message.

4.2.1.3 Advantages and Disadvantages

❖ **Strengths**

- Since AODV establishes the routes based on an on-demand, the sequence numbers are used in order to guarantee loop-free and routes updated constantly that contribute to the decrease of connection setup delay.

- The AODV has great advantage in overhead over other protocols, which need to keep the entire route from the source node to the destination node in their messages.
- The bandwidth usage in the network can be saved and node power can be conserved by inactive node sleep mode. This is due to local Hello message broadcasting the connectivity information. In case a node is included in an active route the node uses a Hello message. Therefore, in case of an inactive node occurs, a periodic beaconing is not needed by AODV protocol.
- Unused routes expire even if topology does not change.
- Optimisation can be used to reduce overhead and increase scalability.

❖ **Weaknesses**

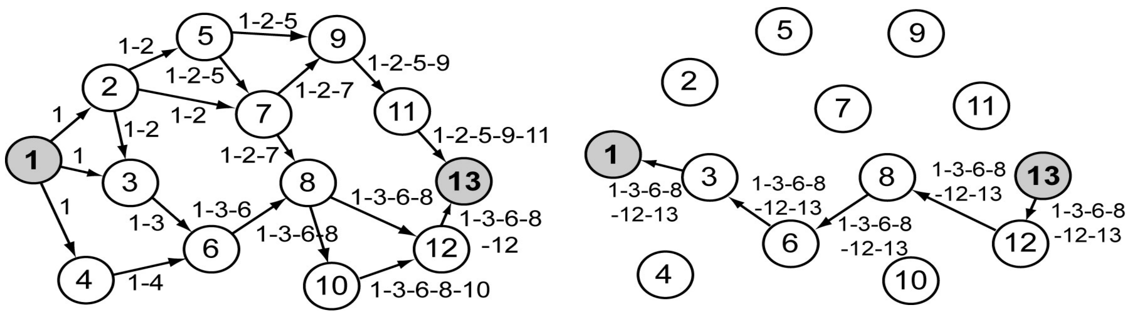
- If the source sequence number is very old and the intermediate nodes have a higher but not the latest destination sequence number, then having stale entries may lead to inconsistent routes by the intermediate node.
- Having multiple *Route Reply* packets in response to a single *Route Request* from the source node may create a heavy control overhead.
- The periodic beaconing for the active nodes may lead to unnecessary bandwidth consumption.

- There is route latency when a new route is needed, because AODV queues data packets while discovering new routes and the queued packets are sent out only when new routes are found. This situation causes throughput loss in high mobility scenarios, because the packets get dropped quickly due to unstable route selection.

4.2.2 Dynamic Source Routing Protocol

The Dynamic Source Routing (DSR) protocol [17] is an on-demand routing protocol based on source routing. A sender determines the exact sequence of nodes through which to propagate a packet, which is known as source routing technique.

In the case of DSR protocol, every mobile node in the network maintains a *route cache* where the source route that has been learned is cached. In case a node wishes to send a packet to some other node, it first checks its route cache for source routes to the destination. If a path is found, the sender node uses this path to propagate the packet. Otherwise, the source node initiates the route discovery process. *Route discovery* and *route maintenance* are the two main elements of the DSR protocols that exist, as in the previous mentioned protocol AODV.



(a) Building of the route record. **(b) Propagation of the route reply.**

Figure 4.4: DSR route discovery process.

4.2.2.1 Route Discovery

If a source node wants to send a packet, it first consults its route cache. If the required route has not been expired, it will be used and the route information will be included inside the data packet before sending it. However, if the node does not have such a route, the source node initiates a *Route discovery* operation by broadcasting a route request packet. A route request packet contains the address of the destination host, referred to as the *target* of the route discovery [66], the source's address, a *route record* field and a unique identification number. At the end, the source node should receive a *route reply* packet containing a list of network nodes through which it should propagate the packets, supposing that the route discovery process was successful (either the *route request* packet reached the desired destination or whatever node that has a connected route to the destination node in its route cache).

During the route discovery process, the route record field is used to accumulate the sequence of hops taken. At first the source that initiated the request packet contains route record as a list with a single element itself. The node that is not the destination node or does not see the same *route request* packet as before will append itself to the list and so on. *Request_id* is a unique identification number that is included on each route request packet. It works as a counter that increases whenever a new route request packet is being sent by the source node. Therefore, every route request packet is distinguished through its initiator's address and request_id. The following process is performed by node receiving (intermediate node) the route request packet to ensure the prevention of loop formation and multiple transmissions of the same *Route Request* received by multiple paths:

- The packet will be discarded when the pair (source node address, request_id) is found in the list of recent route requests.
- If the intermediate node address is already listed in the request route record, the packet is also deleted.

- If the destination address in the route request matches the host address, the route record filed contains their route by which the request reached this host from the source node. A *route reply* packet is sent back to the source node containing a copy of this route. Otherwise, the host's address will be added to the route record field of the route request packet and the packet re-broadcast.

In the case of route replies, there are two different methods that can be used by DSR for either symmetric or asymmetric links. In case of symmetric links, the node producing the route reply utilises the reverse route of the route record. However, in the latter case, the node needs to initiate its own route discovery process and piggyback the route reply on the new route request.

4.2.2.2 Route Maintenance

The DSR *Maintenance* mechanism can be accomplished by two different operations:

- Hop-by-hop acknowledgment at the data link layer provides an early detection and retransmission of lost or corrupt packets. A *route error* packet is generated and sent back to the sender of the packet. The *route error* packet contains the address of the node detecting the error and host's address, to which it was trying to transmit the packet. Whenever a node receives a *route error* packet, it removes the hop in error from its route cache and truncates all routes contained by that hop at the breaking point.
- End-to-end acknowledgement can be used in a case when wireless transmission between two nodes does not work equally well in both

directions. As long as a route is active by which the two end nodes are able to communicate, route maintenance is possible. Since there might be different routes in both directions, replies or acknowledgement on the application or transport layer may be utilised to indicate the status of the route from one node to the other. The limitation of this approach is that the possibility of finding out the hop that has been in error is not there.

4.2.2.3 Advantages and Disadvantages

- **Strengths**
  - A periodic beaconing is not needed by DSR. Thus, “nodes can enter sleep mode to conserve their power and bandwidth” [67].
  - DSR performs well in static and low-mobility environments [2] since it decreases the network node delay due to node capability to store multiple routes in their route cache.
  - Storing multiple routes to destination in their route cache is beneficial especially when a link failure occurs, there may not need to initiate a new route discovery process in case a path is found to the destination in the source’s route cache.
- **Weaknesses**
  - The route maintenance mechanism does not locally repair a broken link.

- For large network sizes, DSR is not suitable due to the overhead that result in bandwidth consumption [68] and high-mobility environments due to route latency when a new route is needed [2].
- The source routing method implemented by DSR produces an overhead and the routing overhead is increased as the route lengths increases.

4.2.3 The Optimised Link State Routing Protocol

The Optimised Link State Routing (OLSR) [16] is a proactive routing protocol based on link state algorithm (as mentioned in section 2.3). This protocol optimises the pure link state routing protocols. Optimisation is performed in two ways: by reducing the size of the control packets and by reducing the number of links that are used for forwarding the link state packets. Declaring only a subset of the links in the link state updates makes the reduction in the size of link state packets. These subsets of links or neighbours that are designated for link state updates and are assigned the responsibility of packet forwarding are called *multipoint relays* (MPR).

The strategy MPR lies in that each node uses 'Hello' message to discover what nodes are in a one-hop distance and makes a list. Each node selects a group of neighbours of that list that are able to reach all the nodes in a distance of two hops with regard to the node that is making the selection. For instance, in figure 4.5 nodes B, C, K and N were selected as MPR nodes by node A, since they are capable of reaching all the nodes at two hops distance with regard to the node A.

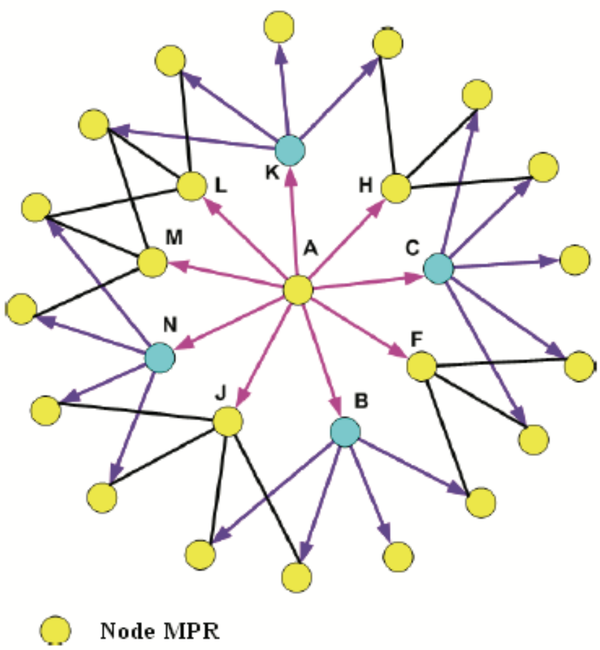


Figure 4.5: ***MPR*** **nodes in the OLSR routing protocol [69].**

These selected neighbours are the only nodes responsible for relaying the routing packets and are called MPRs. The rest can process the routing packets that they receive but cannot relay them. Each node decides an optimum path in terms of the number of hops to each destination using the stored information in its topology routing table and in routing tables of their neighbours.

4.2.3.1 Advantages and Disadvantages

❖ **Strengths**

- OLSR protocol is for the application, which does not allow the long delays in the transmission of the data packets. The best working environment for OLSR protocol is a dense network, where the majority of the communication is concentrated between a large numbers of nodes [70].
- The proactive characteristic of the protocol provides that the protocol has all the routing information to all participating nodes in

the network. OLSR protocol requires that each node periodically sends the updated topology information throughout the entire network. Thus, the bandwidth usage is increased, but the use of MPRs minimises the flooding in comparison with other proactive routing protocols.

❖ **Weaknesses**

- OLSR as a proactive routing protocol that requires periodic beaconing (Hello messages), topology control messages, forwarded around all the nodes in the network. Such messages may create an overhead and increase the network load. Obviously, as the size of the network increases (number of nodes in the network) the load in the network will increase as well. Even though the use of MPRs partially solves the problem, the overhead in terms of packets is still high compared to reactive routing protocols such as AODV and DSR.
- OLSR has routing delays and bandwidth overheads at MPR nodes as they act as localised forwarding routers.

4.2.4 Temporally Order Routing Protocol

Temporally ordered routing algorithm (TORA) [19] is a source-initiated on-demand routing protocol, which uses *link reversal algorithm* and guarantees that all routes are loop-free (temporary loops may form). In TORA, each node maintains its one-hop local topology information and also has the ability to detect partitions. A unique feature that TORA has is limiting the control packet to a small region during the reconfiguration process initiated by a route/path failure.

As in figure 4.6 shows the distance metric used in TORA is nothing but the length of the path (or height) from the destination. H (I) refers to the height of node I from the destination. TORA can be separated into three basic functions: route establishment, maintaining routes, and erasing routes.

When the source wants to transmit to the destination with an absence of a direct path, the route establishment is performed. This process establishes a destination-oriented directed acyclic graph (DAG) using a *Query/Update* mechanism. If we consider the network topology shown in figure 4.5, when the source node 1 has a data packet to be transmitted to the destination node 7, a *Query* packet is generated by node 1 with the destination address enclosed. The intermediate nodes 2,3,4,5, and 6 would forward the *Query* packet to reach the destination node 7, or any other node which has a path to the destination in this case node 7. The node that ceases the *Query* packet (in this scenario node 7) replies with an *Update* packet containing its distance from the destination (it is zero at the destination node). The node that receives the *Update* packet sets its distance to a value higher than the distance of the sender of the *Update* packet (node 7). A set of links from the source node 1 to the destination node 7 is created. This formation is referred to as DAG. Since the path to the destination is obtained, it is considered to exist as long as the path is available.

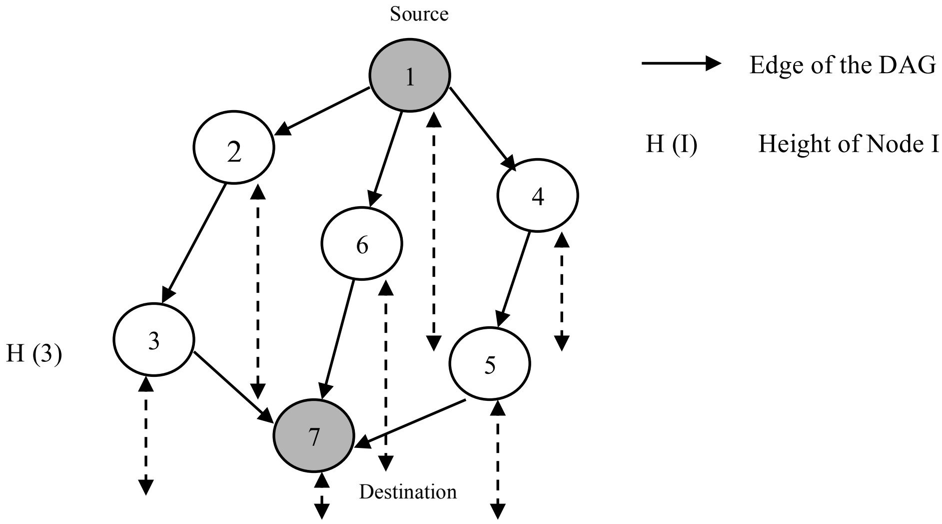
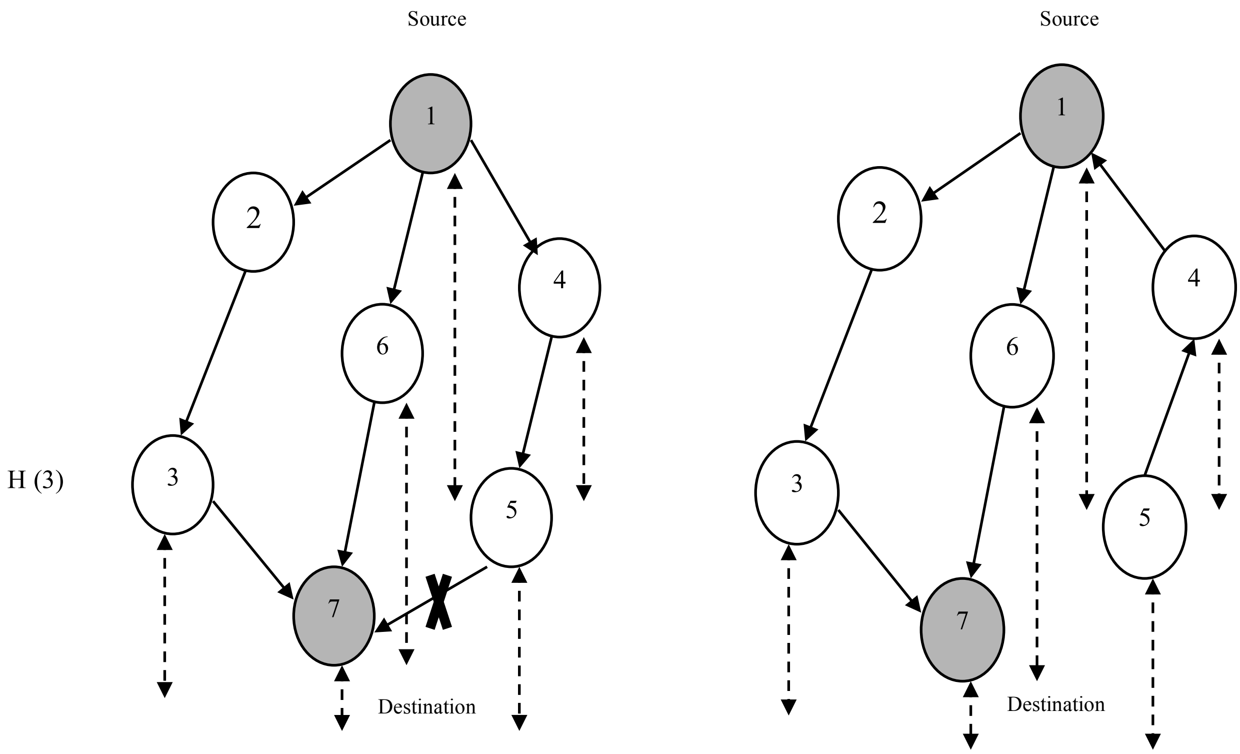


Figure 4.6: Illustration of temporal ordering in TORA

As figure 4.7 shows if the intermediate node 5, for instance, discovers that the path to the destination node is invalid it changes the setting value to a higher value than its neighbours and issues an *Update* packet. Node 4 receives the *Update* packet and reverses the link to node 1and forwards the *Update* packet. The objective of this process is to update the DAG to the destination node 7. Consequently, a change in the DAG formation would take place. The only valid scenario for the source node 1 is to initiate a fresh *Query/Update* procedure all over again, when there is no exiting valid path between the source neighbours and node 7. In case of a link failure between node 1 and 4, node 4 reverses the path between itself and node 5 and sends an update message to node 5.



(a) Link break between Node 5 and 7

(b) Node 4 and 5 reverse their links in order to update the path

Figure 4.7: Illustration of route maintenance in TORA.

4.2.4.1 Advantages and Disadvantages

The strength that TORA has is its capability to recover very quickly from link failures in densely connected networks. In such networks, there are many alternate routes to the destination. A node that loses its downstream link is set a high value, as discussed in the section above, and propagates the *Update* packet. If any of the neighbouring nodes have an alternate route, then nothing needs to be done as reversing the link make changes to the routing path. However, in the same network environment TORA suffers a key drawback. TORA control packets consume a considerable amount of bandwidth. The reason for this is that when TORA is running for each possible destination, the number of control packets increases with an increase in the number of destinations. Moreover, even if one node is transmitting data, other nodes exchange some control packets. Finally, as mentioned in section 4.3.4 temporary loops may form which in turn causes large delays.

4.2.5 Geographic Routing Protocol

Geographic routing protocol (GRP) [20][21] is a proactive and position based routing protocol in which nodes aware of their own and immediate neighbour's geographical position. The node periodically updates the position of its immediate neighbours by beaconing. The routing tabledoes not use routing data to destination; in contrast it relies on information available within each node about its immediate neighbours. Global Positioning System (GPS) facilitates the messages delivery by marking the position of each node and flooding is optimised by using quadrants. Hello message will be exchanged between nodes to identify their neighbours and their position as mention previously. At the same time, a node can return its packet to the last node (backtracking mechanism) by means of route locking, when it cannot keep on sending the packet to the next node. Furthermore, eeach node maintains three tables, i.e., destination table, neighbour table and backtracking table.

4.2.5.1 GRP Quadrant

As GRP inherits the flooding of periodic messages form the link state category, flooding GRP divides Ad Hoc network into many quadrants to reduce this drawback as in figure 4.8 shows using the division method. The customisation of quadrant size can be specified in meters and they should be squares. As such, the entire world is divided into quadrant from Lat, Long (-90, -180) Lat, Long (+90, +180) [73]. All the quadrants are organized in a hierarchical manner. As in figure 4.7 the entire network (squared in shape) is divided into two top layers namely level 1 and level 2. Level 1 quadrant A and B. Each quadrant is further divided into four quadrants to form level 2. For example, quadrant B (level 1) is divided into four quadrants $B_{a, b, c, d}$ and similarly quadrant A into $A_{a, b, c, d}$. Each quadrant in level 2 is divided into four lower level quadrants such as $A_{a1, 2, 3, 4}$. Even though each quadrant in the lower level is further divided into four quadrants, [73] considers three levels are enough.

4.2.5.2 GRP Routing Table / Next Hop Selection

As specified in section 4.3.5, every node retains three routing tables; destination table, neighbour table and backtracking table.

To confirm if a node is known or whether a destination node is available in the network the destination table is utilised. If the current node knows a node, its related information is stored in the destination table of the current node. The destination table is updated when a node receives a flooding message. However, if it moves more than a specified distance or crosses a quadrant boundary, the node floods a new location message. Regarding nodes' movement, there are two possible scenarios. Either the node moves within its same quadrant, as such the nodes residing within the same quadrant will only receive the flooding message. Or moving to another quadrant by crossing the boundary, in this case, flooding message will be received by the nodes in the same high-level quadrant thus avoiding flooding the entire network to save the network resources. An example may elaborate the concept; a beacon message will be flooded within quadrant B_a if a node moves from B_{a1} to B_{a2}. However, if the node moves from quadrant B_a to quadrant B_b the beacon will flood in quadrant B (the high-level B).

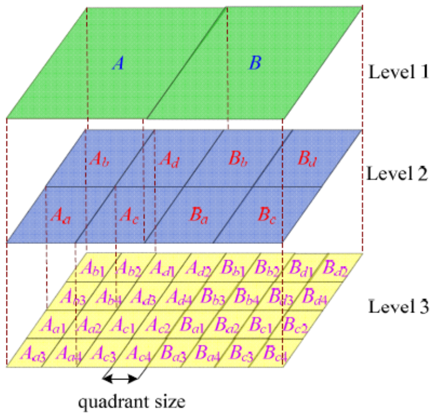


Figure 4.8: Regional Neighbourhoods (quadrants) in GRP [71,72].

There is two kinds of location information that can be stored in a node: summarized position information or the exact and complete position information. For instance, if node 2 receives a flooding message from node 1, thenboth nodes located in the same quadrant node 2 will maintain the exact position information of node 1. Yet, if node 1 position is located in the adjacent quadrant or other quadrant, then node 2 will keep node 2's summarised position information.

Each node keeps a list of neighbour nodes and each node to its neighbours periodically broadcasts a hello message for exchange of position information and updating the neighbour table. The backtracking table is used to record a path when a routing path is found. The GRP performs a fuzzy routing for the closest distance strategy. In case a node cannot forward a packet to the next hop node, it performs a backtracking for the packet to the previous node according to the backtracking table for a new path. The process will keep repeating in case there is no available node unless at last the packet returns back to the source node then it will be deleted.

If a packet is received by a node, it first decides whether it is the destination node, otherwise, it searches in its destination table whether it stores the exact location information or a summarized information of the destination available in the table.

The packet that will be sent is based on the records stored in the table to the next hop node. In case the destination node is unknown to the current node, a backtrack mechanism will be initiated. If the packet backtracked to its source node, it will be dropped immediately.

4.2.5.3 Advantages and Disadvantages

The use of quadrant division is useful to reduce the flooding overhead. The effect on the overall network performance is considered proactive inheritance. However, the problem of routing loop exists sometimes, particularly in a large-scale networks [71,72]. Moreover, GPS can increase the cost and power consumption of small mobile nodes.

4.3 Summary

The nature of MANET dynamic topology, which experiences a lot of node movement, has led to the design of various routing protocols. The aim of each protocol is to solve problems for specific MANET topology conditions; therefore, the designer or developer should have a prior knowledge of the condition or the context of the network targeted with his/her routing protocol design. Therefore, different routing protocols perform differently with different network conditions such as level of mobility, size of the network in terms of number of connected nodes or type of packets being routed in the network. Once the network has established connectivity, a specific routing protocol will be in use and cannot be changed, however the condition of the network may change to a scenario that the specified routing protocol might perform poorly.

I-MMS suggests a different approach where the network context is taken into account by selecting the appropriate routing protocol based on the network conditions. The intelligent node in the system that informs the rest of the nodes in the network finds the suitable routing protocol to run for the current context. This system includes five routing protocols in its list (different routing protocols can be added or removed) and then selects the best protocol to operate based on the network needs. I-MMS is an effort to provide a capability for a mobile node to accomplish it finest performance as it travels throughout the network and the routing protocol selection method is based on the network's current conditions.

Chapter 5: MANET Simulation

Simulation Environments of MANET

The first building block for our proposed Intelligent MANET Management System is MANET simulation. Opnet^{TM} 17.5 (64-bits) modeller was used to implement the network implementation. This modeller includes five MANET routing protocols: AODV, DSR, OLSR, GRP and TORA. For each MANET routing protocol, the same general simulation parameters remain constant in all the scenarios as defined in Tables 3.1.

Table 5-1: Common parameters in the simulation scenarios

MANET Network Parameter	Simulation Value
Area	1000X1000 (m^2)
Network Size (number of nodes)	10,50,100
Mobility model	Random way point
Mobility Speed	0,1,10,20 (m/s)
Pause Time	10 s
Traffic Applications	File Transfer Protocol (FTP), VOIP, Video Conferencing
BSS Identifier	Auto Assigned
Physical Characteristics	Direct Sequence
Data Rate (bps)	11Mbps

Channel Settings	Auto Assigned
Transmit Power	0.030
RTS (Request to Send) Threshold	None
Packet-Reception Threshold	-95
Short Retry Limit	7
Long Retry Limit	4
AP beacon Interval (seconds)	0.02
Max Receive Lifetime (seconds)	0.5
Buffer Size (bits)	102400000
Large Packet Processing	Fragment
Simulation Time	3600 (sec)

5.1.1 Mobility Model

There are two types of mobility models used in simulation networks: traces and synthetic models [74]. Traces are those mobility patterns that are observed in real life systems. They provide accurate information when they involve a large network size (in terms of number of nodes) and an appropriately long observation time. However, new network environments like Ad Hoc networks are not easily modelled if traces have been created. In this type of situation it is necessary to use synthetic models. Synthetic models attempt to realistically represent the behaviour of MANET nodes without the use of traces. Different synthetic entity mobility models for Ad Hoc networks can be found in [74].

Every node in the simulation scenarios that were considered had its own Random Way-Point Mobility Model (RWPMM). It includes pause times between changes in direction and / or speed. A node begins by staying in one location for a certain period of time (pause time set in our simulation is 10 seconds). Once this time expires, the node chooses a random destination in the simulation area.

The number of simulations (number of scenarios) depends on the number of mobility levels of the networks. The number of scenarios incremented as the mobility different levels increases as described in section 5.2.4.

Each individual node in the network travels with its own speed and direction; the average mobility for the entire network is calculated by summing averaging nodes speeds. The determined average mobility are as follow; 0 (m/s), 1 (m/s) both for slow mobility, 10 (m/s) for medium mobility, and 20 (m/s) for fast mobility.

5.1.2 Application's Specification

In order to regulate the user behavior activities in the network that form the traffic model, Traffic Mix parameter has to be determined. Other important parameters are configured such as DSCP ToS.The illustration of traffic configuration are explained as follow:

V**oIP Traffic Configuration:** The voice over IP (VoIP) traffic is configured with G.711 encoder scheme, which is a speech codec working with 64 (kbit/sec) bit rate. EF is defined for DSCP type for the voice application as mentioned previously.

Application Parameter	**Configured Value**

Voice Frames per Packet	1
Encoder Scheme	G.711
Differentiated Services Code Point (DSCP)	Expedited Forwarding (EF)
Traffic Mix (%)	All Discrete
Conversation Environment	Land phone- Quiet room

FTP Traffic Configuration: The configuration of file transfer protocol (FTP) in the all simulation scenarios the file size 0.5 (Mb per each transmitted file). The "Command Mix" specifies the ratio between the numbers of get operations and total number of FTP operations. In our case, the value of this attribute is set 50% of all FTP operations, which will be get operations, while the remaining half will be put operations. The "Inter-Request Time" value specifies the amount of time between consecutive FTP operations, which is set in our simulation to 1 second.

Application Parameter	**Configured Value**
Inter-Request Time (seconds)	Constant (1)
Command Mix (Get/Total)	50%
File Size (bytes)	Constant (50000)
Differentiated Services Code Point (DSCP)	Expedited Forwarding (EF)

Video Conferencing Traffic Configuration: 128 x 240 pixels is determined for the all simulated using video application. The used setting for inter-arrival time for frames is 15 (frames/second). The application runs over the UDP transport protocol to avoid connection management and other delays associated with the TCP protocol. DSCP setting determines the kind of service in VC defined as expedited forwarding.

Application Parameter	Configured Value
Frame Size Info. (bytes)	128 x 240 pixels
Frame Inter-arrival Time Info.	15 frames/sec
Traffic Mix (%)	All Discrete
Differentiated Services Code Point (DSCP)	Expedited Forwarding (EF)

5.1.3 Performance Metrics

Four key performance metrics were selected and utilised for the simulated network with five routing protocols for their performance and behaviour under different network contexts, such as:

- *Delay (seconds):* the end-to-end delay experienced by all nodes in the network. This is considered as how long it takes a bit of data to travel across the network from one endpoint to another.

- *Retransmission Attempt (packets)*: the entire number of repeated transmission attempts by the entire network nodes.

- *Load (bits/s)*: the total data (traffic) being received by all nodes in the network.

- *Throughout (bits/s)*: the total number of bits received by all nodes in the network.

5.1.4 MANET Scenarios

The result of the freedom given to nodes to join or leave MANET networks will keep affecting the overall network performance. Thus, different parameters could represent this characteristic. These parameters could be the traffic source, node pause time, application type, node power, etc. However, throughout the research, two main context parameters have been considered to assess the network performance: the network size and the nodes' mobility. However the third parameter is application type that has been used as well but there are some difficulties encountered and explained in chapter 8. These applications are FTP, Voice over IP, and Video Conferencing.

As a result, the number of the simulation scenarios required for AI modelling the MANET network relies on three key parts:

1. Network context parameters identified number.
2. Modelled routing protocols identified number.
3. Number of applications used.

Indeed as the number of mentioned elements increases, the number of simulation scenarios will increase as expressed quation (5.1) [3]. The equation will determine the total number of simulations required.

$$S_T = P_1 \text{ x } P_2 \text{ x } P_3 \text{ x } R_T \quad (5.1)$$

Where S_T is the total number of simulations needed and P_1 is the number of network sizes. Three network size cases where considered to represent small, medium and large (10, 50, 100) node numbers. The number of mobility levels is represented by P_2 and four levels were selected (0 m/s), (1m/s), (10 m/s) and (20 m/s). P_3 represents the three applications that were used: FTP, Voice over IP, and Video Conferencing. Finally, R_T mentioned in Equation (5.1), considers the five routing protocols. Therefore, the total number of simulations required will be 540 (S_T = 3 x 4 x 3 x 5).

5.2 Simulation Results

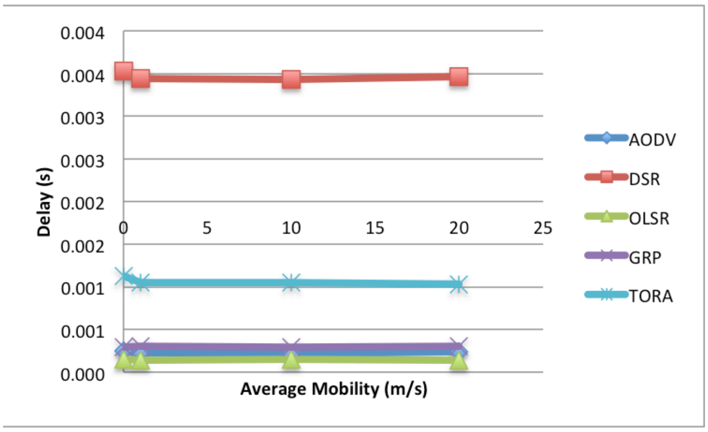
One hour (3600 second) was the simulation time for every simulation scenario, for which each of the four performance metrics were recorded and stored. Moreover, the values of these metrics were presented every 48 seconds during the entire simulation time form the start till the end. All the data concerning the four metrics were collected from 540 scenarios and stored in 2160 data files.

As mentioned earlier all each performance parameters were presented every 48 seconds for one hour. All the data recoded and gathered from all MANET simulation scenarios ought be averaged and then modelled with three AIs techniques as explained in chapter 6.

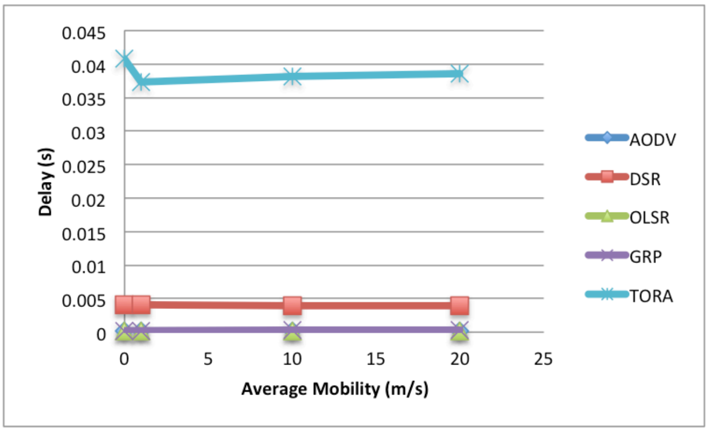
With regards to the averaging the data collected for each of the performance metrics, all the data concerning the four metrics were collected and the mean was calculated for each scenario to represent the network performance during the 3600 seconds. Therefore, Figures 5.1 through 5.12 illustrate the averaged four performance metrics: delay (s), load (bits/s), retransmission attempts (RA) (packets), and throughput (bits/s). These metrics were plotted against mobility and network size for three different applications: FTP, Voice Over IP, and Video Conferencing. However, the subfigure (a) presents network size with 10 nodes, (b) network size with 50 nodes, and (c) network size with 100 nodes. The five curves in each subfigure represent the five operating MANET routing protocols namely: AODV, DSR, OLSR, GRP, and TORA. Finally, the x-axis is labelled as the average mobility (m/s) indicating the four different levels of mobility 0 (m/s), 1(m/s), 10 (m/s) and 20 (m/s)

However, Figure 5.13 through 5.27 is network context in 3D orientation against the organised averaged data. For each application, each 3D represents the averaged performance metric, which is connected to the two network contexts under each of three application of size of the network and average mobility. The z-axis represents the output performance parameter whereas the two network context parameters are represented by number of nodes (x-axis) and mobility level (y-axis).

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

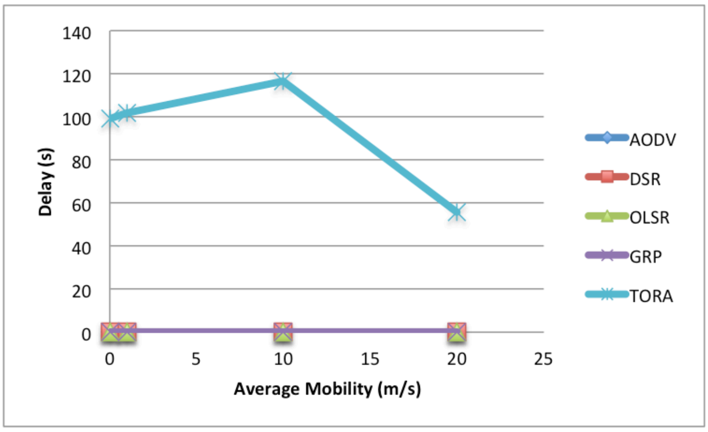
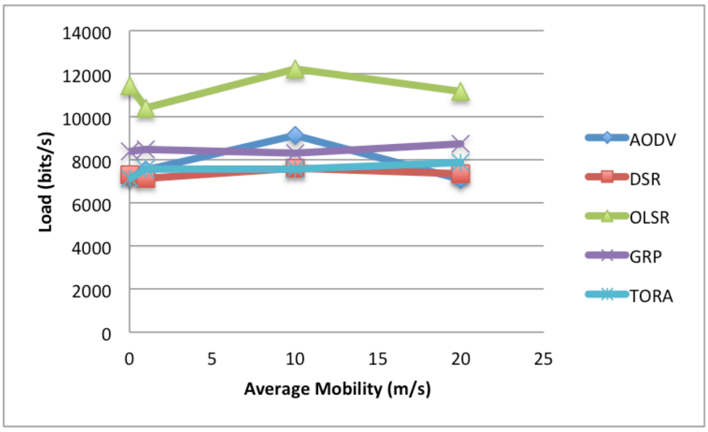
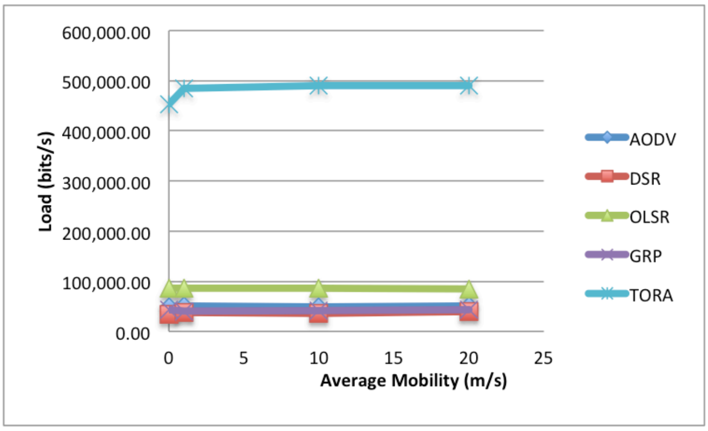


Figure 5.1: FTP application with AODV, DSR, OLSR, GRP, and TORA routing protocol delay results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

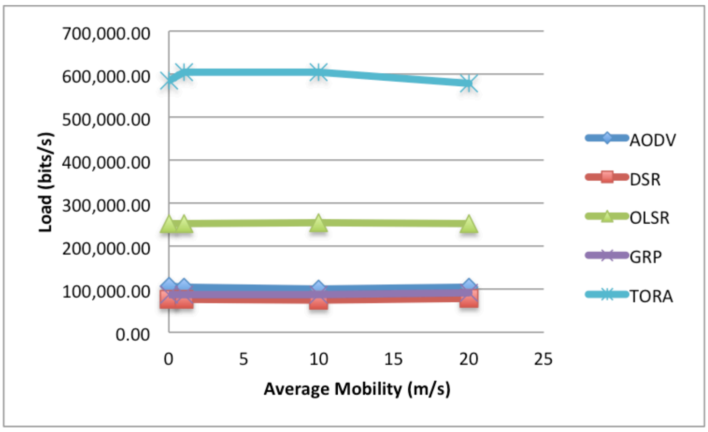
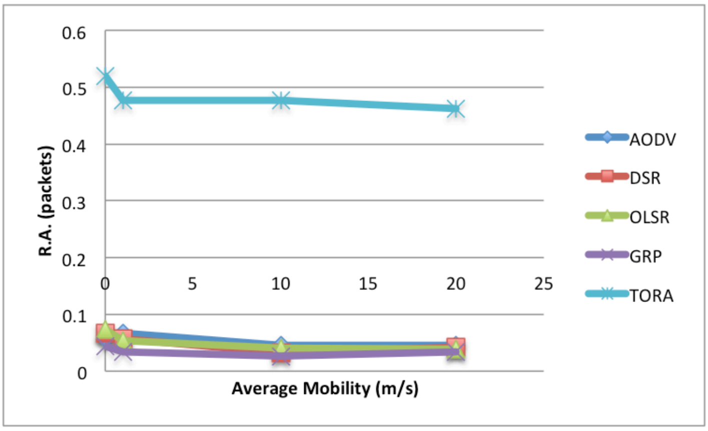
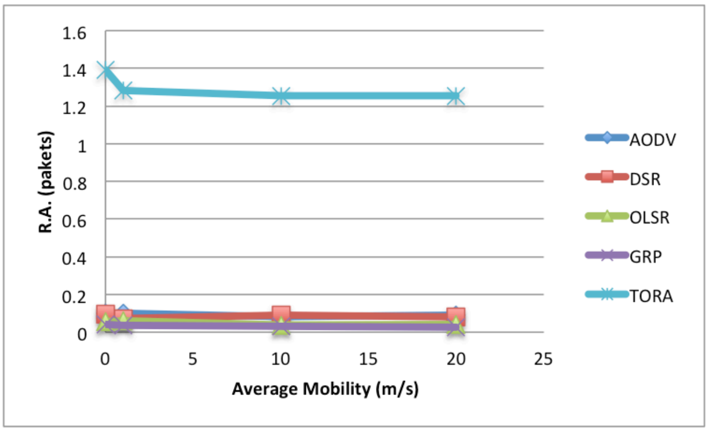


Figure 5.2: FTP application with AODV, DSR, OLSR, GRP, and TORA routing protocol load results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

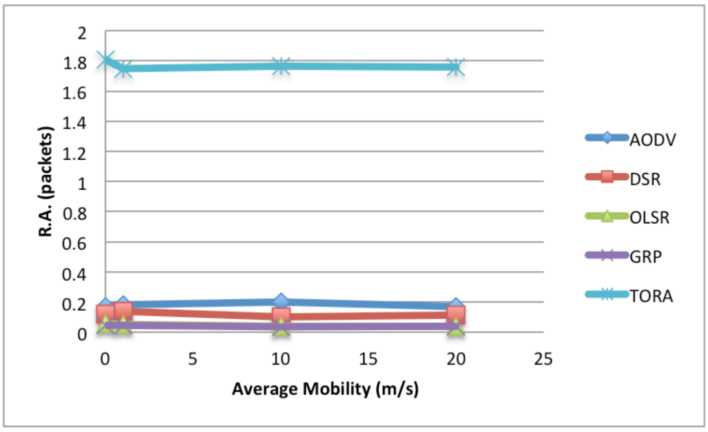
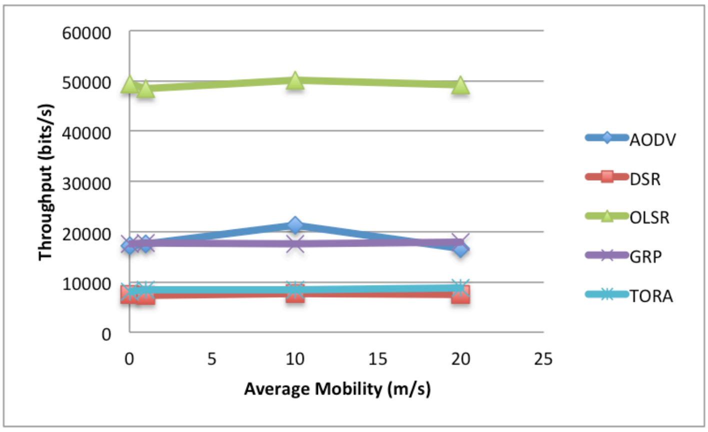
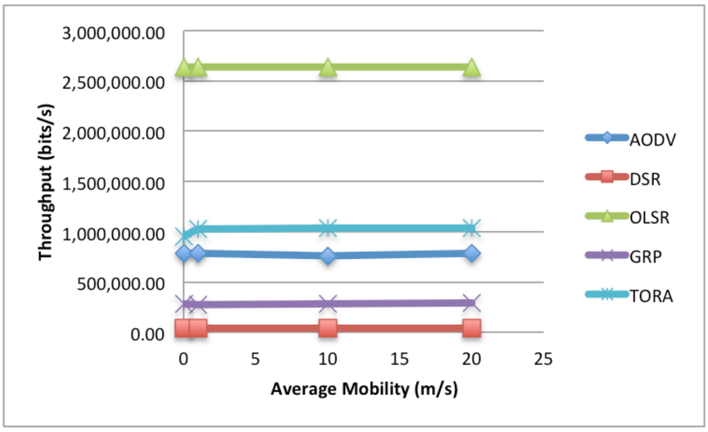


Figure 5.3: FTP application with AODV, DSR, OLSR, GRP, and TORA routing protocol RA results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

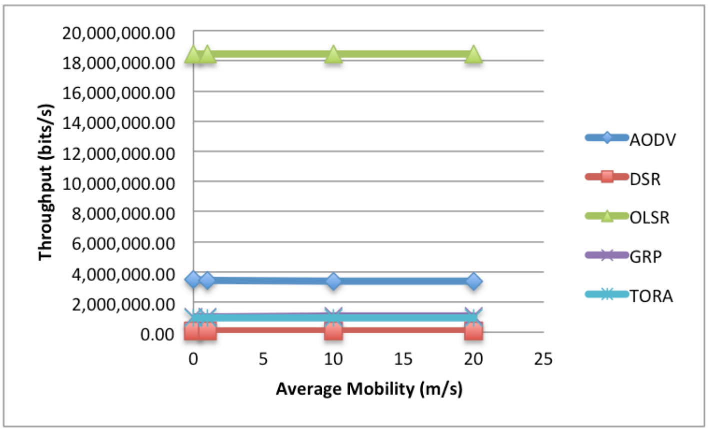
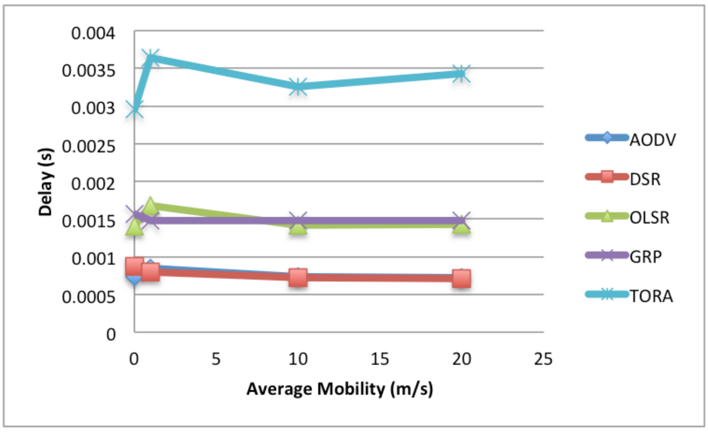
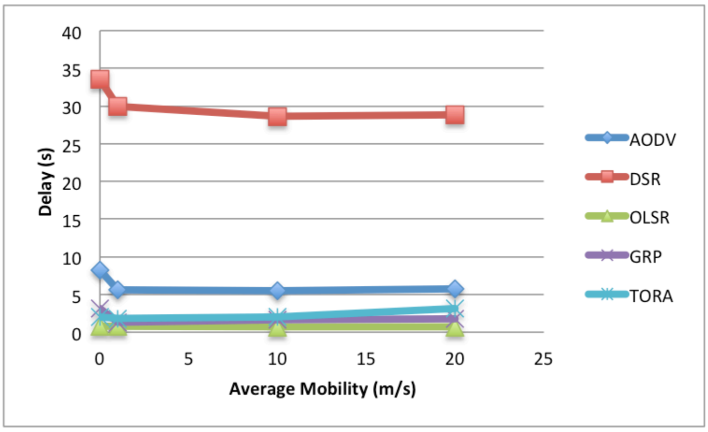


Figure 5.4: FTP application with AODV, DSR, OLSR, GRP, and TORA routing protocol throughput results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

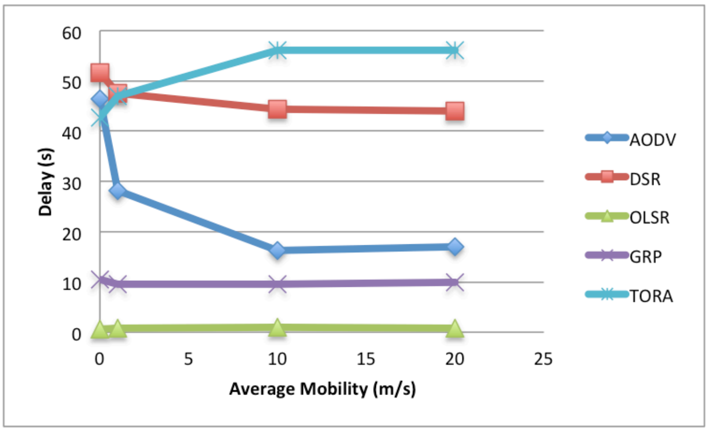
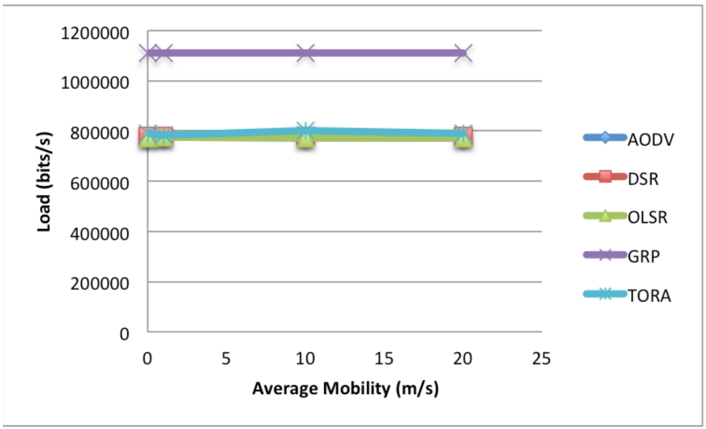
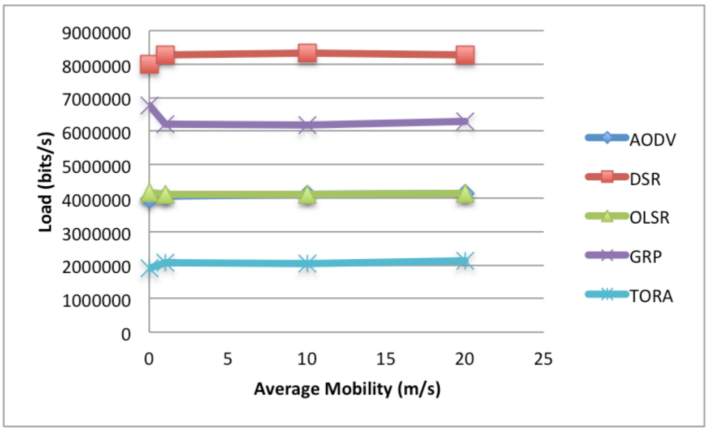


Figure 5.5: VoIP application with AODV, DSR, OLSR, GRP, and TORA routing protocol delay results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

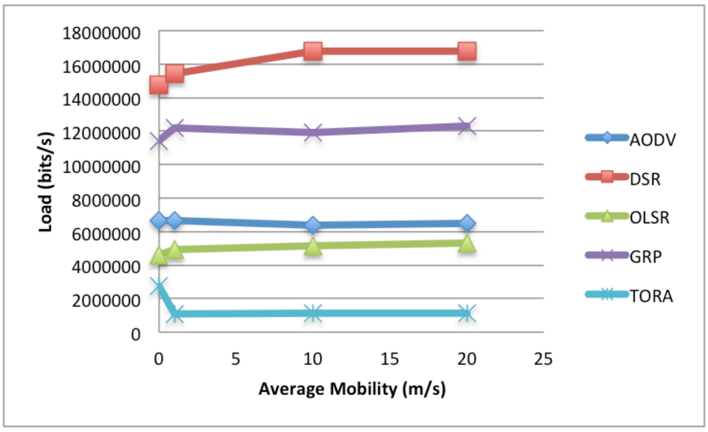
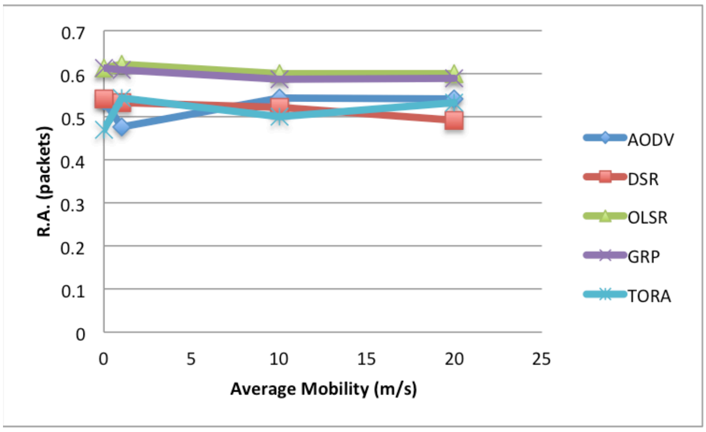
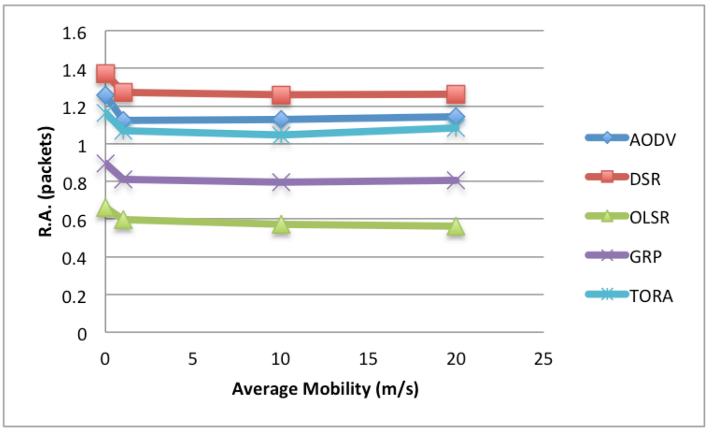


Figure 5.6: VoIP application with AODV, DSR, OLSR, GRP, and TORA routing protocol load results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

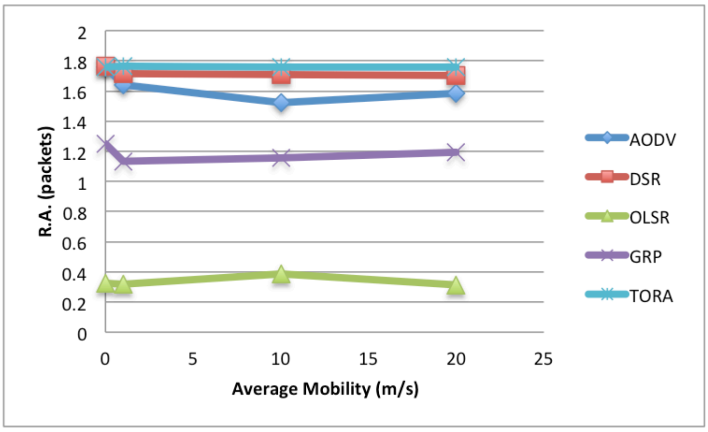
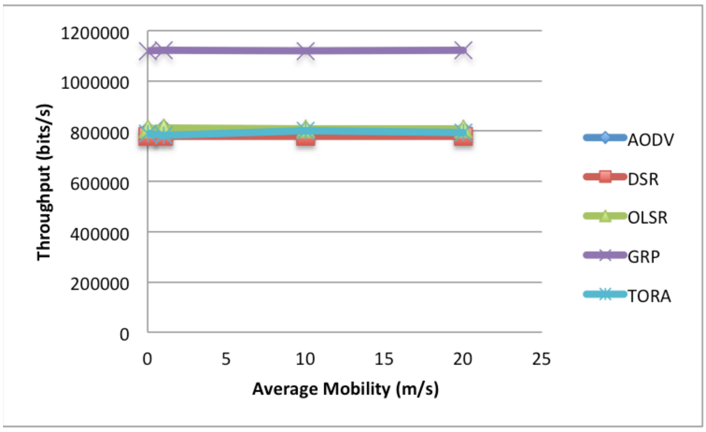
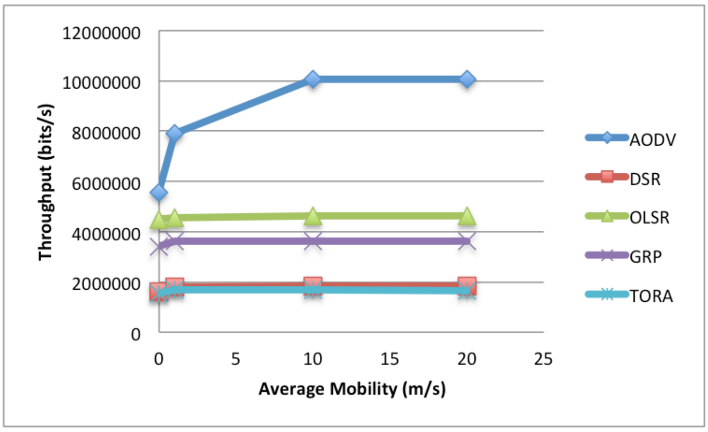


Figure 5.7: VoIP application with AODV, DSR, OLSR, GRP, and TORA routing protocol RA results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

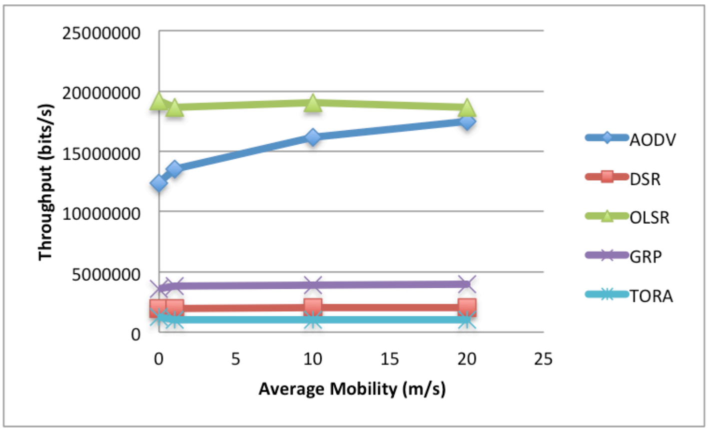
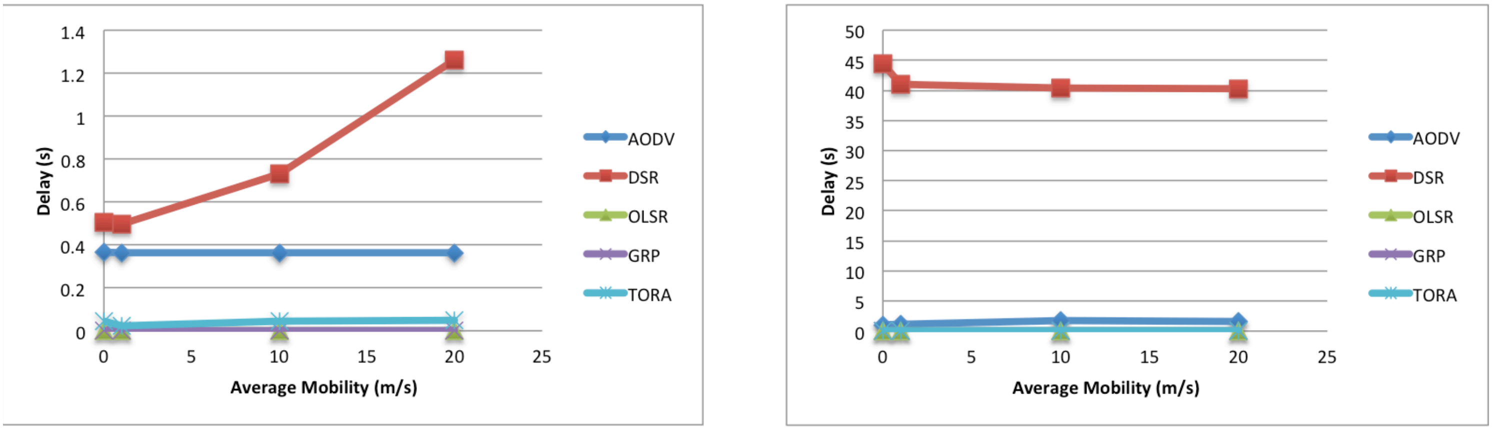


Figure 5.8: VoIP application with AODV, DSR, OLSR, GRP, and TORA routing protocol throughput results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes) (b) Network size (50 nodes)



(c) Network size (100 nodes)

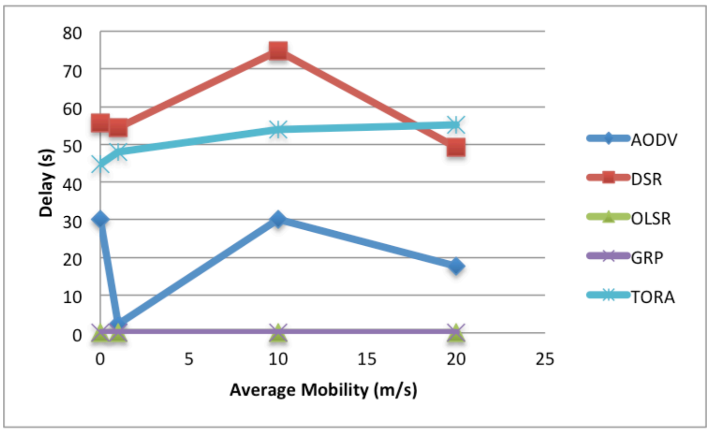
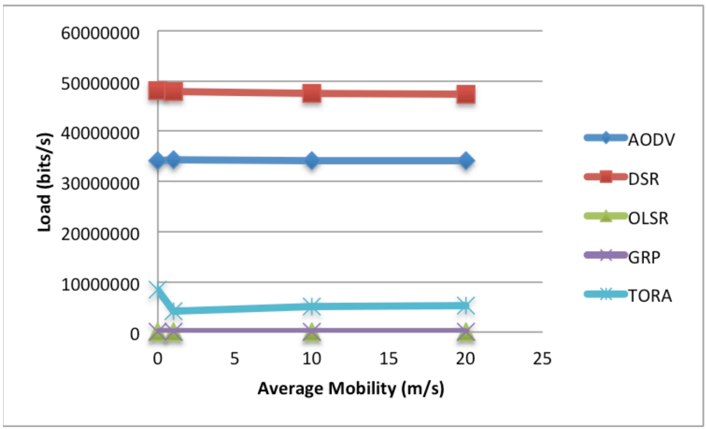
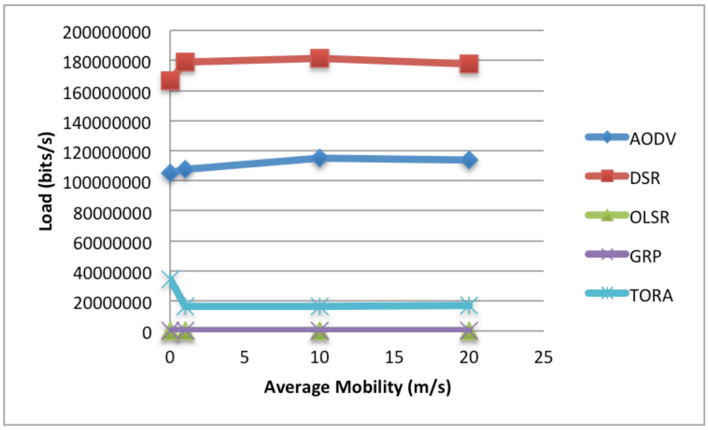


Figure 5.9: VC application with AODV, DSR, OLSR, GRP, and TORA routing protocol delay results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

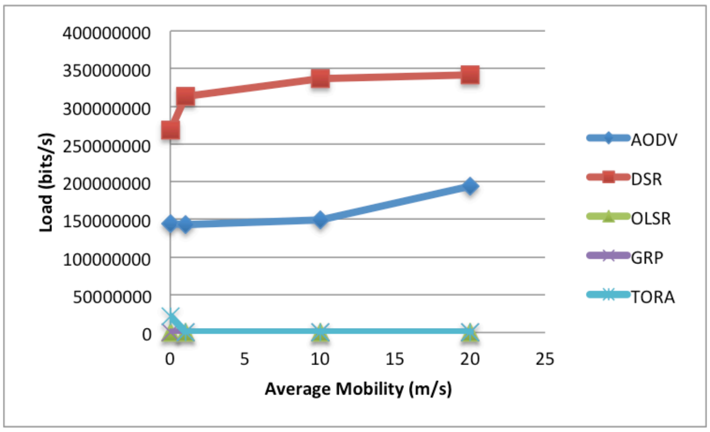
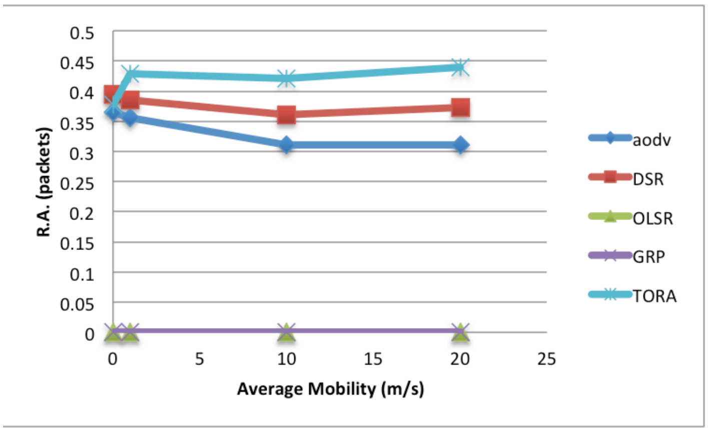
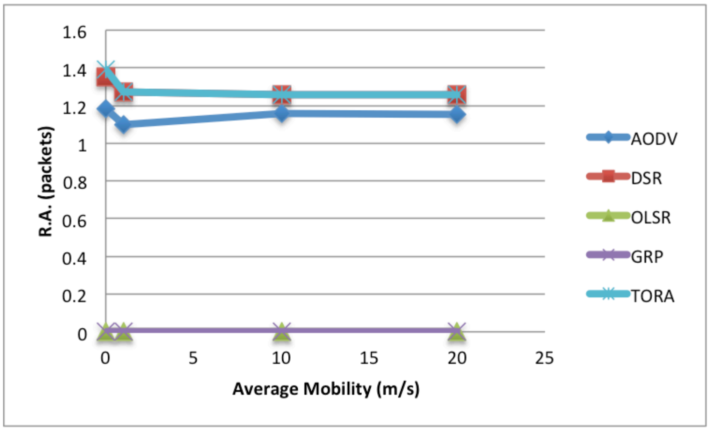


Figure 5.10: VC application with AODV, DSR, OLSR, GRP, and TORA routing protocol load results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

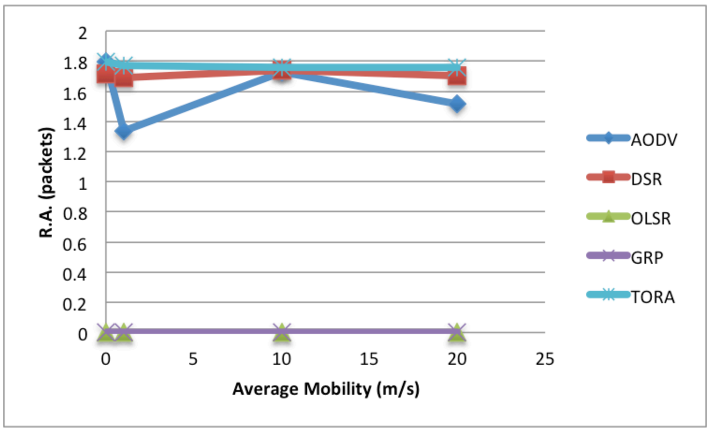
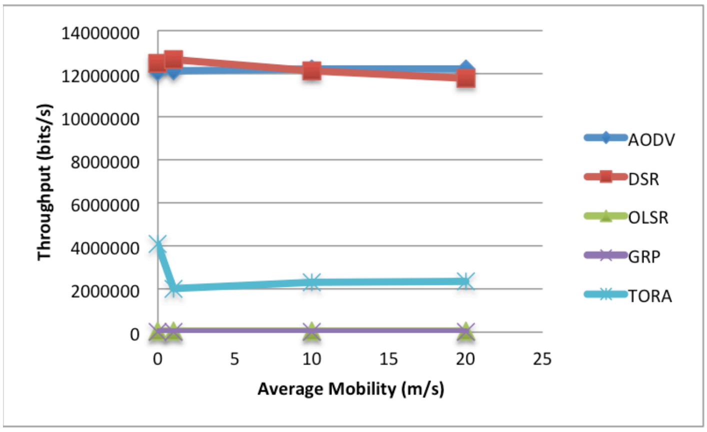
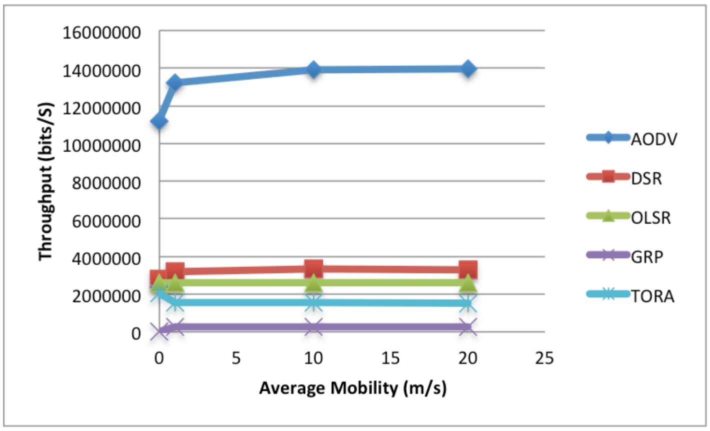


Figure 5.11: VC application with AODV, DSR, OLSR, GRP, and TORA routing protocol RA results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

(a) Network size (10 nodes)



(b) Network size (50 nodes)



(c) Network size (100 nodes)

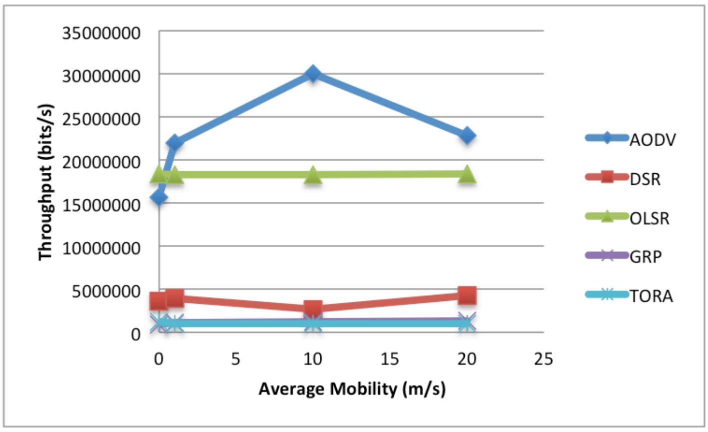


Figure 5.12: VC application with AODV, DSR, OLSR, GRP, and TORA routing protocol throughput results utilising MANET simulation with network size a) 10 nodes, b) 50 nodes, c) 100 nodes.

FTP Application:

Figures 5.13 through 5.17 show the performance of AODV, DSR, OLSR, GRP, and TORA routing protocols versus the no. of nodes and mobility for FTP application; the subfigures represent (a) delay, (b) R.A, (c) load, and (d) throughput.

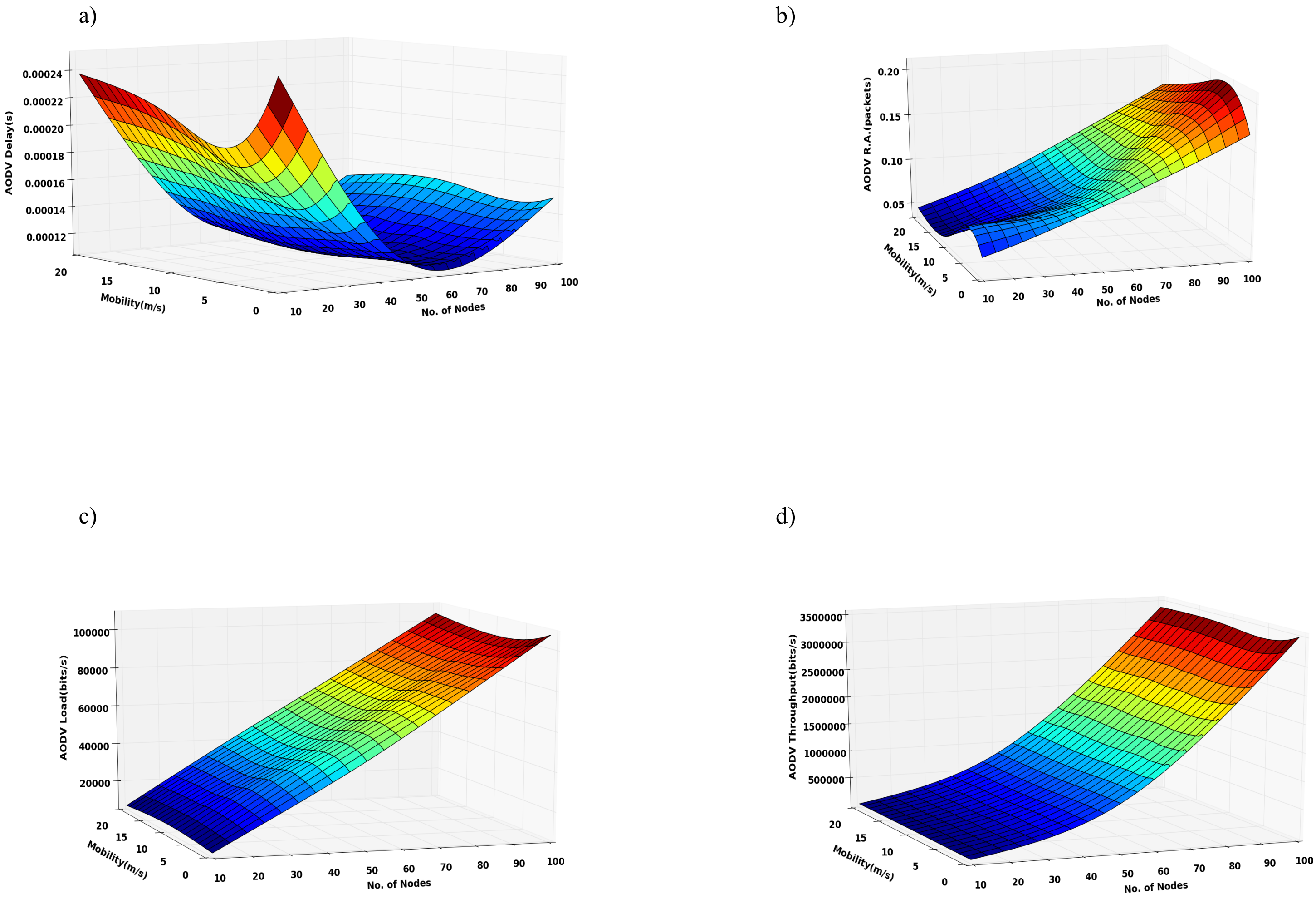


Figure 5.13: The performance metric models for AODV a) Delay, b) RA, c) Load, and d) Throughput.

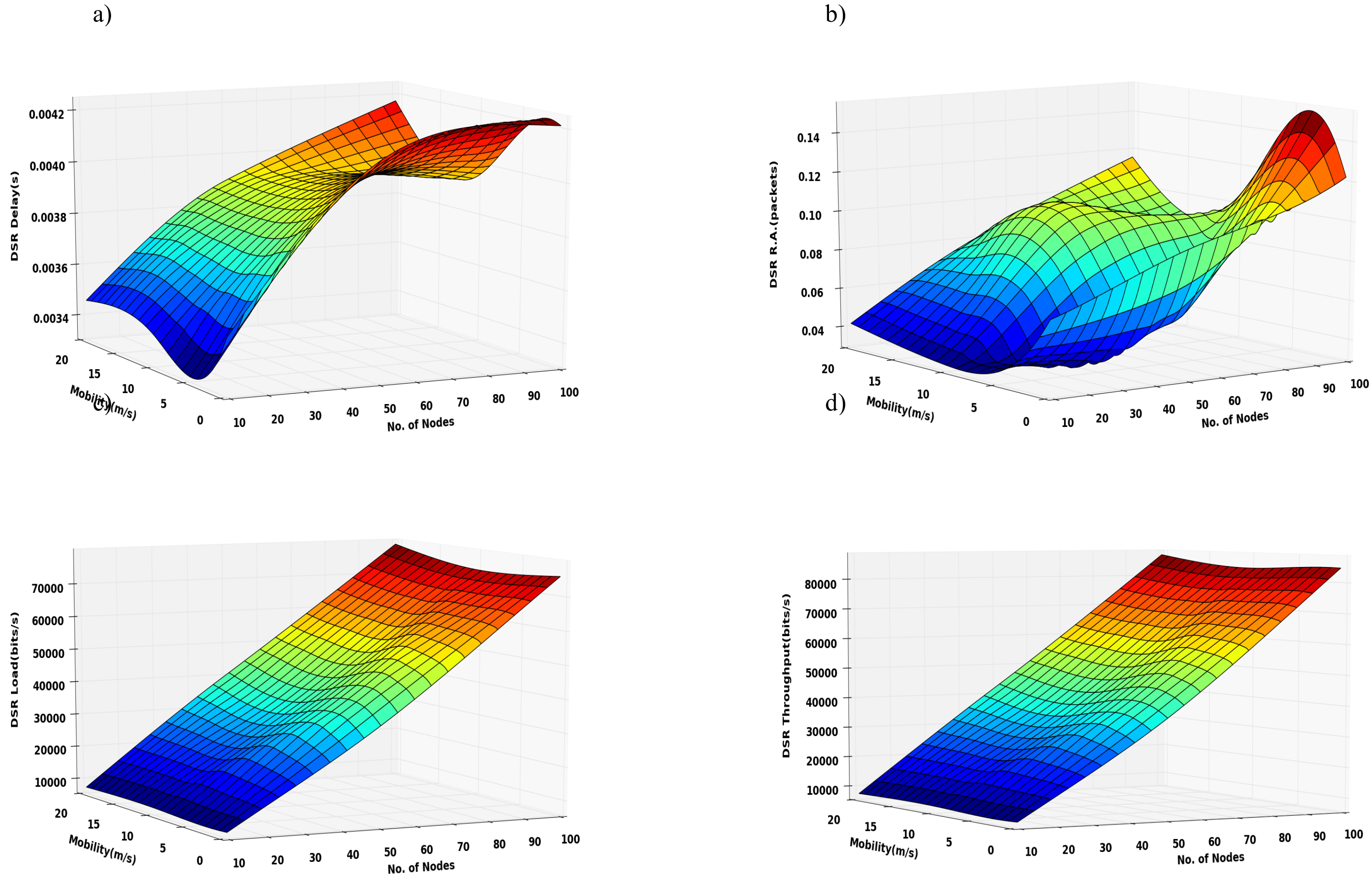


Figure 5.14: The performance metric models for DSR a) Delay, b) RA, c) Load, and d) Throughput.

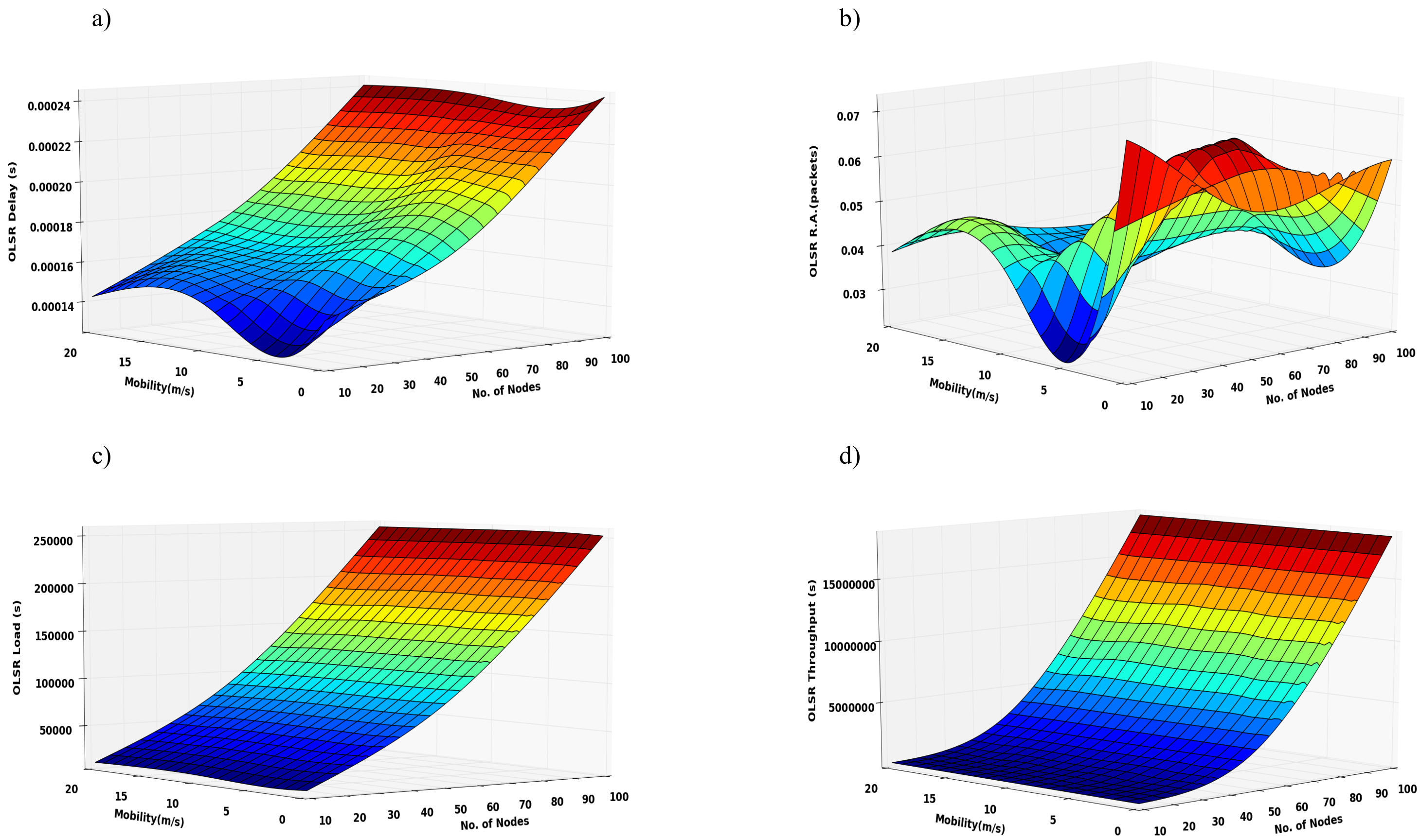
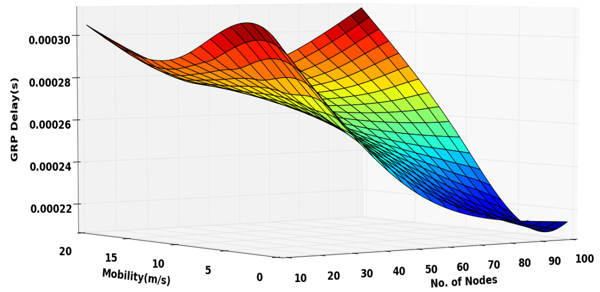
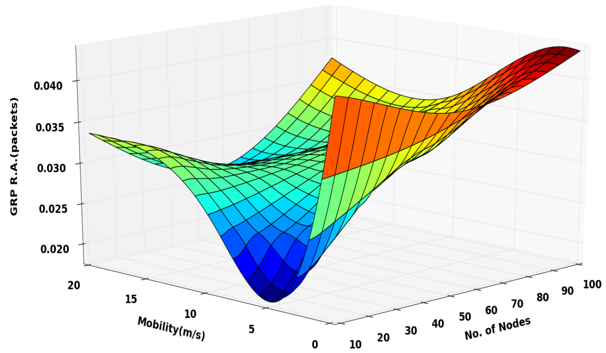


Figure 5.15: The performance metric models for OLSR a) Delay, b) RA, c) Load, and d) Throughput.

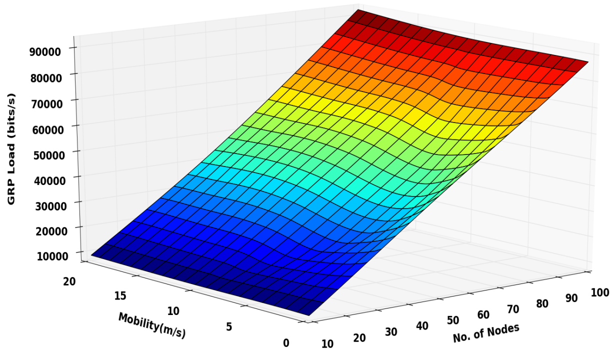
a)



b)



c)



d)

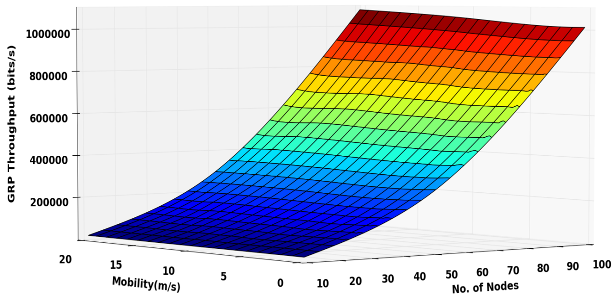


Figure 5.16: The performance metric models for GRP a) Delay, b) RA, c) Load, and d) Throughput.

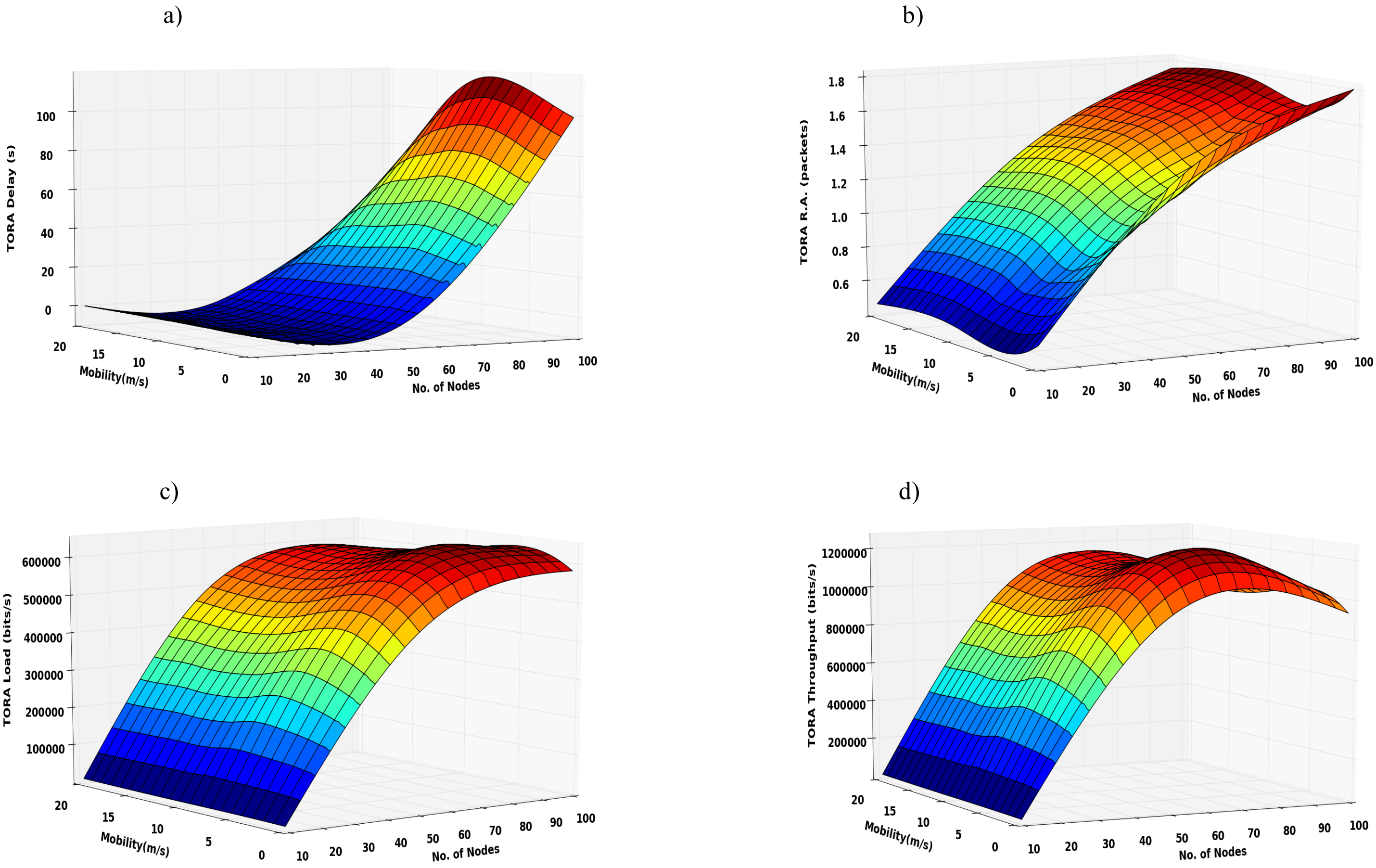


Figure 5.17: The performance metric models for TORA a) Delay, b) RA, c) Load, and d) Throughput.

VoIP Application:

Figures 5.18 through 5.22 show the performance of AODV, DSR, OLSR, GRP, and TORA routing protocols versus the no. of nodes and mobility for VoIP application; the subfigures represent (a) delay, (b) R.A, (c) load, and (d) throughput.

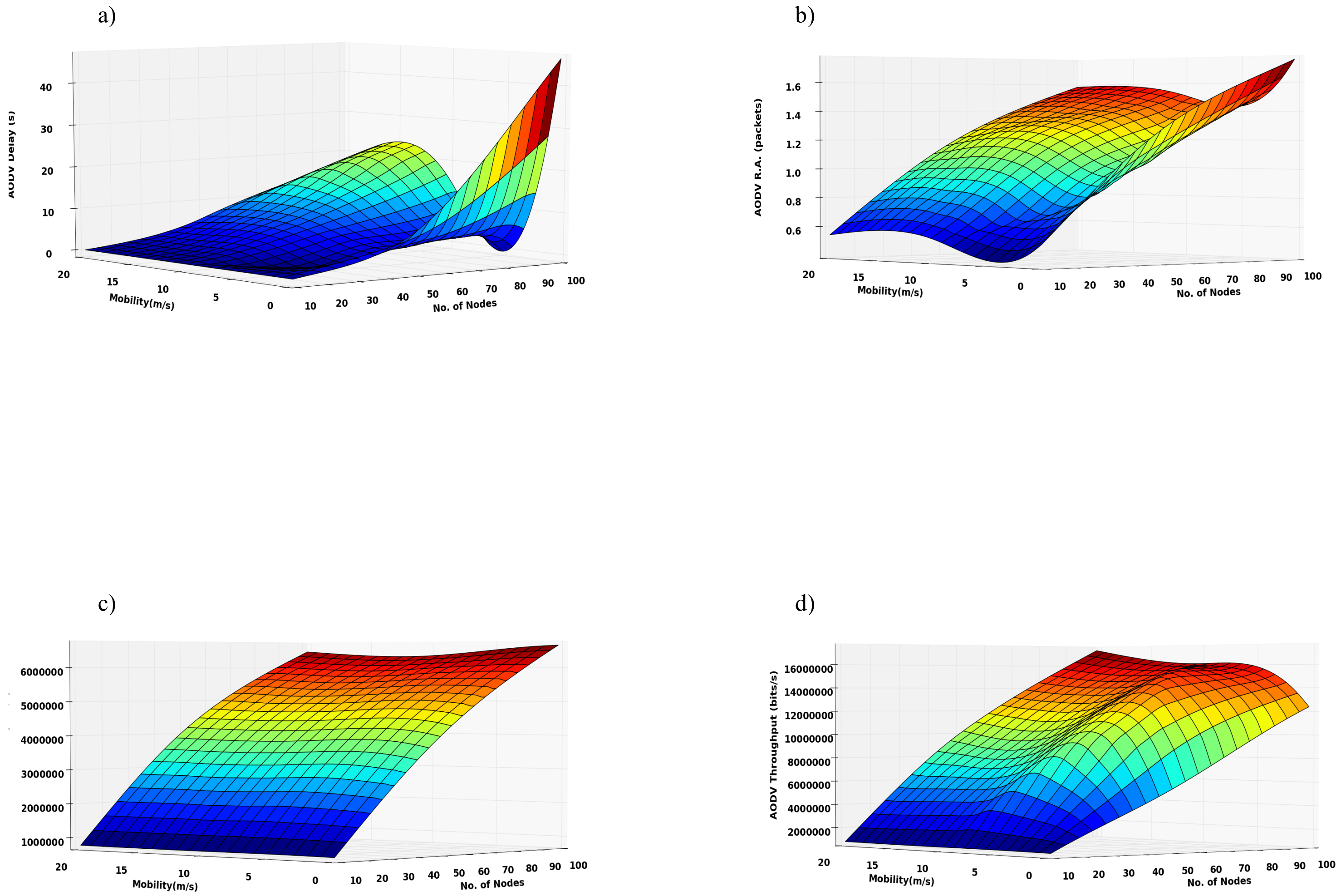


Figure 5.18: The performance metric models for AODV a) Delay, b) RA, c) Load, and d) Throughput.

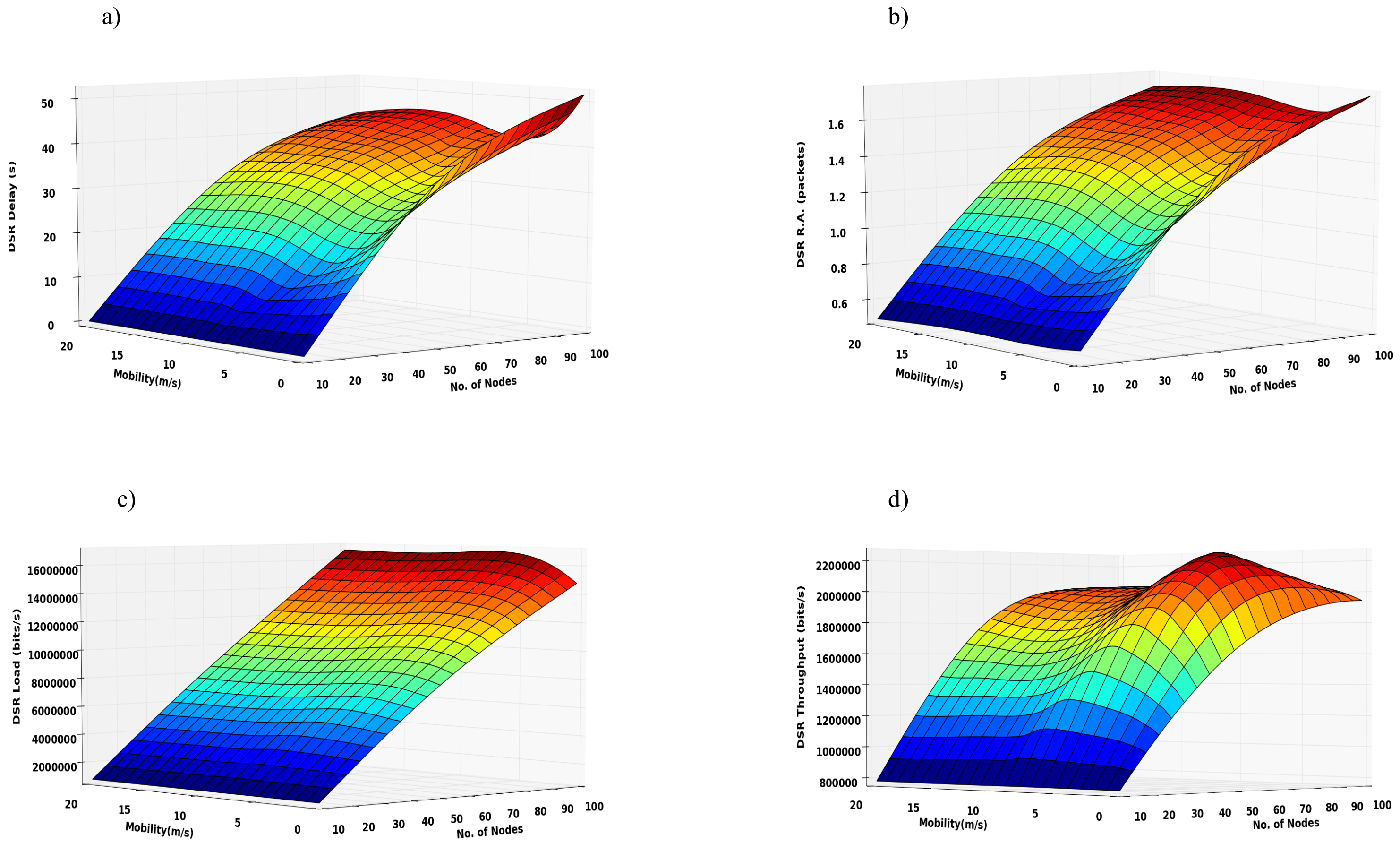


Figure 5.19: The performance metric models for DSR a) Delay, b) RA, c) Load, and d) Throughput.

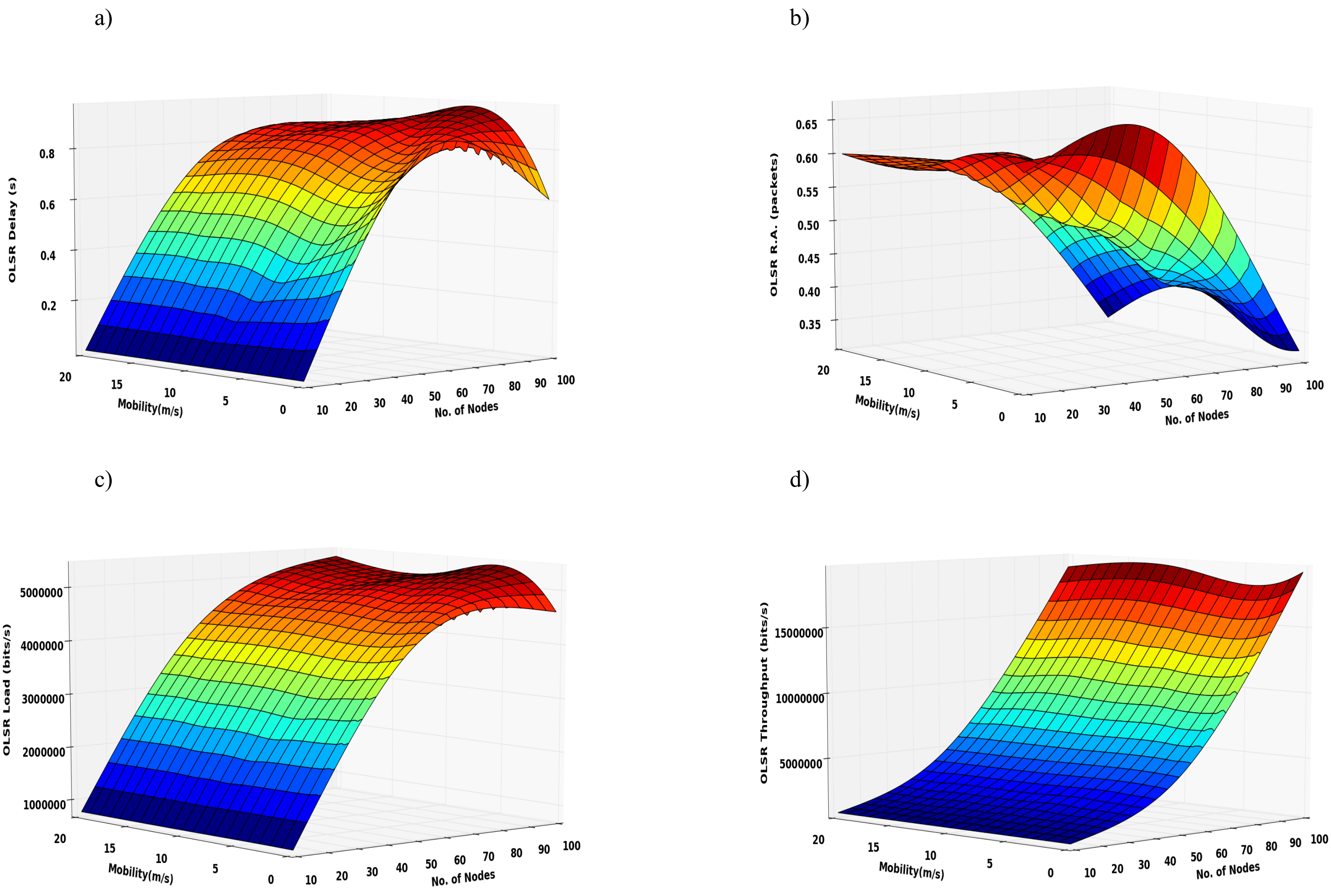


Figure 5.20: The performance metric models for OLSR a) Delay, b) RA, c) Load, and d) Throughput.

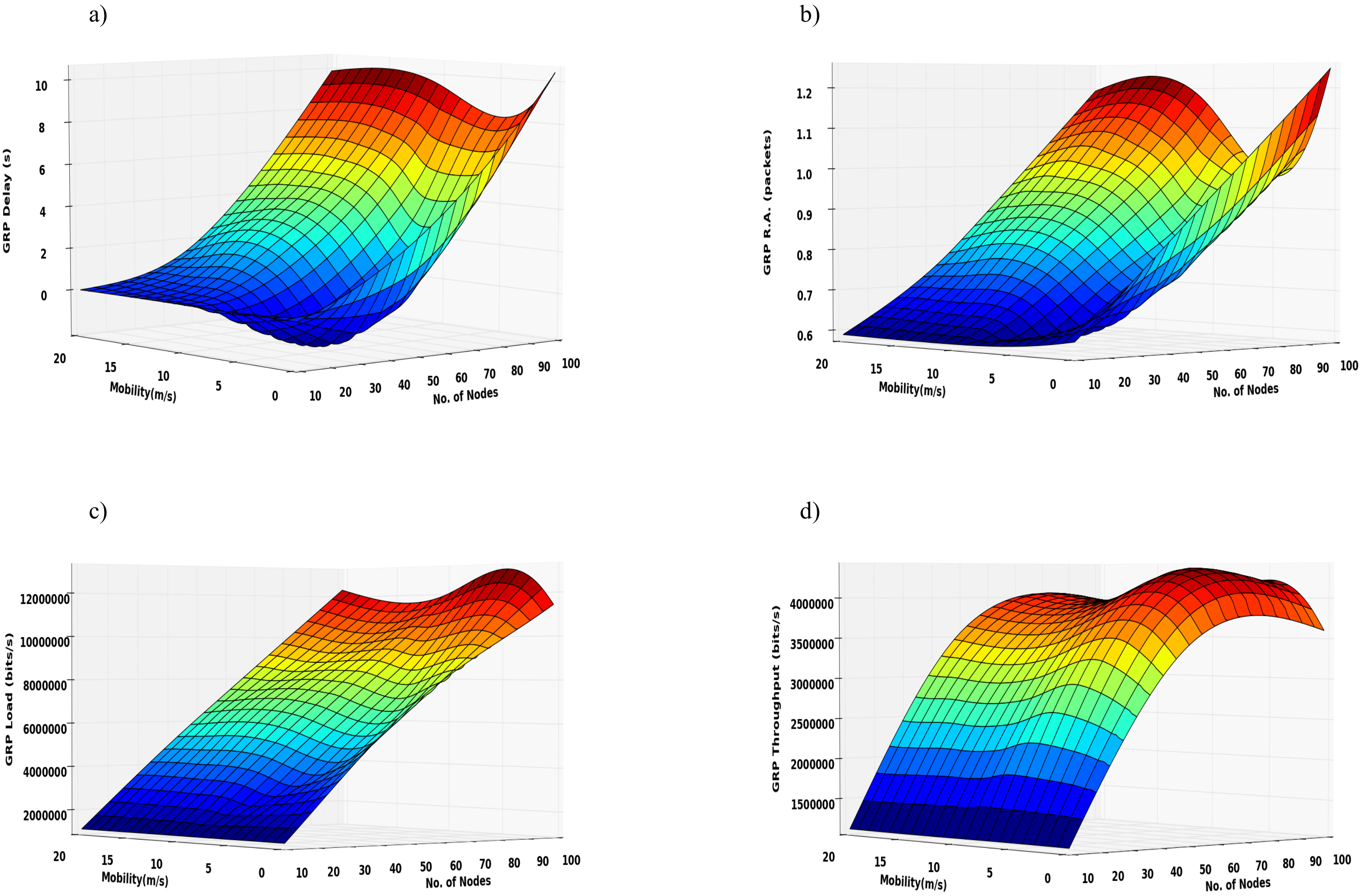


Figure 5.21: The performance metric models for GRP a) Delay, b) RA, c) Load, and d) Throughput.

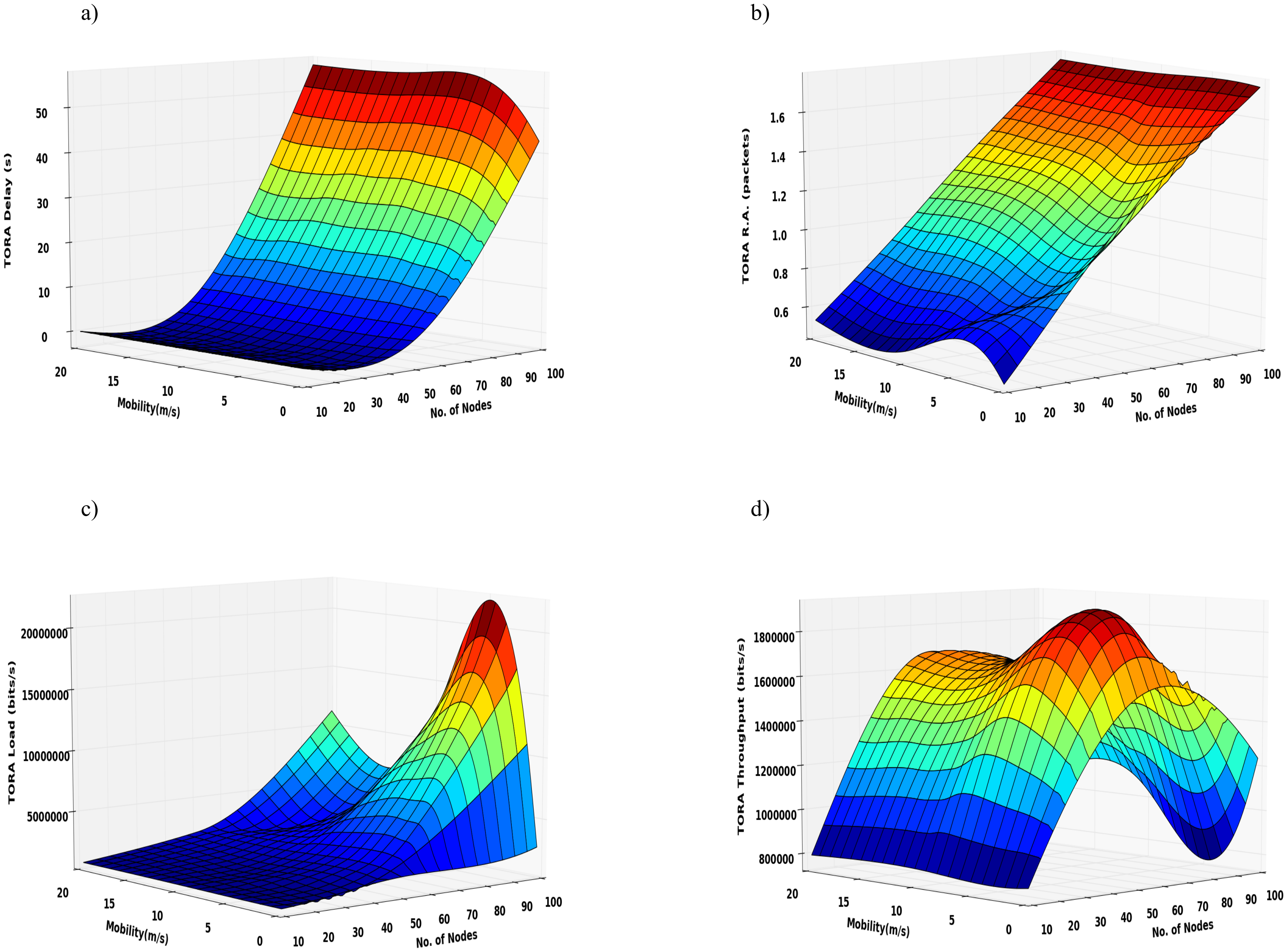


Figure 5.22: The performance metric models for TORA a) Delay, b) RA, c) Load, and d) Throughput.

Videoconferencing Application:

Figures 5.23 through 5.27 show the performance of AODV, DSR, OLSR, GRP, and TORA routing protocols versus the no. of nodes and mobility for Videoconferencing application; the subfigures represent (a) delay, (b) R.A, (c) load, and (d) throughput.

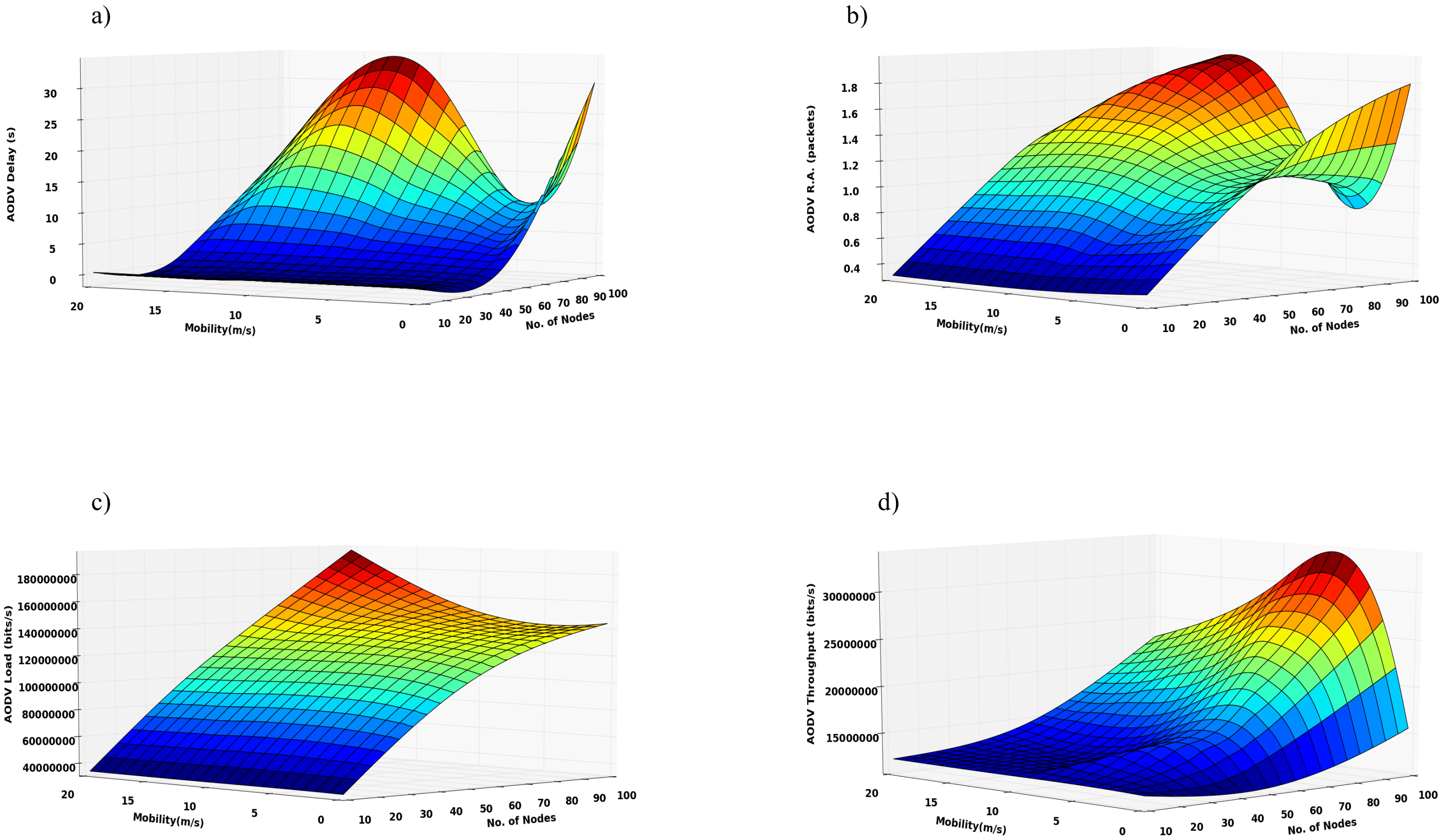


Figure 5.23: The performance metric models for AODV a) Delay, b) RA, c) Load, and d) Throughput.

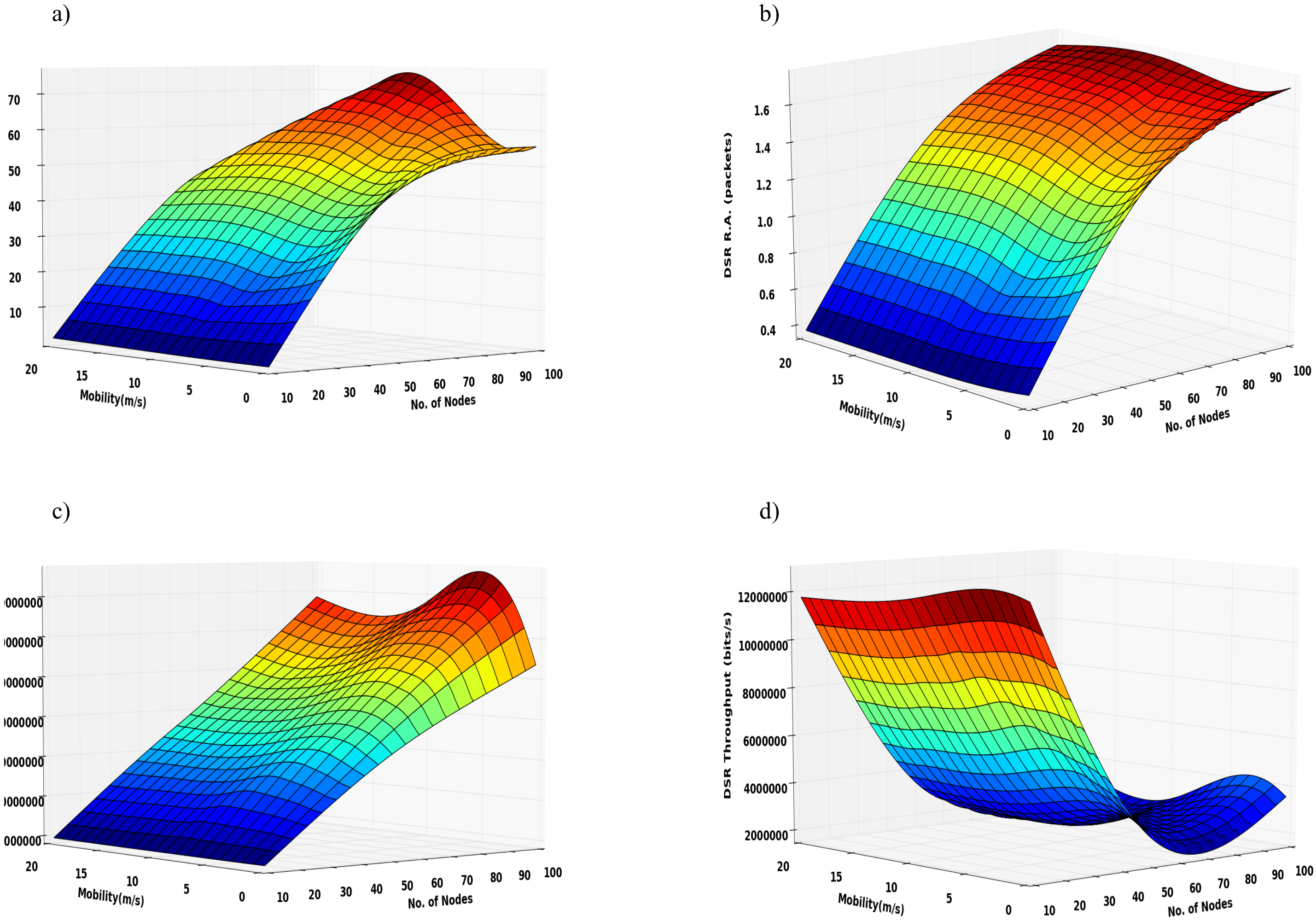


Figure 5.24: The performance metric models for DSR a) Delay, b) RA, c) Load, and d) Throughput.

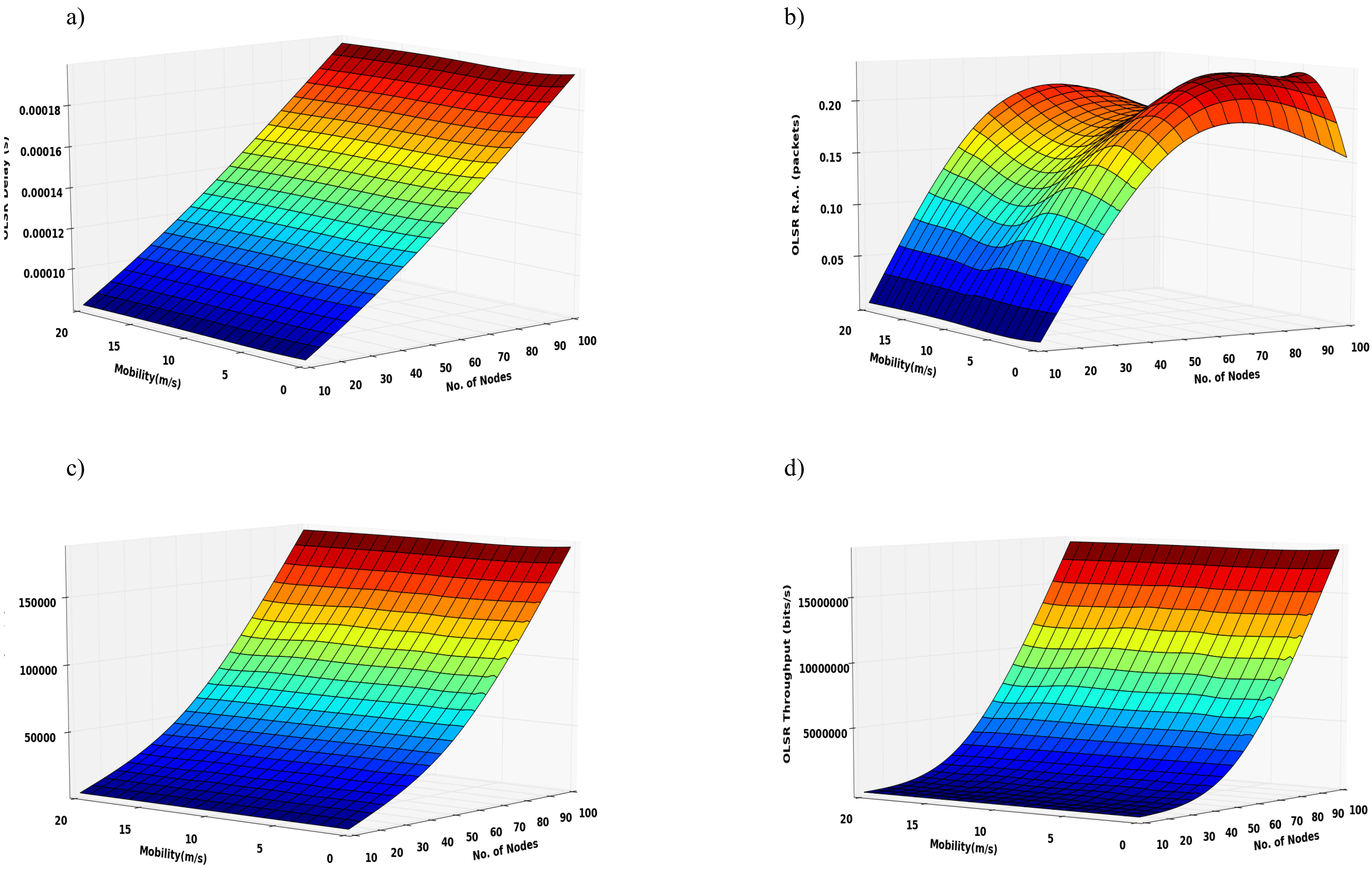


Figure 5.25: The performance metric models for OLSR a) Delay, b) RA, c) Load, and d) Throughput.

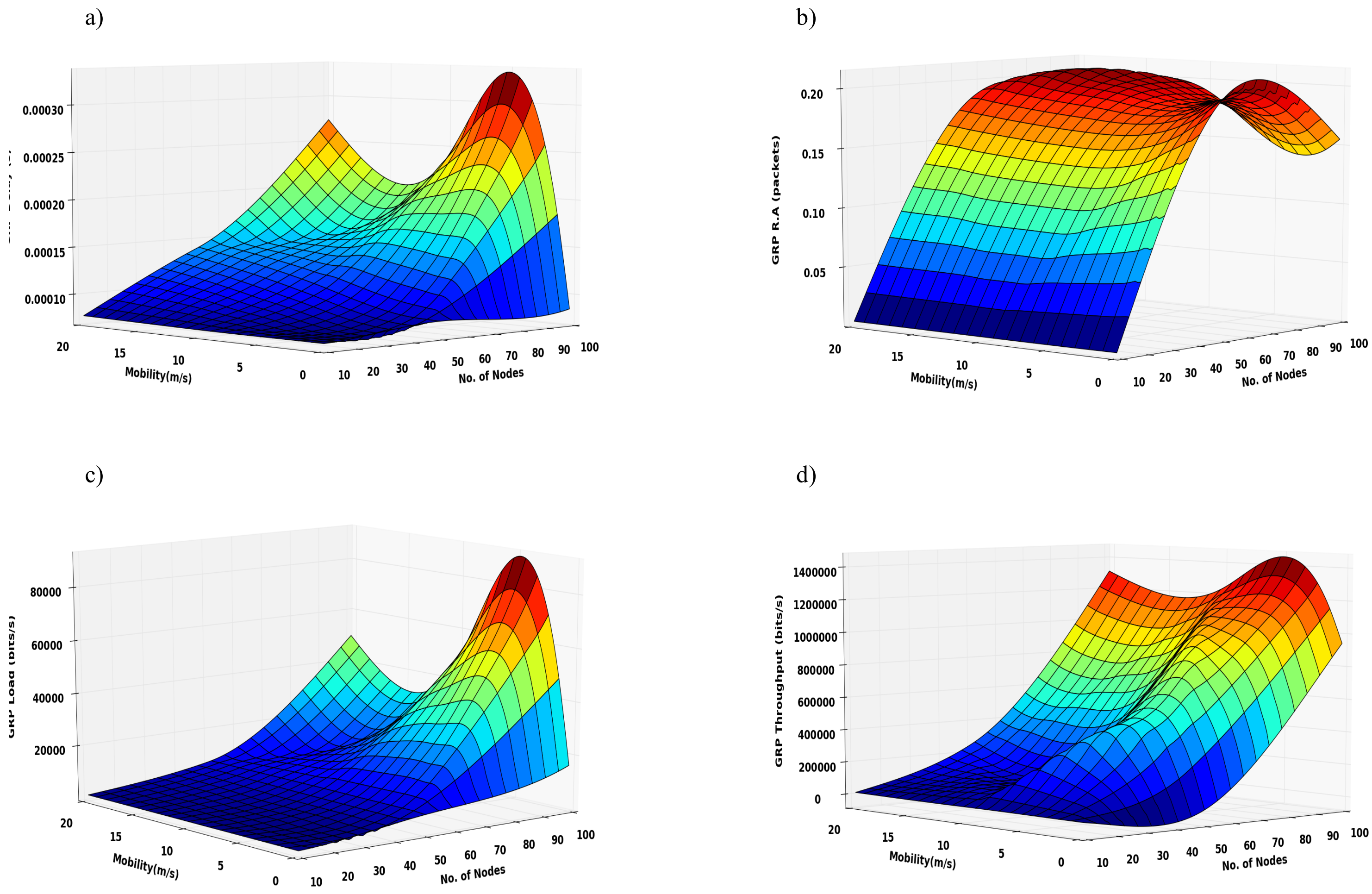


Figure 5.26: The performance metric models for GRP a) Delay, b) RA, c) Load, and d) Throughput.

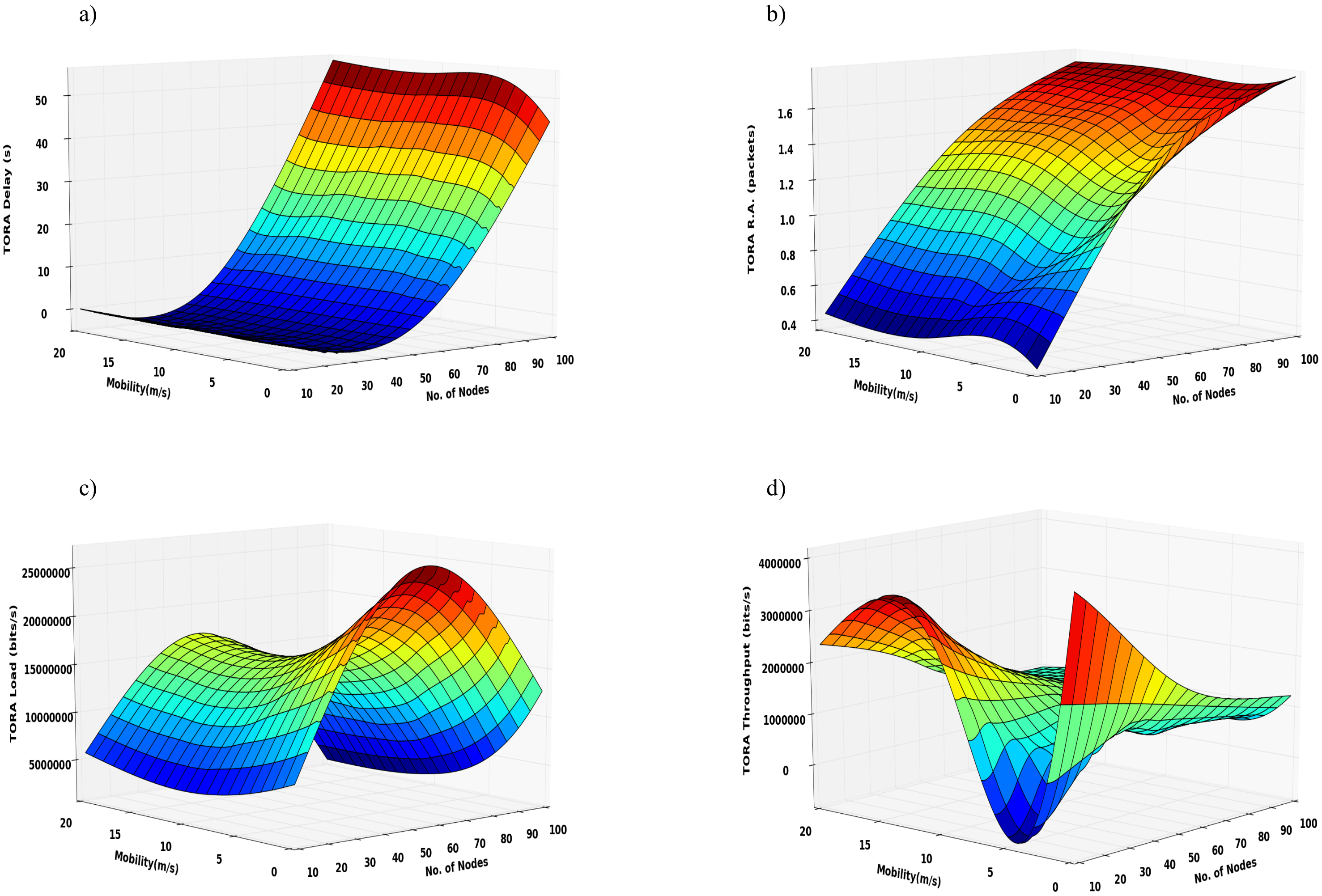


Figure 5.27: The performance metric models for TORA a) Delay, b) RA, c) Load, and d) Throughput.

5.2.1 Result Analysis

This section discusses and analyses the figures 5.1 to 5.12 as presented below.

5.2.1.1 Delay

- ***FTP Application***

  The delay for small sized networks with 10 nodes with AODV and GRP protocols are almost alike. However, DSR was the worst in this size. The high delay recorded by DSR is attributed to the caching strategy used in the protocol as explained in section 4.2.2.3. Once the size increased to the medium and large networks, TORA delay performance increases rapidly throughout the simulation. In contrast, OLSR maintains the lowest performance in all network sizes. This is because of the characterises of proactive routing protocol in this as OLSR where the entire network, the routing table is updated and stored. The other factor attributed to this is the use of MPR through which the efficient neighbour nodes are chosen to repeated the source packet transmission

- ***Videoconferencing***

  DSR was the worst routing protocol in all network sizes and all mobility levels. This poor performance by DSR is because all the routes are stored in the route cache. However, OLSR and GRP maintain the lowest delay as both network size and mobility increases. TORA shows an increase in delay as the network size increases to reach the worst performance with large network at 20 m/s.

- ***VOIP***

  In small network sizes all the five routing protocols had acceptable delay less than 4 milliseconds. However, both DSR and TORA delay increase sharply as both network contexts increase and DSR maintain the highest. AODV and GRP keeps acceptable delay with OLSR the lowest in all the scenarios.

5.2.1.2 Load

- ***FTP Application***

AODV, DSR, and GRP have similar low load throughout the simulation in different network conditions. OLSR has the worst load in small networks, but in medium and large network TORA has the highest load compared to the other four routing protocols.

- ***Videoconferencing***

GRP has the lowest load during all simulations unlike DSR, which is the worst. As it is observed that DSR scored high load values due to the fact that " scalability affects DSR routing protocol" [22]. All other routing protocols have an acceptable load on the entire network.

- ***VOIP***

In small networks GRP has the highest load whereas DSR is the highest in both medium and large networks.

5.2.1.3 Retransmission Attempt (RA)

GRP and OLSR, which are proactive routing protocols, have delivered most of the network packets especially for Videoconferencing and VOIP. However, reactive protocols such as AODV, DSR and TORA, which have both characteristics (proactive and reactive) recorded the worst for all applications in all scenarios. Due to establishment of new path in case the desired destination address is not available in the in the routing table which in turn increases the retransmission attempt in the case with On Demand routing protocols.

5.2.1.4 Throughput

- ***FTP Application***

  Figure.5.4 shows that the highest score in throughput was for the OLSR then AODV, and the worst routing protocol in operation DSR.

- ***Videoconferencing***

  Figure.5.12 indicates that in small networks with stationary and low mobility DSR has the delivered more throughput than other protocols, however with high mobility 10 and 20 m/s AODV outperforms DSR. In medium network, AODV maintains its high throughput. OLSR is the best performer in large network. GRP and OLSR exhibit the lowest in delay and RT compared to 3 routing protocols in networks with 50 nodes. However, networks with 10 nodes OLSR and TORA in networks with 100 shows throughput lower than GRP. Although, GRP present lower in delay, RT and throughput in network with 10 and 100 is not the lowest comparing with other routing protocols.

- ***VOIP***

  Based on Fig 5. 8 GRP has the highest throughput in small network, but AODV takes its place in medium network. The network operating with OLSR in large networks delivers more than the rest of protocols.

5.3 Summary

In this chapter, the context of MANET simulation and parameters were explained. The measurements for different scenarios were selected and used to develop a model. These measurements were utilised to represent the over all performance of MANET networks under three different context: network size, mobility and application. Five MANET protocols (AODV, DSR, GRP, OLSR and TORA) have been simulated for one hour. The simulation results confirmed that each of the five routing protocols performed better than the rest based on particular network context. On the other hand, as the alteration take place in terms of the network context another protocol shows an improvement in its performance and the current protocol will degrade. All in all, with FTP it is noticed that OLSR outperformed the remaining four routing protocol unlike the other two applications where there is a diversity in terms of the best routing protocol.

Chapter 6: MANET Modelling

6.1 Software tools

Two modelling methods were used to model the data generated using Opnet ™ 17.5 simulator used in the previous chapter. These modelling methods were taken into account are the empirical modelling (Regression Equation (RE)) and Artificial Intelligence (AI). The AI is used in this thesis are Artificial Neural Networks denoted as (ANN) and Neuro-Fuzzy denoted as (NF).

The MANET regression equation method was derived from the implementation of The Essential Regression software package [75]. This package uses polynomial and multiple linear regressions to analyse data in a quantitative manner.

On the other hand, Matlab™ was used to create MANET AI models. Matlab stands for "MATrix LABoratory" and is a numerical computing environment. Matlab is based primarily on matrixes as the name emphasizes, allows the ease of matrix calculation, plotting of functions and data, implementation or development of algorithms such as GA (as mentioned in chapter 7), creation of user interfaces, modelling creation interfacing with programs in other languages such as Fortran, C/C++, or Java [76]. MATLAB is used for Artificial Neural Networks and Neuro-Fuzzy to model MANETs. For example Neuro-Fuzzy is implemented by using the ANFIS package, which is part of the Fussy Logic Toolbox, provided by MATLAB in figure 6.1.

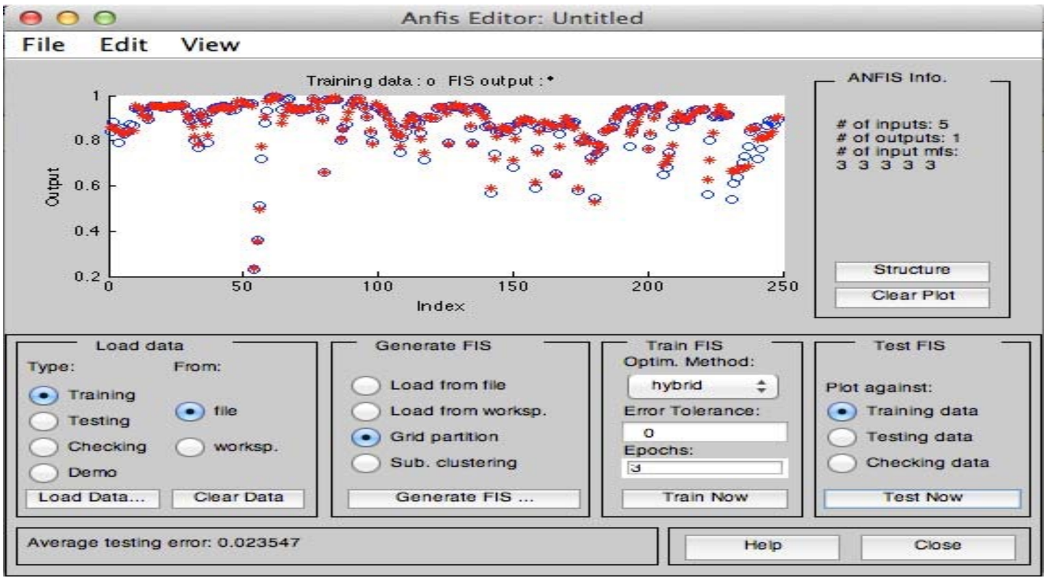


Figure 6.1: ANFIS editior in Matlab.

6.2 Regression Equation Model

Regression is a method of predicting the values of a variable based on the value of another variable by representing the relationship between a scalar dependent variable 'y' and one or more explanatory variables indicated by 'x'. The predicted variable is called dependent variable that will represent the MANET performance. However, the variable used to predict the other variable's value, which is called independent variable will represent the network context. The regression model can be formulated in mathematical equation. In equation (6.1) can be used for a linear equation of first or second order with first interaction:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \varepsilon \tag{6.1}$$

In case of third order (cubic) equation with higher order interaction, the polynomial equation is represented in equation 6.2:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j=i+1}^{k} \beta_{iij} x_i^2 x_j + \sum_{i=1}^{k} \beta_{iii} x_i^3 + \varepsilon \tag{6.2}$$

Where: y is the MANET network performance; k is the number of factors (independent variables); x_i and x_j are the factors value for the network where $j \leq k$; and finally, β_0 is the regression coefficient of independent variable

6.3 Artificial Neural Network

An artificial neural network (ANN) is a system that is based on the biological neural network, such as the brain. The brain has approximately 100 billion neurons, which communicate through electro-chemical signals [79]. As shown in figure 6.2, the neurons are connected through junction called synapse. Each neuron receives thousands of connections with other neurons, continuously receiving incoming signals to reach the cell body. If the sum of the signals exceeds a certain threshold, a response is sent through the axon. Therefore, the sent signals (information) provide the human the capability of learning, analysing, predicting and recognizing information. Based on such a concept, artificial neural networks attempt to recreate the computation mirror of the biological neural networks. However, we cannot compare ANN to the biological neural networks due to its complexity and the number of time it is being used.

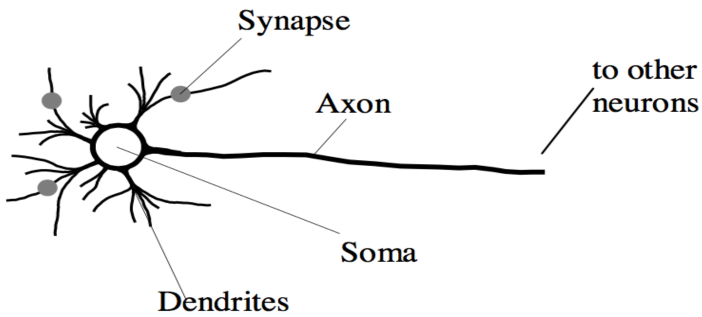


Figure 6.2: Schematic of biological neurons [80].

The network of nodes (artificial neurons) makes up the artificial neural network (ANN). The trained network could perform a specific function by altering the weights (strength) of the connected nodes in order to distinguish and classify and predict the patterns [80].

6.3.1 ANN Training Approach

There are two approaches to training the neural network, respectively, supervised and unsupervised methods. Supervised training involves a mechanism forproviding the network with both the input and the actual output. The network then processes the input and compares its resulting output (target) with the desired output (actual output). Errors are then propagated back through the system, causing the system to adjust the strength (weights), which controls the network and keeps repeated. The set of data, which enables the training, is referred to as "training set". During the training of the network the same set of data is processed may times as the connection weights are refined. In contrast, the unsupervised training, the network only provides input without the desired output. The network will be used to group the input data. This training, my also called self-organization or adaption.

6.3.2 ANN Layers

Artificial neural networks are typically organized in layers. ANN consists of three layers, respectively, *input layer*, *hidden* layer, and *output* layer. The connection is between *input* layer to *output* layer via the *hidden* layer. Information can be fed to the network through the *input* layer. The *input* layer and the strength or weights on the connection between the *input* and *hidden* layer, those govern the *hidden* layer. However, the *hidden* layer and the strength of connection between it and the output layer determine the final layer.

Hidden layer architecture can be single or multiple; in the case of single layer organization refers to one hidden layer in the network, whereas, multi-layer organization (called multilayer perceptron's MLPs), there will be more than one *hidden* layer. The MLP is considered more powerful since each layer can have a different function.

6.3.3 ANN Functions

As stated hitherto, the behaviour of ANNs depend on both the strength and the input-output transfer function that is pre-defined for the layer. Normally, the function considered is rough approximation and falls into one of three categories [81]:

1. Linear unit: the function output is proportional to the function total weighted input.

2. Threshold unit: the function output is set at one of two levels, depending on whether the total input is greater or less than the threshold value.

3. Sigmoid unit: the function output differs continuously with the change in the input. A sigmoid function, such as: $\tanh(x)$, is not a linear function and shows a greater similarity to real neurons than that of the linear or threshold units [3].

6.3.4 ANN Architecture

Feed-forward networks and feedback networks are the two types [81] for ANN architecture.

Feed-forward networks and feedback networks are the two types [81] for ANN architecture.

- **Feed-forward (FF networks)**: are the most widely and popularly used models in many applications particularly in pattern recognition. The main feature of such architecture is that the signals travel in one direction from the input to the output since there is no feedback (loops). As mentioned subsection 6.4.2 the network starts with input layers, which can be connected directly to the output layer or through hidden layer. However, the vast majority of such network at least one hidden layer may be present.

- **Feedback networks (feed-forwarded back propagation)**: In contrast the previous type, the signal may travel in both directions from the input to the output due to loops. Such type can be an incredibly powerful and sophisticated network. Feedback networks are dynamic until they reach an equilibrium point [81]. The equilibrium point will remain till a change in the input and the pursuit for a new equilibrium takes place to be found triggers it. Interactive or recurrent are two terms known for feedback architectures.

6.4 Neuro-Fuzzy Model

In computing framework, Neuro-Fuzzy (NF) is known as hybridization of neural network (discussed in the previous section) and fuzzy system [77]. The fuzzy interference in figure 6.3 is popular in the computing field which relies on the concept of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning [77]. Fuzzy systems were utilized in industrial application; however, the construction of a well performing of such system is not always easy. The issue of finding a suitable membership functions and fuzzy rules is a tiring process of trial and error quiet often. Therefore, there was an urge for applying learning algorithms to fuzzy system. The role of fuzzy system is handling imprecise data and provides explanation to the decision in the context of the existing facts in linguistic form but fuzzy system lacks the capability of learning from the environment. In this aspect, neural network role take place since it has the ability of learning but not capable of reasoning. Thus, the two technologies complement each other.

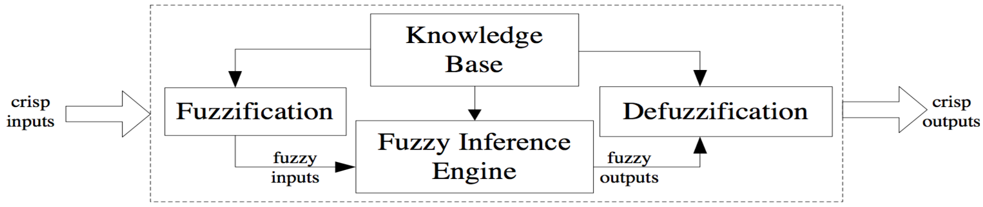


Figure 6.3: Fuzzy inference system [77].

Jang [77] developed the Adaptive-Network-based Fuzzy Inference System (ANFIS). The ANFIS is based on the architecture of the Takagi-Sugeno-type fuzzy inference system. ANFIS is considered one of the most popular and well-documented neural fuzzy systems.

6.4.1 ANFIS Architecture

ANFIS has a similar structure to a typical multi-layered feed-forward neural network as shown in figure 6.4.

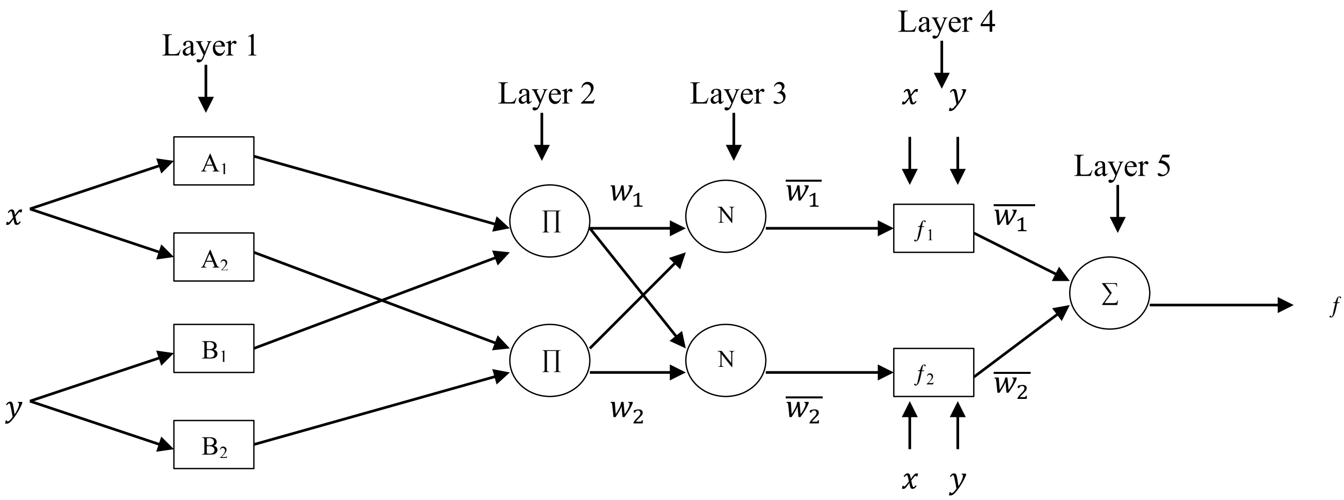


Figure 6.4: ANFIS architecture [78].

Both x and y are the input to the first layer that performs fuzzification, which includes labelling. There are four labelling for the two inputs x and y; A_1, A_2, B_1, B_2 according to ANFIS structure figure 6.3.

In order to transform the input membership function mf a popular function is implemented such as Gaussian function. The member function has a bell shape function and the shape is affected by the mf parameters,

$$mf_{A_i} = \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^2\right]^{b_i}} \tag{6.3}$$

$$mf_{B_i} = \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^2\right]^{b_i}} \tag{6.4}$$

Where a_i, b_i, c_i are the parameters that control, respectively, the centre, width and slope of the bell-shaped function [78].

The fuzzy AND of the $\prod$ labelled node in figure 6.3 is executed in the second layer,

$$w_i = mf_{A_i}(x)\times mf_{B_i}(y), \quad where\ i = 1{,}2 \tag{6.5}$$

Normalized mfs according to figure 6.3 take place in the third layer,

$$\overline{w}_i = \frac{w_i}{w_1+w_2} \tag{6.6}$$

The fourth layer in figure 6.3 is an adaptive node with node function,

$$f_1 = p_1x + q_1y \tag{6.7}$$

$$f_2 = p_2x + q_2y \tag{6.8}$$

Where $p_i$and q_i are the parameter set of the node in this layer and referred to as consequent parameters.

Finally, the fifth layer in figure 6.3 that computes the overall output as the summation of all incoming from the fourth layer.

$$f = \overline{w}_1f + \overline{w}_2f_2 \tag{6.9}$$

NF has been used in optimisation as mentioned in the literature, Moreover, a single attempt to model MANET parameters for three routing protocols was accomplished [3]. Yet, as far as our concern, MANET parameters models for five routing protocols and for three different applications have not been attempted.

6.5 MANET Models

Opnet™ 17.5 (64-bits) was used to generated data (mentioned in Chapter 5) needed to create the models for MANET in this research. A 3D MANET graphs related to data information was ready to be modelled. Three modelling techniques described in the previous subsections were chosen for MANET modelling; thus the three modelling techniques were fed with these data. The four network performance as the output including delay, load, RA, and throughput, whereas the inputs are the two main network contexts as number of nodes and mobility. However, three applications were considered namely FTP, VoIP, and Videoconferencing.

6.5.1 MANET Regression Models

FTP Application:

As in Table 6.1 indicates four equations, which represent the output network performance for each of the five routing protocol. The MANET regression equation were second order, where M is the average mobility and N is the network size.

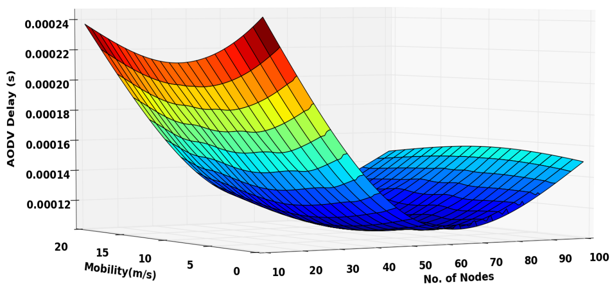
Table 6.1: MANET performance parameter's regression equation results from five working routing protocols

AODV	$Delay = 0.000296 - 6.60059 * 10^{-6}M - 5.60766 * 10^{-6}N + 2.99727 * 10^{-7}M^2 + 1.00223 * 10^{-7}MN + 4.1493 * 10^{-8}N^2 - 3.63977 * 10^{-9}M^2N - 2.28669 * 10^{-10}MN^2.$ $R.A. = 0.06019 - 0.00473M + 0.000423N + 0.000192M^2 + 8.17102 * 10^{-5}MN + 7.18924 * 10^{-6}N^2 - 3.99906 * 10^{-6}M^2N + 5.59007 * 10^{-8}MN^2.$ $Load = -2702.3 + 521.99M + 971.98N - 29.54M^2 - 9.183MN + 1.298N^2 + 0.818M^2N - 0.08008MN^2.$ $Throughput = 18004 + 1957.3M - 3980.9N - 121.66M^2 - 89.13MN + 386.12N^2 + 7.222M^2N - 0.941MN^2.$
DSR	$Delay = 0.00326 - 1.09882 * 10^{-6}M + 2.47315 * 10^{-5}N + 1.93658 * 10^{-7}M^2 - 9.36266 * 10^{-7}MN - 1.48733 * 10^{-7}N^2 + 2.28927 * 10^{-8}M^2N + 4.14845 * 10^{-9}MN^2.$ $R.A. = 0.05723 - 0.004M + 0.00052N + 0.000112M^2 + 5.39963 * 10^{-6}MN + 2.08855 * 10^{-6}N^2 + 2.9390 * 10^{-7}M^2N - 5.10737 * 10^{-7}MN^2.$ $Load = 701.38 + 22.23M + 644.05N - 4.957M^2 + 2.123MN + 1.101N^2 + 0.355M^2N - 0.06915MN^2.$ $Throughput = 605.57 - 5.345M + 658.16N - 3.56M^2 + 3.558MN + 1.861N^2 + 0.293M^2N\ \_0.075MN^2.$
OLSR	$Delay = 0.000138 + 5.989510^{-7}M + 4.33810^{-7}N - 2.89610^{-8}M^2 - 1.34610^{-8}MN + 6.03910^{-9}N^2 + 5.47110^{-10}M^2N + 1.78910^{-11}MN^2.$ $R.A. = 0.0655 - 0.0036M - 0.00013N + 0.00012M^2 + 4.253410^{-6}MN + 4.192910^{-7}N^2.$ $Load = 236.22 + 233.88M + 904.9N - 8.692M^2 - 3.659MN + 16.17N^2 - 0.0568M^2N + 0.04717MN^2.$ $Throughput = 797187 - 31.47M - 102729N + 8.168M^2 + 7.264MN + 2791.8N^2 - 0.984M^2N + 0.152MN^2.$
GRP	$Delay = 0.00032 - 8.619 * 10^{-7}M - 2.2378 * 10^{-6}N + 2.4763 * 10^{-8}M^2 + 4.6659 * 10^{-8}MN + 1.13833 * 10^{-8}N^2 + 4.527 * 10^{-10}M^2N - 2.11727 * 10^{-11}MN^2.$ $R.A. = 0.0408 - 0.0017M - 0.000152N + 6.2409 * 10^{-5}M^2 + 1.956 * 10^{-6}N^2.$ $Load = 415.05 - 57.7M + 807.09N + 5.413M^2 - 6.655MN + 0.65N^2 + 0.13M^2N + 0.06052MN^2.$ $Throughput = 312.98 - 107.55M + 900.9N + 12.35M^2 - 15.4MN + 92.14N^2 - 0.086M^2N + 0.516MN^2.$
TORA	$Delay = 11.58 + 4.034M + 48.53N + 9.327M^2 - 0.571MN + 30.63N^2 - 12.35M^2N - 5.453MN^2.$ $R.A. = 0.232 - 0.0056M + 0.0287N + 0.00026M^2 - 0.00016MN - 0.000132N^2 + 1.2189 * 10^{-7}M^2N + 1.53411 * 10^{-6}MN^2.$ $Load = -158399 - 710.64M + 17519.5N + 3.45M^2 + 121.21MN - 100.24N^2 - 2.384M^2N - 0.739MN^2.$

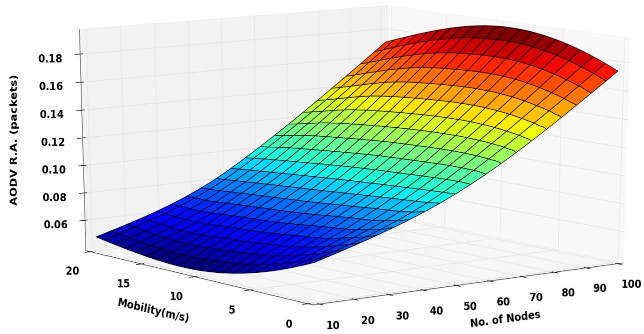
	$Throughput = -380358 + 57.44M + 41435.4N - 66.95M^2 + 183.5MN - 281.11N^2 - 2.19M^2N - 1.211MN^2.$

The equations modeled the performance parameters for AODV, as shown in subfigures (a), (b), (c), and (d) in Figure 6.5.

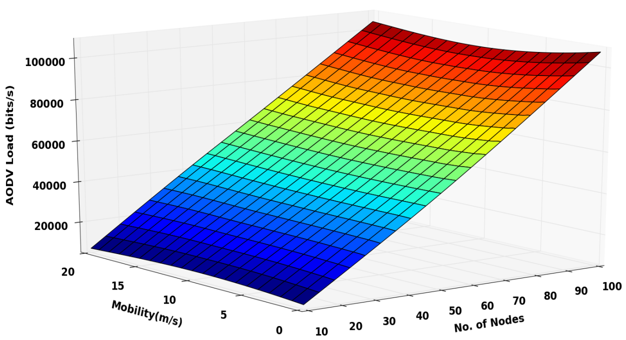
a)



b)



c)



d)

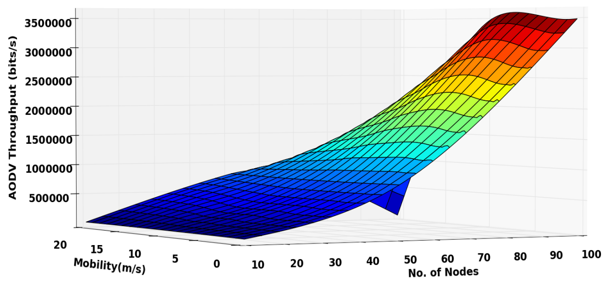


Figure 6.5: MANET output performance RE models using AODV routing protocol.

The equations modeled the performance parameters for DSR, as shown in subfigures (a), (b), (c), and (d) in Figure 6.6.

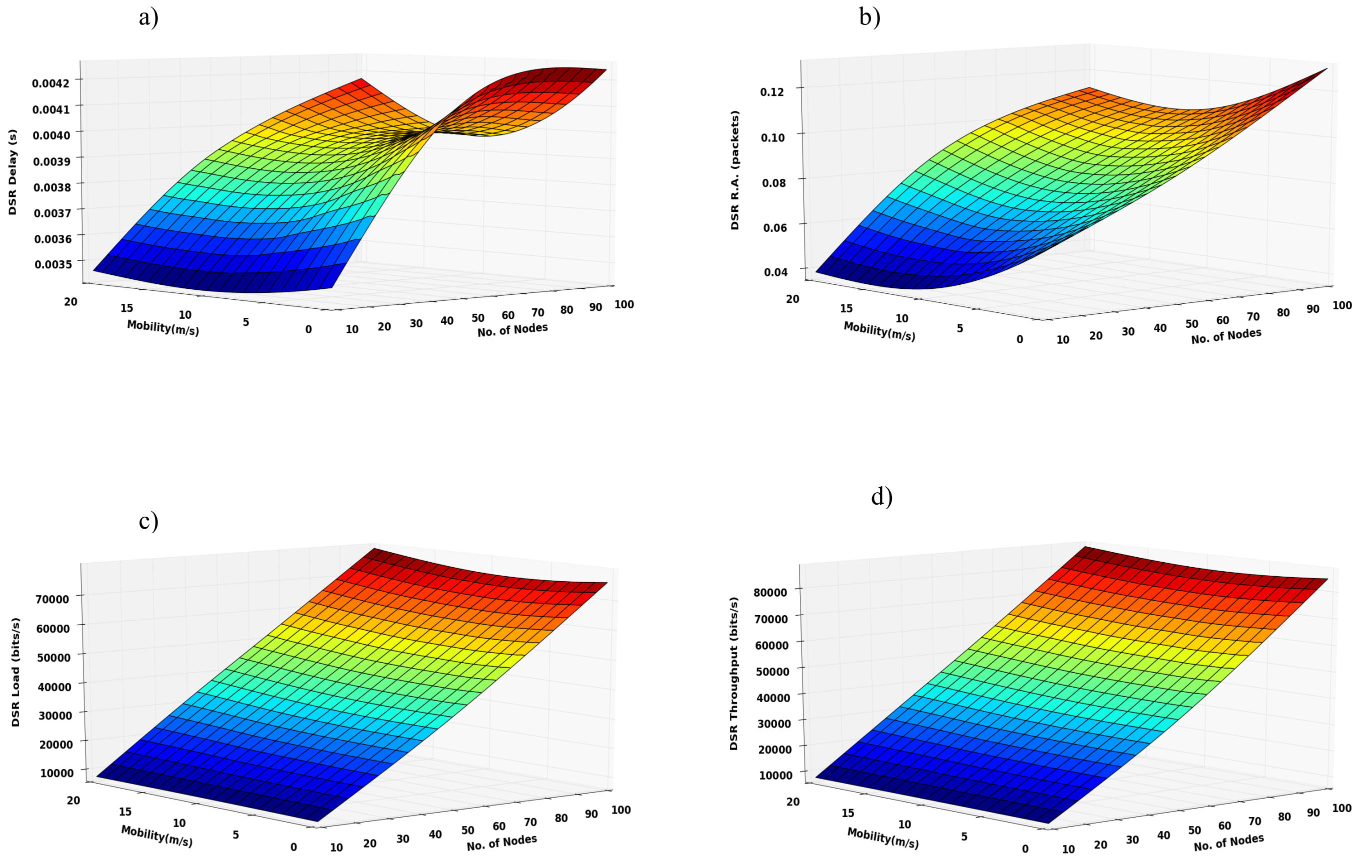


Figure 6.6: MANET output performance RE models using DSR routing protocol.

The equations modeled the performance parameters for OLSR, as shown in subfigures (a), (b), (c), and (d) in Figure 6.7.

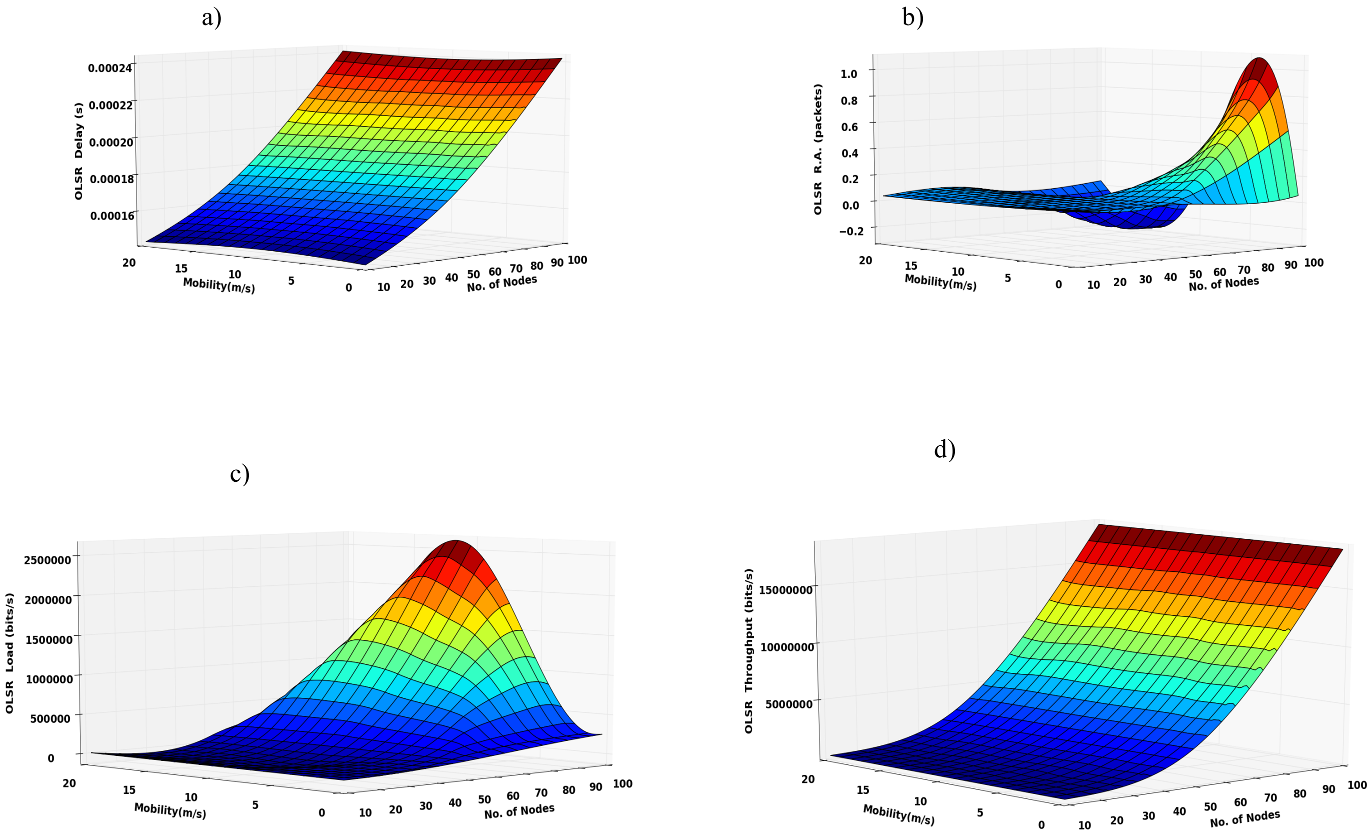


Figure 6.7: MANET output performance RE models using OLSR routing protocol.

The equations modeled the performance parameters for GRP, as shown in subfigures (a), (b), (c), and (d) in Figure 6.8.

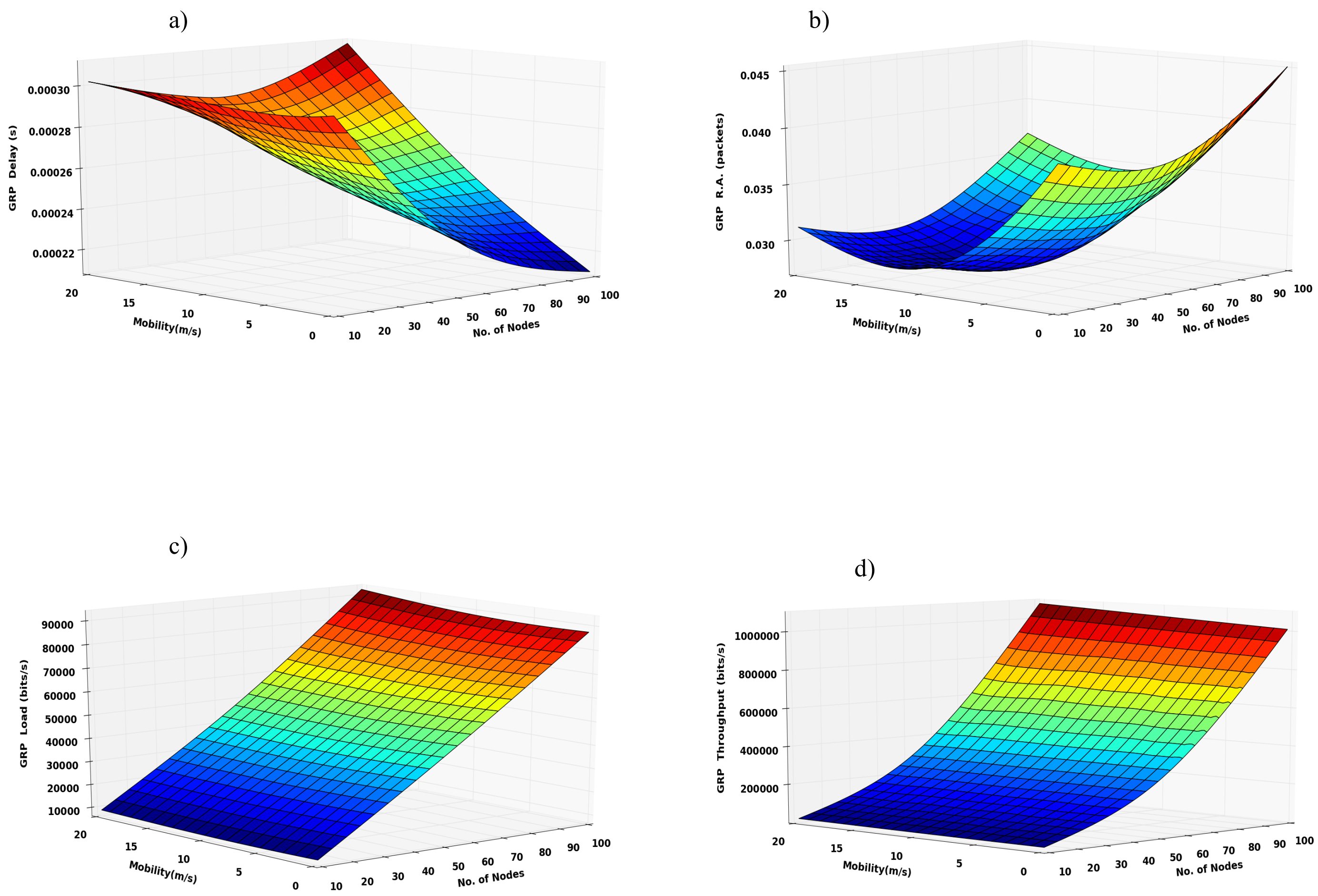


Figure 6.8: MANET output performance RE models using GRP routing protocol.

The equations modeled the performance parameters for TORA, as shown in subfigures (a), (b), (c), and (d) in Figure 6.9.

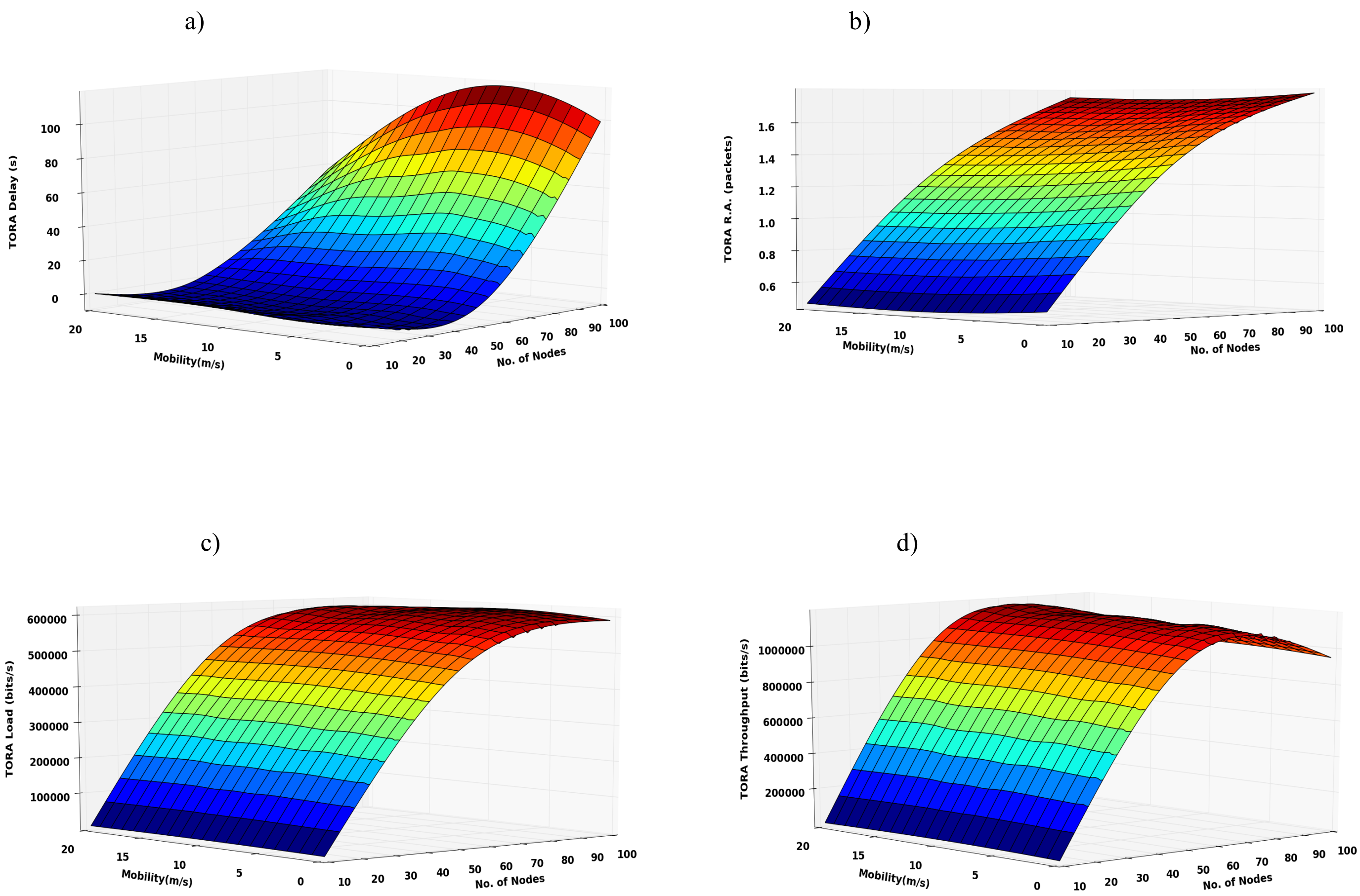


Figure 6.9: MANET output performance RE models using TORA routing protocol.

VoIP Application:

As shown in Table 6.2, four equations that represent the output network performance for each routing protocol. Based on Equation (6.1) in section 6.3, the MANET regression equation were second order, where M is the average mobility and N is the network size.

Table 6.2: MANET performance parameter's regression equation results from five operating routing protocols

AODV	$Delay = 11.08 + 4.786M - 2.31N - 5.737M^2 - 12.16MN + 20.11N^2 + 18.98M^2N - 13.38MN^2.$ $R.A. = 0.295 + 0.00874M + 0.022N - 0.0028M^2 - 0.00047MN - 7.7957 * 10^{-5}N^2 + 1.6726 * 10^{-5}M^2N + 3.831 * 10^{-7}MN^2.$ $Load = 219786 + 10774.7M + 101342N - 760.57M^2 - 49.62MN - 324.01N^2 + 25.93M^2N - 5.170MN^2.$ $Throughput = 1024103.64 + 19812.4M + 171328N - 4472.3M^2 + 9466.1MN - 351.9N^2 - 115.76M^2N - 41.12MN^2.$
DSR	$Delay = 25.7 + 0.45M + 41.75N - 0.0432M^2 - 7.172MN - 21.17N^2 + 4.02M^2N + 0.803MN^2.$ $R.A. = 0.286 - 0.0029M + 0.0268N + 6.076 * 10^{-5}M^2 - 0.000113MN - 0.000122N^2 + 2.51 * 10^{-6}M^2N + 5.984 * 10^{-7}MN^2.$ $Load = 1247915.53 - 33816.0M + 209941N + 2003.8M^2 + 1392.5MN - 475.83N^2 - 107.11M^2N + 15.83MN^2.$ $Throughput = 443568 + 1038.3M + 34806.2N - 216.44M^2 + 438.41MN - 197.49N^2 - 4.536M^2N - 2.833MN^2.$
OLSR	$Delay = 0.502 - 0.097M + 1.235N + 0.124M^2 + 0.117MN - 1.006N^2 - 0.301M^2N + 0.223MN^2.$ $R.A. = 0.59 - 0.0067M + 0.00405N + 0.000367M^2 + 5.076 * 10^{-6}MN - 6.751 * 10^{-5}N^2 - 8.7024 * 10^{-6}M^2N + 1.621 * 10^{-6}MN^2.$ $Load = -44161 - 8241.4M + 131161N + 600.05M^2 - 5209MN - 794.36N^2 - 19.87M^2N + 7.108MN^2.$ $Throughput = 973381 - 10041.3M - 37753.3N + 279.18M^2 + 877.23MN + 2173.5N^2 - 19.44M^2N - 5.634MN^2.$
GRP	$Delay = 3.927 - 0.04926M - 0.421N + 0.170M^2 - 1.596MN + 4.902N^2 + 0.657M^2N + 0.768MN^2.$ $R.A. = 0.56 - 0.00372M + 0.0055N + 0.000169M^2 - 0.000172MN + 9.215 * 10^{-6}N^2 + 4.047 * 10^{-6}M^2N + 9.277 * 10^{-7}MN^2.$ $Load = -353060 - 11157M + 152350N + 1042.8M^2 - 1067.9MN - 309.4N^2 + 0.785M^2N + 12.28MN^2.$ $Throughput = 211466 - 1584.7M + 96784.1N + 15.18M^2 + 359.42MN - 618.84N^2 - 11.73M^2N + 0.145MN^2.$
TORA	$Delay = 17.58 - 2.879M - 20.35N + 3.34M^2 + 5.755MN + 40.67N^2 - 8.925M^2N + 6.77.1MN^2.$ $R.A. = 0.348 - 0.00349M + 0.0165N + 0.000325M^2 - 0.000156MN - 2.276 * 10^{-5}N^2 - 1.138 * 10^{-6}M^2N + 1.459 * 10^{-6}MN^2.$ $Load = 262102 + 29876.3M + 52947.1N - 1943.3M^2 - 484.6MN - 351.03N^2 + 75.87M^2N - 14.02MN^2.$ $Throughput = 393417 + 9583.1M + 41691.5N - 561.06M^2 + 48.57MN - 342.34N^2 + 8.093M^2N - 2.518MN^2.$

The equations modeled the performance parameters for AODV, as shown in subfigures (a), (b), (c), and (d) in Figure 6.10.

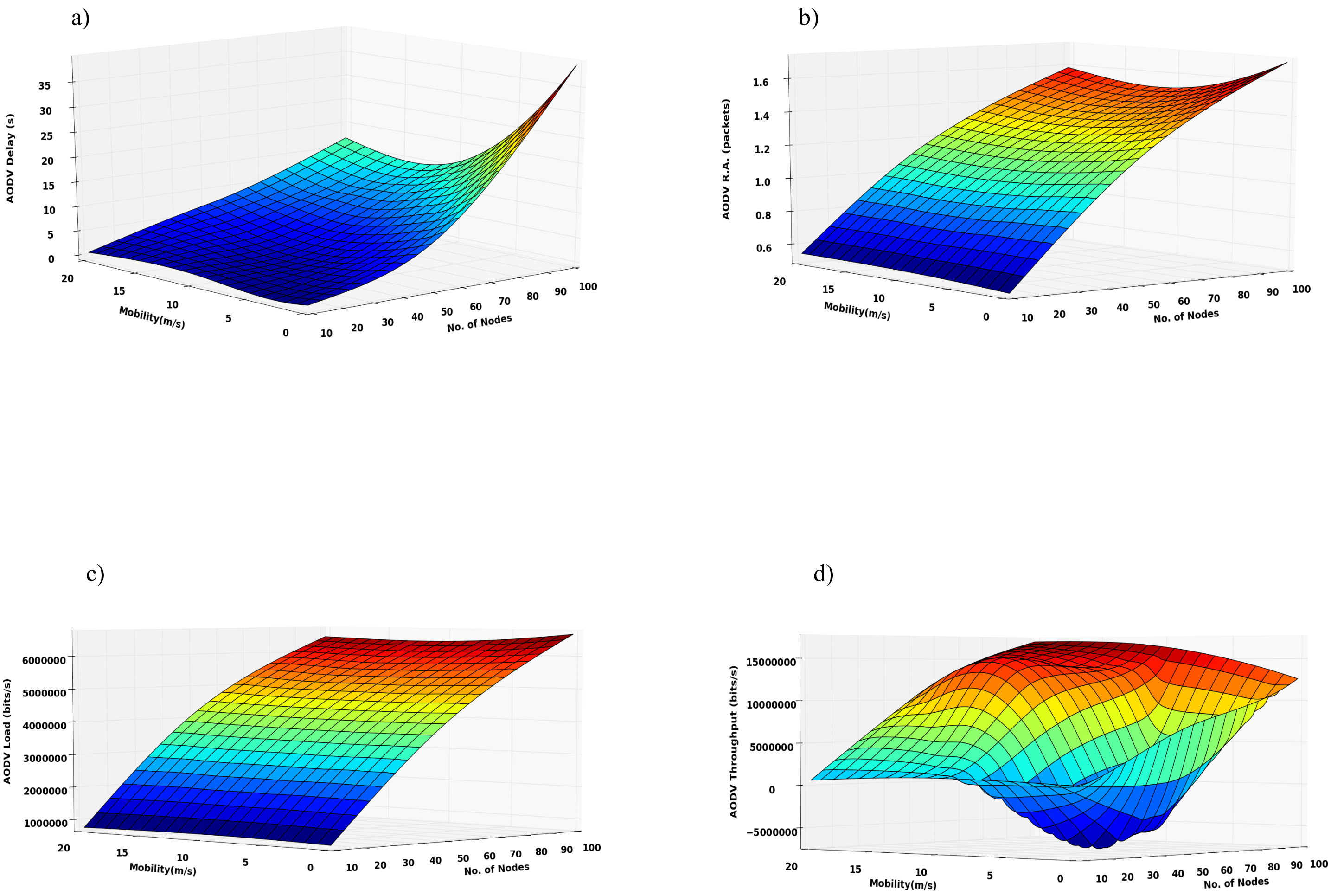


Figure 6.10: MANET output performance RE models using AODV routing protocol.

The equations modeled the performance parameters for DSR, as shown in subfigures (a), (b), (c), and (d) in Figure 6.11.

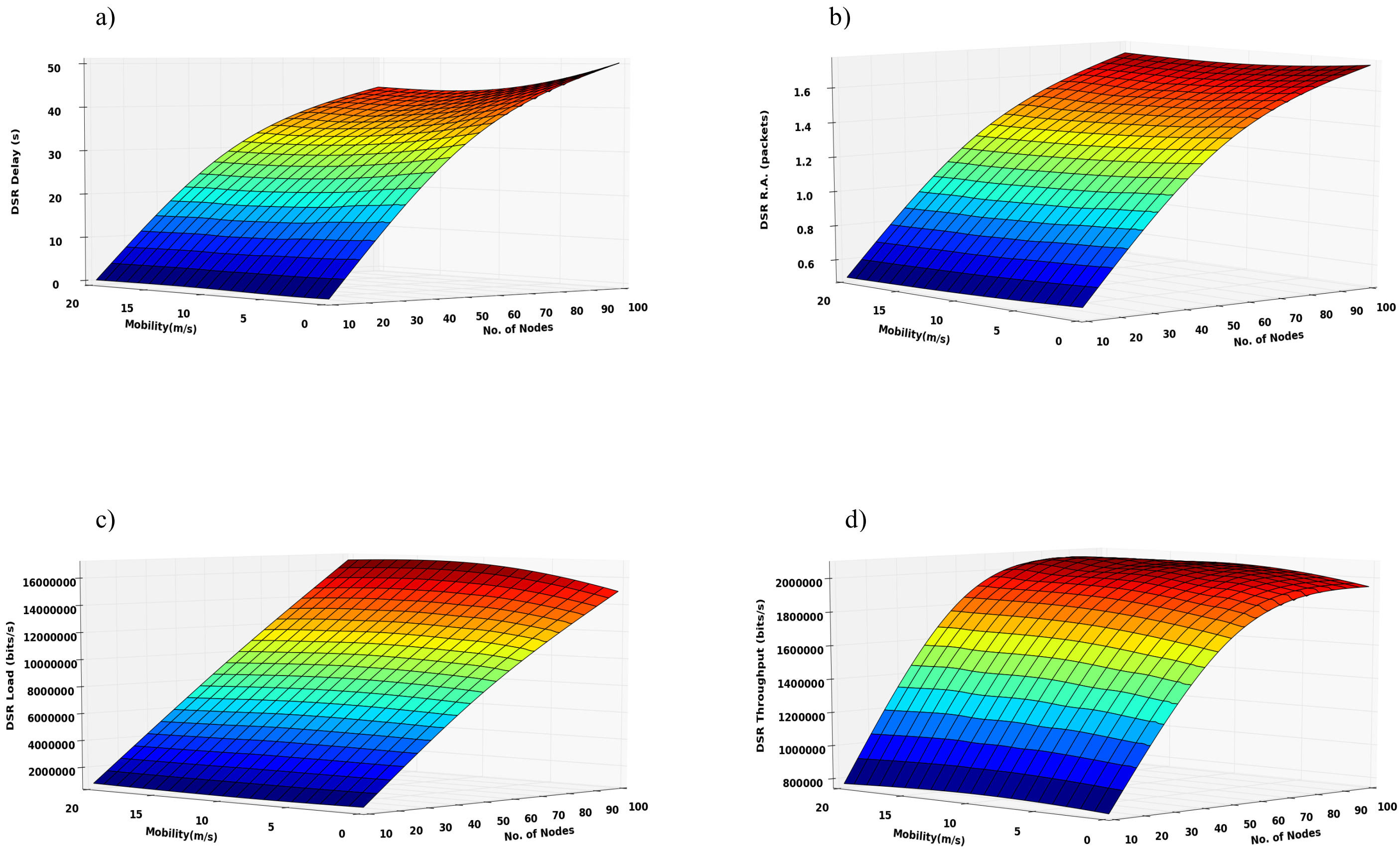


Figure 6.11: MANET output performance RE models using DSR routing protocol.

The equations modeled the performance parameters for OLSR, as shown in subfigures (a), (b), (c), and (d) in Figure 6.12.

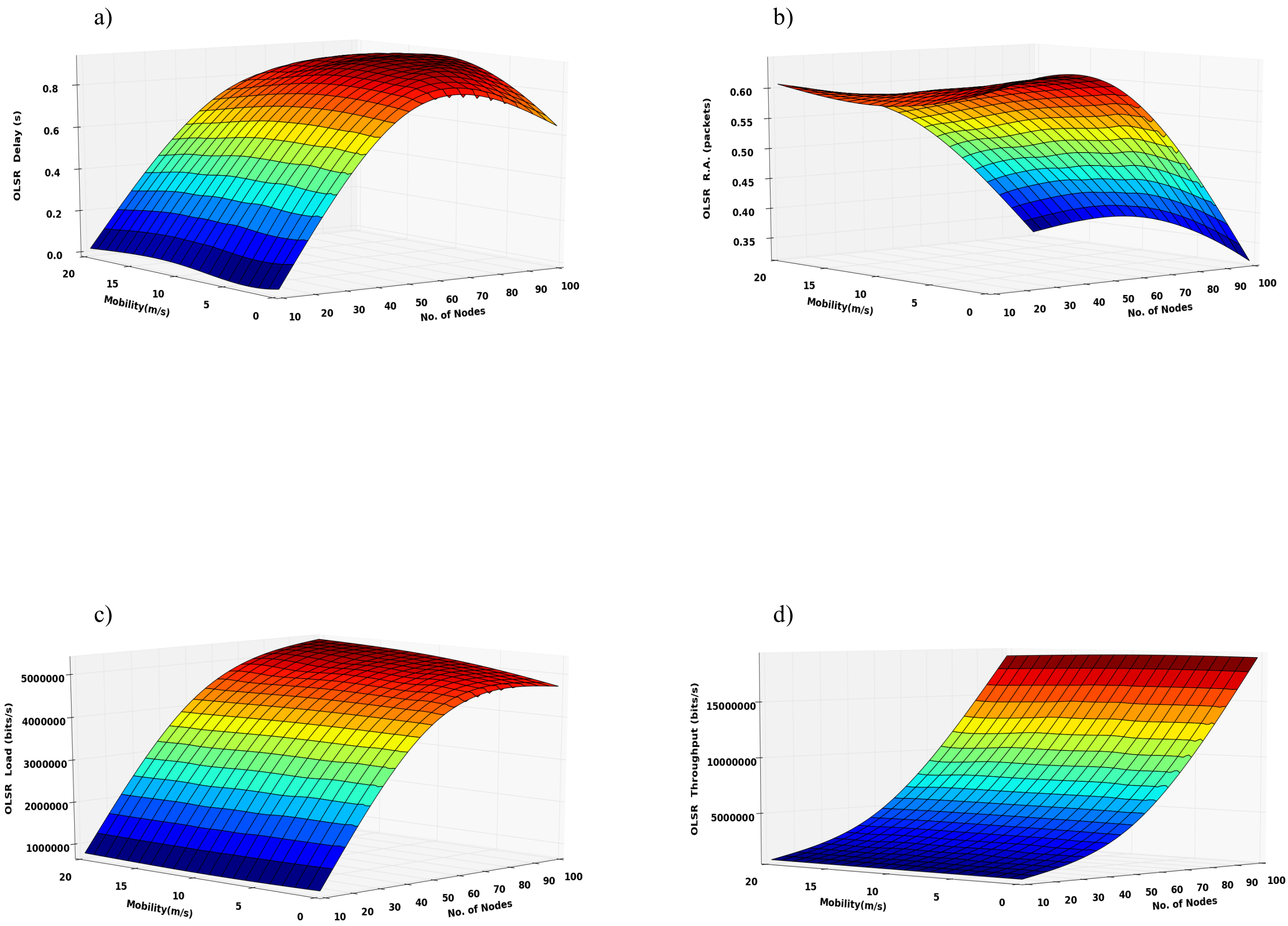
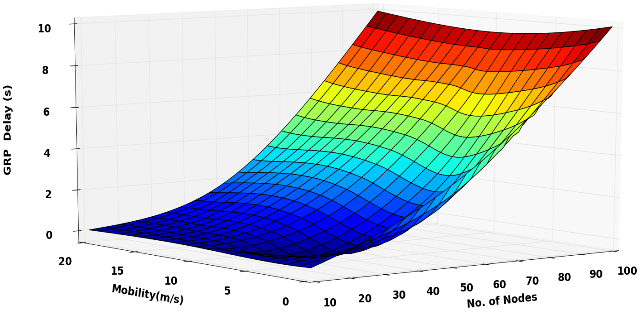


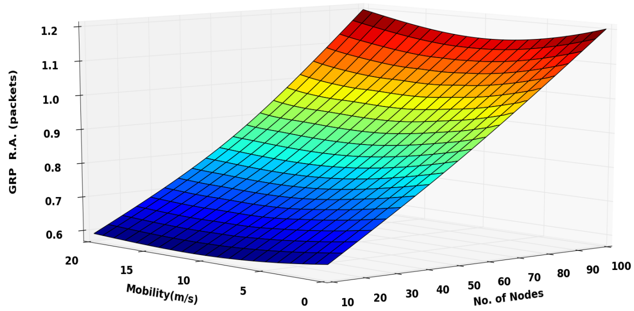
Figure 6.12: MANET output performance RE models using OLSR routing protocol.

The equations modeled the performance parameters for GRP, as shown in subfigures (a), (b), (c), and (d) in Figure 6.13.

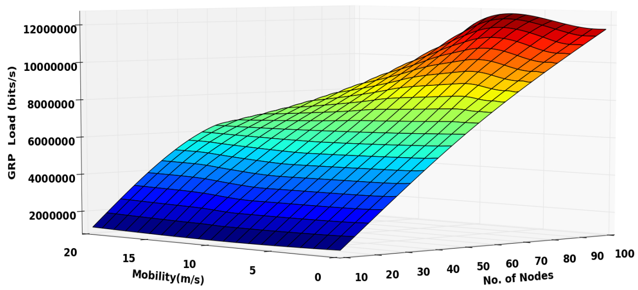
a)



a)



c)



d)

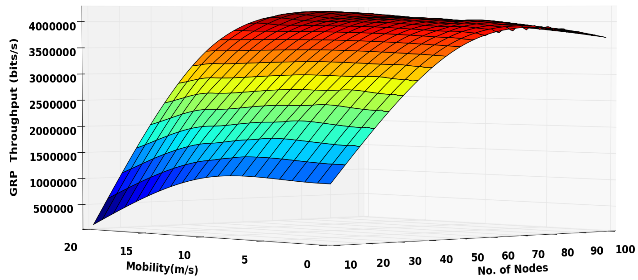


Figure 6.13: MANET output performance RE models using GRP routing protocol.

The equations modeled the performance parameters for TORA, as shown in subfigures (a), (b), (c), and (d) in Figure 6.14.

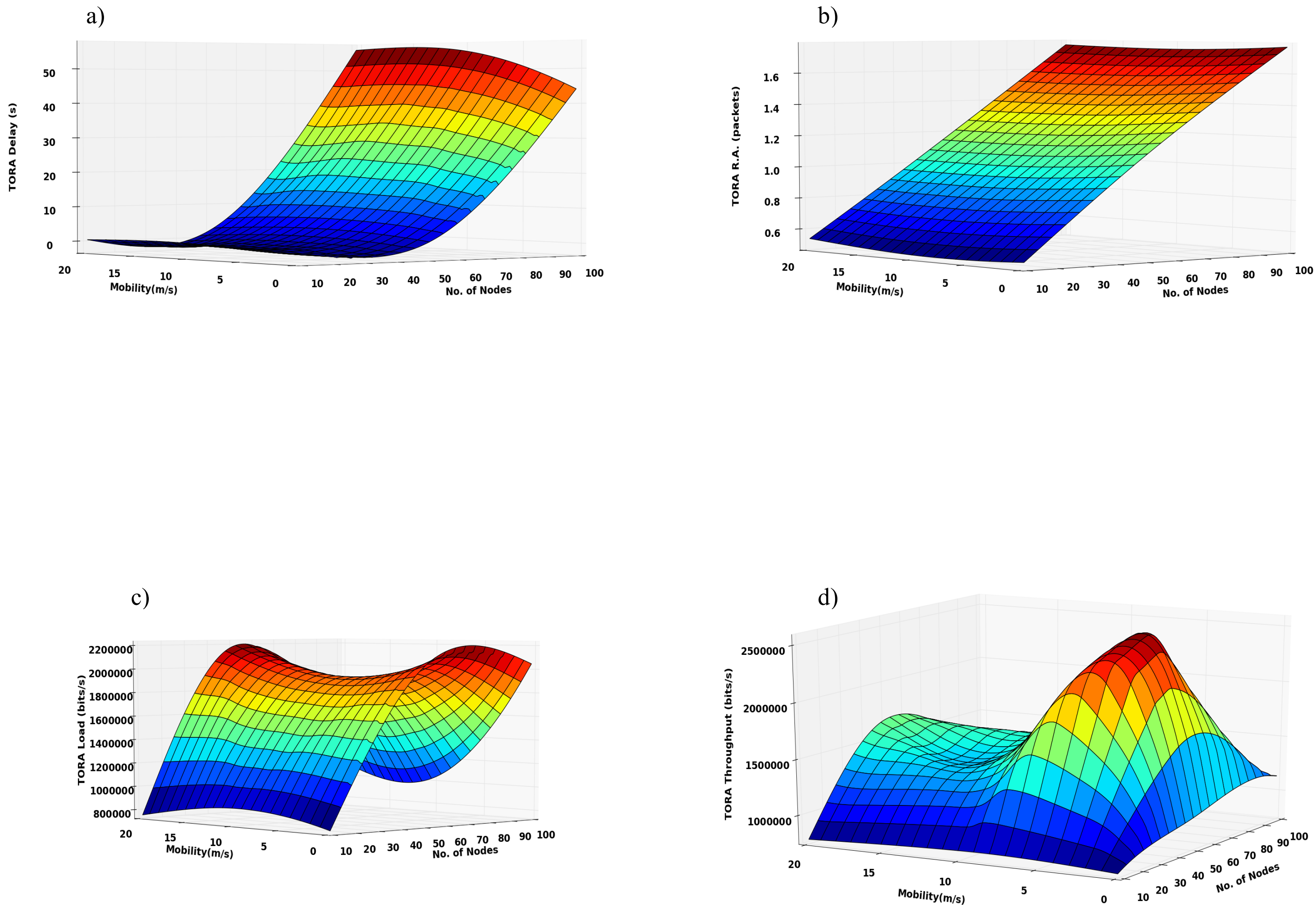


Figure 6.14: MANET output performance RE models using TORA routing protocol.

Video Conferencing Application:

Table 6.2 shows four equations that represent the output network performance for each routing protocol. Based on Equation (6.1) in section 6.3, the MANET regression equation were second order, where M is the average mobility and N is the network size.

Table 6.3: MANET performance parameter's regression equation results from five operating routing protocols

AODV	$Delay = 7.2813 - 4.231M - 9.07N + 4.367M^2 + 13.4MN + 16.57N^2 - 13.31M^2N + 0.896MN^2.$ $R.A. = 0.119 - 0.016M + 0.026N + 0.00059M^2 + 0.00051MN - 0.00012N^2 - 1.698 * 10^{-5}M^2N - 1.503 * 10^{-6}MN^2.$ $Load = 7454879.43 + 1508084.2M + 2667030.6N - 74358.7M^2 - 52620.5MN - 13116.7N^2 + 2249.2M^2N + 32083MN^2.$ $Throughput = 13560087 - 476117M - 129823N + 23915.1M^2 + 24211.8MN + 1722.5N^2 - 1168.3M^2N + 17.6MN^2.$
DSR	$Delay = 33.61 - 10.92M + 56.32N + 12.27M^2 + 27.72MN - 35.32N^2 - 32.36M^2N + 3.55MN^2.$ $R.A. = 0.08415 - 0.00862M + 0.033N + 0.0004M^2 - 2.1443 * 10^{-6}MN - 0.00017N^2 - 6.743 * 10^{-6}M^2N + 1.348 * 10^{-6}MN^2.$ $Load = 13672588.43 - 808643M + 3560422.2N + 46521M^2 + 41689.3MN - 8430N^2 - 3076.1M^2N + 466.27MN^2.$ $Throughput = 16223116.05 + 30339.9M - 4009002N - 4784.2M^2 - 507.89MN + 2765.2N^2 + 152.14M^2N - 17.03MN^2.$
OLSR	$Delay = 7.19 * 10^{-5} + 1.02 * 10^{-8}M + 9.985 * 10^{-7}N - 6.562 * 10^{-10}M^2 - 1.202 * 10^{-9}MN + 2.512 * 10^{-9}N^2 + 6.49 * 10^{-11}M^2N - 3.822 * 10^{-12}MN^2.$ $R.A. = 0.275 - 0.00034M + 0.00213N + 0.000067M^2 + 6.024 * 10^{-8}MN - 4.051 * 10^{-6}N^2 - 5.7043 * 10^{-7}M^2N + 0.712 * 10^{-7}MN^2$ $Load = 117.87 + 37.68M + 249.15N - 1.953M^2 - 1.557MN + 15.87N^2 + 0.0814M^2N - 0.00104MN^2.$ $Throughput = 787883 + 3713.7M - 102714N - 190.87M^2 - 150.35MN + 2785.1N^2 + 7.854M^2N - 0.0894MN^2.$
GRP	$Delay = 8.16187 * 10^{-5} - 3.27383 * 10^{-6}M - 4.70067 * 10^{-7}N + 1.4507 * 10^{-7}M^2 + 1.544 * 10^{-7}MN + 8.971 * 10^{-9}N^2 - 5.505 * 10^{-9}M^2N + 3.4125 * 10^{-10}MN^2.$ $R.A. = 0.479 - 0.00057M + 0.00035N + 0.0003224M^2 + 9.096 * 10^{-7}MN - 2.551 * 10^{-5}N^2 - 9.2025 * 10^{-6}M^2N + 1.421 * 10^{-6}MN^2$ $Load = 2697.9 - 506.76M - 157.69N + 30.76M^2 + 13.07MN + 4.290N^2 - 1.266M^2N + 0.211MN^2.$ $Throughput = 451329 - 1392.2M - 299153N - 18347.4M^2 + 259292MN + 762528N^2 - 112528M^2N - 40245MN^2.$
TORA	$Delay = 16.84 - 1.254M - 24.23N + 1.785M^2 + 1.094MN + 45.5N^2 - 5.16M^2N + 6.645MN^2.$ $R.A. = 0.09415 + 0.00285M + 0.03263N + 9.85859 * 10^{-5}M^2 - 0.000347MN - 0.000157N^2 + 2.21182 * 10^{-6}M^2N + 2.39639 * 10^{-6}MN^2.$ $Load = 10843381.92 - 2076276.262M + 37989332.14N + 2872684.15M^2 - 18815371.21MN - 3697036.27N^2 + 8756014.26M^2N + 5535947.14MN^2.$

	$Throughput = 1799006.514 - 903432M - 1441025.178N + 555769M^2 + 243745MN + 637428N^2$.

The equations modeled the performance parameters for AODV, as shown in subfigures (a), (b), (c), and (d) in Figure 6.15.

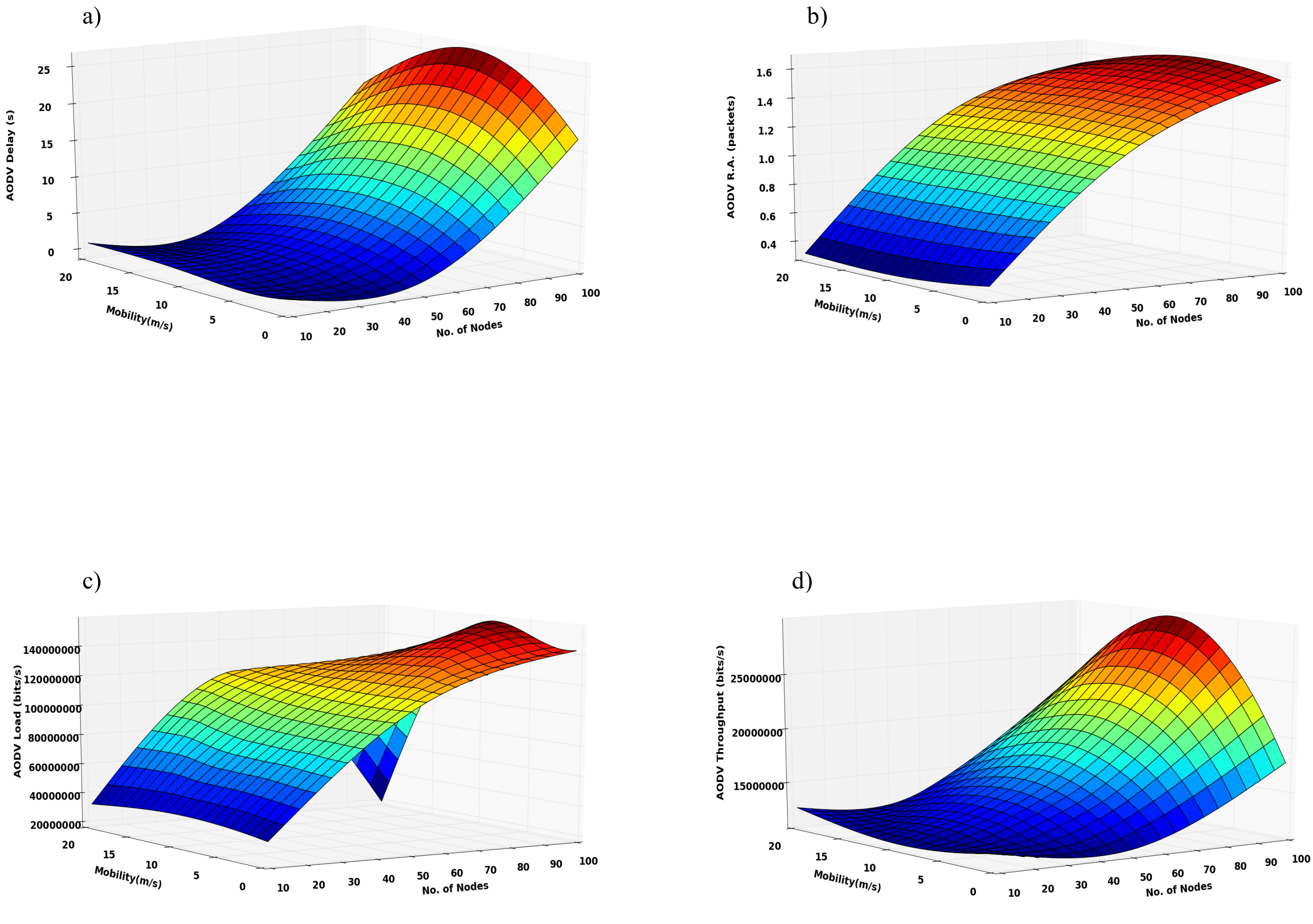


Figure 6.15: MANET output performance RE models using AODV routing protocol.

The equations modeled the performance parameters for DSR, as shown in subfigures (a), (b), (c), and (d) in Figure 6.16.

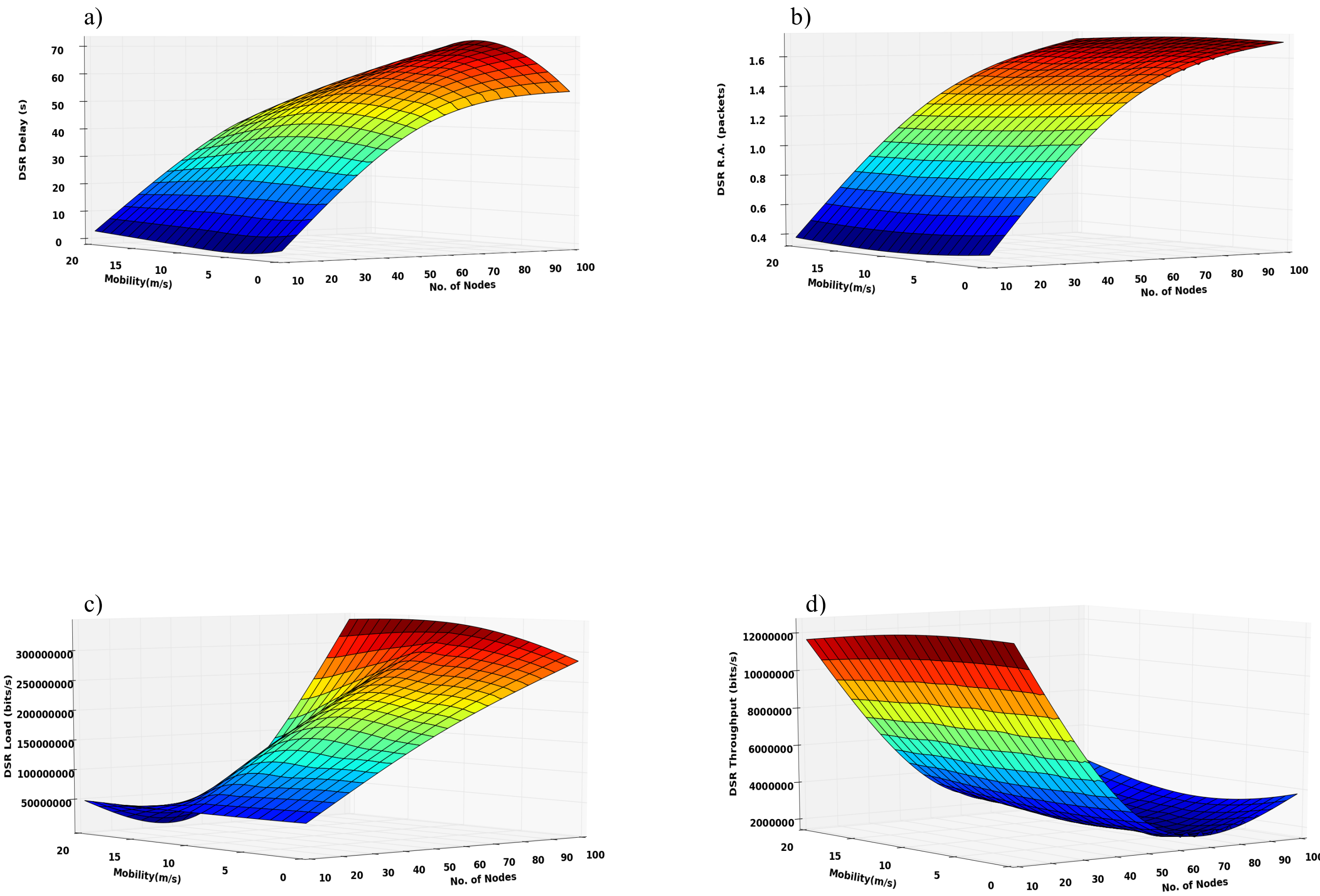


Figure 6.16: MANET output performance RE models using DSR routing protocol.

The equations modeled the performance parameters for OLSR, as shown in subfigures (a), (b), (c), and (d) in Figure 6.17.

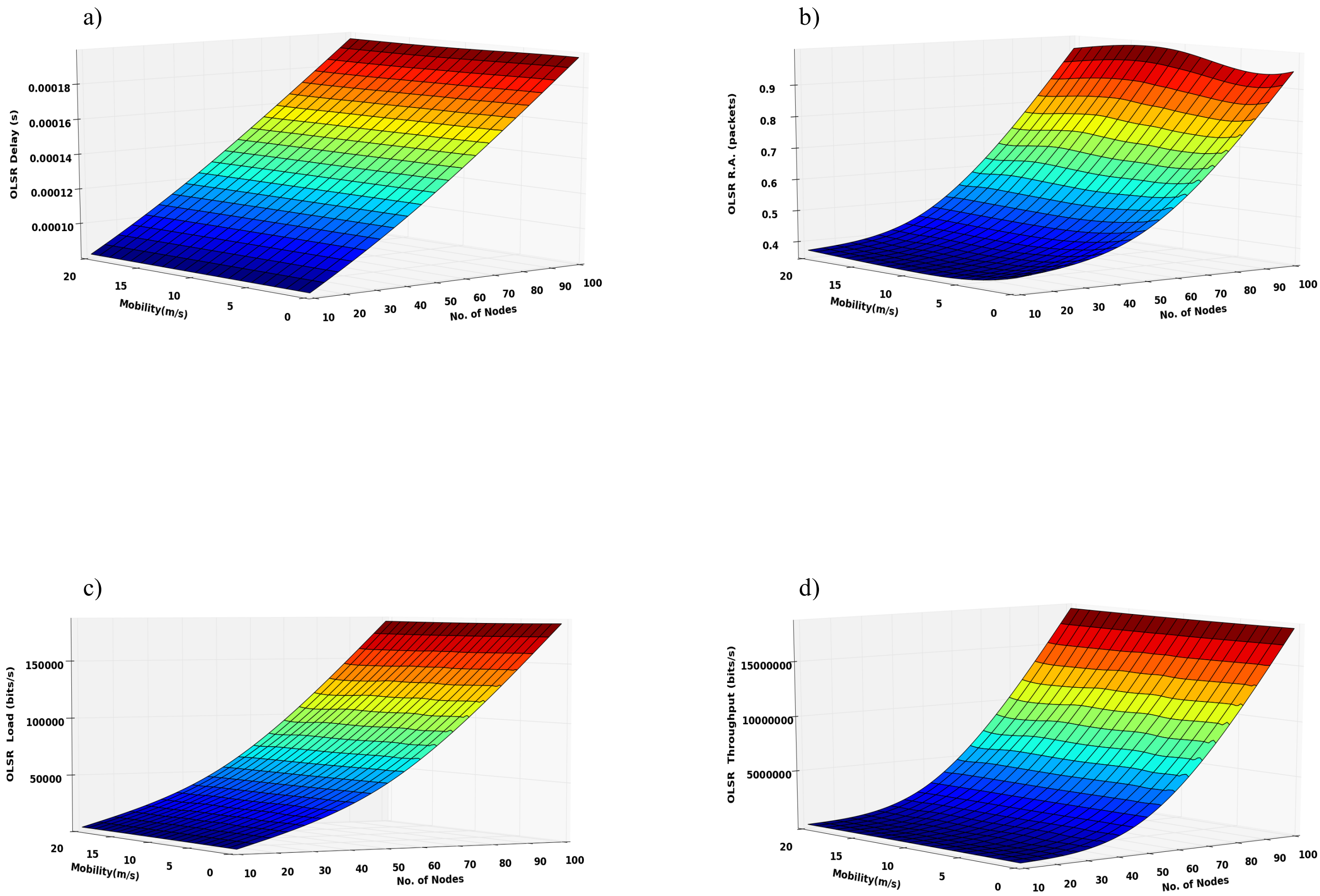


Figure 6.17: MANET output performance RE models using OLSR routing protocol.

The equations modeled the performance parameters for GRP, as shown in subfigures (a), (b), (c), and (d) in Figure 6.18.

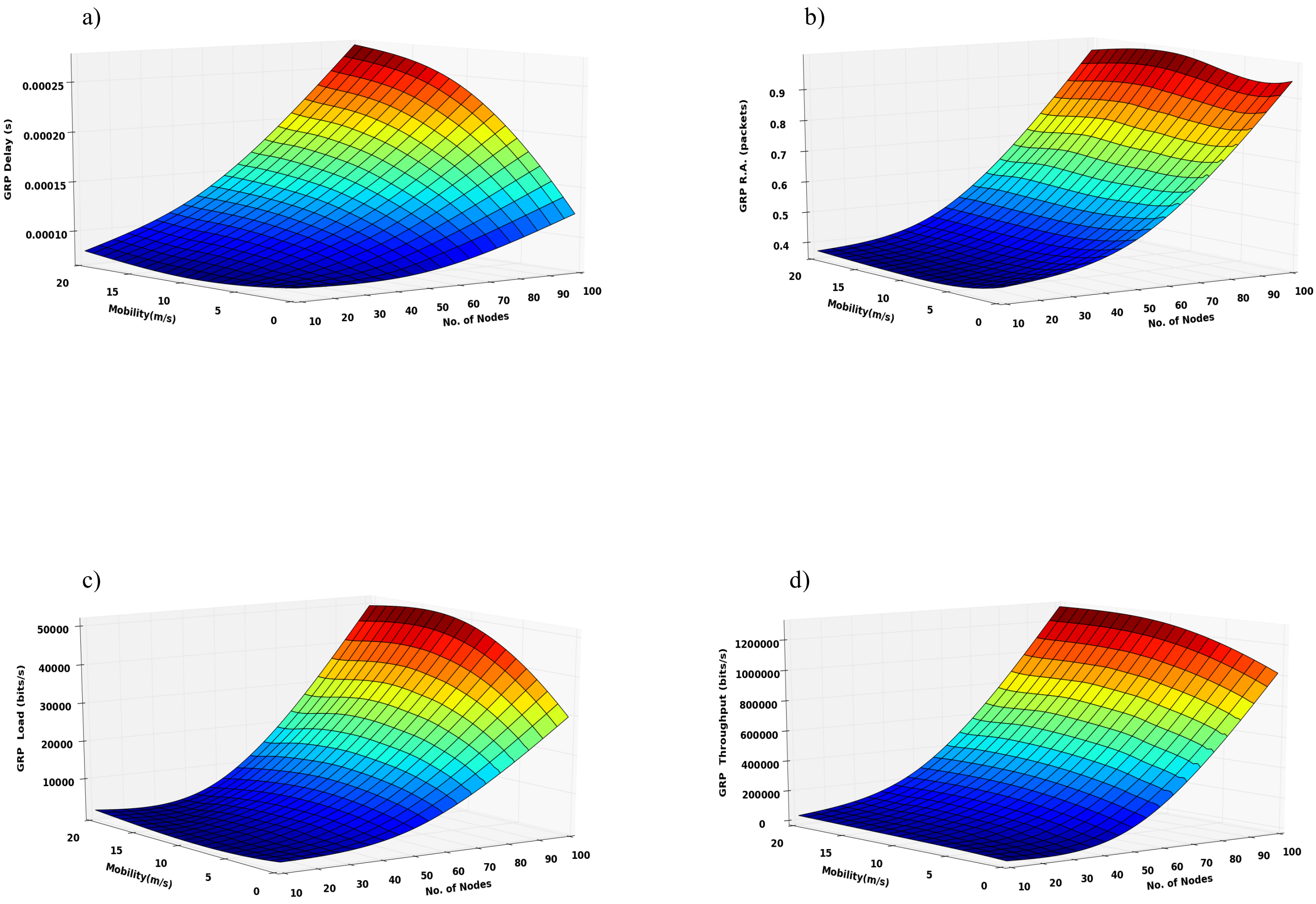
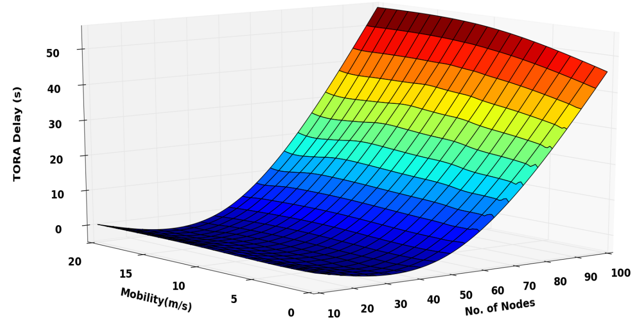


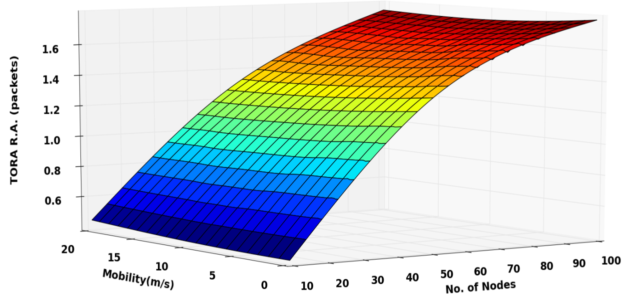
Figure 6.18: MANET output performance RE models using GRP routing protocol.

The equations modeled the performance parameters for TORA, as shown in subfigures (a), (b), (c), and (d) in Figure 6.19.

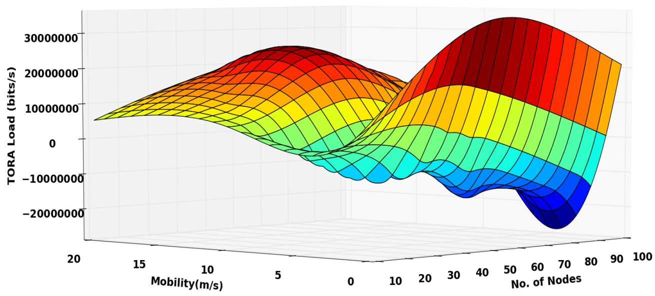
a)



b)



c)



d)

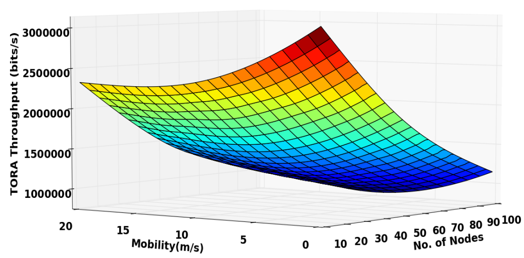


Figure 6.19: MANET output performance RE models using TORA routing protocol.

6.5.2 ANN MANET Models

The three layers for the created ANN modular are: input, hidden, and output. Moreover, feed forwarded back propagation network was employed as shown in Figure (6.20). The neural modular was programmed by MATLAB™.

For each MANET routing protocol (AODV, DSR, OLSR, GRP, and TORA), four ANN models were trained for each of the applications (FTP, VoIP, and Videoconferencing). Every model represents one for the five performance parameters (ANN models output) versus the network context (two nodes inputs in ANN model); 10 epochs were set for training. The number models were established for each application and for the five routing protocols are 20 models, thus, the total numbers of models are 60 ANN models.

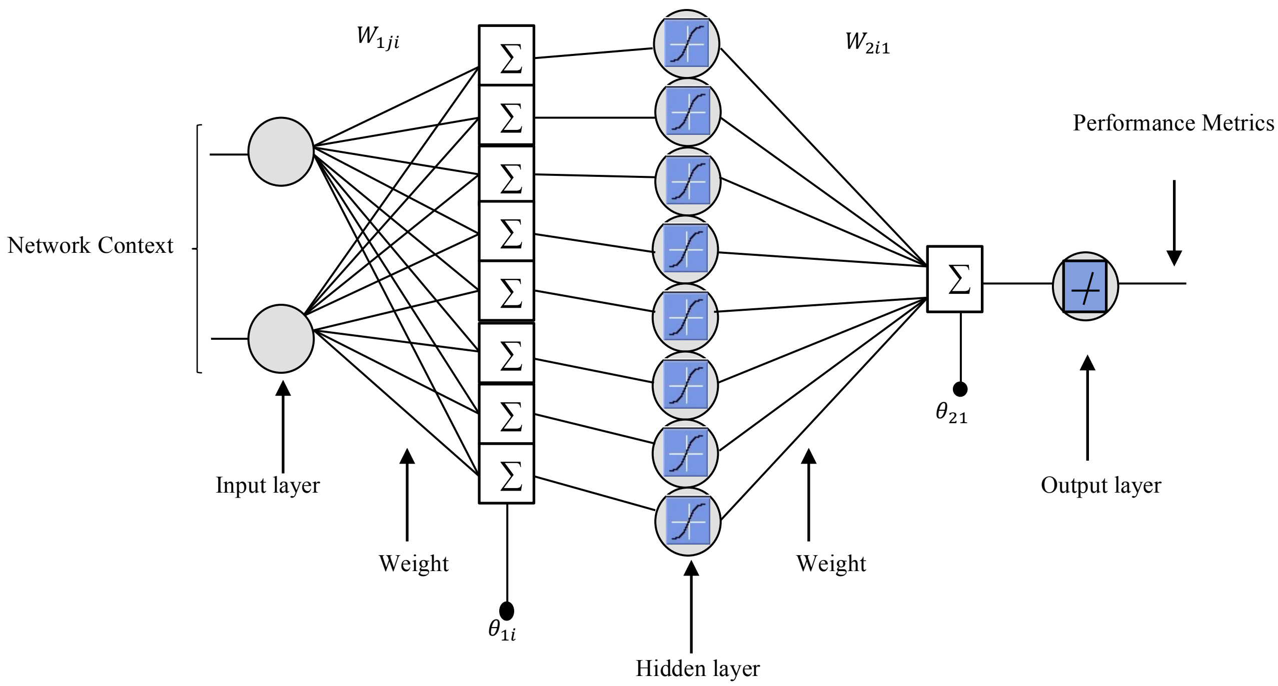


Figure 6.20: ANN model for MANET.

The number of neurons in each layer as follows:

- Input layer: two neurons.
- Hidden layer: eight neurons.
- Output layer: one neuron.

Hyperbolic tangent sigmoid function was used in the hidden layer neurons to compute the output layer, as presented in Equation (6.10) [78]. The transfer function is equal to the $tanh$ function mathematically.

$$Tansig\ (n) = \frac{2}{\left(1+exp(2n)\right)^{-1}} \tag{6.10}$$

where n is defied as

$$n = \sum_{j=1}^{k} w_{1\ ji} x_i + \theta_{1i} \tag{6.11}$$

The first layer to node j is x_j; the weight between no j in the first layer and node i in the hidden layer is $w1ji$. Where the bias of node i in the hidden layer is θ_{1i}, whereas, the weight between the node in the output layer and node i in the hidden layer is w_{2i1}. The linear transfer function in Equations (6.7) and (6.8) are used in the output layer y. The predicted MANET performance denoted by y as shown in Figure 6.20 can be expressed by the Equation (6.12).

$$y = purelin(\sum_{i=1}^{8} w_{2i1} \times Transig\ (n) + \theta_{21}) \tag{6.12}$$

The following pages shows the subfigures (a), (b), (c), and (d) for MANET performance 3D shapes for ANN models for every routing protocol and three applications. The model shows the response of each protocol parameter based to the two network contexts as each subfigure represent one of the four performance metrics. For instance, subfigure (d) Figure 6.23 represents OLSR throughput response to mobility range from 0 to 20 and network sizes 10, 50, and 100 nodes.

These 3D Figures can be compared with the MANET 3D original performance models in Chapter 5.

FTP Application:

MANET performance 3D shapes for ANN models for each routing protocol are as follows:

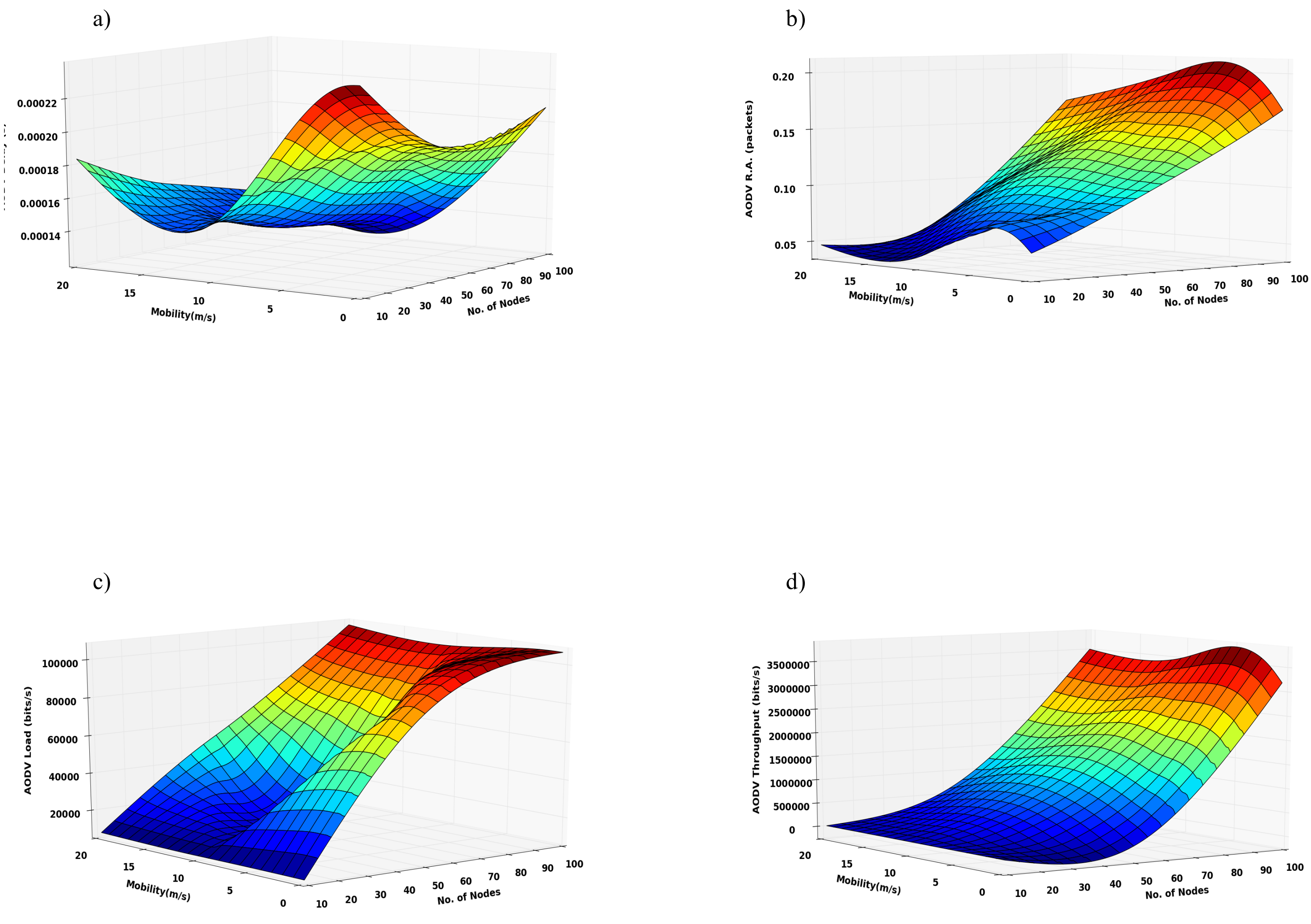


Figure 6.21: MANET output performance ANN models using AODV routing protocol.

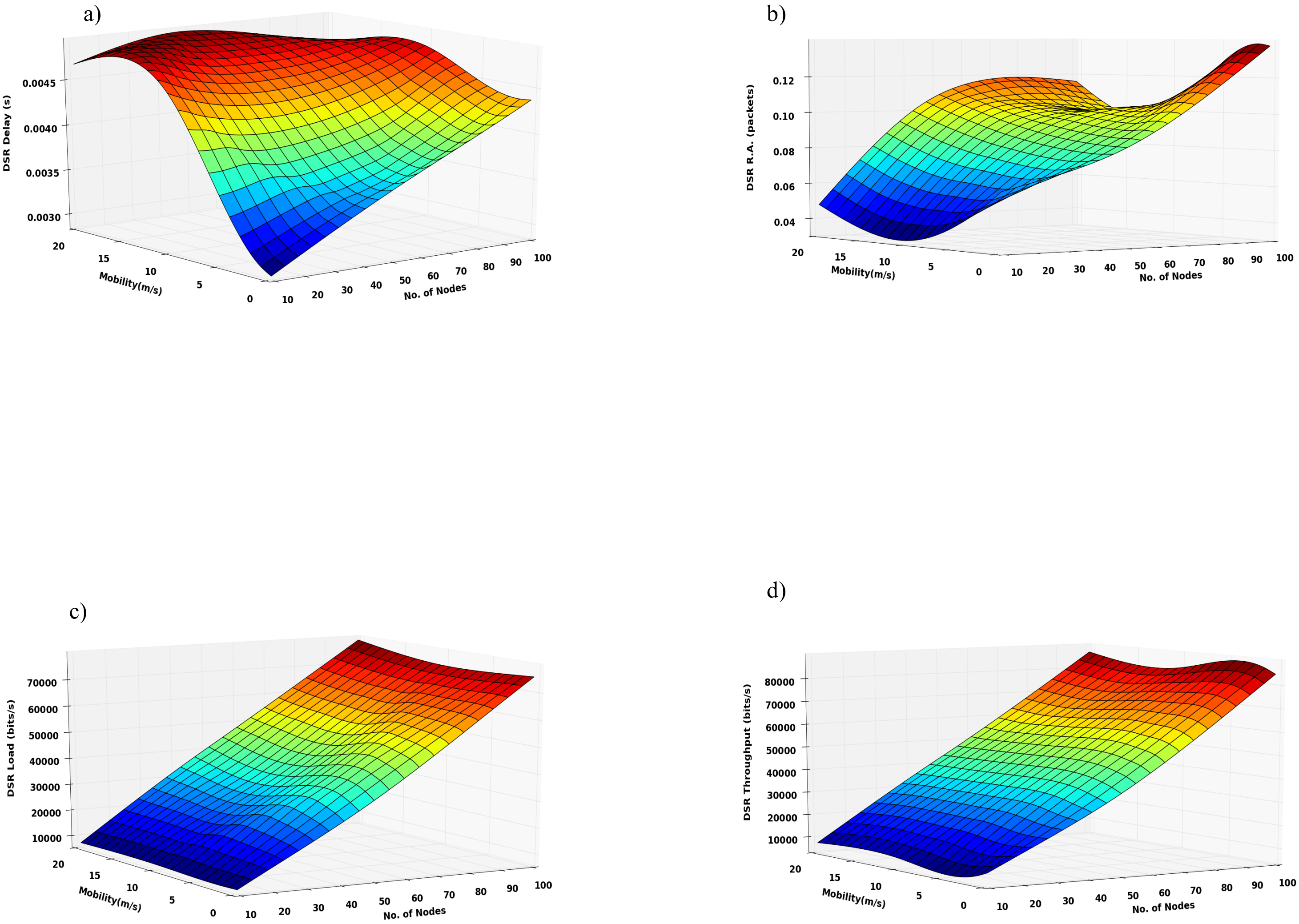


Figure 6.22: MANET output performance ANN models using DSR routing protocol.

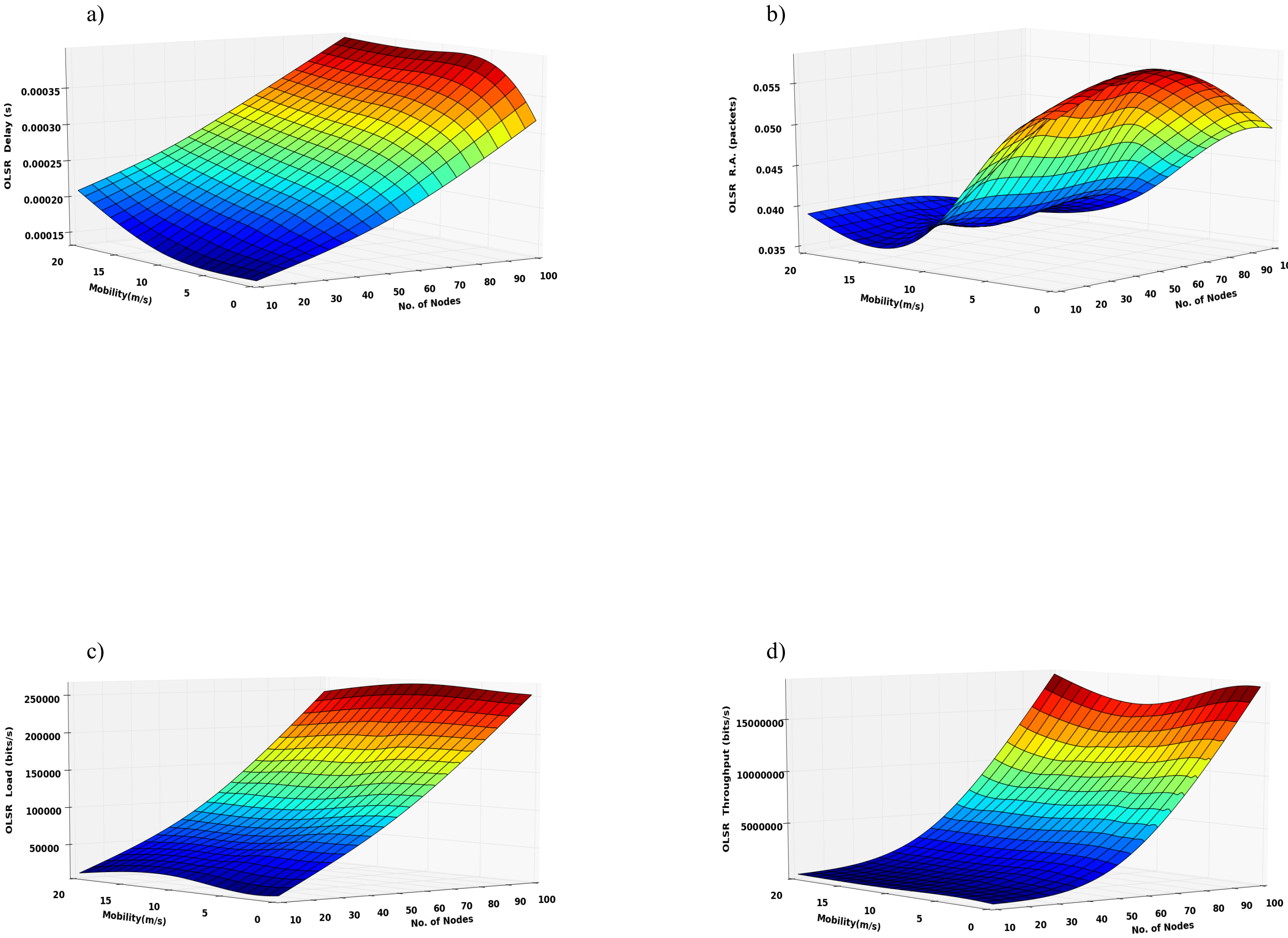


Figure 6.23: MANET output performance ANN models using OLSR routing protocol.

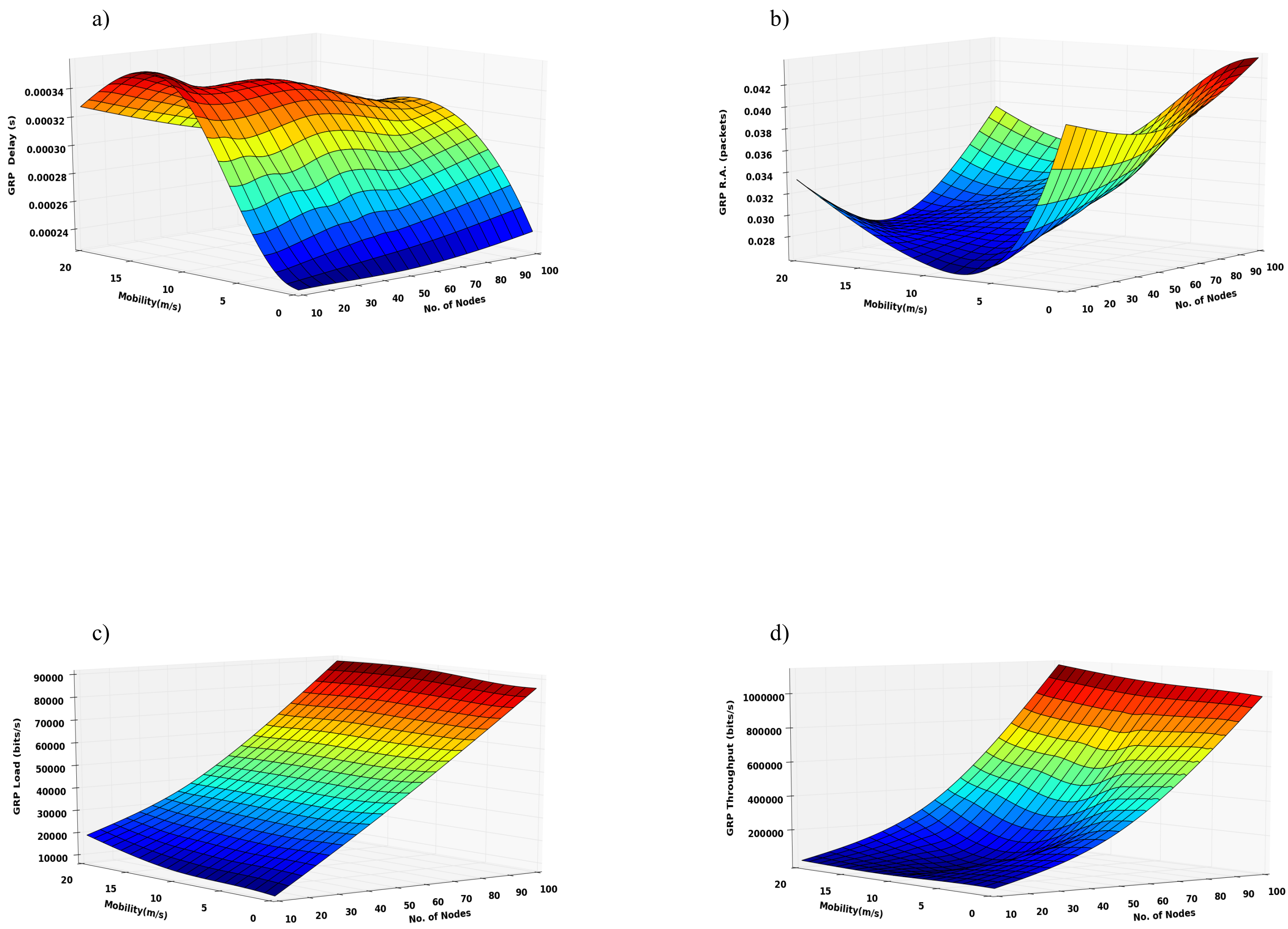


Figure 6.24: MANET output performance ANN models using GRP routing protocol.

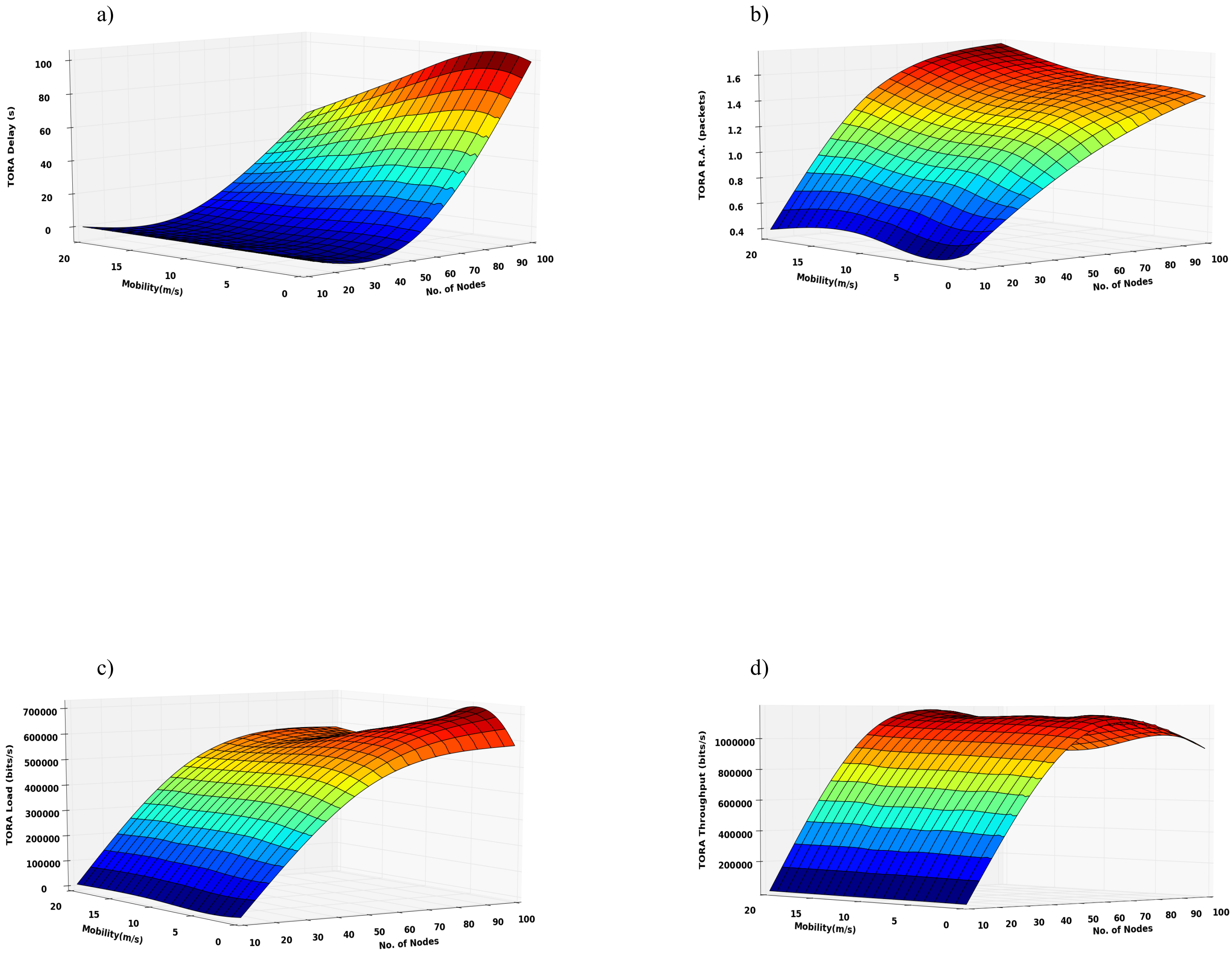


Figure 6.25: MANET output performance ANN models using TORA routing protocol.

VoIP Application:

MANET performance 3D shapes for ANN models for each routing protocol are as follows:

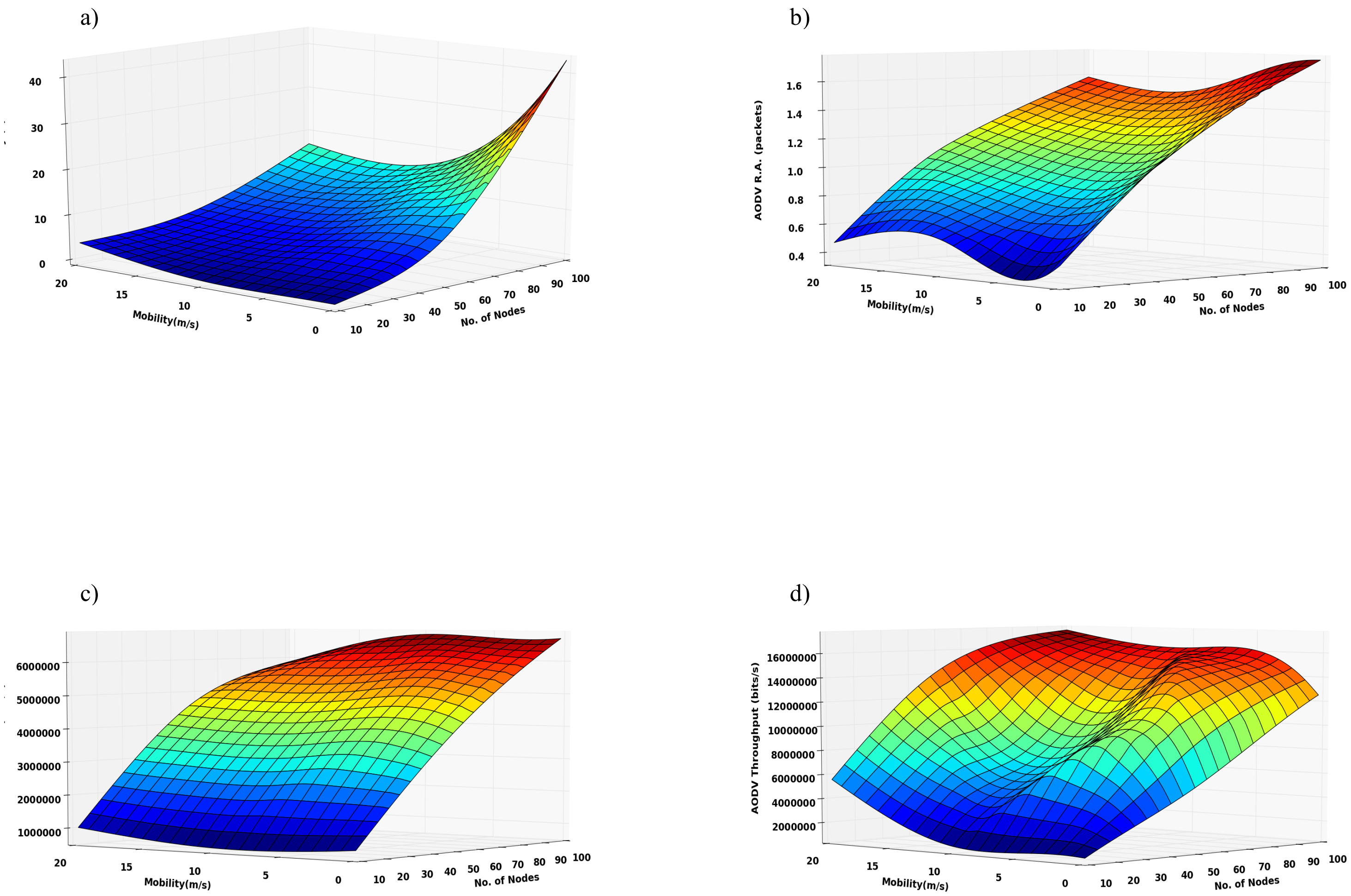


Figure 6.26: MANET output performance ANN models using AODV routing protocol.

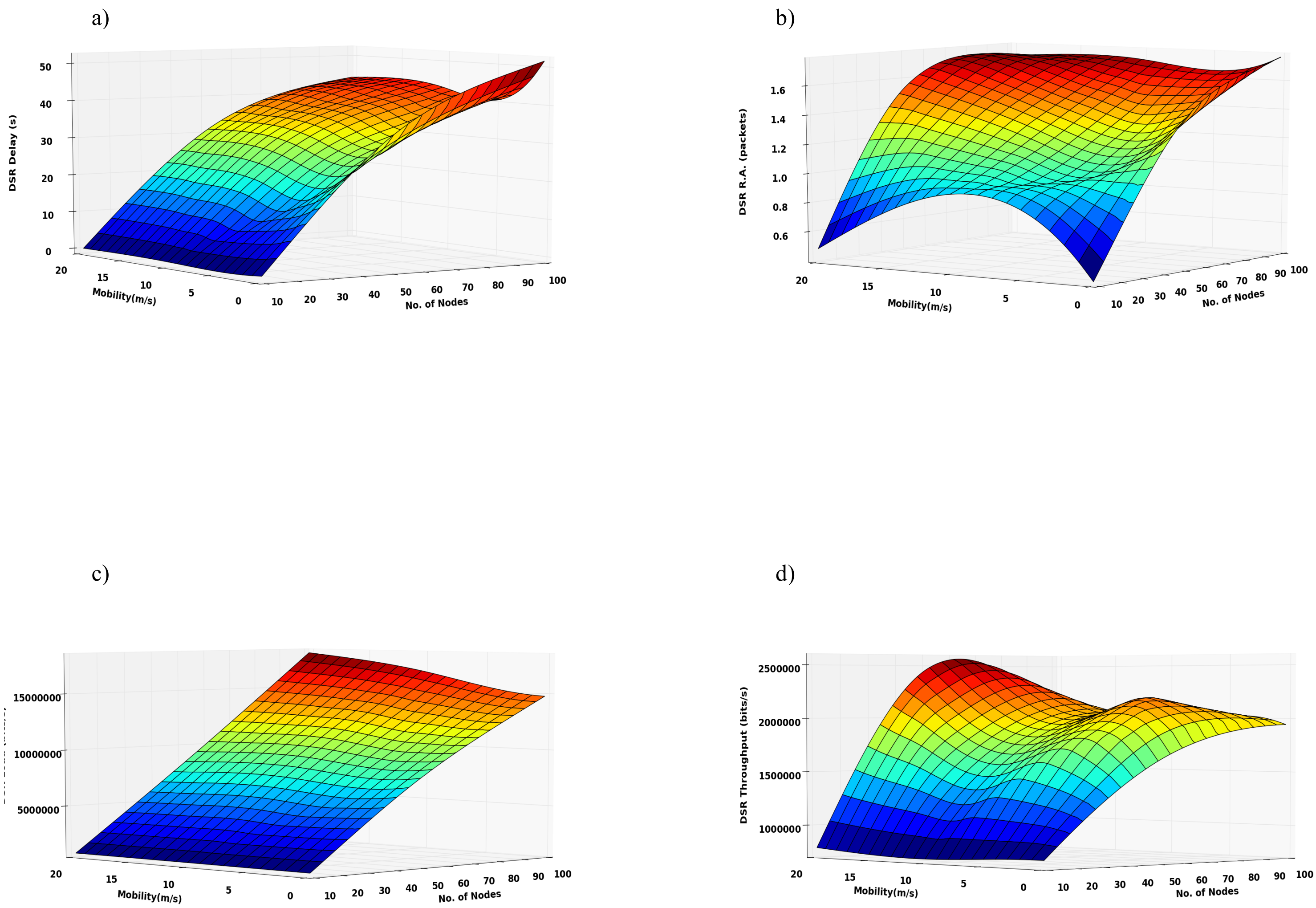


Figure 6.27: MANET output performance ANN models using DSR routing protocol.

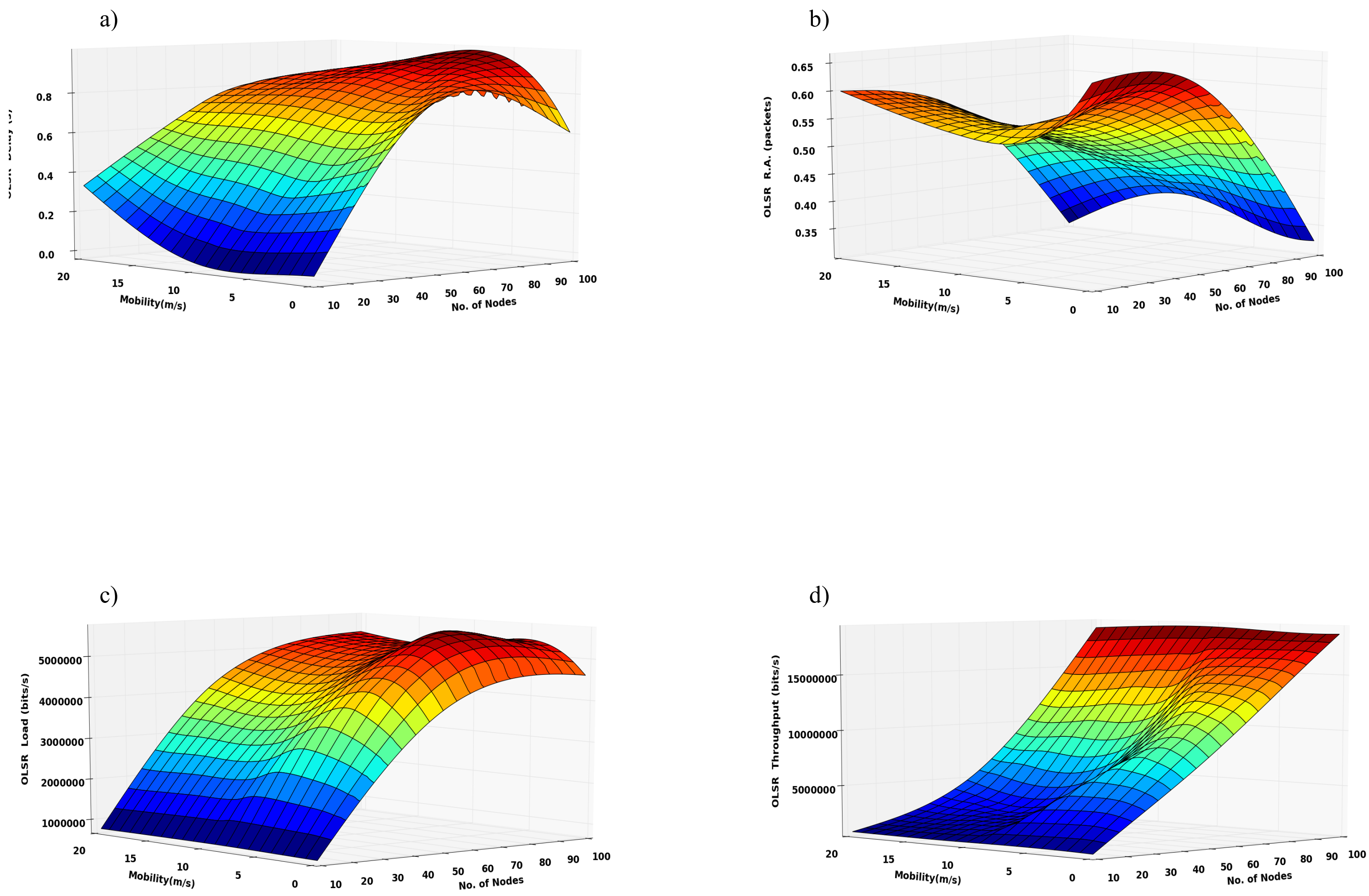


Figure 6.28: MANET output performance ANN models using OLSR routing protocol.

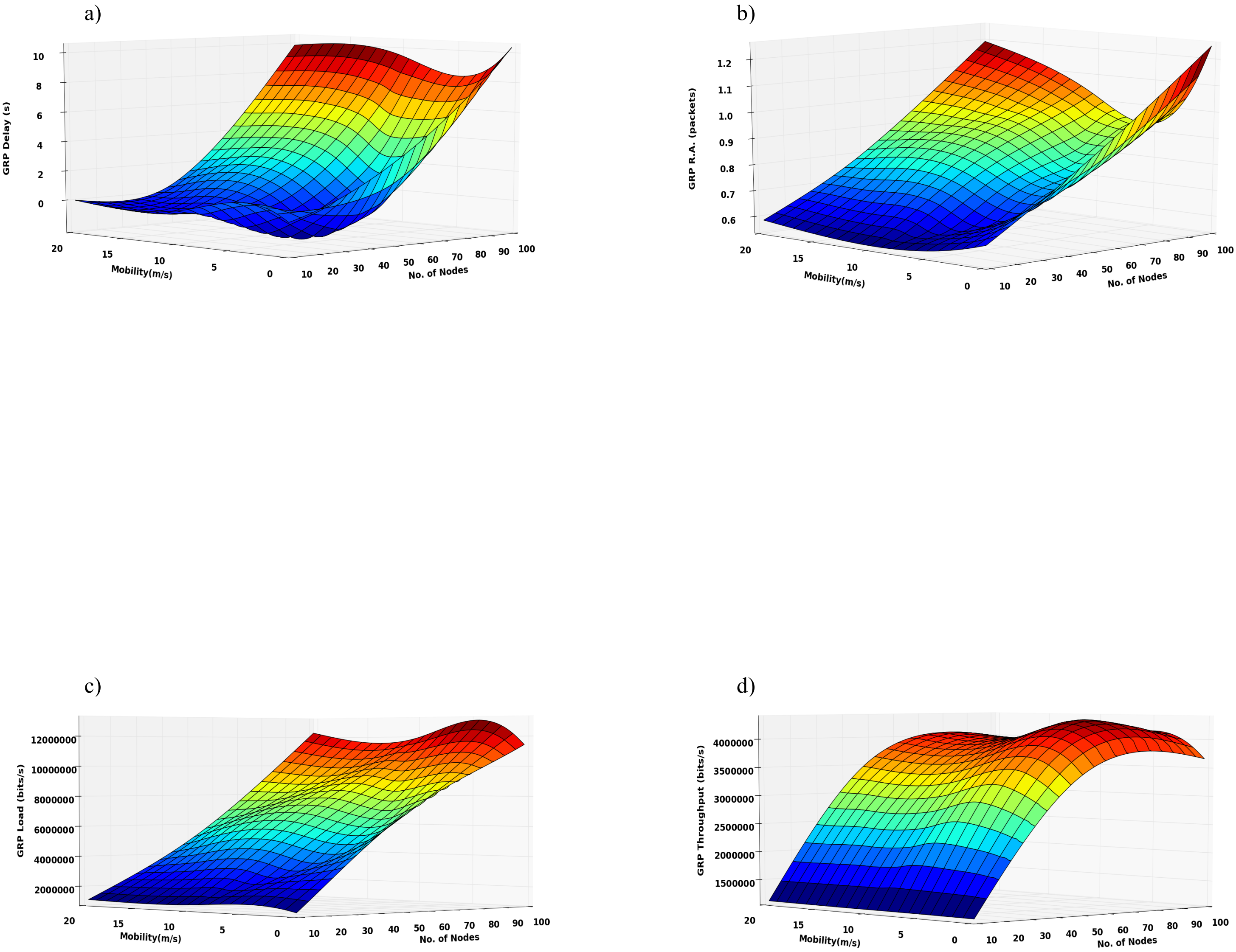


Figure 6.29: MANET output performance ANN models using GRP routing protocol.

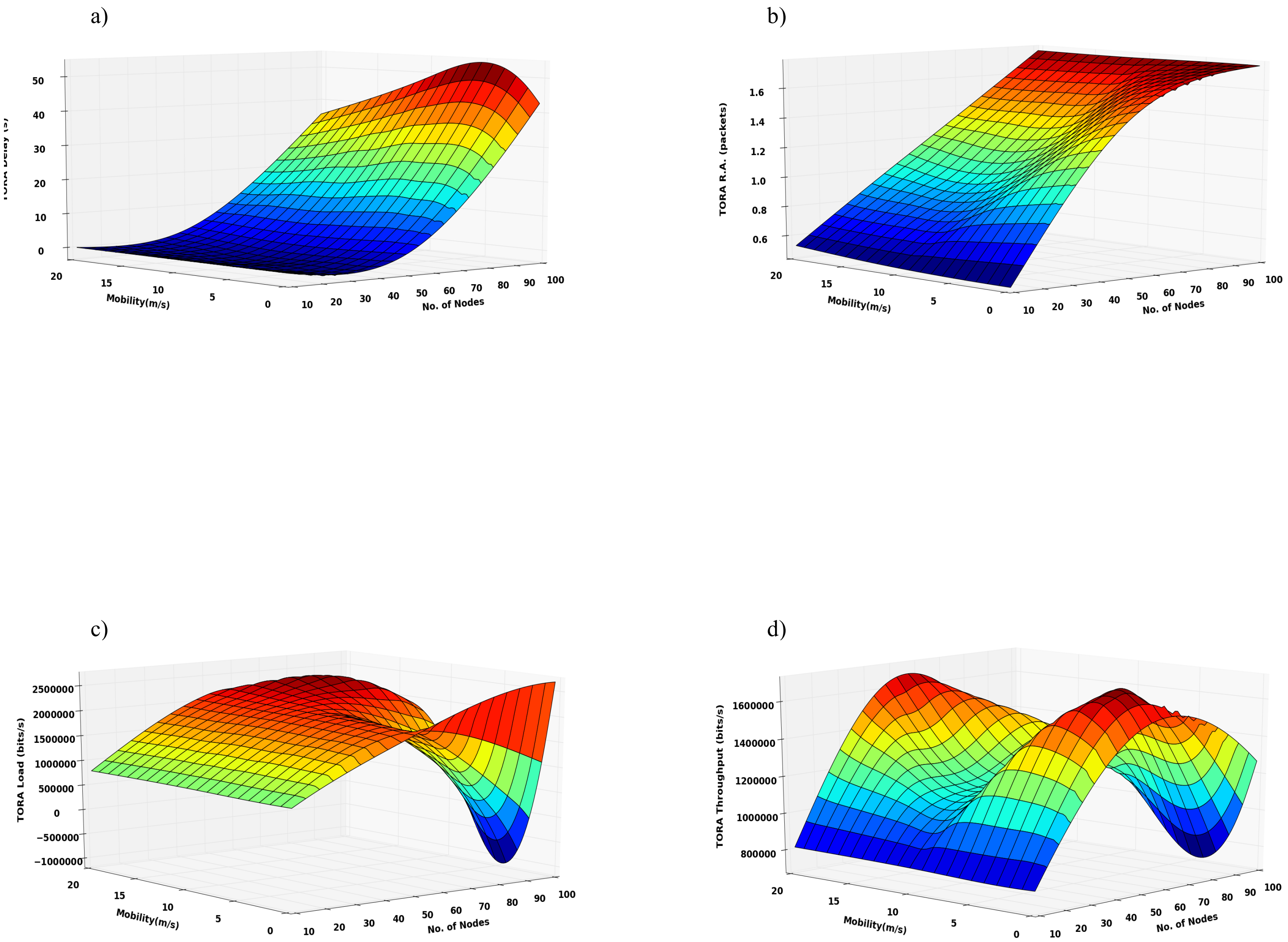


Figure 6.30: MANET output performance ANN models using TORA routing protocol.

Videoconferencing Application:

MANET performance 3D shapes for ANN models for each routing protocol are as follows:

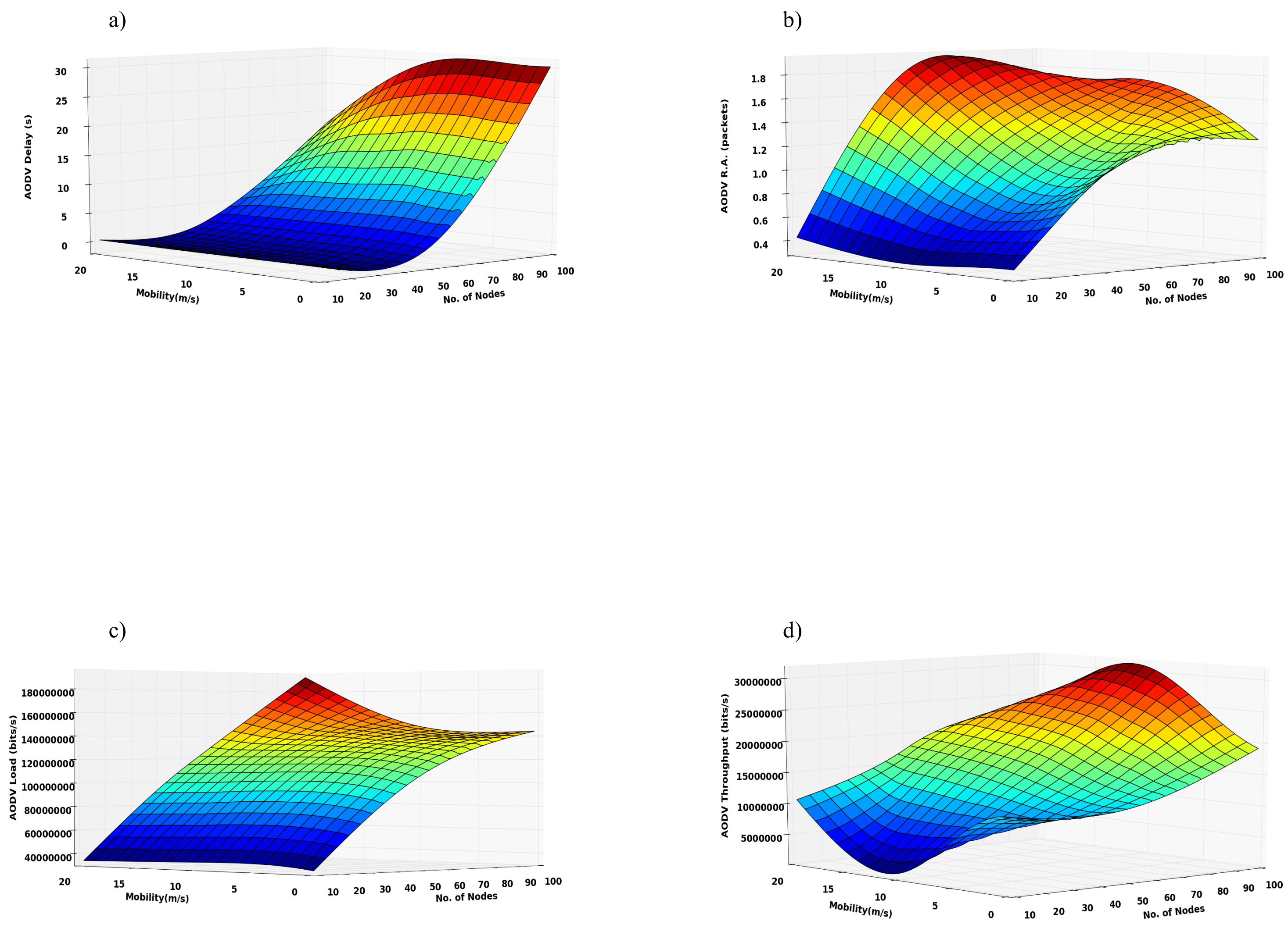


Figure 6.31: MANET output performance ANN models using AODV routing protocol.

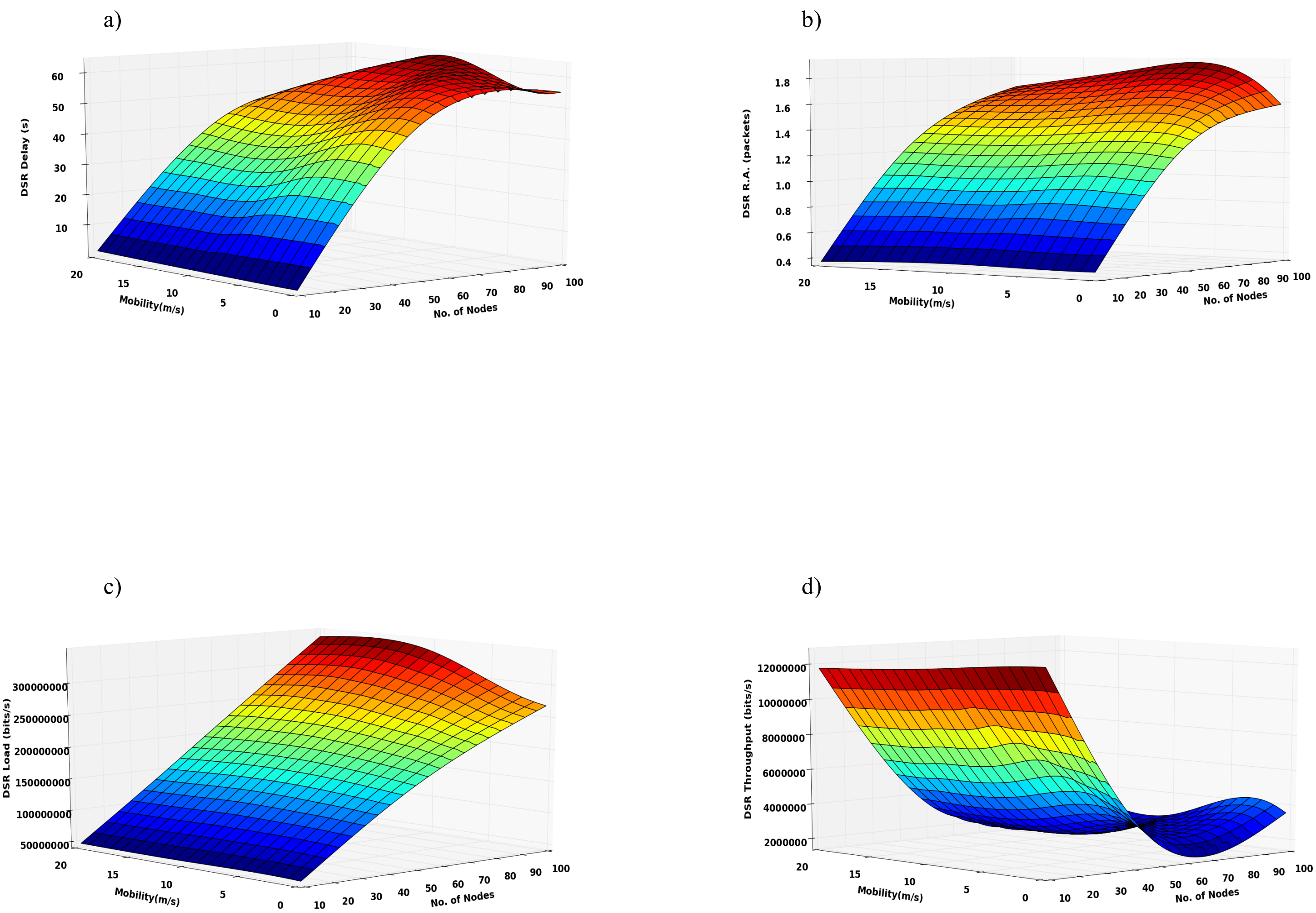


Figure 6.32: MANET output performance ANN models using DSR routing protocol.

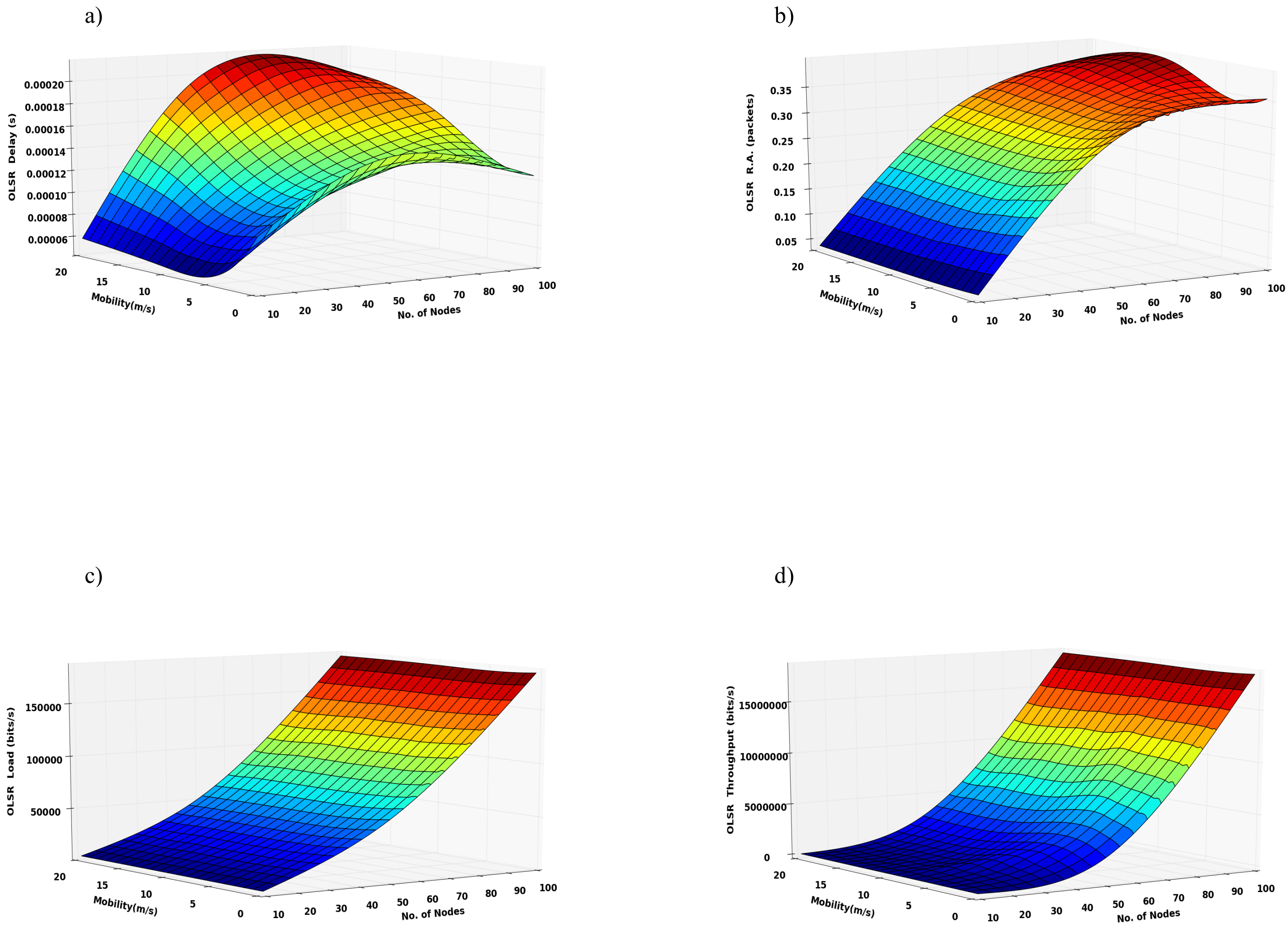


Figure 6.33: MANET output performance ANN models using OLSR routing protocol.

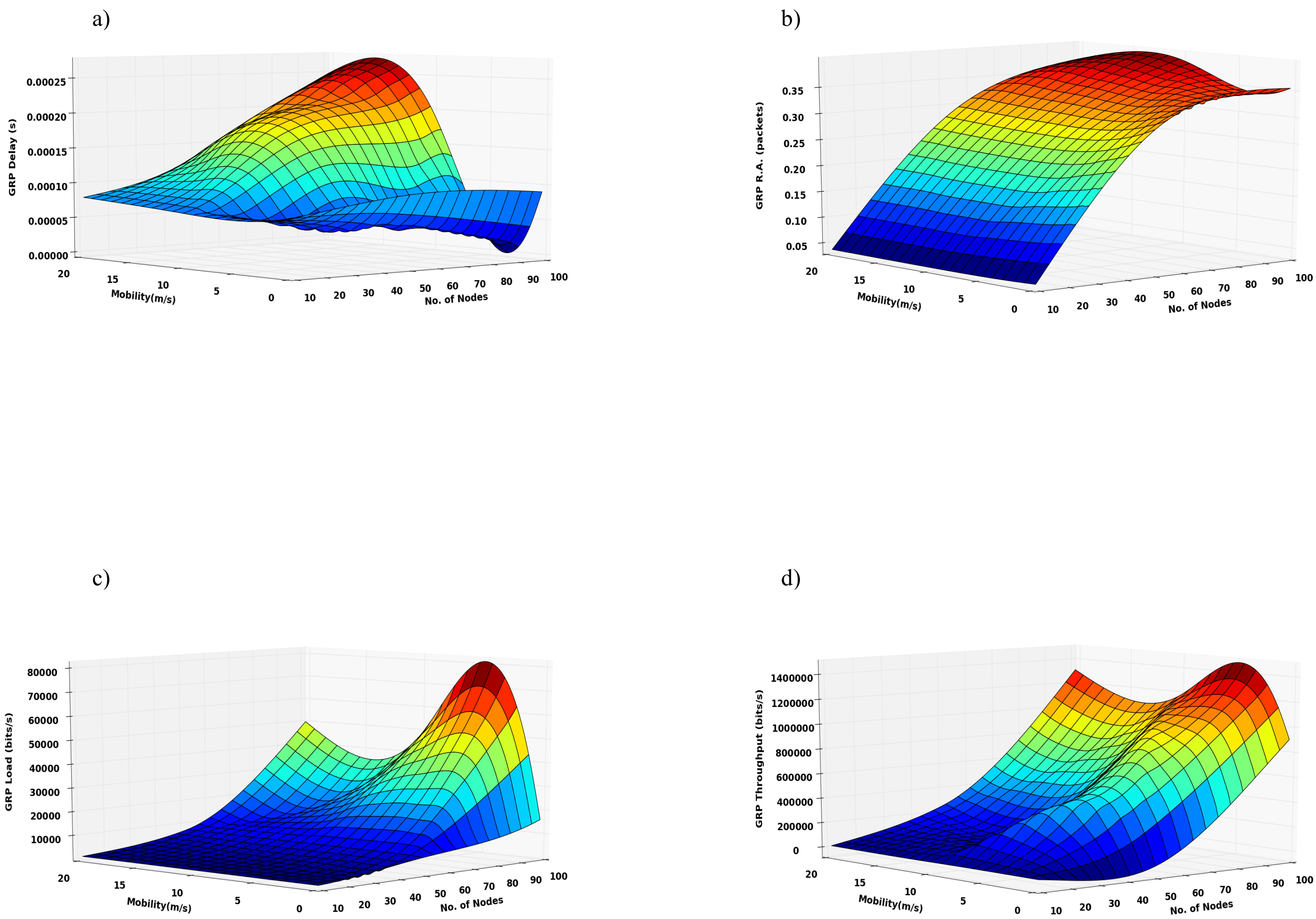


Figure 6.34: MANET output performance ANN models using GRP routing protocol.

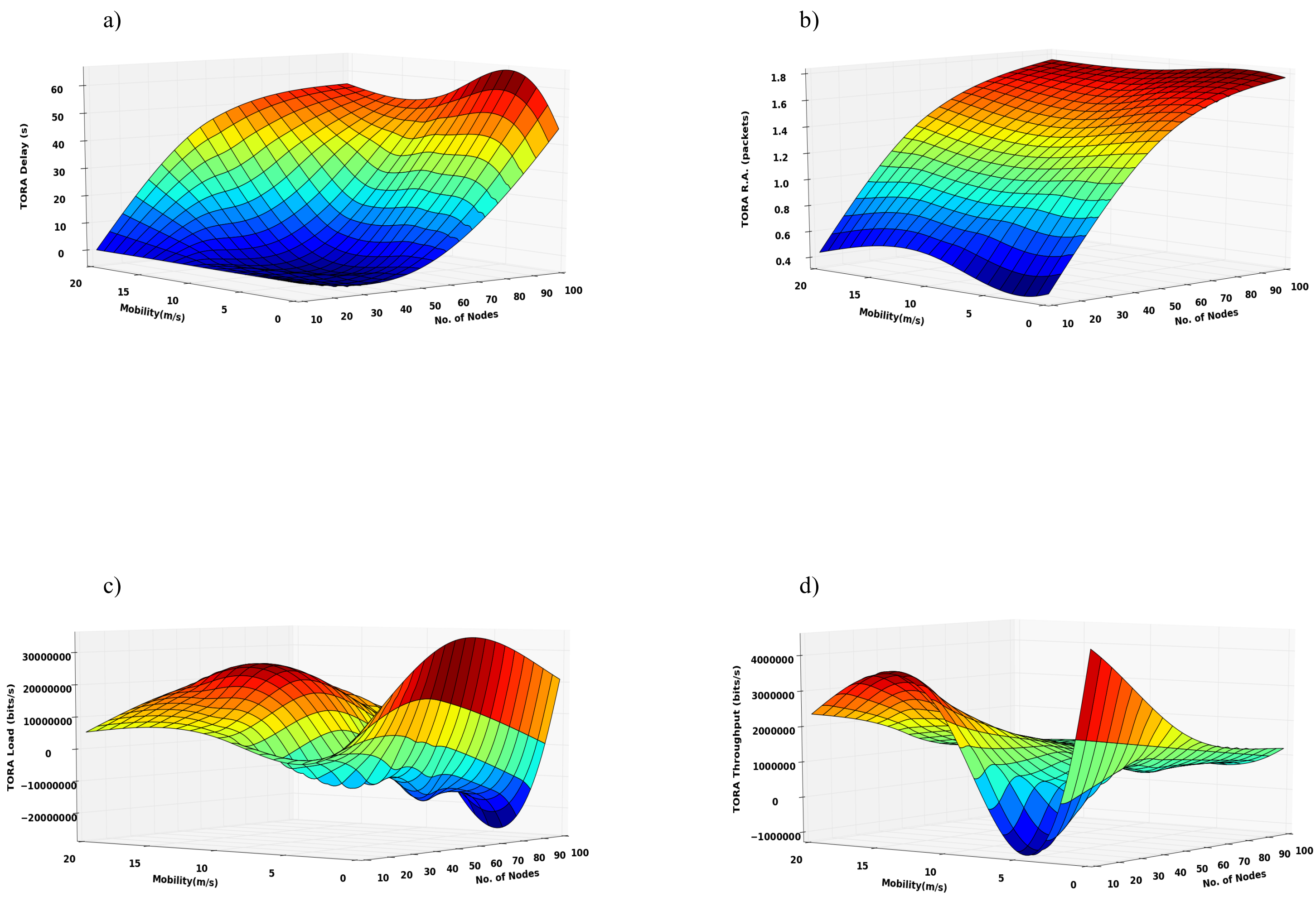


Figure 6.35: MANET output performance ANN models using TORA routing protocol.

6.5.3 NF MANET Models

The Fuzzy Logic Toolbox in MATLAB™ was used to develop MANET NF models. The models were created using the ANFIS package. Two Gaussian membership functions for the two input variables based on the MANET simulator the mfs and fuzzy rules were established to create 195 NF rules for the output parameters of the five routing protocols with FTP application as shown in table 6.4. In case of VoIP and videoconferencing the mfs and fuzzy rules were established to create 193, 198 NF rules respectively as shown in Table 6.5 and 6.6.

Table 6.4: Performance's NF membership function and five protocols' fuzzy rules with FTP application.

Routing Protocol	Linguistic Labels	Delay	Retransmission Attempt	Load	Throughput
AODV	$mf1\ x\ mf2$	$3\ x\ 3$	$4\ x\ 4$	$4\ x\ 4$	$2\ x\ 3$
	$rules$	9	16	16	6
DSR	$mf1\ x\ mf2$	$4\ x\ 3$	$4\ x\ 4$	$3\ x\ 3$	$3\ x\ 3$
	$rules$	12	16	9	3
OLSR	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$
	$rules$	9	9	9	9
GRP	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$
	$rules$	9	9	9	9
TORA	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 2$	$4\ x\ 3$	$3\ x\ 3$
	$rules$	9	6	12	9

Table 6.5: Performance's NF membership function and five protocols' fuzzy rules with VoIP application.

Routing Protocol	Linguistic Labels	Delay	Retransmission Attempt	Load	Throughput
AODV	$mf1\ x\ mf2$	$3\ x\ 3$	$4\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$
	$rules$	9	12	9	9
DSR	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 3$	$4\ x\ 3$	$3\ x\ 3$
	$rules$	9	9	12	9
OLSR	$mf1\ x\ mf2$	$2\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$	$2\ x\ 3$
	$rules$	6	9	9	6
GRP	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 3$	$4\ x\ 4$	$3\ x\ 3$
	$rules$	9	9	16	9
TORA	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 3$	$4\ x\ 3$	$4\ x\ 3$
	$rules$	9	9	12	12

Table 6.6: Performance's NF membership function and five protocols' fuzzy rules with videoconferencing.

Routing Protocol	Linguistic Labels	Delay	Retransmission Attempt	Load	Throughput
AODV	$mf1\ x\ mf2$	$4\ x\ 3$	$3\ x\ 3$	$4\ x\ 3$	$4\ x\ 3$
	$rules$	12	9	12	12
DSR	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 3$	$4\ x\ 4$	$4\ x\ 3$
	$rules$	9	9	16	12
OLSR	$mf1\ x\ mf2$	$3\ x\ 3$	$2\ x\ 2$	$3\ x\ 3$	$4\ x\ 3$
	$rules$	9	4	9	12
GRP	$mf1\ x\ mf2$	$4\ x\ 3$	$2\ x\ 2$	$3\ x\ 3$	$3\ x\ 3$
	$rules$	12	4	9	9
TORA	$mf1\ x\ mf2$	$3\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$	$3\ x\ 3$
	$rules$	9	9	12	9

As can be seen from Tables 6.4-6.6, the increase in the number of membership function is an indicator to the rapid changes in the output performance data. Since the number of rules is a result of multiplying the membership function of the input parameters as in Equation (6.5), it will be affected as well. Thus, the increase in the rules is directly proportional to the increase in the membership functions. If we take Table 6.6 as an example, the DSR load model requires ($4\ mfs\ x\ 4\ mfs$).

Consequently, 16 fuzzy rules considered for the DSR load model, as the number of rules relays on the number of membership functions. On the other hand, it can be observed with the GRP and OLSR R.A. models require ($2\ mfs\ x\ 2\ mfs$) that create 4 fuzzy rules. For each routing protocol in each application, four NF models were trained. 20 models were developed for the five protocols in each application. Thus, the over all numbers of NF models are 60 models. In the following pages shows the 3D shapes for NF models for each routing protocol. The models indicate the five routing protocols parameters react based on the two inputs in each application.

FTP Application:

MANET performance 3D shapes for NF models for each routing protocol are as follows:

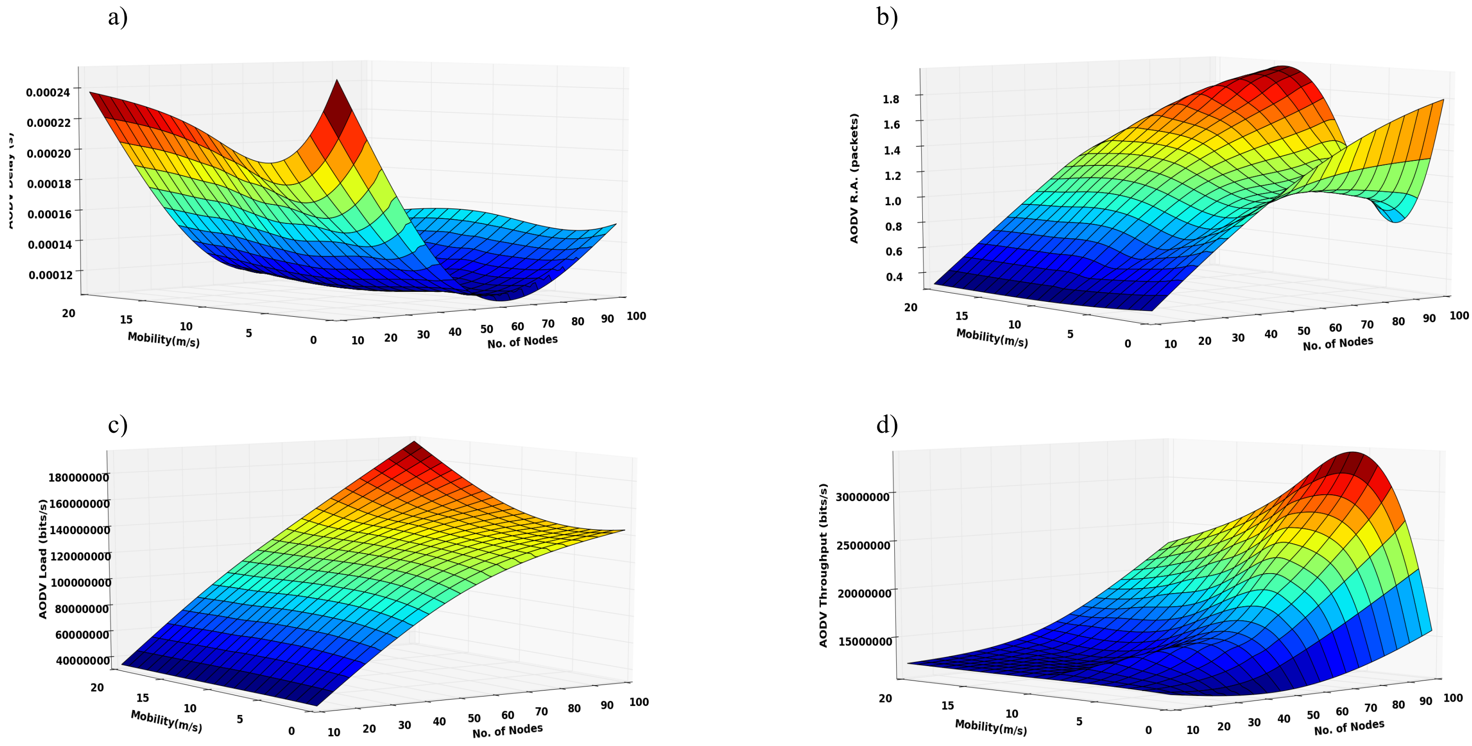


Figure 6.36: MANET output performance ANN models using AODV routing protocol.

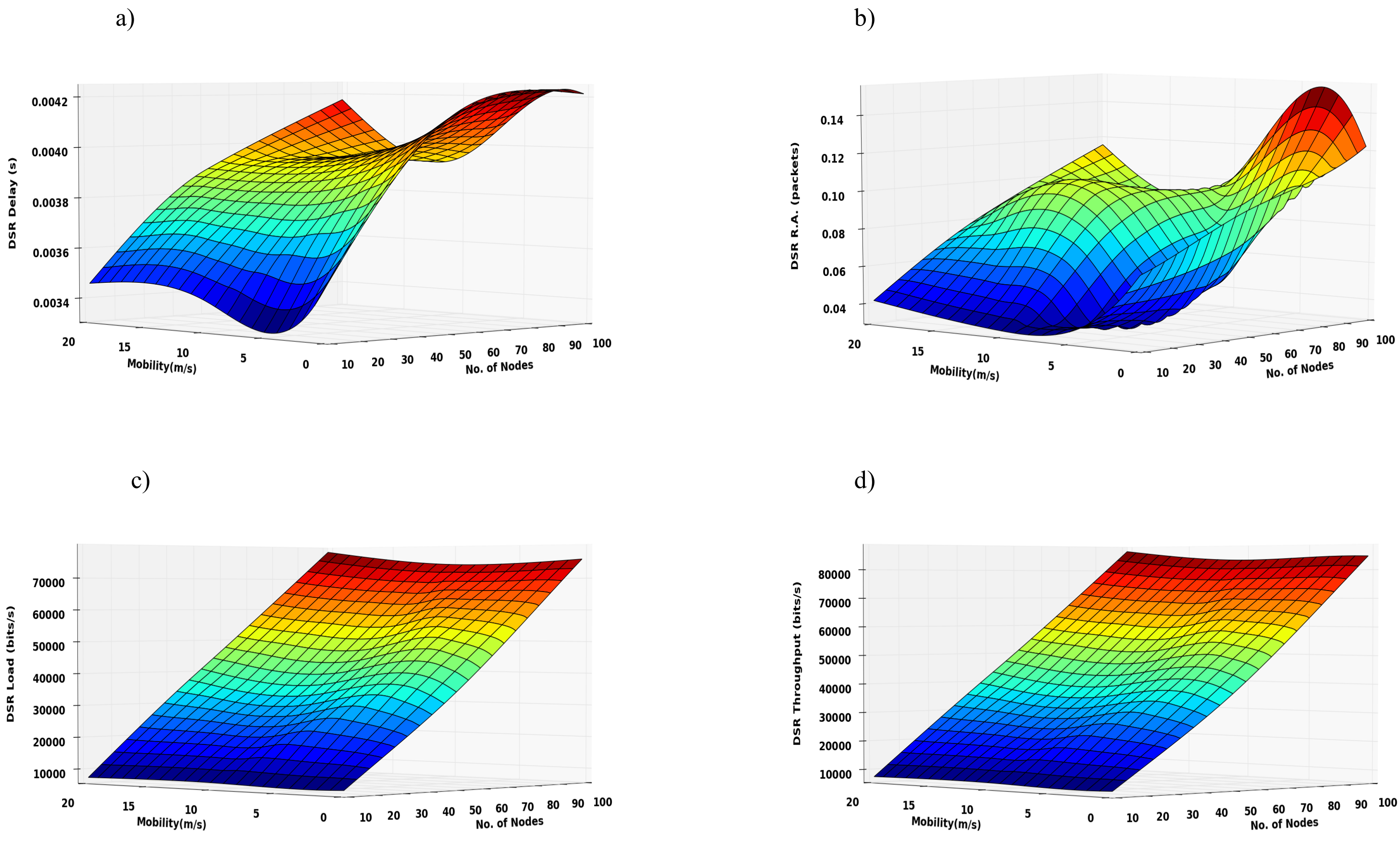


Figure 6.37: MANET output performance NF models using DSR routing protocol.

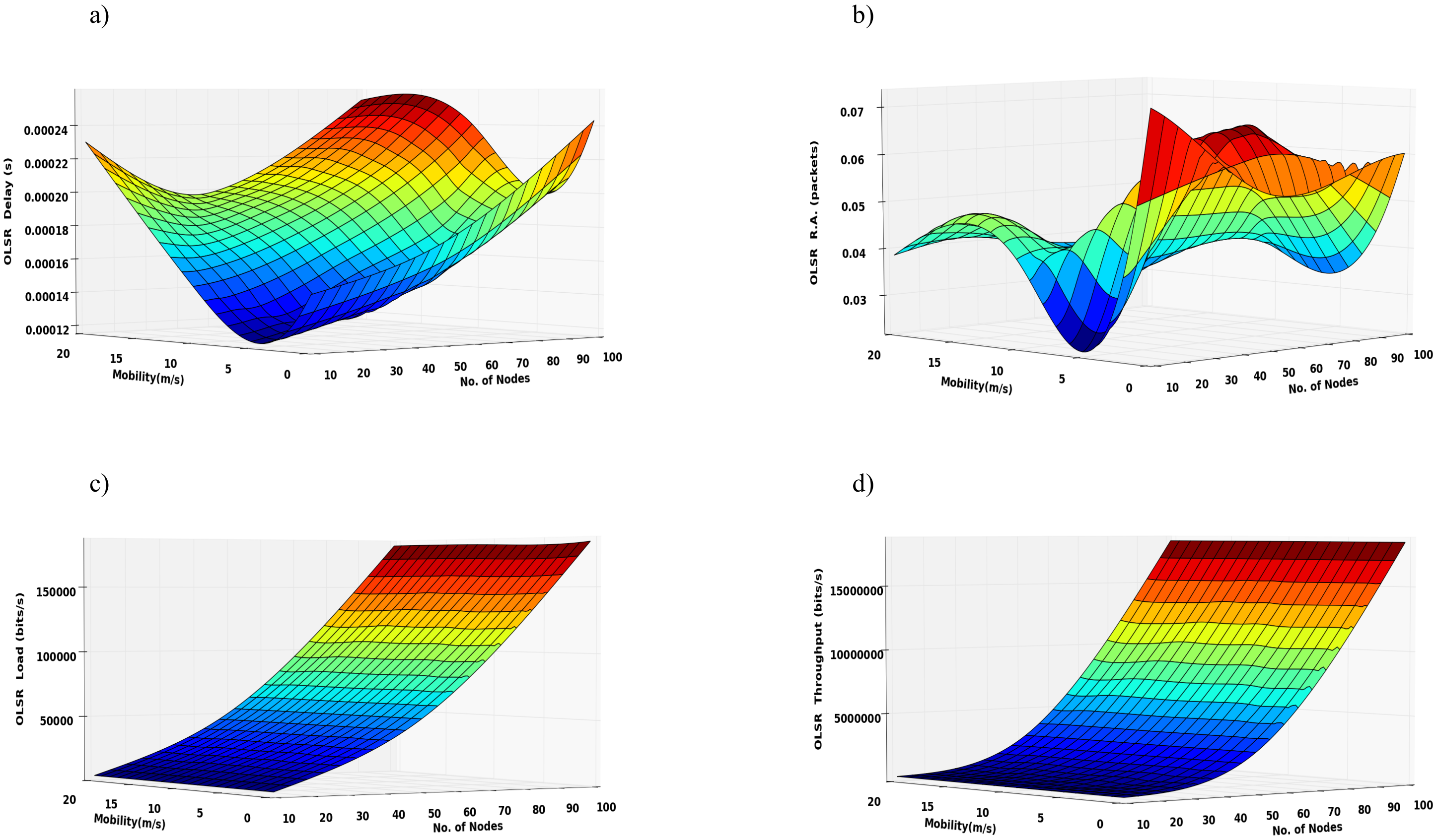


Figure 6.38: MANET output performance NF models using OLSR routing protocol.

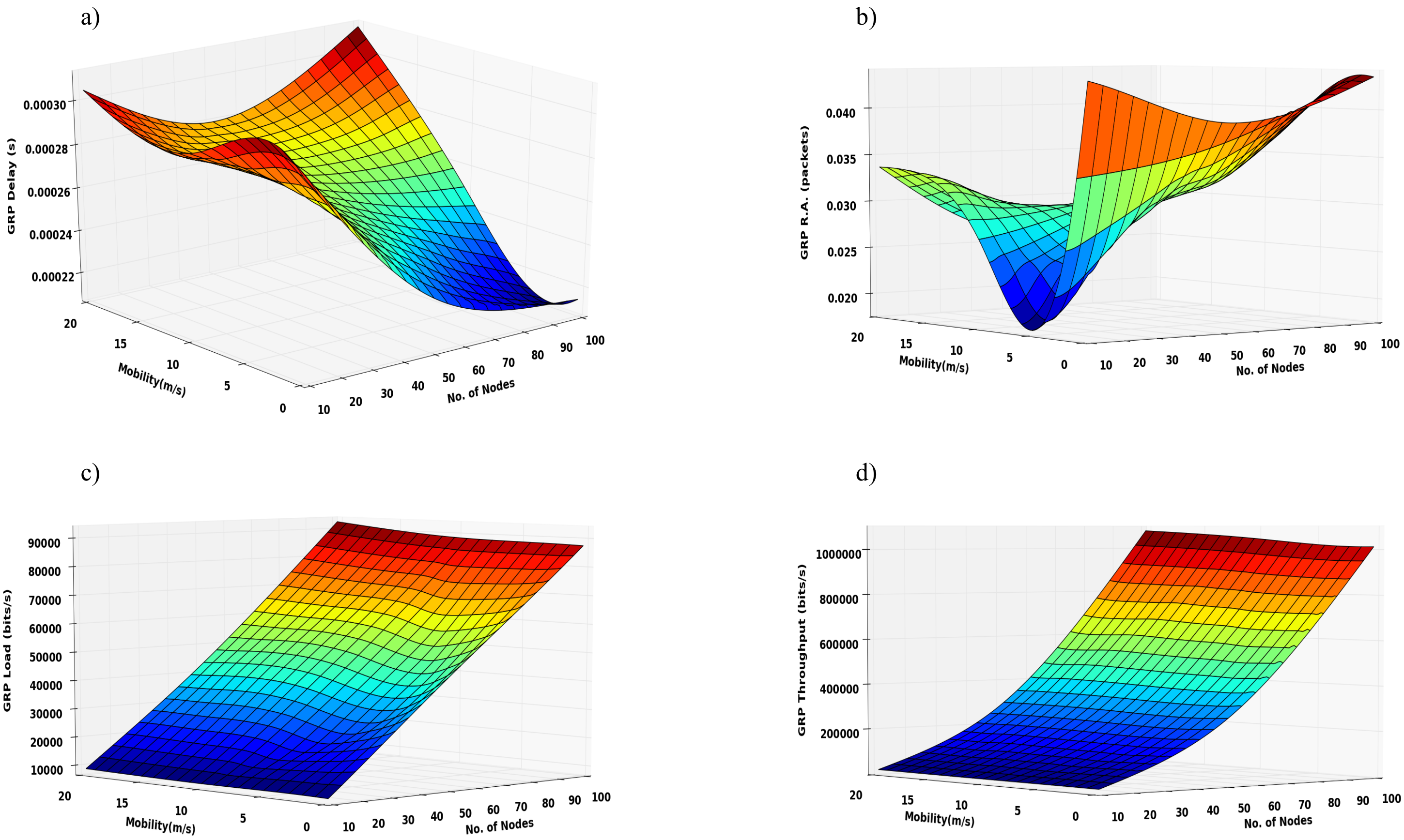


Figure 6.39: MANET output performance NF models using GRP routing protocol.

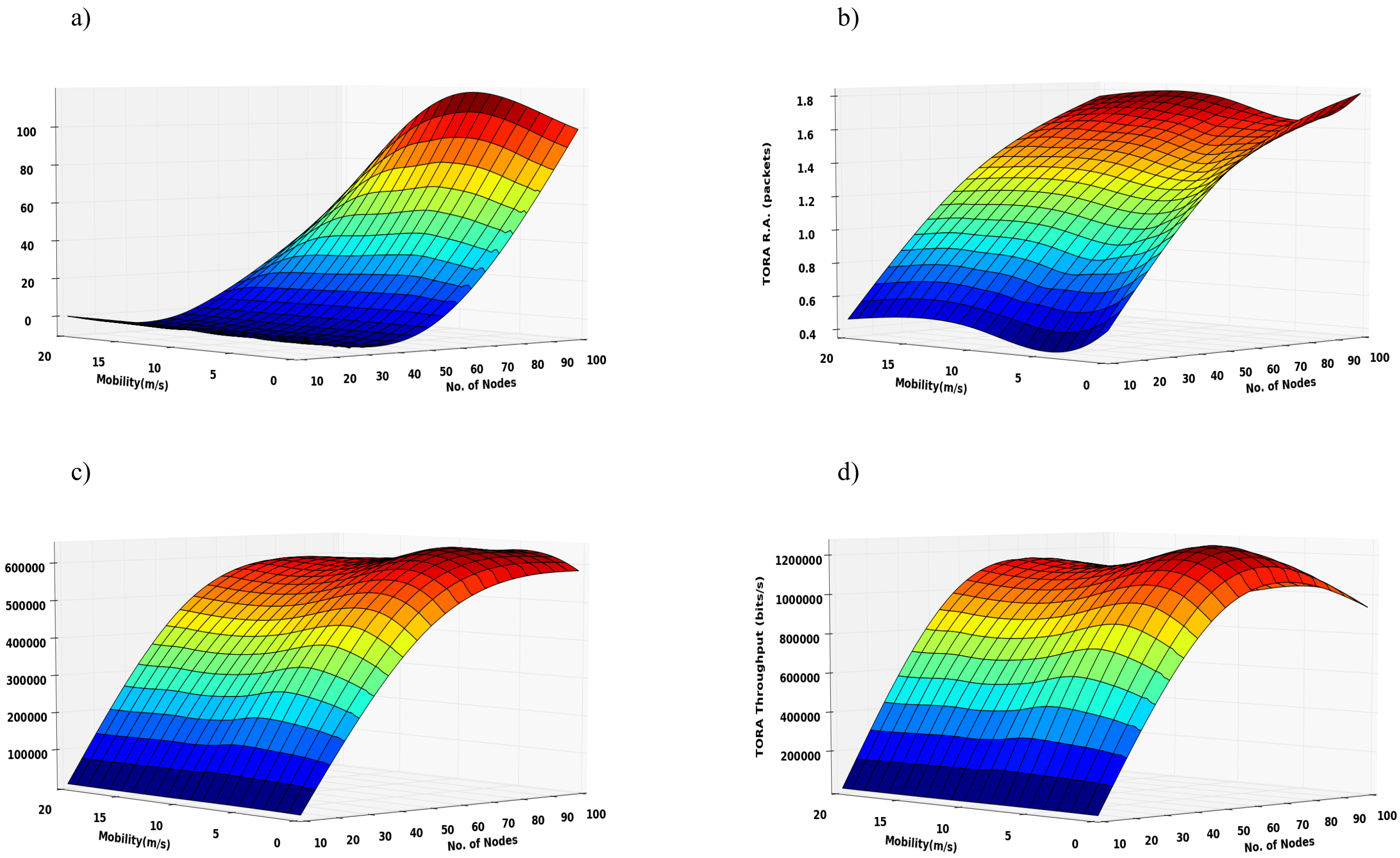


Figure 6.40: MANET output performance NF models using GRP routing protocol.

VoIP Application:

MANET performance 3D shapes for NF models for each routing protocol as follow:

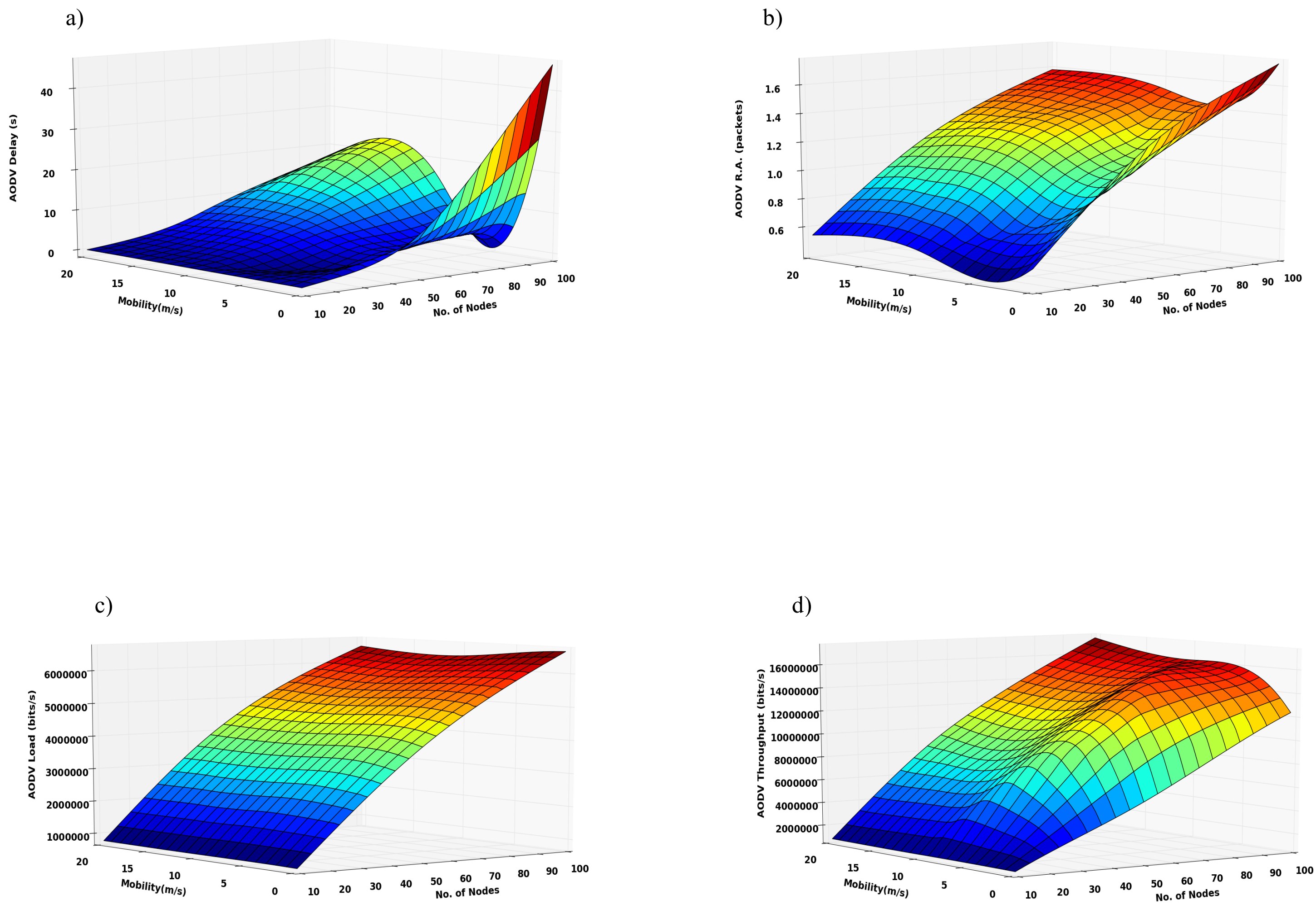


Figure 6.41: MANET output performance NF models using AODV routing protocol.

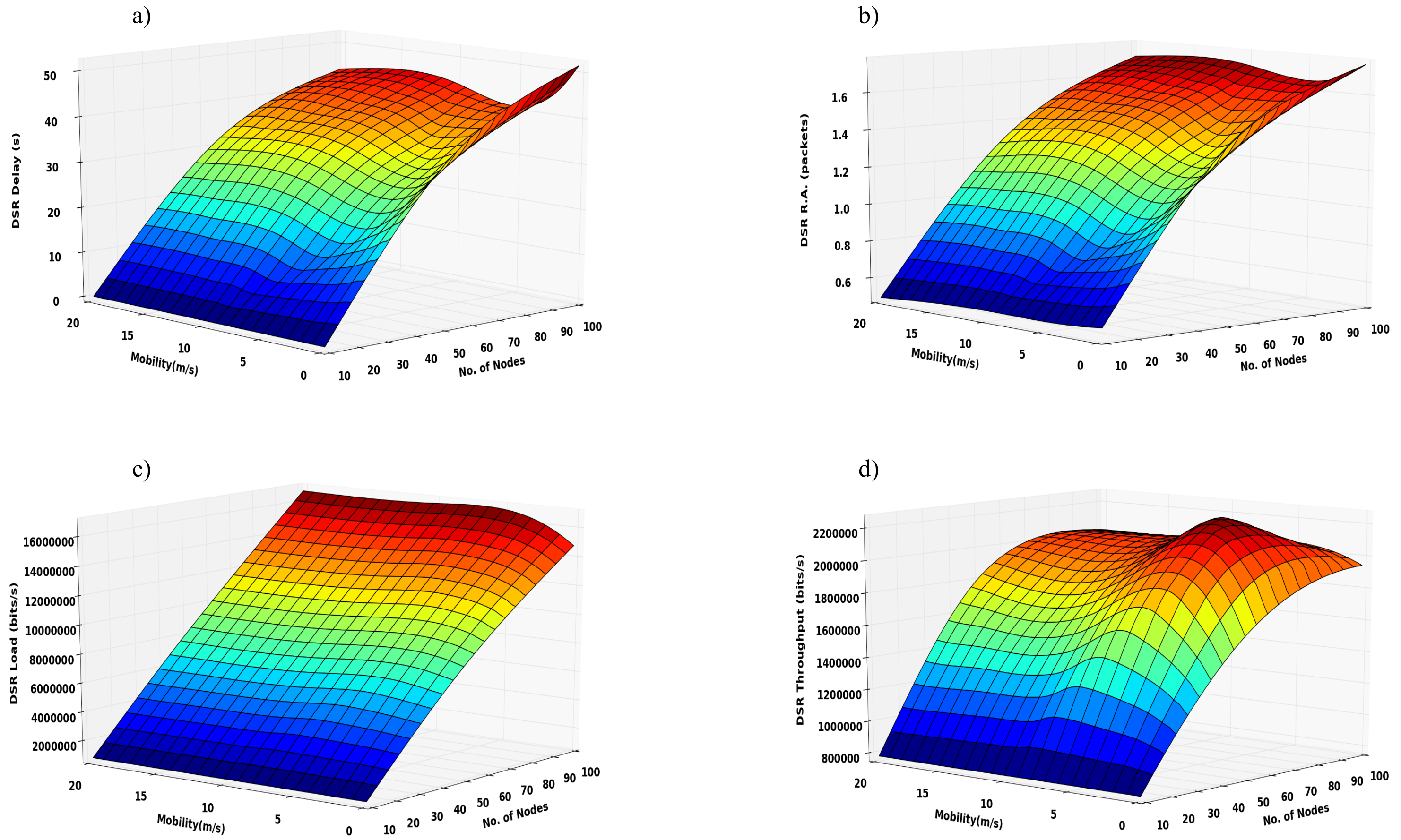


Figure 6.42: MANET output performance NF models using DSR routing protocol.

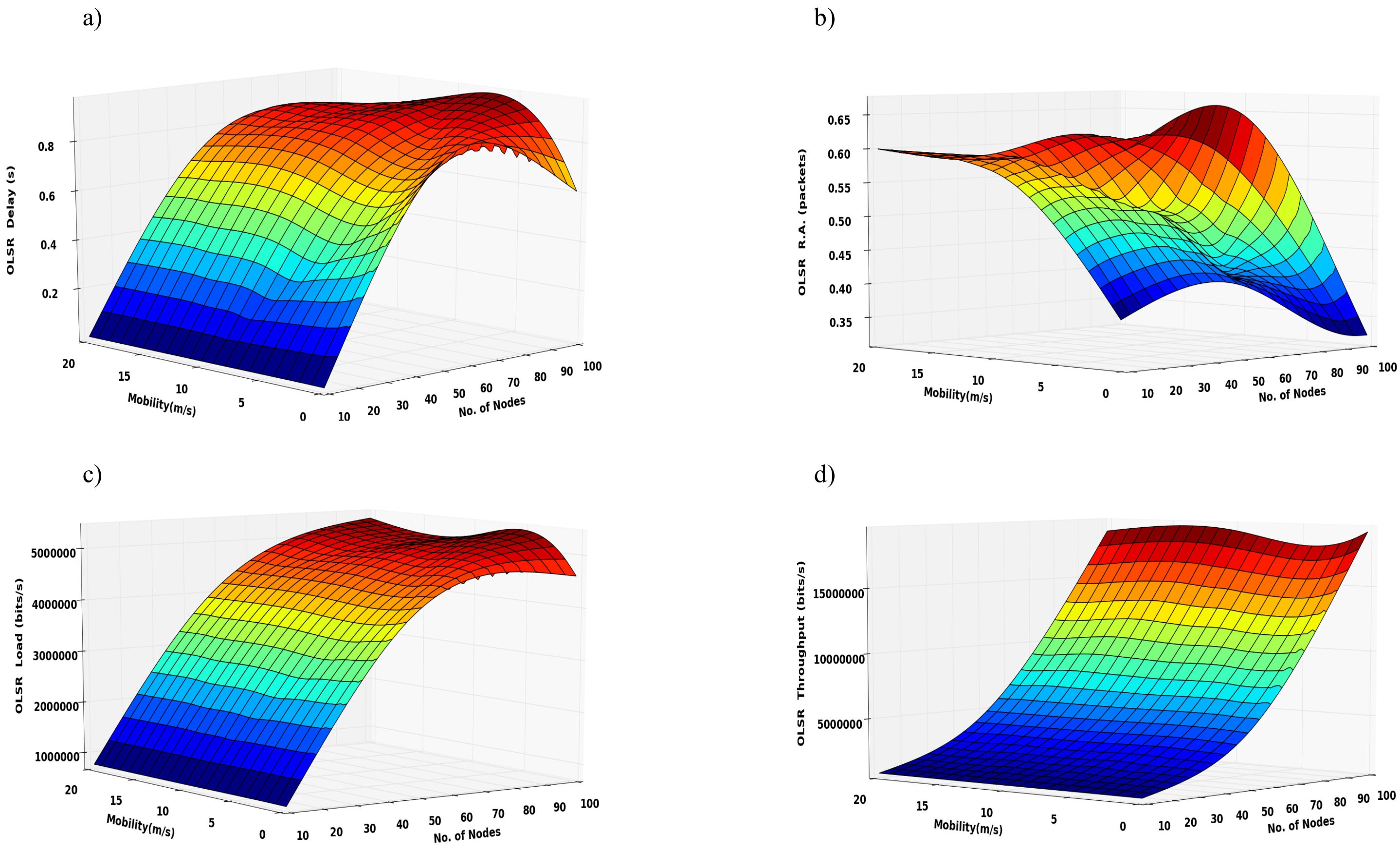


Figure 6.43: MANET output performance NF models using OLSR routing protocol.

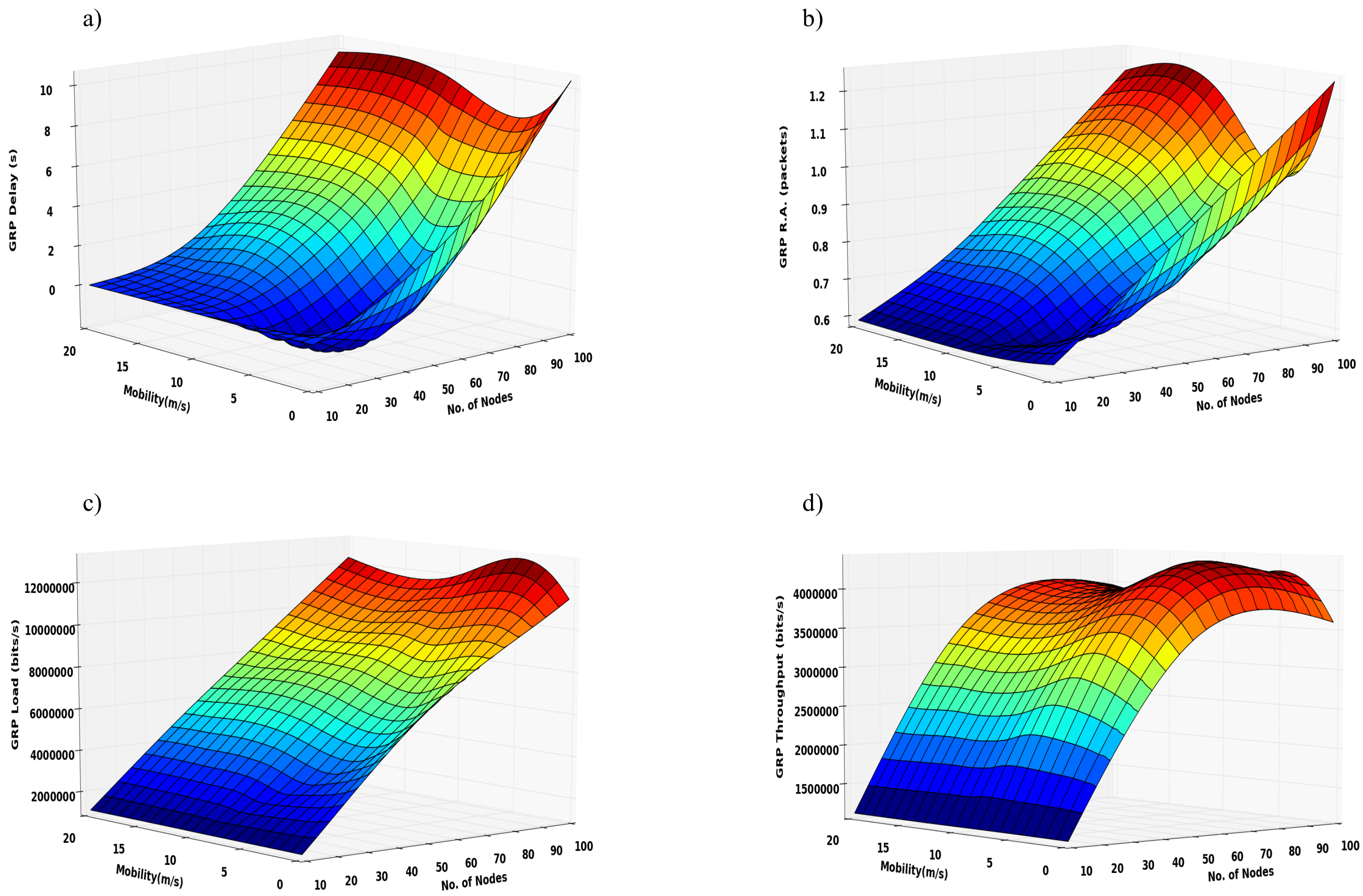


Figure 6.44: MANET output performance NF models using GRP routing protocol.

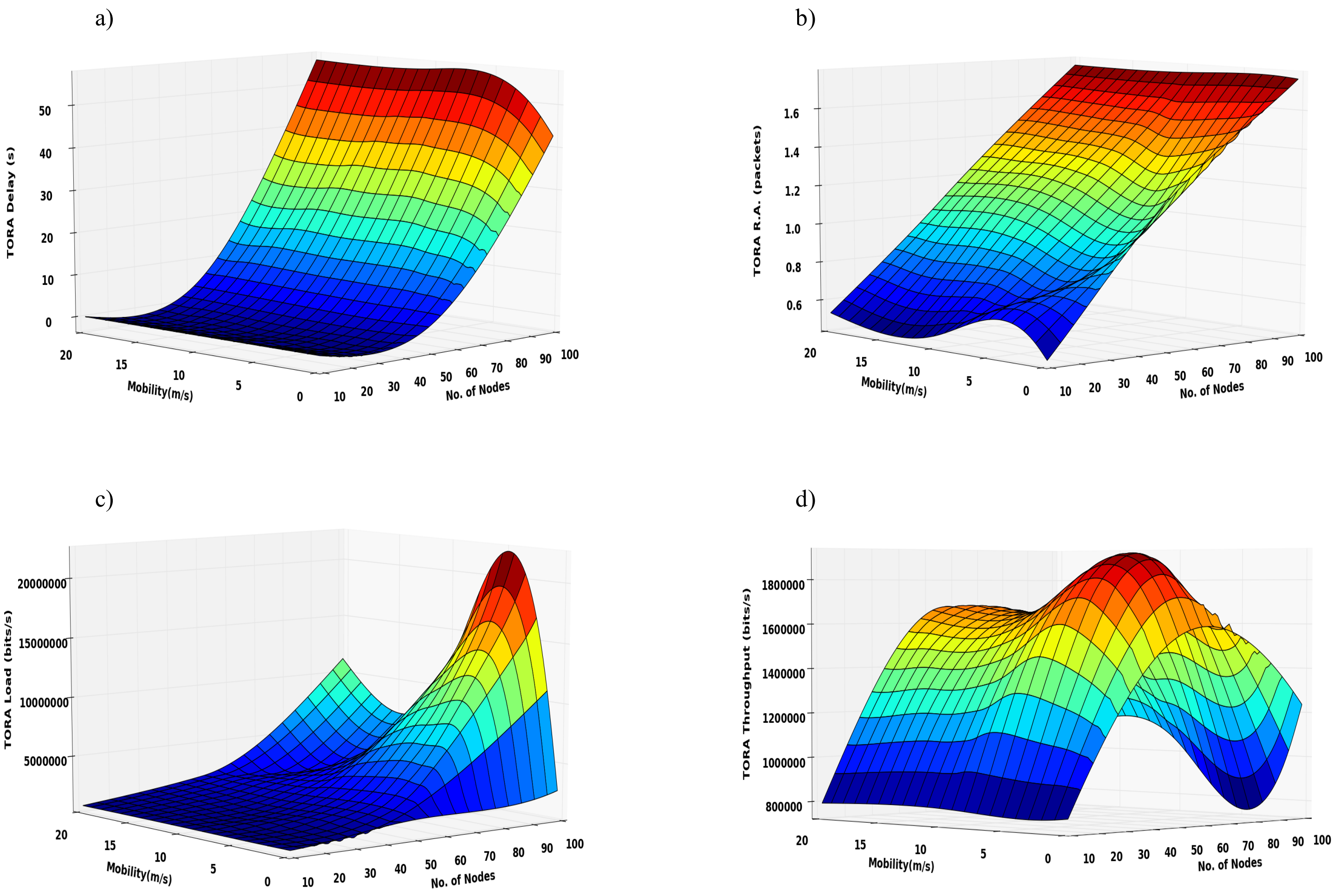


Figure 6.45: MANET output performance NF models using TORA routing protocol.

Videoconferencing Application:

MANET performance 3D shapes for NF models for each routing protocol are as follows:

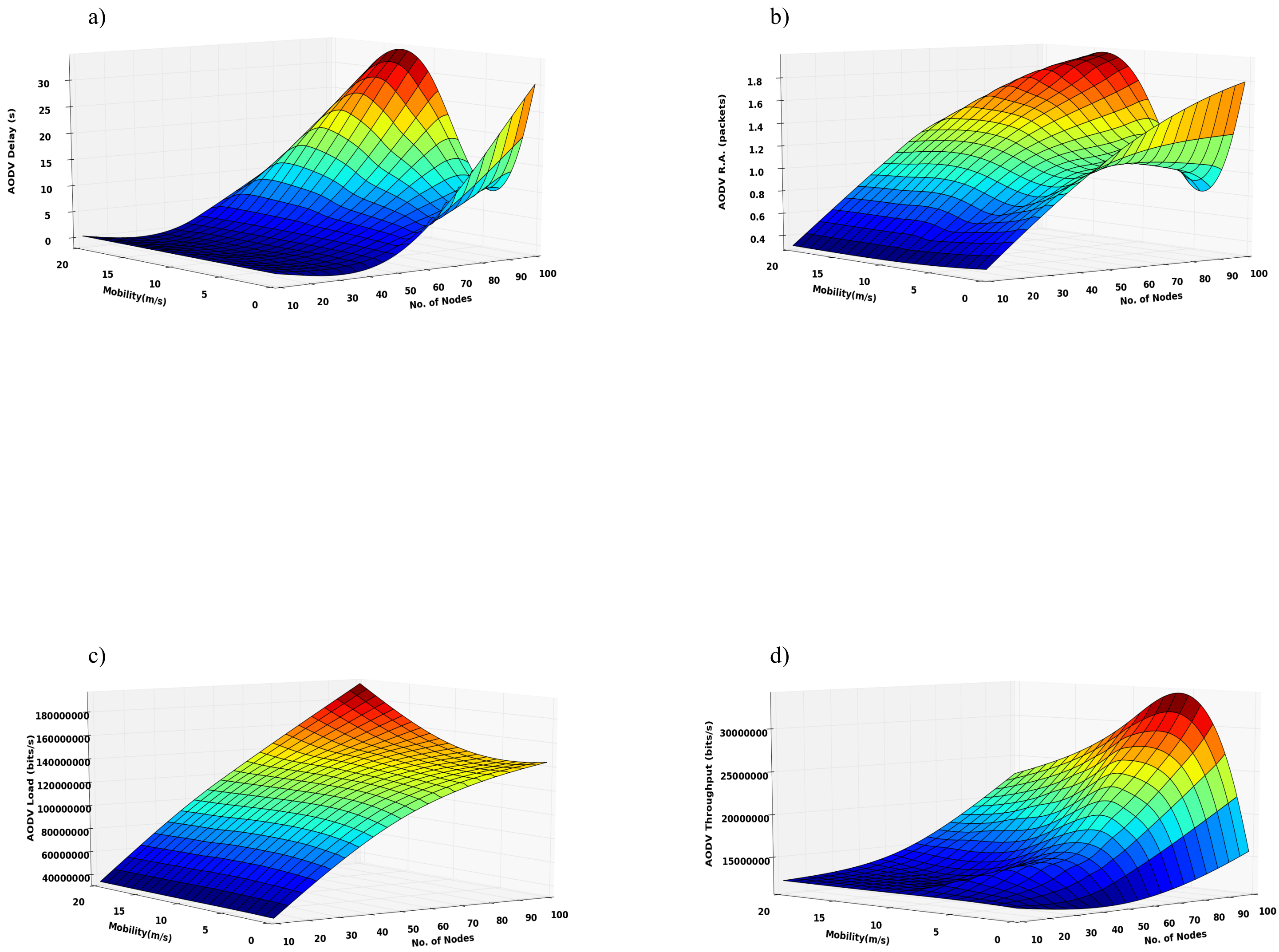


Figure 6.46: MANET output performance NF models using AODV routing protocol.

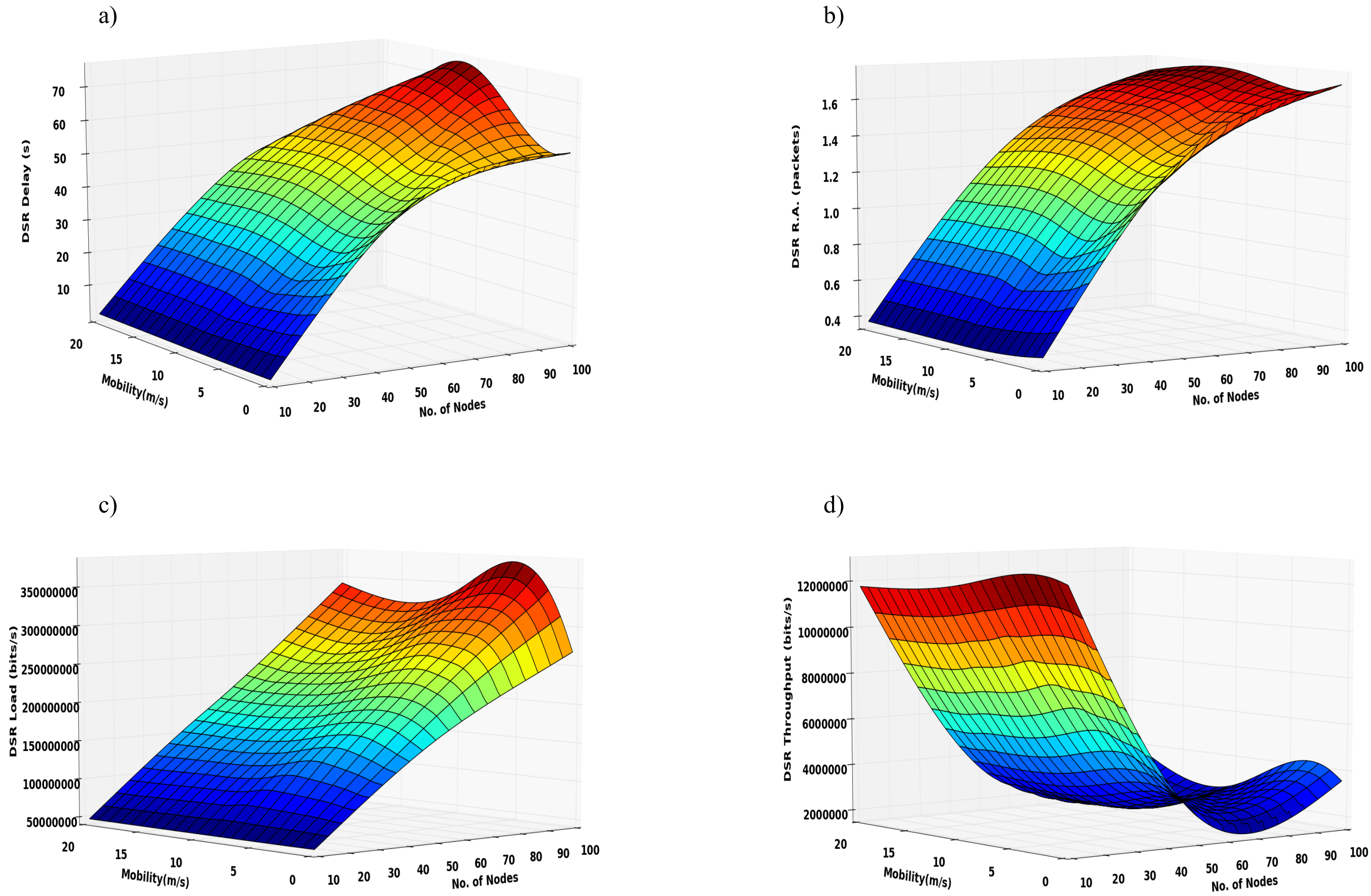


Figure 6.47: MANET output performance NF models using DSR routing protocol.

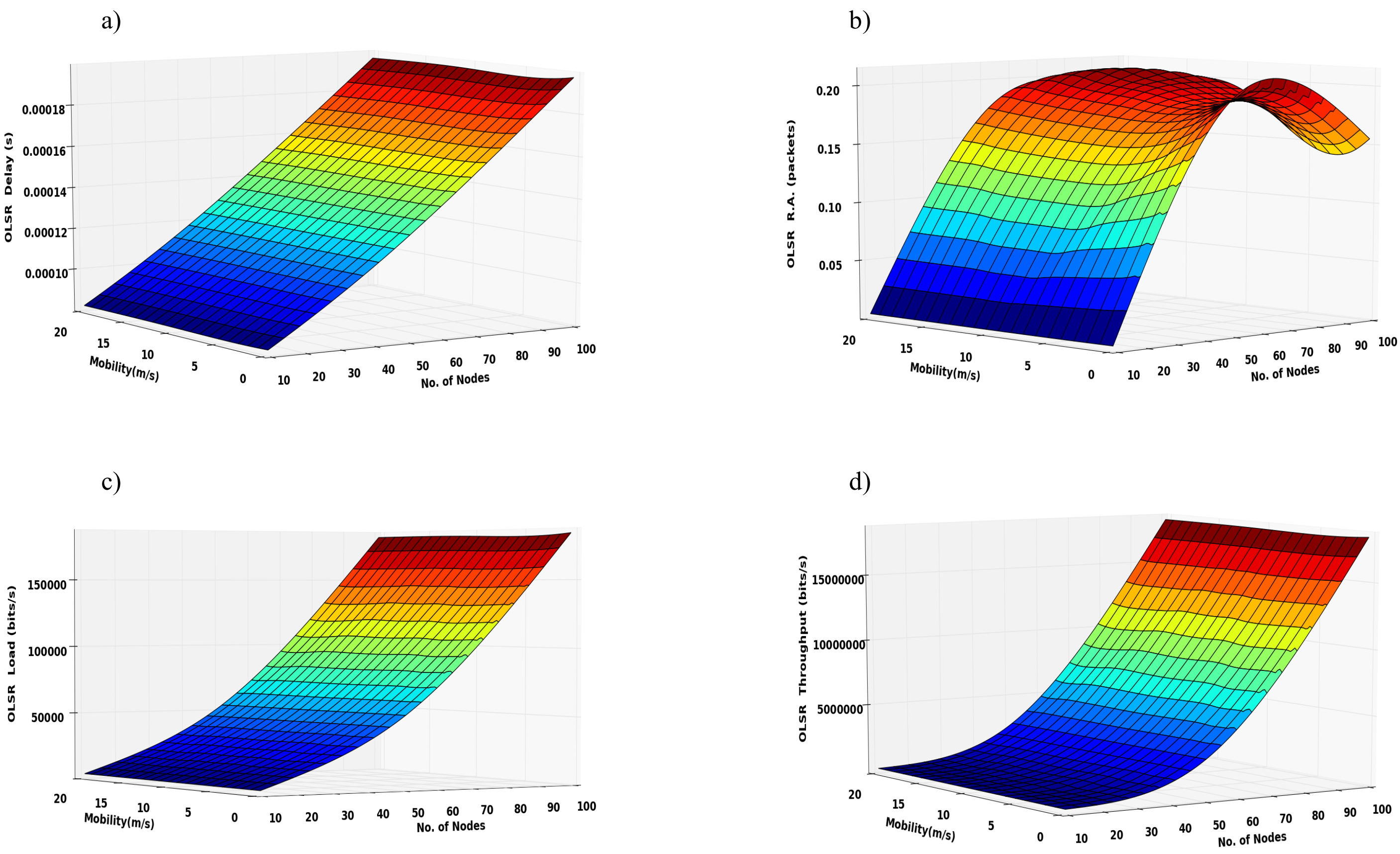


Figure 6.48: MANET output performance NF models using OLSR routing protocol.

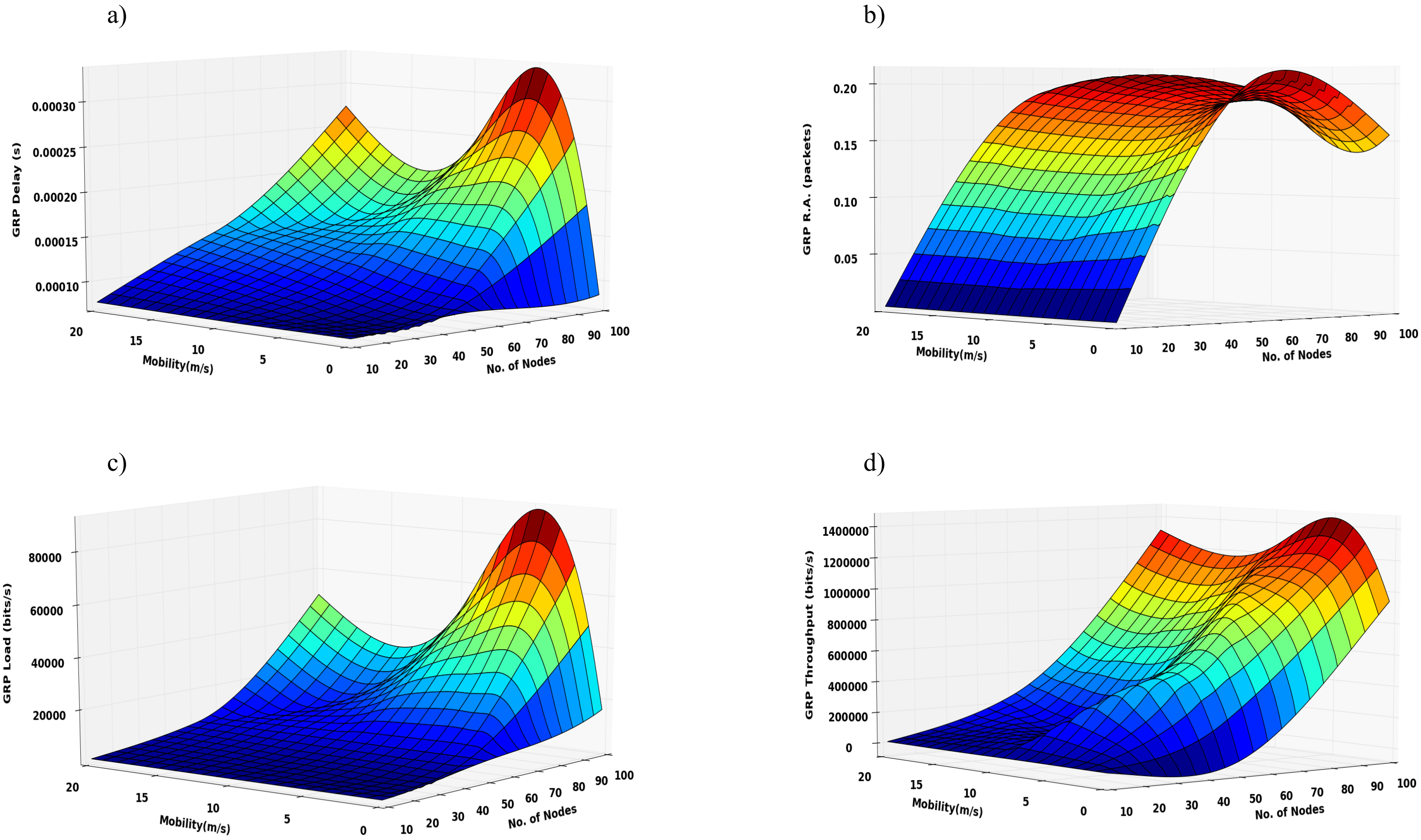


Figure 6.49: MANET output performance NF models using GRP routing protocol.

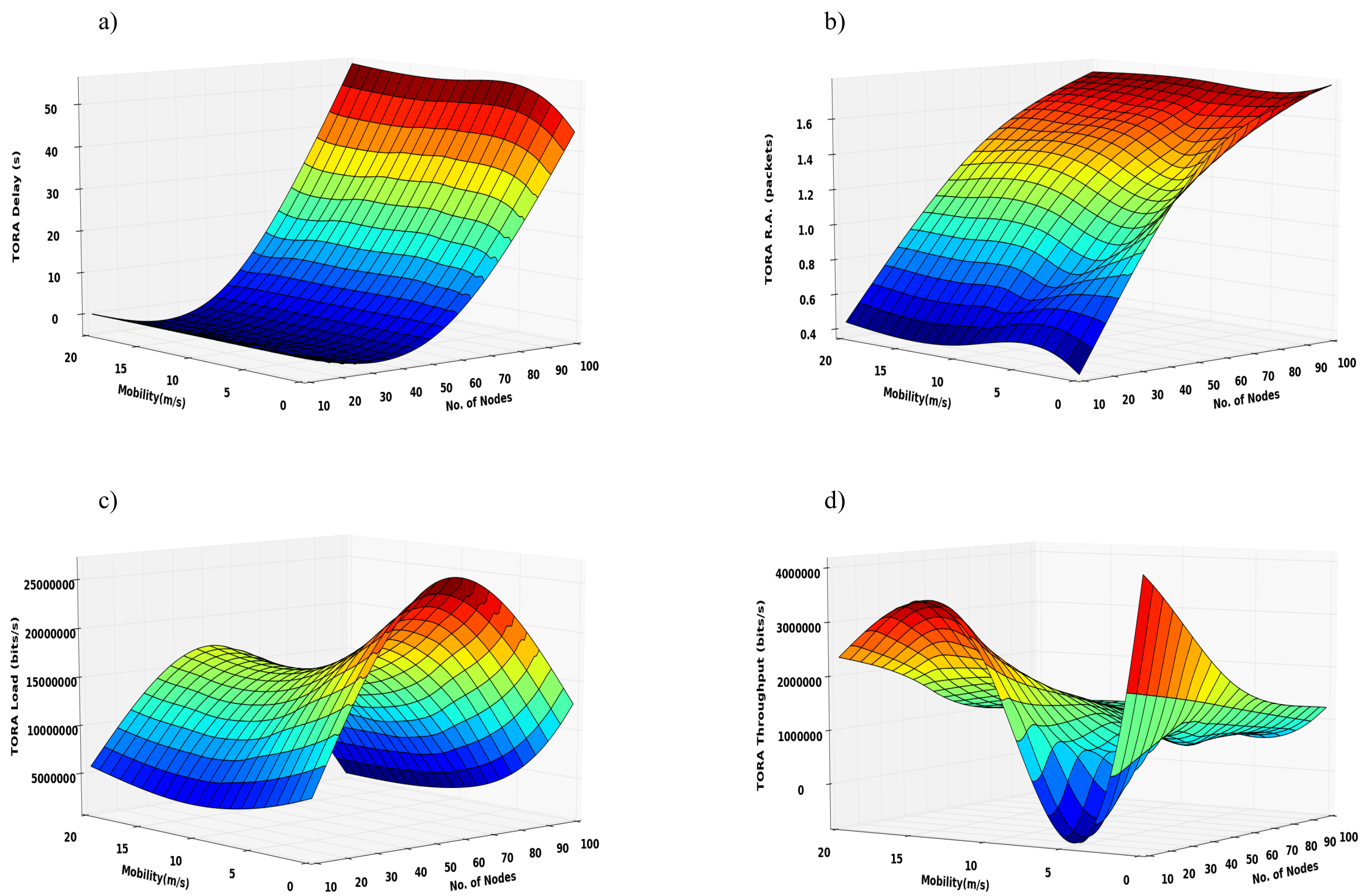


Figure 6.50: MANET output performance NF models using TORA routing protocol.

6.5.4 MANET Models Comparison

The useful purposes of utilising MANET performance models are predictions and decision making process; the optimiser will depend on prediction performed by models for the output performance in the system and select the suitable protocol which will be discussed in chapter 7. The more accurate are the models that represent the MANET performance, the more accurate the optimiser decision.

Comparison performed between the three techniques RE, ANN, and NF based on the results obtained in order to choose the modeller that will be employed by I-MMs and support the optimiser as in Chapter 7.

The NF model is apparently more successful to represent the MANET performance compared to its AI counterpart ANN and the regression models. The NF models are smoother, more accurate and efficient than ANN. The overtraining issue was the reason for the corrupting ANN models. Moreover, The regression model fails to represent the alterations in the performance data in a representative curvy model.

A measurable analysis was carried out to select the finest models that represent MANET models. The Percentage Error of the original data (y) and model data ($\hat{y}$) was computed for each output performance parameter, as shown in Equation (6.13).

$$\text{Percentage Error } = \frac{\hat{y}-y}{y} \times 100\% \tag{6.13}$$

Table 6.7 through 6.21 are Percentage Error (PE) calculation outcome employing RE, ANN, and NF for MANET employing the five routing protocols. For the four-performance outputs delay, RA, load, and throughput, NF scored the lowest PEcompared to the other techniques. Therefore, based on the table results, it was concluded that NF is the best model to represent the MANET performance and will be useful to the proposed system optimiser, which will rely on.

FTP Application:

Table 6.7: Percentage Error for MANET output parameters employing AODV routing protocol.

AODV			
PE (%)	RE	ANN	NF
Delay (s)	2.54	2.07	1.43
RA (packets)	3.01	2.11	1.92
Load (bits/s)	2.51	2.89	2.23
Throughput (bits/s)	3.01	2.15	1.90

Table 6.8: Percentage Error for MANET output parameters employing DSR routing protocol.

DSR			
PE (%)	RE	ANN	NF
Delay (s)	1.78	1.63	1.03
RA (packets)	2.04	1.55	1.43
Load (bits/s)	2.45	1.36	1.29
Throughput (bits/s)	2.84	1.52	1.70

Table 6.9: Percentage Error for MANET output parameters employing OLSR routing protocol.

OLSR			
PE (%)	RE	ANN	NF
Delay (s)	2.39	1.77	1.69
RA (packets)	2.14	1.58	1.43
Load (bits/s)	2.84	2.33	1.77
Throughput (bits/s)	3.12	2.72	1.88

Table 6.10: Percentage Error for MANET output parameters employing GRP routing protocol.

GRP			
PE (%)	RE	ANN	NF
Delay (s)	3.23	1.76	1.26
RA (packets)	2.05	1.91	1.67
Load (bits/s)	2.70	1.38	1.04
Throughput (bits/s)	2.44	1.89	1.33

Table 6.11: Percentage Error for MANET output parameters employing TORA routing protocol.

TORA			
PE (%)	RE	ANN	NF
Delay (s)	3.50	1.68	1.41
RA (packets)	2.25	1.99	1.55
Load (bits/s)	2.73	1.57	1.28
Throughput (bits/s)	2.14	1.86	1.52

VoIP Application:

Table 6.12: Percentage Error for MANET output parameters employing AODV routing protocol.

AODV			
PE (%)	RE	ANN	NF
Delay (s)	3.17	2.50	1.92
RA (packets)	2.92	1.86	1.47
Load (bits/s)	1.89	1.47	1.20
Throughput (bits/s)	2.16	1.64	1.35

Table 6.13: Percentage Error for MANET output parameters employing DSR routing protocol.

DSR			
PE (%)	RE	ANN	NF
Delay (s)	2.92	1.67	1.33
RA (packets)	1.65	1.81	1.35
Load (bits/s)	1.70	1.09	1.13
Throughput (bits/s)	1.43	1.80	1.40

Table 6.14: Percentage Error for MANET output parameters employing OLSR routing protocol.

OLSR			
PE (%)	RE	ANN	NF
Delay (s)	1.84	1.60	1.55
RA (packets)	1.52	1.27	1.19
Load (bits/s)	1.31	1.11	1.02
Throughput (bits/s)	1.86	1.68	1.48

Table 6.15: Percentage Error for MANET output parameters employing GRP routing protocol.

GRP			
PE (%)	RE	ANN	NF
Delay (s)	2.65	1.57	1.01
RA (packets)	1.20	1.37	1.29
Load (bits/s)	1.85	1.33	1.18
Throughput (bits/s)	1.72	1.63	1.49

Table 6.16: Percentage Error for MANET output parameters employing TORA routing protocol.

TORA			
PE (%)	RE	ANN	NF
Delay (s)	2.21	1.66	1.32
RA (packets)	2.90	1.51	1.13
Load (bits/s)	2.34	1.70	1.08
Throughput (bits/s)	2.78	1.63	1.41

Videoconferencing Application:

Table 6.17: Percentage Error for MANET output parameters employing AODV routing protocol.

AODV			
PE (%)	RE	ANN	NF
Delay (s)	2.14	2.05	1.45
RA (packets)	1.80	1.79	1.38
Load (bits/s)	2.50	2.41	1.71
Throughput (bits/s)	2.34	1.60	1.39

Table 6.18: Percentage Error for MANET output parameters employing DSR routing protocol.

DSR			
PE (%)	RE	ANN	NF
Delay (s)	3.62	2.08	1.92
RA (packets)	2.78	1.33	1.26
Load (bits/s)	3.46	2.57	1.65
Throughput (bits/s)	2.98	2.66	1.23

Table 6.19: Percentage Error for MANET output parameters employing OLSR routing protocol.

OLSR			
PE (%)	RE	ANN	NF
Delay (s)	2.85	1.94	1.70
RA (packets)	2.53	2.12	1.41
Load (bits/s)	3.43	2.87	1.06
Throughput (bits/s)	3.82	3.03	1.53

Table 6.20: Percentage Error for MANET output parameters employing GRP routing protocol.

GRP			
PE (%)	RE	ANN	NF
Delay (s)	4.74	3.56	2.18
RA (packets)	3.53	2.30	1.47
Load (bits/s)	4.81	3.45	2.71
Throughput (bits/s)	3.91	2.19	1.69

Table 6.21: Percentage Error for MANET output parameters employing TORA routing protocol.

TORA			
PE (%)	RE	ANN	NF
Delay (s)	2.11	3.49	1.72
RA (packets)	1.44	1.25	1.25
Load (bits/s)	4.81	3.50	1.91
Throughput (bits/s)	4.25	2.19	1.32

6.6 Summary

In this chapter, two modelling approaches were utilised. Two techniques were employed from AI approach namely artificial neural networks (ANN) and neuro-fuzzy (NF) networks. However, a regression equation was representing the second approach (empirical approach). The models describe the characteristics of each routing protocol, since the protocol's output parameter response was represented by each model and was trained to represent the network history. Moreover, each model is utilised to predict the network performance behaviour for network average mobility from 0 (m/s) up to 20 (m/s), and network sizes 10 up to 100 nodes, and three different applications.

The quantitative approach was employed in this chapter to compare and evaluate the MANET models created by the three modelling techniques (RE, ANN, and NF). The quantitative approach showed that NF is the best technique compared to

RE and ANN to be used in the proposed system to support the decision in selecting the optimum routing protocol.

Chapter 7: Optimisation Techniques

7.1 Optimisation

Optimisation is the act of achieving the best possible results under given circumstances to enable us to take decisions. The objective of all such decisions is either to minimise effort or maximise benefit. Both effort and benefit can be expressed in the form of a function of certain variables. Therefore, optimisation is the process of finding the conditions that give the maximum or the minimum value of a function.

Smart (intelligent) optimisation systems utilize methods, such as, using genetic algorithms, simulated annealing, particle swarm optimisation, ant colony, artificial bee colony, and tabu search. Such methods were applied to resolve difficult problems on a realistic scale.

The focus of this chapter is on describing and applying Genetic Algorithm (GA) [84], Simulated Annealing (SA) [85], and Particle Swarm Optimisation (PSO) [86].

7.2 Genetic Algorithm

Genetic algorithms were invented to mimic some of the processes observed in natural evolution. The idea behind the use of GA's power of evolution is to solve optimisation problems such as engineering optimisation problems. The father of the original GA was John Holland who invented it in the 1960s [82]. It was part of his study on the phenomenon of adaptation as it happens in nature and simulating the principle of natural genetics to solve specific problems [83]. GA is a metaheuristic methodology, which does not require mathematical interpretations of the optimisation matter. However, it depends on the objective function in order to assess the fitness of a specific solution for the matter being referred to.

GA is capable of providing a strong and effective finding in the population space. Figure 7.1 illustrates the flowchart of the fundamental Genetic Algorithm's operations.

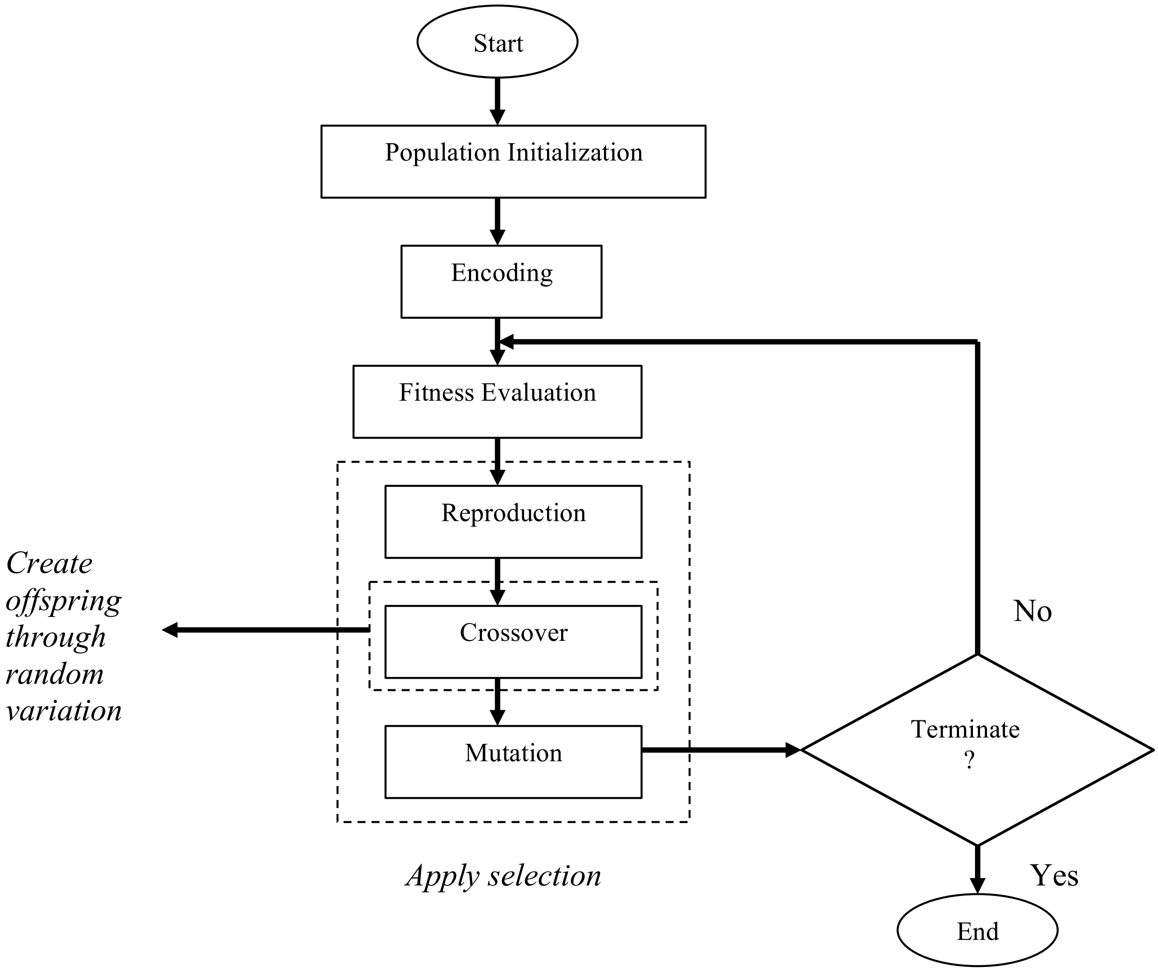


Figure 7.1: Genetic algorithms flowchart.

As indicated in Figure 7.1, the procedure included in GA is as follows:

- *Population initialization*: GA maintains a population pool of candidate solutions called strings or chromosomes that are created randomly. Each chromosome is a collection of building blocks known as genes, which are instantiated with values that can be either binary, symbols, numerical or characters depending on the problem required to be solved.

- *Encoding*: The issue (problem) is encoded into chromosomes and each individual encoded into a binary string holding an overall characterized number of bits (1's and 0's). A chromosome illustration is shown in Figure 7.2 (a), whereas a chromosome of a group of genes is converted into either 0s or 1s, as demonstrated in Figure 7.2 (b).

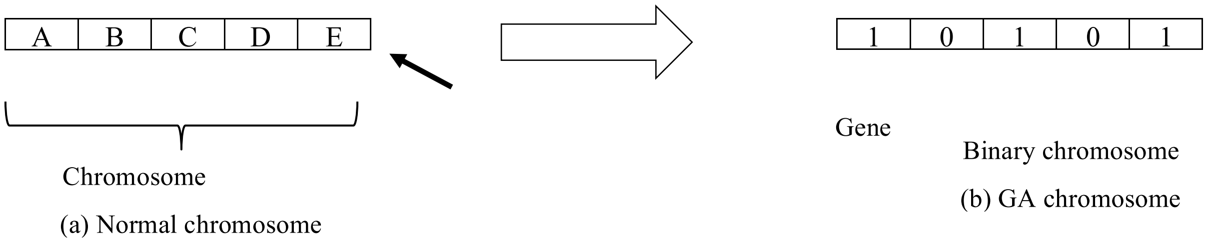


Figure 7.2: Chromosome.

- *Evaluation*: Each individual in the population (chromosome) is associated with a fitness value, which is determined by a user-defined function, called the fitness function (cost function). The value or magnitude returned by the function determines the probability of survival. Chromosome's survival and reproduction depends on the value of individual fitness function
- *Reproduction*: The chromosome with higher fitness value in the previous process (Evaluation process) is positioned as indicated in Figure 7.3 based on the fitness value. The operation models the common "survival of the fittest" system. The fitter results survive and are duplicated or selected for

the next generation while the frail ones die.

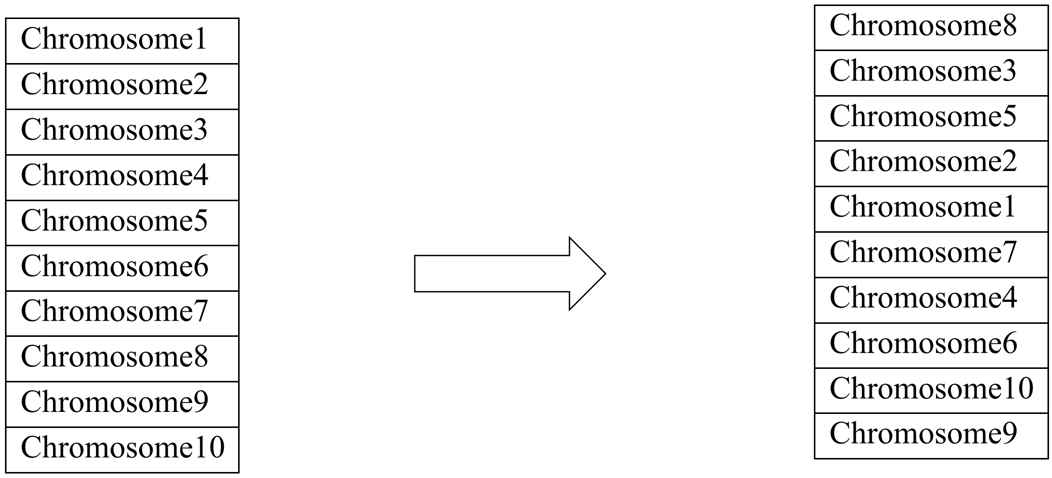


Figure 7.3: GA reproduction.

- *Crossover*: Crossover is the process of taking two parent solutions and producing from them a child. After the selection (reproduction) process, the population is enriched with better individuals. Reproduction makes clones of good strings but does not create new ones. Crossover operator is applied to the mating pool with the hope that it creates a better offspring.
    - *Single point crossover*: The traditional genetic algorithm uses single point crossover, where the two mating chromosomes are cut once at corresponding points and the sections after the cuts are exchanged. Here, a cross-site or crossover point is selected randomly along the length of the mated strings and bits next to the cross-sites are exchanged. If an appropriate site is chosen, better children can be obtained by combining good parents else it severely hampers string quality. The following Figure 7.4

illustrates single point crossover and it can be observed that the bits next to the crossover point are exchanged to produce children. The crossover point can be chosen randomly.

Parent 1	1 0 1 1 0 ⋮ 0 1 0
Parent 2	1 0 1 0 1 ⋮ 1 1 1

Child 1	1 0 1 1 0 ⋮ 1 1 1
Child 2	1 0 1 0 1 ⋮ 0 1 0

Figure 7.4: Single point crossover.

- *Two Point Crossover*: Apart from single point crossover, many different crossover algorithms have been devised, often involving more than one cut point. It should be noted that adding further crossover points reduces the performance of the GA. The problem with adding additional crossover points is that building blocks are more likely to be disrupted. However, an advantage of having more crossover points is that the problem space may be searched more thoroughly. In a two-point crossover, two crossover points are chosen and the contents between these points are exchanged between two mated parents. In the following Figure 7.5 the dotted lines indicate the crossover points. Thus the contents between these points are exchanged between the parents to produce new children for mating in the next generation.

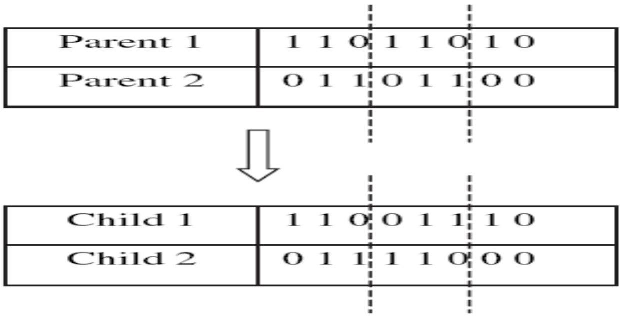


Figure 7.5: Two point corssover.

- *Uniform Crossover*: Uniform crossover is quite different from the N-point crossover. Copying the corresponding gene from one or the other parent is chosen according to a random generated binary crossover mask of the same length as the chromosomes and this creates each gene in the offspring. Where there is a 1 in the crossover mask, the gene is copied from the first parent, and where there is a 0 in the mask the gene is copied from the second parent. A new crossover mask is randomly generated for each pair of parents. Therefore, offsprings contain a mixture of genes from each parent. The number of effective crossing point is not fixed, but will average L/2 (where L is the chromosome length). In Figure 7.6, new children are produced using the uniform crossover approach. It can be noticed, that while producing child 1, when there is a 1 in the mask, the gene is copied from parent 1 else from parent 2. On producing child 2, when there is a 1 in the mask, the gene is copied from parent 2, when there is a 0 in the mask; the gene is copied from parent 1.

Parent 1	1 0 1 1 0 0 1 1
Parent 2	0 0 0 1 1 0 1 0
Mask	1 1 0 1 0 1 1 0
Child 1	1 0 0 1 1 0 1 0
Child 2	0 0 1 1 0 0 1 1

Figure 7.6: Uniform crossover.

- *Mutation*: such an operator is used to keep genetic diversity. This process is accomplished by altering one or more gene values in a chromosome (flipping bits 0's to 1's and 1's to 0's) as shown in figure 7.6. The reason behind such a process is to assist in speeding up the convergence by avoiding the population from being controlled by the same individuals.

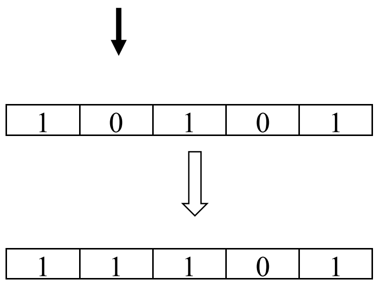


Figure 7.7: GA mutation.

This procedure is repeated several times till a termination condition has been fulfilled. Basic termination terms are [87]:

1. A solution is discovered that satisfies the least criterion.
2. The generation fixed number satisfied.
3. Reaching a cost plan assigned, such as budget money or computing time allocated.

4. The case when the highest fitness solution has been reached and no further improvement can lead to a better result.
5. Manual inspection.
6. Any mixture of the above.

In MANET, GA was utilised as presented by Barolli, et al [63] who proposed a based routing method for Mobile Ad Hoc Network (GAMAN), while in [88] GA was involved in improving the MANET routing algorithm by mobility prediction using movement history. Aspal Jindal et al. [89] in the year 2013 have proposed Fuzzy Improved Genetic Approach for Route Optimisation in MANET. In this work, the proposed routing algorithm was inspired from the genetic approach. Instead of using the shortest path, authors have selected a genetic inspired path to avoid congestion over the network. In this work, the selection of the next cross over child path has been identified on the basis of cyclic fuzzy logic. Authors have observed that the results obtained from a genetic based approach in which fuzzy is applied at the crossover show better path optimisation. The fuzzy improved genetic approach provides an energy efficient path that is needed for route optimisation in MANET.

Finally, it is worth mentioning that the reason for GA's wide acceptance and application is due to its advantages over traditional methods, some of which are:

- GA search is parallel from a population of points. Thus, it has the ability to avoid being trapped in a local optimal solution as is the case with traditional methods, which search from a single point.
- The use of probabilistic selection rule, not deterministic ones.
- The algorithm works effectively as a global optimiser.
- GA uses a fitness score, which is obtained from the objective function, without other derivative or auxiliary information.

7.3 Simulated Annealing Algorithm

Simulated annealing (SA) is a metaheuristic approach to approximate global optimisation in a large search space. The motivation and aspiration behind simulated annealing is by an analogy to annealing in solid bodies. The process of annealing is that if a solid is heated till it passes the melting point and then cooled the structural properties of the solid would depend on the cooling rate. If the liquid is cooled slowly enough large crystals will be formed. On the other hand, if the cooling is fast (quenched) the crystals will contain imperfections.

Metropolis et al [90] in 1953 published a paper that included an algorithm that simulated the material as a particle system. The algorithm simulates the cooling process by gradually lowering the temperature of the system until it converges to a frozen state. In 1982, such an algorithm was applied to an optimisation problem by Kirkpatrick et al [91] and then SA process has been utilised to search for possible solutions that converge to an optimal solution.

SA is applied to a problem by starting with a random solution in a solution space. It keeps searching in this solution space for a better solution at each of its iterations, and every time when a new solution occurs, it will either be accepted or rejected based on the satisfaction of a criterion adopted by the problem to obtain the new solution. The iteration is repeated until the algorithm reaches a terminating point. The possible termination conditions are listed as follows:

1. A given minimum value of the temperature have been reached.
2. Certain number of iterations (or temperatures) has passed without acceptance of a new solution.
3. A specific number of total iterations has been executed.

The probability of making the transition from the current state to a candidate new state is specified by the *acceptance probability function*. The formula used for calculating the acceptable probability is:

$$P = e^{\frac{-\Delta E}{kT}} \tag{7.1}$$

ΔE refers to the difference between the current energy state (objective function) and new energy state. T refers to the current temperature value while k is a constant known as Boltzmann's constant. Another crucial part in SA is the cooling schedule. It is considered as a set of values called cooling constants. The higher the cooling value, the larger is the solution space. As the cooling constant continues to decrease, the solution space shrinks gradually.

The advantages of using simulated annealing are:

- A mathematical model is not required.
- SA is relatively easy to be implemented.
- The algorithm's ability to provide reasonably good solution for many combinatorial problems.

As mentioned previously, simulated annealing is a technique, which starts with a random solution and does iterations in a step-by-step process. The ultimate goal is near optimal solution achievement. SA general algorithm is as follows:

Algorithm 7.1 Simulated Annealing

1. **Start with a random initial solution**
2. **For each value of current temperature**
3. **Loop until number of iteration > 0**
4. **Perform a new iteration and get new solution**
5. **Check if ΔE is positive**
6. **If true, go to (7)**
7. **Accept new solution and decrement number of iteration and go to (3)**
8. **Else, calculate $P = e^{\frac{-\Delta E}{kT}}$ and generate probability generated in current iteration (p)**
9. **Check if p ∈ P, if true, go to (7)**
10. **Else, discard new solution, decrement number of iteration and go to (3)**
11. **End loop.**

7.4 Particle Swarm Algorithm

Particle Swarm Optimisation (PSO) was developed by James Kennedy and Russell Eberhart in 1995 [93] after being inspired by the study of birds flocking or fish schooling behaviour by biologist Frank Heppner. It is related to evolution-inspired problem solving techniques such as genetic algorithms. It is a technique used for global optimisation. Later, several PSO algorithms have been proposed that have been used to solve various optimisation problems. Since then the number of applications where PSO has been utilised has increased dramatically.

As mentioned earlier, PSO simulates the behaviour of birds flocking or fish schooling. For instance, we consider a scenario where a group of birds are randomly searching for food in an area where there is only one piece of food. All birds do not know where the abouts of the food. Therefore the effective strategy is to follow the bird that is nearest to the food. PSO learns from this scenario and is used to solve optimisation problem by accelerating each bird towards its local best and global best locations with random weighted acceleration at each moment or iteration.

To clarify the idea, when PSO is employed to learn the best solution for a problem that is treated as a point, every particle (bird) is allocated a value based on particle's position. The best particle position that is observed carries such position to other particles in the swarm. In turn the swarm particles change their positions concentrating around the new position. The interaction can be common to the entire swarm or be divided into local neighbourhoods of particles. The general features of particle swarm algorithm are as follows [92]:

First and foremost, PSO utilizes a population of particles.

Secondly, the correspondence among the particles is governed in PSO with *gbest* and *pbest* topology or mathematical properties. The traditional topology is the use of *gbest* where fully interconnected population is considered therefore, every other member influences every particle of the population. In this case, if a particle has found the best solution so far, it can affect all the particles in the population. However, *pbest* topology is considered as a loop cross-section or a partial interconnected population where each particle is associated with the neighbouring particles and formulating a number of subpopulations sets. Such an arrangement can lead to different optima in the search space. However, there is a drawback to this topology that it is slower to converge on an ideal solution.

Third, every particle in the population changes its position based on the position equation (7.3).

Fourth, the interaction rule known as velocity equation as shown in Equation (7.2) specifies the next point of the particle that will be checked in the search space, wherein particles treat their best and some other particles' best as a benchmark that affects the next particle that is considered.

Considering the former characteristics in execution, Clerc and Kenndey [92] presented the basic assertive version of PSO, as shown in Figure 7.8 Flowchart in Figure 7.9 shows a population that is initialised with random generated position x (t) and velocities v (t) and a fitness function is assessed, utilising the PSO.

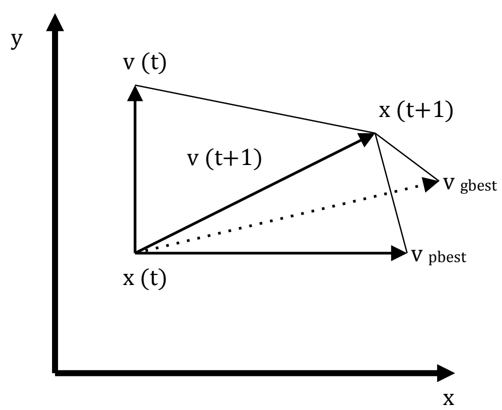


Figure 7.8: Concept of modification of searching point by PSO.

The concepts of PSO mathematically have been represented in the following equations (7.2) and (7.3)

$$v(t+1) = wv(t) + c_1 r_1 \big(pbest(t) - x(t)\big) + c_2 r_2 (gbest(t) - x(t)) \qquad (7.2)$$

Where w is inertia weight that can be either a constant or a value that changes linearly with time; c_1 and c_2 are called “cognitive” and “social” parameters respectively and they are random positive unchanged constants that weight the influence of the two different swarm memories; $r_1$and r_2 are uniform distributed numbers between 0 and 1.

Once the velocity vector has been calculated, the positions of particles are updated based on equation (7.3).

$$x(t+1) = x(t) + v(t+1) \qquad (7.3)$$

The use of PSO in various applications is due to its advantages as follows:

- PSO does not have genetic operators such as crossover and mutation.
- Easy to implement.
- Compared to SA and GA optimisers it is faster.
- Using real numbers not binary numbers.

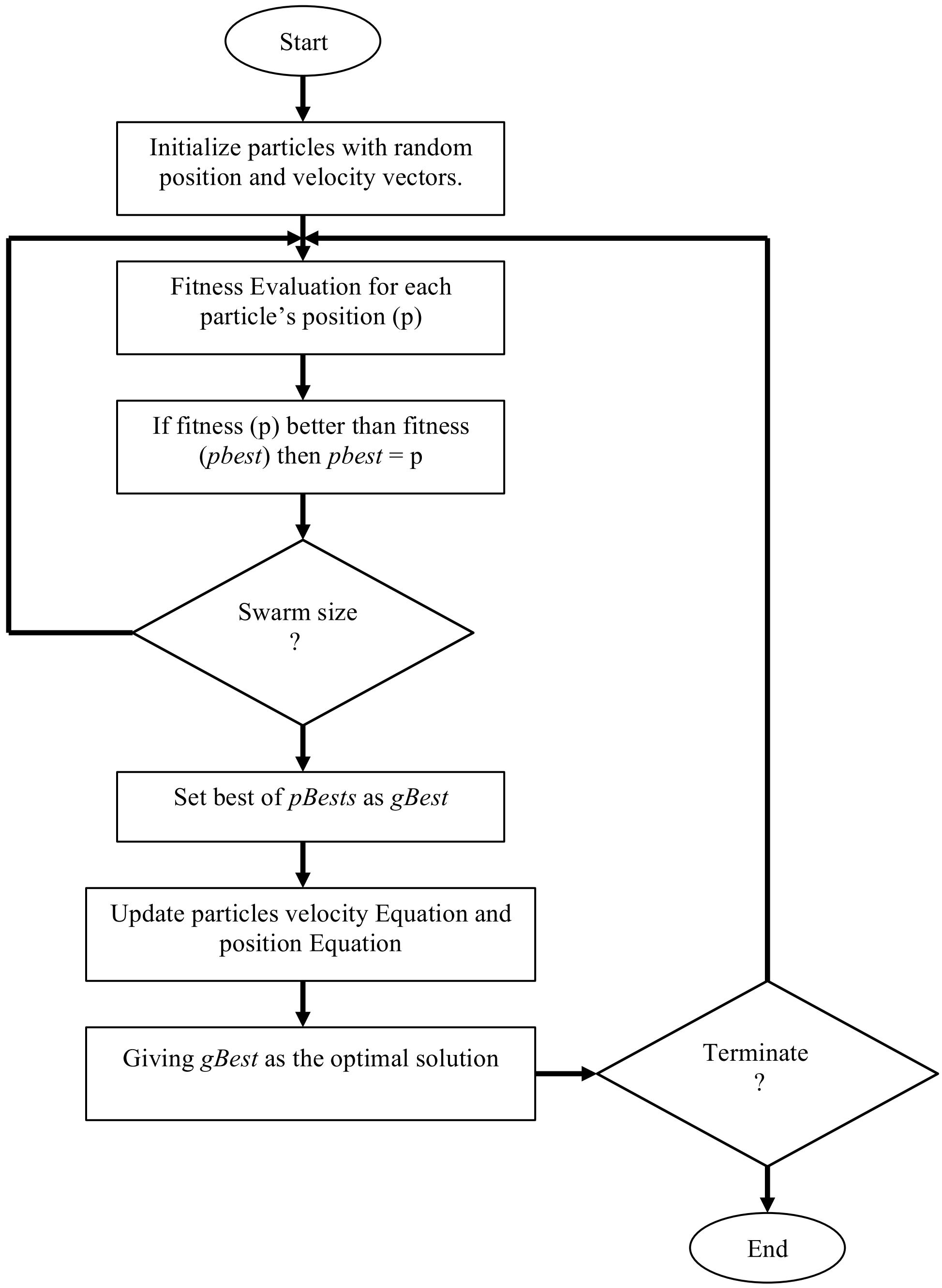


Figure 7.9: Typical flowchart for Particle Swarm Optimisation.

7.5 I-MMS Optimiser

The network history was represented by a MANET AI model for each routing protocol (presented in the previous chapter) to predict the network performance behaviour for different network contexts. *Metaheuristic* algorithms are much quicker and more adjustable to alterations in the environment based on the knowledge on how to resolve an issue and finding the optimum solution for such a problem.

Three different optimisation algorithms were employed to search for the most appropriate parameters for the proposed system in this thesis. The optimiser will compare and evaluate each of the five routing protocols performance with each other in the same network context. The purpose of such an operation is to select one of the three optimisers namely; GA, SA and PSO to be part of our system in which it can propose the optimum routing protocol based on output performance under the current network context.

7.5.1 Constructed Network Context Cases

Two steps were taken prior to examining the three algorithms as an optimiser. These two steps are validation cases and normalisation (described in section 7.5.2). regarding the first step, each of the potential cases for the two input context, network size and average mobility for all the three applications (table 7.1) were considered.

Table 7.1: Validation cases.

Cases no.	Network size	Average mobility (m/s)
Case 1	Large	Fast
Case 2	Large	Medium
Case 3	Large	Slow
Case 4	Medium	Fast
Case 5	Medium	Medium
Case 6	Medium	Slow
Case 7	Small	Fast
Case 8	Small	Medium
Case 9	Small	Slow

All labels for both network size and average mobility were converted to quantitative values as shown in table 7.2 for network size and 7.3 for network average mobility. Each context parameter was organised into three fields, which are constant for all three applications. The collected data for the network size stats range from 2 nodes and with upper limits of 100 nodes. Moreover, the data gathered for network average mobility range from 0 (m/s) up to 20 (m/s)

The size criteria is organised in Table 7.2 as follow:

A small network: $2\, nodes \leq small\ network \leq 20\, nodes$

A medium network in size: $21\, nodes \leq medium\ sized\ network \leq 50\, nodes$

A large network: $51\, nodes \leq large\ network \leq 100\, nodes$

Table 7.2: Network size organisation.

Network Size	Small	Medium	Large
From - to	2 - 20	21 - 50	51 - 100
Studied case	6	30	72

The average network mobility criteria is organised in Table 7.3 as follow:

Network with slow speed: $0 \left(\frac{m}{s}\right) \leq \ network\ low\ level\ of\ mobility \leq 7\ (\frac{m}{s})$

A medium speed network: $7 \left(\frac{m}{s}\right) \leq medium\ speed\ network\ \ \leq 13\ (\frac{m}{s})$

A fast network: $13 \left(\frac{m}{s}\right) \leq \ network\ with\ high\ mobility \leq 20\ (\frac{m}{s})$

Table 7.3: Average mobility organisation.

Mobility (m/s)	Slow	Medium	Fast
From - to	0 - 7	7.1 - 13	31.1 - 20
Studied case	4	9	17

The numbers in the third row in Table 7.2 and 7.3 are selected randomly from the range indicated in the second row in both tables. For instance, the number 72 was chosen arbitrarily from the range ($51\ nodes \leq large\ network \leq 100\ nodes$) to represent a large network and replace the label in Table 7.1. Therefore, this random value will be considered by the three algorithms and will be represented in the final value in the second and third column of the module results shown in Tables 7.4, 7.5, and 7.6.

7.5.2 Normalisation

The three algorithms GA, SA and PSO were utilised as MANET optimisers to determine and choose the optimum routing protocol according to the output performance. GA and PSO optimisers were programmed in MATLAB™ while optimtool in MATLAB™ was used for SA optimiser.

In chapter 6, every output parameter was modelled versus the input parameters. Those models were provided to the three optimisers. Prior to cost function creation, the four performance parameters must be normalised. Normalisation is the process of converting all variables in the data to a definite range. The method was used based on the available and known data. In this thesis, both the highest and the lowest values are known for every parameter thus, Equation 7.4 and 7.5 has been employed as follows:

$$NPP = p\text{-}p_{min} \,/\, p_{max} - p_{min} \tag{7.4}$$

Where NPP is the normalized performance parameter and p is denoted for the parameter value. The Mean Square (MS) of the normalized performance parameter represents the cost function as indicated below:

$$cost\ function = \frac{(Delay)^2+(Load)^2+(RA)^2+(1-Throughput)^2}{4} \tag{7.5}$$

The selection of the optimum routing protocol will depend on the minimum value of the cost function (objective function) for each iteration. The selection will be repeated for each iteration for only the GA and PSO. GA and PSO Optimisation processes will yield a number of solutions equal to the number of iterations. The selected solution represents the optimal routing protocol that has the best objective (lowest MS value).

7.5.3 Mobile Ad Hoc Network Optimisation

Network size (number of nodes) and average mobility are fed into the optimiser as an input to commence the computation. There are nine cases where the two input values used are based on Table 7.2 and 7.3.

7.5.3.1 GA MANET Optimiser

The optimum MANET routing protocol to be adopted is decided by GA optimiser based on the output of the neuro-fuzzy models developed in chapter 6. The GA configuration parameters as follows:

- Three bits of individuals' (chromosomes) length for the three parameters; protocol's name, number of nodes, average mobility.
- The individual value prior to binary conversion was randomly chosen between 0 and 250.
- The size of population was 10 with averaging of the ranking.
- Mutation was 0.06.
- Crossover probability was 0.95.
- 13 generations were used to find the best solution.

The pseudo code for MANET GA was formulated as follow:

```
1. Generate initial population of individuals of size 10.
2. Repeat.
3. Calculate the fitness of each individual.
4. Evaluate the individual fitness's of the population.
5. Select pairs of average-ranking individuals to reproduce.
6. Select a pair of individuals for the crossover and the mutation.
7. Process.
8. Change the genes values to the offspring individual.
9. Place the resulting individual in the new population.

10.If the size of the new generation is not equal to 10 go to 3.
11.Replace the current individual population with the new one.
12.Until termination condition is met.
```

Figure 7.10: MANET GA pseudo code.

Table 7.4 through 7.6 indicates the GA's optimum routing protocol solution for each case with different applications.

Table 7.4: GA module results for FTP

case no.	GA inputs		GA outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	OLSR	0.4033	3
case 2	72	9	OLSR	0.6577	1
case 3	72	4	OLSR	0.7497	10
case 4	30	17	OLSR	0.9485	1
case 5	30	9	OLSR	0.9283	10
case 6	30	4	OLSR	0.9834	1
case 7	6	17	OLSR	0.8693	5
case 8	6	9	OLSR	0.4049	6
case 9	6	4	OLSR	1.0457	6

Table 7.5: GA module results for VoIP

case no.	GA inputs		GA outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	OLSR	1.0238	10
case 2	72	9	OLSR	0.9333	9
case 3	72	4	DSR	0.8211	9
case 4	30	17	AODV	0.9798	1
case 5	30	9	AODV	0.9853	10
case 6	30	4	GRP	1.0073	1
case 7	6	17	AODV	0.8893	1
case 8	6	9	GRP	0.7046	1
case 9	6	4	DSR	1.2457	2

Table 7.6: GA module results for Video Conferencing

case no.	GA inputs		GA outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	AODV	1.0003	5
case 2	72	9	OLSR	1.0516	10
case 3	72	4	OLSR	1.0221	9
case 4	30	17	AODV	1.0792	8
case 5	30	9	DSR	1.1343	10
case 6	30	4	GRP	1.0063	10
case 7	6	17	AODV	0.9693	10
case 8	6	9	AODV	1.0016	12
case 9	6	4	DSR	1.4357	1

7.5.3.2 PSO MANET Optimiser

Matlab is used to carryout PSO as it reads all dependent FIS files that are created by ANFIS as mentioned earlier. The PSO configuration is as follows:

- There are three swarm dimensions represented by protocols' name, number of nodes in the network and average mobility.
- Swarm size was set to 10.

- Iteration number was set to 10 times.
- Error acceptance was less than $1x10^{-10}$.
- Equation (7.2) and (7.3) were used for position and velocity.
- 'c1 = 1.49618', 'c2 = 1.49618, 'w = 0.7298' as Eberhart and Shi [93] confirmed that inertia weight of 07298 and acceleration coefficient of 1.49618 are good parameter choices for trajectories convergence.

```
•  Initialize the three swarm dimension,
•  Do:
•     For each particle:
•       Calculate fitness value,
•       If fitness value is better than the best fitness value
•         (pbest) in history,
•         Set current value as the new pbest,
•     End
•     Find in the best pbest
•     Set best pbest as the new gbest,
•     Calculate particle velocity based on the velocity Equation
•     Update particle position based on the position Equation
•     While maximum iteration not equal to 10 or min accepted error
•       is not less than 1x10^-10.
```

Figure 7.11: MANET PSO pseudo code.

As in Figure 7.11 there are two-termination condition; maximum number of iteration, which was set to 10 iterations and minimum, accepted error that is not less than $1x10^{-10}$. In case the accepted error obtained less the minimum accepted error the program would be terminated regardless to the number of iteration had been reached.

Table 7.7 through 7.9 indicates the PSO's optimum routing protocol solution for each case with different applications.

Table 7.7: PSO module results for FTP

case no.	PSO inputs		PSO outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	OLSR	0.31513	5
case 2	72	9	OLSR	0.32900	1
case 3	72	4	OLSR	0.32363	6
case 4	30	17	OLSR	0.62895	10
case 5	30	9	OLSR	0.29781	8
case 6	30	4	OLSR	0.27257	7
case 7	6	17	OLSR	0.26381	7
case 8	6	9	OLSR	0.21572	5
case 9	6	4	OLSR	0.51571	8

Table 7.8: PSO module results for VoIP

case no.	PSO inputs		PSO outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	OLSR	0.62929	1
case 2	72	9	OLSR	0.63761	1
case 3	72	4	DSR	0.87953	3
case 4	30	17	AODV	0.7117	1
case 5	30	9	AODV	0.53817	8
case 6	30	4	GRP	0.51244	3
case 7	6	17	AODV	0.73461	3
case 8	6	9	GRP	0.51645	10
case 9	6	4	DSR	0.51642	2

Table 7.9: PSO module results for Video Conferencing

case no.	PSO inputs		PSO outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	AODV	0.9047	7
case 2	72	9	OLSR	0.9207	9
case 3	72	4	OLSR	1.0077	9
case 4	30	17	AODV	1.0035	5
case 5	30	9	DSR	0.7023	1
case 6	30	4	GRP	0.8798	1
case 7	6	17	AODV	0.8052	2
case 8	6	9	AODV	0.9063	7
case 9	6	4	DSR	0.9254	1

7.5.3.3 SA MANET Optimiser using optimtool and Optimisationapp

The optimtool called Optimisationapp chooses the optimisation algorithm, or solver, as it is known as, to optimise the function. It opens a GUI that can be fed with the function or problem, the optimisation option and the solver. The optimisation app can be used to run any Optimisation Toolbox solver and any Global Optimisation Toolbox Solver except Global Search and MultiStart. Results can be exported to a file or the MATLAB workspace. Moreover, code can be generated and can be converted later to either C or C++ programming language. First the solver was selected then the algorithm was picked. In the SA case, the solver is called *Simulannealband* and it is the only available algorithm. After that a starting point was entered. The fitness function was used on the objective function, which has been included. Then the maximum iteration number was selected to be 100 times. Boltzmann as the annealing function and temperature update function was set as exponential as shown in Figure (7.12) and the remaining settings remained as the default settings such as the tolerance function as 10^{-6}.

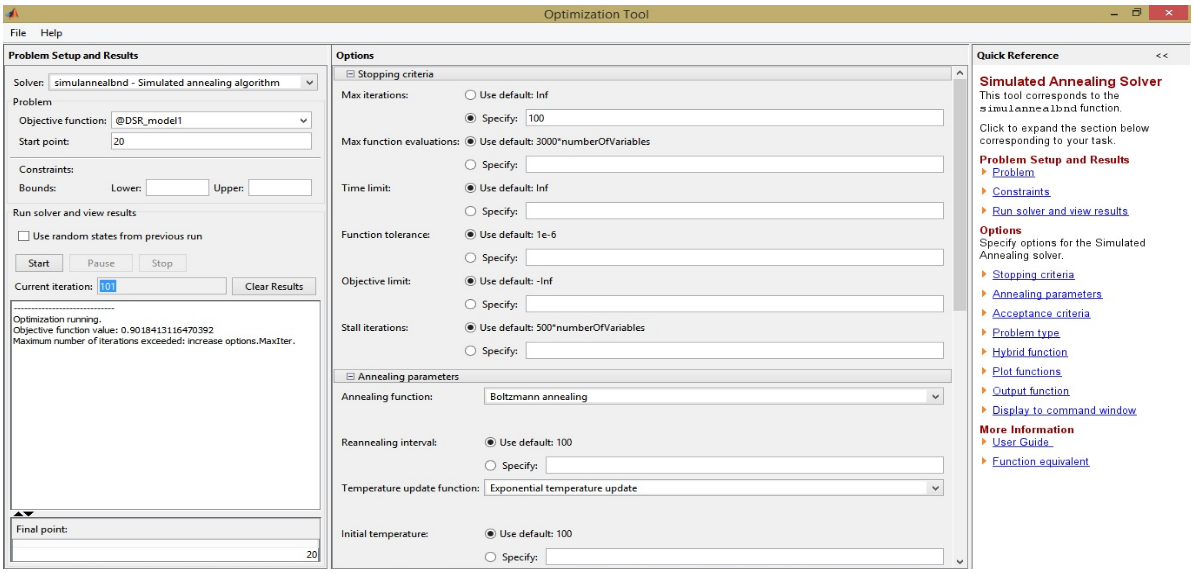


Figure 7.12: Optimisation tool setting for SA algorithm.

Figures (7.13) through (7.15) shows the reading of FIS using ‘readfis’ command and calculating the output of the NF model using ‘evalfis’. Finally, the predicted values of the four dependent variables were used to create a cost_f after normalizing the variables. Tables 7.10 through 7.12 indicates the SA's optimum routing protocol solution for each case with different applications.

```
%Reading the FIS using 'readfis' command for AODV

    AODV_Delay_fis=readfis('AodvDealyModel.fis');

    AODV_Load_fis=readfis('AodvLoadModel.fis');

    AODV_Ra_fis=readfis('AodvraModel.fis');

    AODV_Th_fis=readfis('AodvThroughputModel.fis');

%Reading the FIS using 'readfis' command for DSR

    DSR_Delay_fis=readfis('DsrDelayModel.fis');

    DSR_Load_fis=readfis('DsrLoadModel.fis');

    DSR_Ra_fis=readfis('DSRraModel.fis');

    DSR_Th_fis=readfis('DsrThrouModel.fis');

%Reading the FIS using 'readfis' command for OLSR

    OLSR_Delay_fis=readfis('OlsrDelayModel.fis');

    OLSR_Load_fis=readfis('OlsrLoadModel.fis');

    OLSR_Ra_fis=readfis('OLSRraModel.fis');

    OLSR_Th_fis=readfis('OlsrThrouModel.fis');

%Reading the FIS using 'readfis' command for GRP

    GRP_Delay_fis=readfis('GrpDelayModel.fis');

    GRP_Load_fis=readfis('GrpLoadModel.fis');

    GRP_Ra_fis=readfis('GRPraModel.fis');

    GRP_Th_fis=readfis('GrpThrouModel.fis');

%Reading the FIS using 'readfis' command for AODV

    TORA_Delay_fis=readfis('ToraDelayModel.fis');

    TORA_Load_fis=readfis('ToraLoadModel.fis');

    TORA_Ra_fis=readfis('TORAraModel.fis');

    TORA_Th_fis=readfis('ToraThrouModel.fis');
```

Figure 7.13: Sample of reading FIS used in all three optimisation algorithms.

```
%Evaluate the output of a neuro-fuzzy inference system

if (protocol==1)

  Delay=evalfis([mobility,no_of_nodes],AODV_Delay_fis);

  Load=evalfis([mobility,no_of_nodes],AODV_Load_fis);

  RA = evalfis ([mobility, no_of_nodes],AODV_Ra_fis);

  Throughput=evalfis([mobility,no_of_nodes],AODV_Th_fis);

elseif (protocol==2)

  Delay=evalfis([mobility,no_of_nodes],DSR_Delay_fis);

  Load=evalfis([mobility,no_of_nodes],DSR_Load_fis);

  RA = evalfis ([mobility, no_of_nodes],DSR_Ra_fis);

  Throughput=evalfis([mobility,no_of_nodes],DSR_Th_fis);

elseif (protocol==3)

  Delay=evalfis([mobility,no_of_nodes],OLSR_Delay_fis);

  Load=evalfis([mobility,no_of_nodes],OLSR_Load_fis);

  RA = evalfis ([mobility, no_of_nodes],OLSR_Ra_fis);

  Throughput=evalfis([mobility,no_of_nodes], OLSR_Th_fis);

elseif (protocol==4)

 Delay=evalfis([mobility,no_of_nodes],GRP_Delay_fis);

 Load=evalfis([mobility,no_of_nodes],GRP_Load_fis);

 RA = evalfis ([mobility, no_of_nodes],GRP_Ra_fis);
Throughput=evalfis([mobility,no_of_nodes],GRP_Th_fis);

else

 Delay=evalfis([mobility,no_of_nodes],TORA_Delay_fis);

 Load=evalfis([mobility,no_of_nodes],TORA_Load_fis);

 RA = evalfis ([mobility, no_of_nodes],TORA_Ra_fis);

 Throughput=evalfis([mobility,no_of_nodes],TORA_Th_fis);

end;
```

Figure 7.14: Sample of evaluating the NF output in all three optimisation algorithms.

```
%Normalising the four dependent variables

Delay=(Dsr_Delay-0.003427)/0.000801;

Load= (Dsr_Load-7141.061)/72011.43;
```

```
Ra=(Dsr_Ra-0.032332)/0.106391;

Throughput=(Dsr_Throughput-7237.531)/79978.63;

%Mean Square of the normalized dependent variables for cost function

%Protocol performance in FTP Application.

cost_f = mean((Delay.^2) + (Load.^2) + (Ra.^2) + ((1-Throughput).^2));
```

Figure 7.15: Sample of cost function used in all three optimisation algorithms.

Table 7.10 through 7.12 indicates the SA's optimum routing protocol solution for each case with different applications.

Table 7.10:SA module results for FTP

case no.	SA inputs		SA outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	OLSR	0.70268	54
case 2	72	9	OLSR	0.32914	68
case 3	72	4	OLSR	0.84019	77
case 4	30	17	OLSR	0.7698	13
case 5	30	9	OLSR	0.63526	52
case 6	30	4	OLSR	0.9851	44
case 7	6	17	OLSR	1.1107	16
case 8	6	9	OLSR	0.48395	81
case 9	6	4	OLSR	1.31401	16

Table 7.11: SA module results for VoIP

case no.	SA inputs		SA outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	OLSR	1.16208	97
case 2	72	9	OLSR	1.1029	59
case 3	72	4	DSR	1.2522	33
case 4	30	17	AODV	0.9	33
case 5	30	9	AODV	1.0031	36
case 6	30	4	GRP	0.9918	15
case 7	6	17	AODV	1.4108	88
case 8	6	9	GRP	0.7392	76
case 9	6	4	DSR	0.8166	55

Table 7.12: SA module results for Video Conferencing

case no.	SA inputs		SA outputs		
	Network size	Average mobility (m/s)	Routing protocol	Best objective	Iteration no.
case 1	72	17	AODV	1.0233	49
case 2	72	9	OLSR	1.376	34
case 3	72	4	OLSR	1.2577	26
case 4	30	17	AODV	0.9824	52
case 5	30	9	DSR	1.2066	55
case 6	30	4	GRP	1.3204	61
case 7	6	17	AODV	0.8996	37
case 8	6	9	AODV	1.0798	61
case 9	6	4	DSR	1.2007	22

7.5.4 MANET Optimiser Selection

Tables (7.4) through (7.12) show that GA, PSO and SA optimisers selected the same routing protocols for the same cases, however, it is important to be noticed that in the two applications: VoIP and VC, the results verify that the optimisers chose different routing protocols through different cases except FTP application where OLSR dominated the entire scenarios even when there were two network contexts; when the network size and average mobility changed the same routing protocol was selected as expected from the simulation results presented in chapter 5. However, the results with VoIP and VC shows the possible scenario that could happen in MANET, namely that different routing protocols depend on the network context changes (network size and average mobility) for their performance. Therefore, the three optimisers selected different routing protocols as the two contexts changed. For instance, for a network using VoIP application with 6 nodes for a small network with slow average speed (4 m/s), DSR was selected as the optimum routing protocol whereas as the speed reached a medium speed with 9 (m/s), GRP was selected, however, when the network nodes reached to a very fast mobility with 17 (m/s), AODV was chosen as the optimum routing protocol.

Comparing the efficiency of the three techniques quantitatively, the best objectives in all the tables were examined. After examining the objective value of the three optimisers, PSO best objective was always lower than SA and GA best objective. Thus, it is obviously shown in Tables 7.13 through 7.15 that PSO has the minimum MS. Therefore, based on the comparison results to evaluate each optimiser, PSO optimiser was utilized in I-MMS optimisation system .

Table 7.13: Optimisation techniques best objective comparison for FTP

case no.	GA	PSO	SA	Routing protocol
	Best objective	Best objective	Best objective	
case 1	0.4033	0.31513	1.16208	OLSR
case 2	0.6577	0.32900	1.1029	OLSR
case 3	0.7497	0.32363	1.2522	OLSR
case 4	0.9485	0.62895	0.9	OLSR
case 5	0.9283	0.29781	1.0031	OLSR
case 6	0.9834	0.27257	0.9918	OLSR
case 7	0.8693	0.26381	1.4108	OLSR
case 8	0.4049	0.21572	0.7392	OLSR
case 9	1.0457	0.51571	0.8166	OLSR

Table 7.14: Optimisation techniques best objective comparison for VoIP

case no.	GA	PSO	SA	Routing protocol
	Best objective	Best objective	Best objective	
case 1	1.0238	0.62929	0.70268	OLSR
case 2	0.9333	0.63761	0.32914	OLSR
case 3	0.8211	0.87953	0.84019	DSR
case 4	0.9798	0.7117	0.7698	AODV
case 5	0.9853	0.53817	0.63526	AODV
case 6	1.0073	0.51244	0.9851	GRP
case 7	0.8893	0.73461	1.1107	AODV
case 8	0.7046	0.51645	0.48395	GRP
case 9	1.2457	0.51642	1.31401	DSR

Table 7.15: Optimisation techniques best objective comparison for Video Conferencing

case no.	GA	PSO	SA	Routing protocol
	Best objective	Best objective	Best objective	
case 1	1.0003	0.9047	1.0233	AODV
case 2	1.0516	0.9207	1.376	OLSR
case 3	1.0221	1.0077	1.2577	OLSR
case 4	1.0792	1.0035	0.9824	AODV
case 5	1.1343	0.7023	1.2066	DSR
case 6	1.0063	0.8798	1.3204	GRP
case 7	0.9693	0.8052	0.8996	AODV
case 8	1.0016	0.9063	1.0798	AODV
case 9	1.4357	0.9254	1.2007	DSR

7.6 Summary

In this chapter, the essence of employing the Artificial Intelligence (AI) methods for optimising MANET has been stressed since AI is known for its capability to adjust to variations in the environment and its algorithms' rapid convergence that makes it ideal for MANET environment. Furthermore, the processes for each GA, SA and PSO algorithms were also clarified in detail. Besides, three MANET Optimisers were created: one with GA, the second with SA and finally with PSO. All the chosen routing protocols for different cases were exactly the same for the three optimisers.

Consequently, three optimisation model results were created to include all possible context changes for all three applications. The results in the table obviously indicate that the optimiser chooses a different routing protocol in different cases. Moreover, the table results particularly for VoIP and VC applications verify that the variations in the network context would influence on the overall network performance; thus, for improved network performance, the optimiser will chose a different routing protocol if the network context changes. As the three optimisers have been examined in this chapter, a conclusion was drawn that PSO optimisation algorithm will be employed in I-MMS optimisation system since it performed with the minimum MS values. However, it is worth mentioning that GA performance can be enhanced and improved if more iteration is used. In this case it will open the door for researchers to replace PSO with GA in the system.

Chapter 8: System Implementation

8.1 I-MMS Optimisation System

In this chapter, the intelligent system designed in Chapter 4 will be implemented. However, in order to implement such system both the NF modeller and PSO optimiser created and selected in Chapter 6 and 7 respectively, must be embedded to create MANET network. Since, the system components do not exist in Opnet^{TM} 17.5 modeller, several changes or modifications should take place within the original nodes.

Before, diving into the details of node modification, system implementation and testing, the need for a smart node must be discussed to shed the light on its important role it ought to play into providing context-awareness in MANET routing. As it is well known, Ad Hoc network (except the zone protocols) operates with only one routing protocol once the network has been established. Such routing protocol is responsible for packet delivery from a source to a desired destination. Therefore, a node in a mobile Ad Hoc network cannot decide the best routing protocol to be in operation once it establishes or joins the network without consulting or referring to the rest of the nodes in the network.

Consequently, the need for a node that is aware of the network context is imperative to be considered as a referee to make decision on which routing protocol to be utilised. A node is granted the capability to consult all other network nodes to gain the required knowledge about the network context, draw a conclusion for which routing protocol should be in operation and order the other nodes to switch to that particular protocol. To enable the node to accomplish such tasks, optimisation unit must be embedded to help the node's decision in selecting an optimum routing protocol, and such node is called "Smart node". In this thesis, such decision capability and responsibility is granted to a single node as illustrated in Figure 8.1

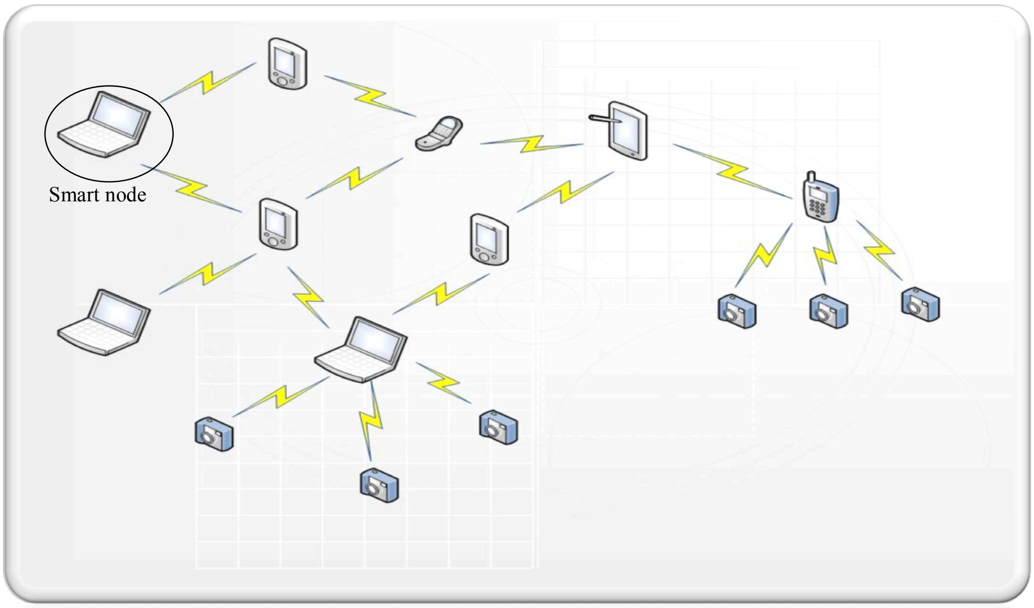


Figure 8.1: Smart node in MANET network.

Since the nodes connected in MANET networks have constrained battery life [42], by providing the optimisation process responsibilities to a single smart device will release the burden of data processing from the rest of the nodes in the network. Consequently, power consumption will be saved for the MANET nodes and can keep forwarding periodically the topology packets to enable the smart node to make its decision.

Indeed, there is a possibility of a single-point-of-failure in case the smart node battery died or moved out of the network coverage. Thus, this optimisation process will not take place in the network to suggest the optimum solution but installing the optimisation unit in all MANET nodes could be an ideal solution for such a case. If the smart node disconnects from the network for any possible reason and after a specified threshold time the first nominee’s optimisation unit will be triggered and take over from the previous smart node. However, such a scenario is out the scope of this thesis and suggested in Chapter 9.

8.2 System Operation

The network topology information is required by the system, thus a topology packet that holds the node average mobility and the name of protocol in operation are sent to the optimisation unit. The block diagram of the unit, as shown in Figure (8.2), is installed in the smart node. The unit is made up of the Communication Pipeline, Information Bank, Decision Process (modeller and optimiser), and Decision Maker. The illustration below shows the operation of I-MMS optimisation unit in order.

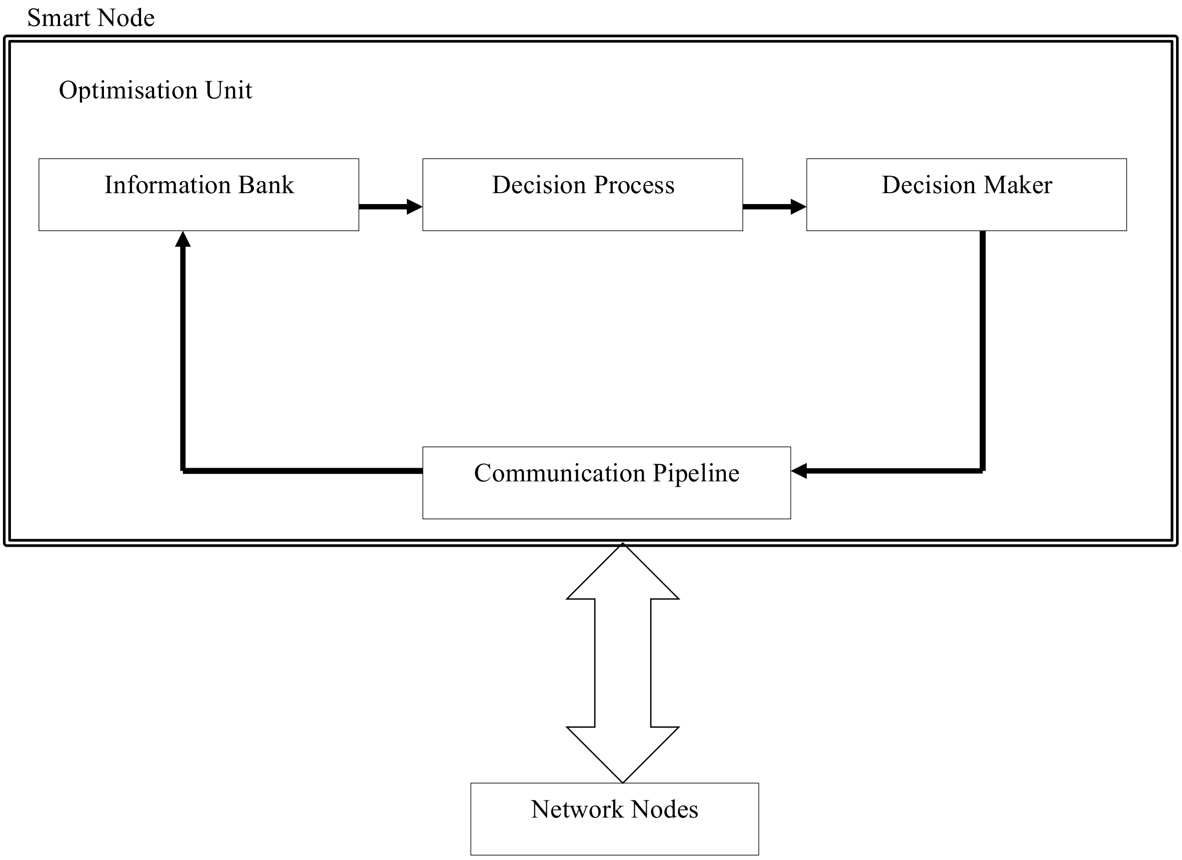


Figure 8.2 : Block diagram of I-MMS optimisation unit.

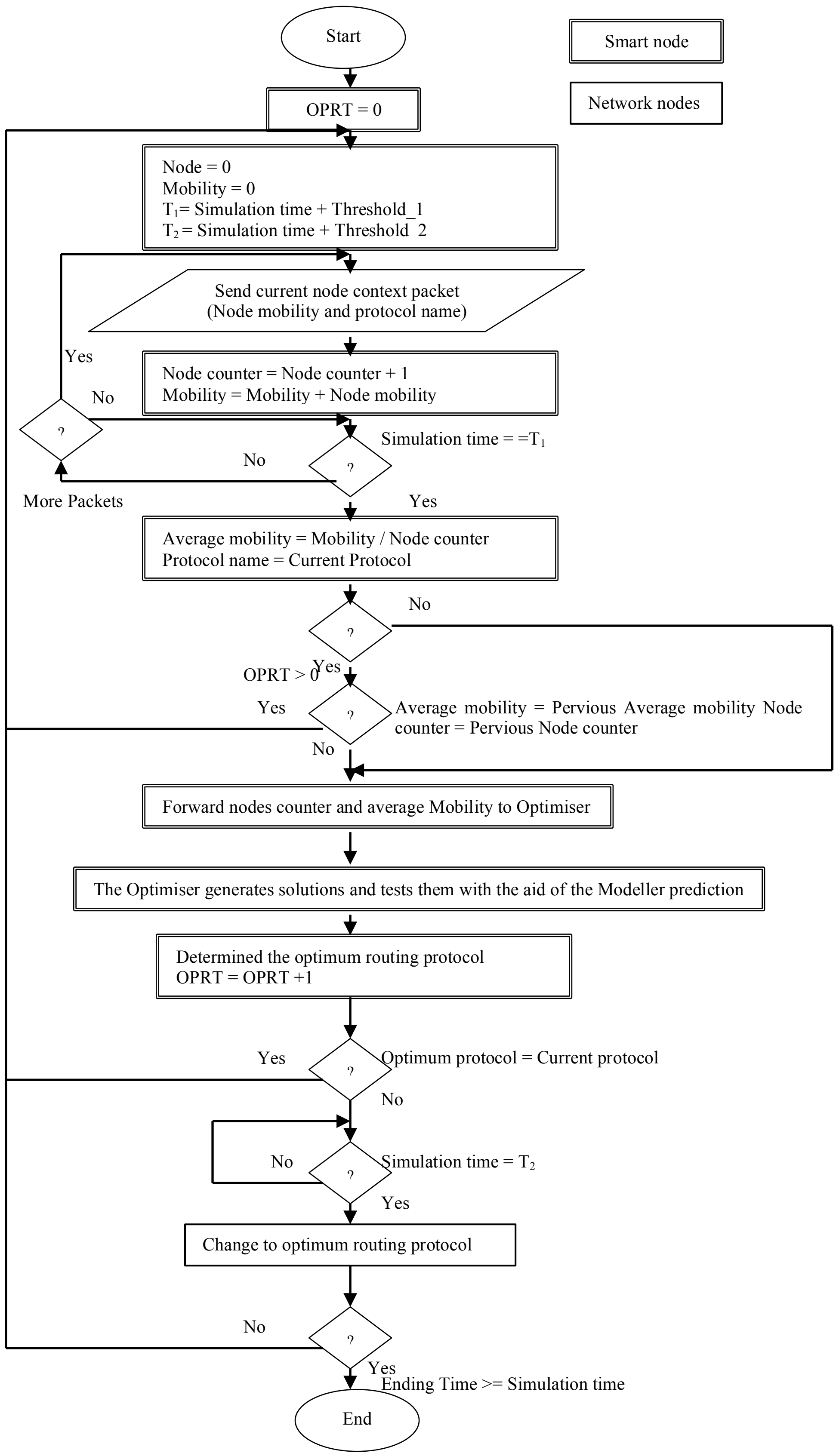
The Topology packet that has been received from the nodes in the network will be forwarded to the Information Bank via the Communication Pipeline unit. Once the Information bank receives a Topology packet, it will extract the required information enclosed in the packet (the current average mobility and network size). Then the Decision Process (optimiser) will be updated with the new current network context. As explained in Chapter 7, the optimiser will commence to generate its solutions based on the current network context in support of the modeler in order to predict the network performance under the current context. This process enables the optimiser to evaluate both the current protocol performance metric and specifies the optimum routing protocol that suites the current conditions. Indeed, a protocol is selected based on the best cost value consisting of combined performance matric values), namely: low Delay, low RA, low Load, and high Throughput. Consequently, the optimum routing protocol will be chosen. Then the decision will be sent to the Decision Maker where it will add the switching time and the new optimal protocol to be used within a Decision packet, which is sent to all the network nodes through the communication pipeline.

The I-MMS optimisation system, as shown in Figure (8.3), starts with the system parameters' initialization, which is OPRT (Optimiser Run Time) and which gives the indication whether the optimiser has been active by receiving a Topology packet or not. If the value of OPRT = 0, then this means that it is the first run for the optimiser since it had no prior knowledge of the current network context. However, if OPRT > 0, this indicates that it was triggered before and an best suited routing protocol was selected when Topology packet had been received to enable the optimiser to be aware of the current context.

Once Communication Pipeline forwards the Topology packet to the information bank then the latter will be triggered to commence the following steps:

- The Topology packets are gathered and counted to obtain the total number of nodes in the network by a node counter.

- Extracting the protocol name and averaged node's mobility from each Topology packet and summing the node's mobility.
- Topology information is buffered until time T_1 as in the equation if Figure (8.3) where T_1 is the estimated time for the Topology packet received by the smart node from all the network nodes.
- The total Topology packets received in addition to smart node itself is used to calculate the total number of nodes in the network (network size). Moreover, each node sending the Topology packet add its average mobility value which in turn is extracted by the Information Bank. It adds it to the previous average mobility and at the same time calculates the accumulated Topology packets plus 1, which represents the number of nodes in the network. Then the mobility counter is divided by the node counter to produce the network averaged mobility value at time T1.



Start
Smart node
Network nodes
OPRT = 0
Node = 0
Mobility = 0
T1= Simulation time + Threshold_1
T2 = Simulation time + Threshold_2
Send current node context packet
(Node mobility and protocol name)
Yes
No
Node counter = Node counter + 1
Mobility = Mobility + Node mobility
?
Simulation time = =T1
No
?
More Packets
Yes
Average mobility = Mobility / Node counter
Protocol name = Current Protocol
No
?
OPRT > 0
Yes
Yes
?
Average mobility = Pervious Average mobility Node counter = Pervious Node counter
No
Forward nodes counter and average Mobility to Optimiser
The Optimiser generates solutions and tests them with the aid of the Modeller prediction
Determined the optimum routing protocol
OPRT = OPRT +1
Yes
?
Optimum protocol = Current protocol
No
No
?
Simulation time = T2
Yes
Change to optimum routing protocol
No
?
Yes
Ending Time >= Simulation time
End

Figure 8.3: I-MMS implementaion flowchart.

As stated before, if OPRT = 0 means that the optimiser is not aware of the current network context and so the default routing protocol is made operational. Therefore, the Information Bank will forward the network context directly to the optimiser. Yet, if the value of parameter OPRT > 0 the current context has to be compared with the previous one and there are two scenarios. In the first scenario, when the comparison process yields a negative or positive value then there is a change in the network context and new inputs to the optimiser. However, the second scenario takes place when the comparison process yields a match and the value is 0. Then there are no new inputs to the optimiser and the current routing protocol is considered as the optimum one. Consequently, there will be no need for a decision packet to be broadcasted by the smart node to all nodes in the network .

If the first scenario takes place and there are new inputs for the optimiser, then the modeller will be activated to predict the network performance for the five routing protocols. The inputs are sent to the optimiser for the cost function to determine the most suitable protocol for the new inputs. Then the name of the optimum routing protocol is sent to the Decision Maker to examine whether the suggested protocol is matching the current protocol or a different one. If it is the same no decision packet needs to be broadcasted, but if there is no match then the packet will be broadcasted through the Communication Pipeline. The packet will include the switching simulation time (T_2) and the new routing protocol for all network nodes.

8.3 Node Modification

I-MMS optimisation system was implemented in Opnet™ 17.5 modeller, which uses C/C++ programming language. Prior to the system evaluation, two main components are required to be modified. The first component is the smart node where the optimisation unit is embedded. The second component is the network nodes; in order to be able to change its current routing protocol to the selected one change must take place. Figure 8.4 shows the node model where the IP process is located inside the MANET node. This unmodified IP process model for MANET nodes in Opnet™ 17.5 modeller is where the optimisation unit and changing protocol techniques will be installed.

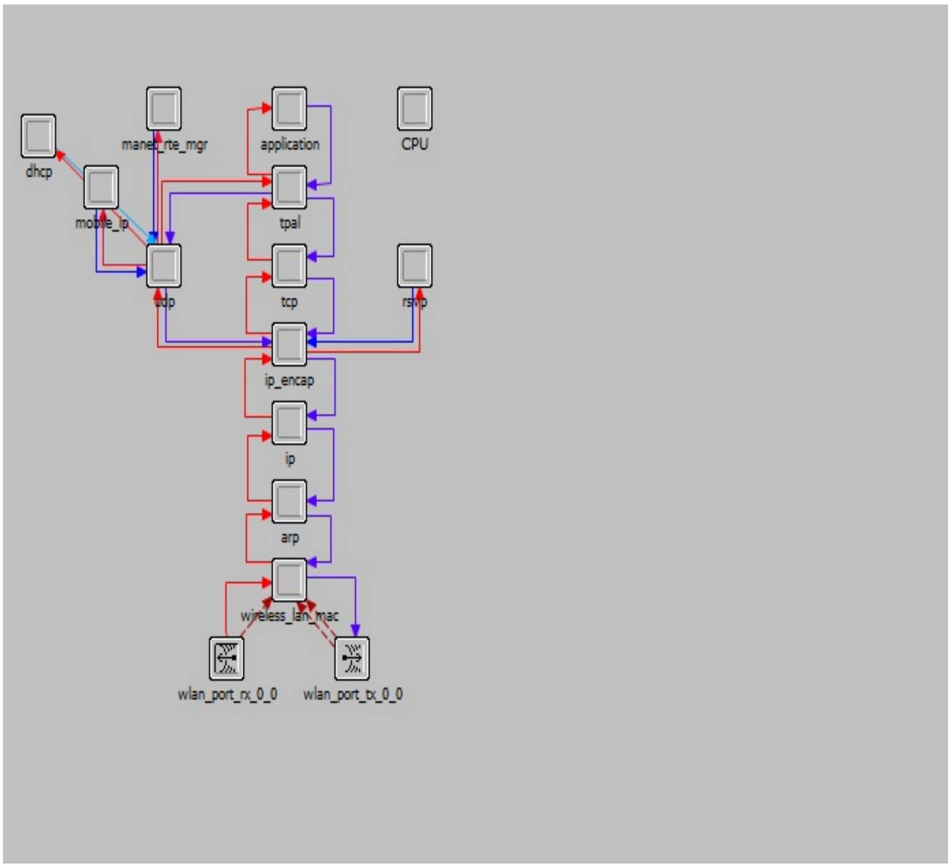


Figure 8.4: Node process fo MANET node in Opnet™ 17.5 modeller.

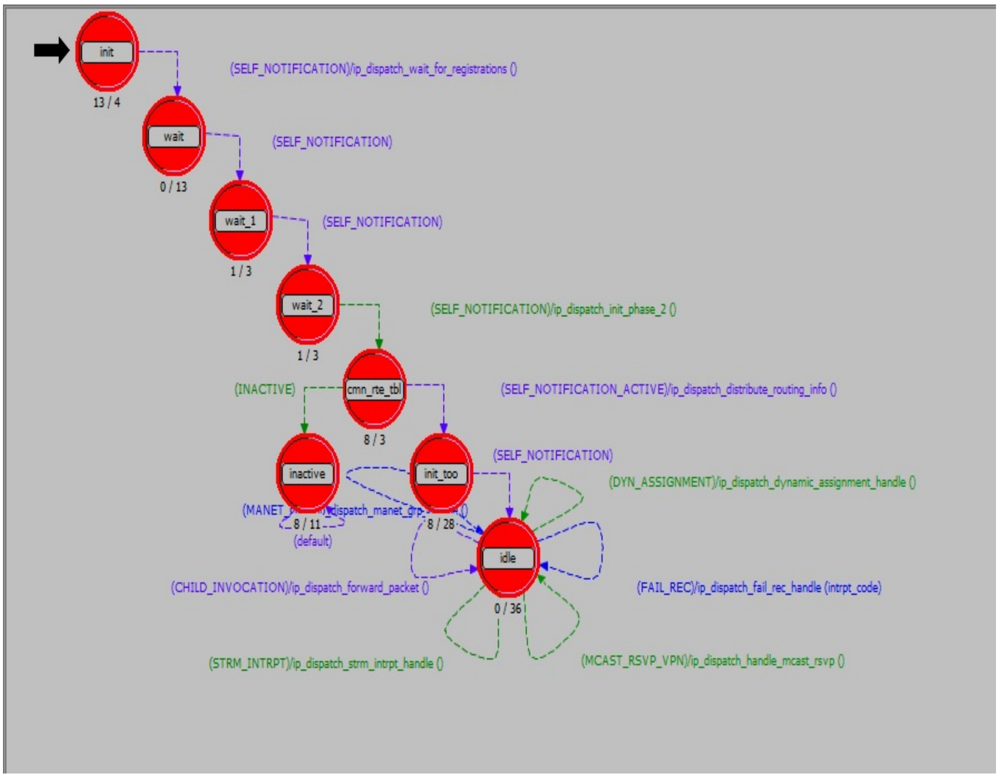


Figure 8.5: Unmodified IP process for MANET node in Opnet™ 17.5 modeller.

8.3.1 Constructing Smart Node

As discussed in the previous sections the system will be embedded in a single node therefore, the complete optimisation unit in the block diagram (Figure 8.2) will be added in the process model of MANET node in Opnet™ 17.5 modeller. Figure (8.6) shows the modified process model in which the Information bank is installed in the two processors (*init* and *idle*). The Decision Process (NF modeller and the PSO optimiser) is contained in the green processor named NF-PSO. The Decision Maker is located in the idle processor.

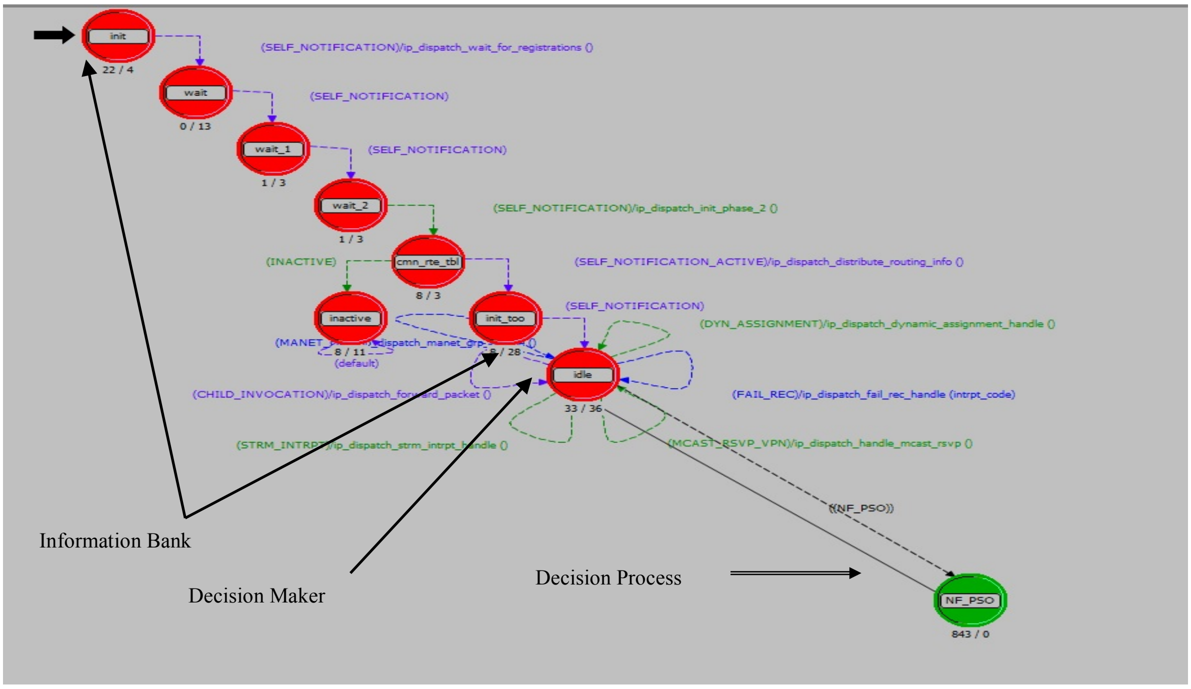


Figure 8.6: The modified IP process model for smart MANET node in Opnet^{TM}17.5 modeller.

8.3.1.1 Smart Node Information Bank

As indicated in Figure 8.6 the two counters: Mobility and Node counters are activated and created by *init* processor. Once the Topology packet is forwarded from the communication Pipeline, the *init* processor will send an interruption signal to the *idle* processor and the node counter will increment by one for each packet received. The increment will last until T_1 is reached and the total number of nodes in the network is equal to the node counter.

Every topology packet contains the node's mobility, which is extracted and added in the mobility counter and then the topology packet is discarded and this mobility summing continues until T_1. Then the average mobility is obtained by dividing the mobility counted by the node number calculated.

8.3.1.2 Smart Node NF modeller

The *idle* processor will send an interrupt signal to trigger the NF-PSO process after T_1 and the two contexts calculated. The NF modeller will start predicting by using the MANET performance models. The NF modeller, created in Chapter 6, will generate the performance metrics for delay, RA, load, and throughput for the five MANET routing protocols based on the current network context.

8.3.1.3 Smart Node PSO Optimiser

The value of the performance parameter is sent by the modeller to the cost function for each iteration loop to enable the optimiser to commence the optimisation process. This process takes place in the NF-PSO process model based on the selected PSO. The detailed operation and configurations of the optimiser can be found in Chapter 7. Finally, the results are yielded from the optimisation process and will be delivered to the Decision Maker.

8.3.1.4 Smart Node Decision Maker

The first step taken by the Decision Maker is to compare the suggested new routing protocol that has been received from the optimiser with the current protocol. If the suggested protocol is different from the current one, T_2 (which is the time required for all MANET nodes to change their protocol and adopt the new one) is calculated and added with the name of the new protocol in the decision packet to be sent to all MANET nodes. The other scenario is that there is no difference between the new and current protocol in use, thus, no required decision packet needs to be sent.

8.3.2 Constructing MANET Nodes

As it has been mentioned, the MANET nodes will have extra functionality compared to the original node model in Opnet^{TM}. Firstly, the Topology packet is created and sent periodically within a specified time by each node in the network to provide the smart node with its mobility and the protocol in use. Secondly, once the node receives the decision packet, the protocol changing time and the new protocol will be extracted and then the received packet is discarded. Then thirdly, the simulation time and protocol changing time are compared if they are equivalent. Then the protocol changing technique is triggered by initialising the process of adapting the new protocol as shown in Figure 8.7 (where the arrow is pointing to (Changing _Protocol)).

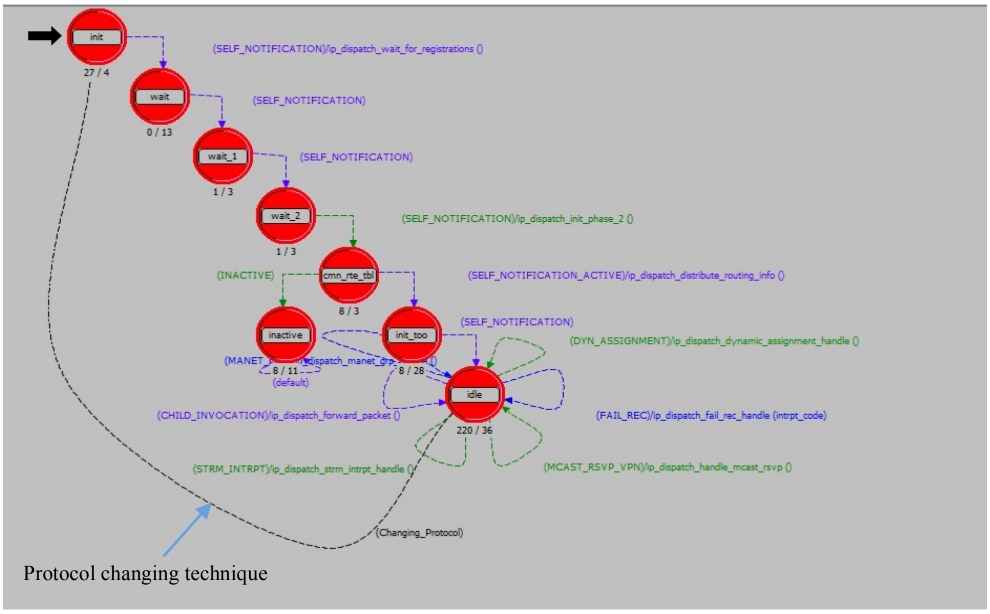


Figure 8.7:Protocol changing technique in the IP process model for smart node.

8.4 Case Study

In this section the proposed I-MMS optimisation system will be evaluated with a changing network context scenario. The network that is enhanced with the embedded system and with the five routing protocols and working with VoIP applications should be compared with networks without the embedded system for the same application scenario conditions.

8.4.1 Simulation Environment

The exact network scenario was carried out six times: first with the AODV routing protocol, followed by DSR, then with the OLSR, fourth with GRP, fifth with TORA and sixth with I-MMS. The application chosen was VoIP and each scenario ran for 1hr and 20 minutes. All the scenarios were conducted with five context cases and each context case approximately lasted for 16 minutes as shown in Table 8.1.

Table 8.1: The Scenarios with five context cases.

Context Case	Time (minutes)	Network size	Average mobility (m/s)
Context 1	0 to 16	18	8
Context 2	16 to 32	18	5
Context 3	32 to 48	75	16
Context 4	48 to 64	25	16
Context 5	64 to 80	25	8

Figure 8.8 shows the MANET network that ran context 1 and 2 for the sixth simulation with the I-MMS system scenario. The figure shows the operating and the failed nodes. There are 18 working nodes for the network size.

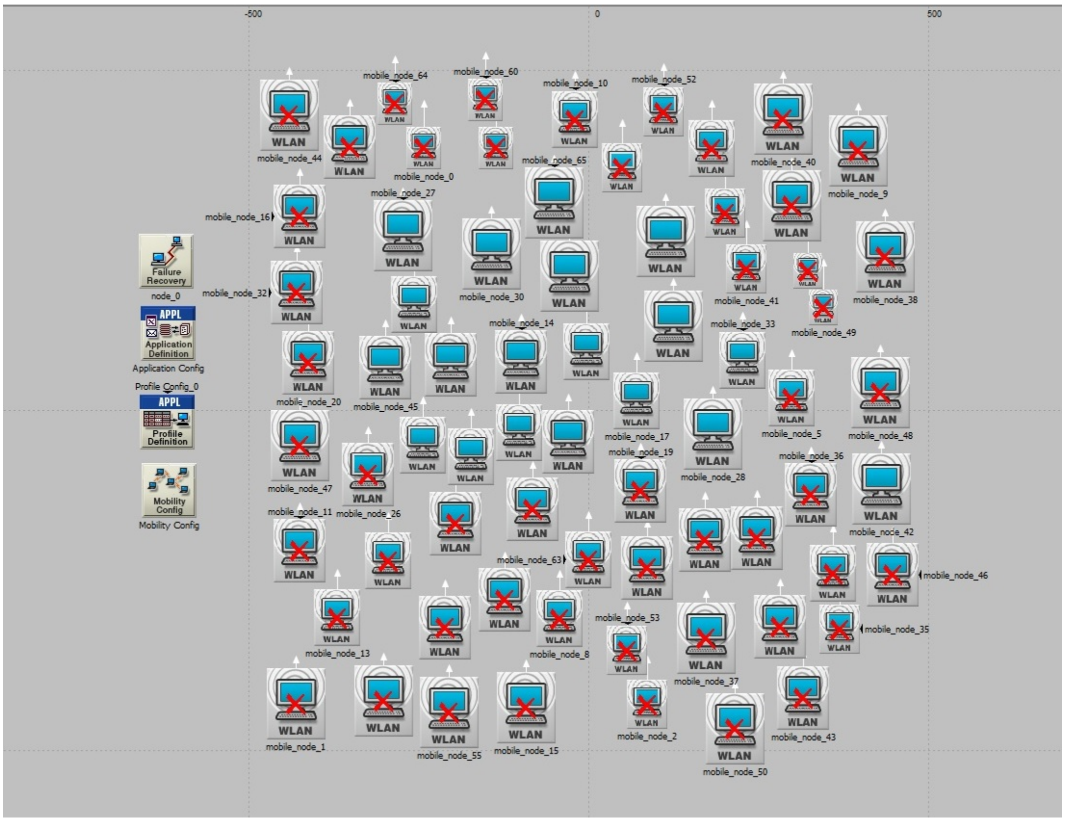


Figure 8.8: MANET network for part of I-MMS scenarios: context1 and context 2.

Figure 8.9 illustrates MANET ran context 3 for the same scenario with all operating nodes and with 75 nodes in total to represent the large network. As known the nodes were moving arbitrarily thus, this figure does not represent the node's positions for context 3 as in Figure 8.8.

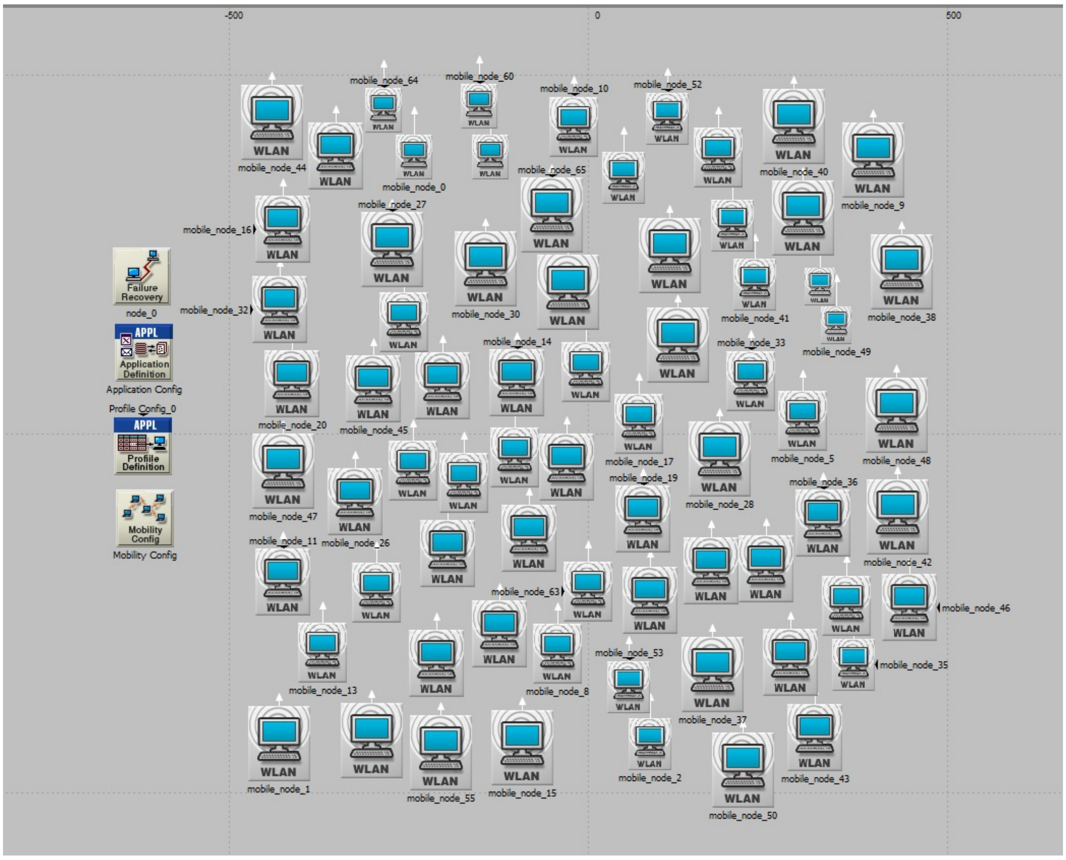


Figure 8.9: MANET network for part of I-MMS scenarios: context 3.

Figure 8.10 illustrates MANET ran context 4 and 5 for the same scenario with all working nodes and with 25 nodes in total to represent the medium network. As mentioned the nodes were moving arbitrarily thus, this figure does not represent the node's positions for context 4 and 5.

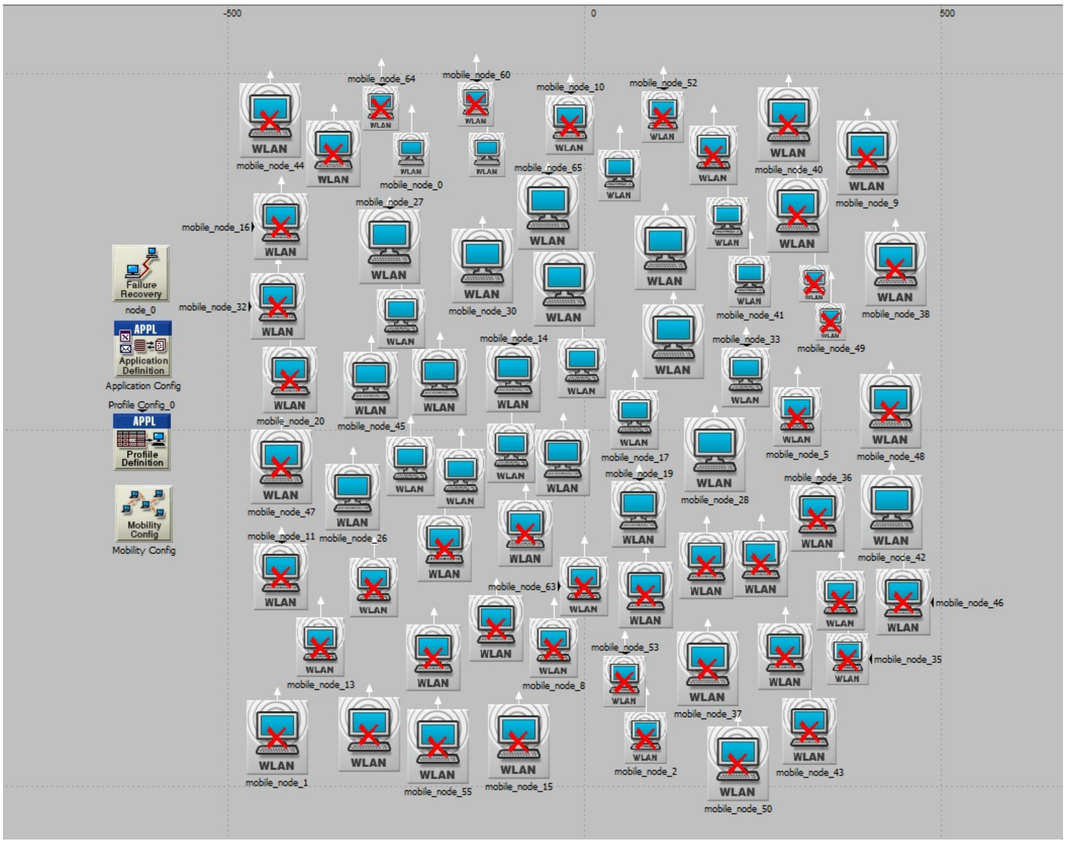


Figure 8.10: MANET network for part of I_MMS scenarios: context 4 and context 5.

As for the five routing protocols scenario, it has the same average mobility and network size and network parameters as for I-MMS. Moreover, the same number of working and failed nodes scenarios were simulated for different cases whose only difference is the absent role and functionality of the smart nodes. They have the same images of Figure 8.8 through 8.10 for the five contexts as for I-MMS scenarios.

8.4.2 Experiment Setting

We have to emphasize on the concept of I-MMS system. There is no new routing protocol devised or modified. However, there was changing and adapting of a routing protocol from a list of available routing protocols, in our case five routing protocols namely; AODV, DSR, OLSR, GRP, and TORA. Whenever I-MMS protocol is mentioned in the following sections, it refers to a protocol that selects one of the five routing protocols and not a new protocol.

If I-MMS is mentioned, it is merely representing the selected optimum protocol in operation and contains the original advantages and disadvantages as explained in Chapter 4.

The optimiser in I-MMS scenario uses the normalisation and cost equation to determine the best suited routing protocol for the current network context.

In case of I-MMS scenario, there are two packets sent by MANET nodes: data packet (VoIP traffic) and Topology packet. Five Topology packets are sent by MANET nodes throughout the simulation time. At time 320s the first Topology packet is sent and the remaining four packets are sent at approximately from 960s till the simulation terminates with 960s Inter-Arrival time. In addition, the first and second thresholds (Threshold_1,and Threshold_2) were specified at 0.5s to be sufficient for all packets to reach the smart node from all the MANET nodes and in reverse the decision packet with Thresold_2 to be received by all MANET nodes from the smart node.

8.4.3 Simulation Results

Table 8.2 shows the optimal protocol selected by I-MMS against the network context; the size of network and average mobility and the changes of the routing protocol that take place at T_2. Also included in the table is the number of context cases, the previous used routing protocol by MANET nodes, the duration of time used by each context, the current context and finally the I-MMS protocol selected to operate in the specified period of time. The MANET nodes start sending the Topology packet at 320s, as in context 1 and 2. GRP routing protocol is selected to be I-MMS protocol for the period 320s to 960s. It will be operational by all MANET nodes including the smart node after (320s+T_2) up to 960s and context 1 (as shown Table 8.1) shown change and use GRP. As the network size remains constant and the average mobility is decreased from 8 (m/s) to 5 (m/s) as in context 2, DSR was selected as the I-MMS routing protocol. When the network size increased to 75 nodes with high average mobility of 16 (m/s) in context 3, then OLSR was the optimum routing protocol to route the packets and avoid the network performance decline as indicated in Figure 8.9. Then the network size decreased to 25 nodes for context 4 due to number of node failures because battery died out or the node moved out of the network coverage as shown in Figure 8.1 and AODV was selected for I-MMS. Even though, there was a decrease in average mobility level as in the final context yet the AODV was chosen. Therefore, the previous routing protocol matches with AODV for context 5, which means there is no need for decision packet to be broadcasted to the MANET nodes.

Table 8.2: I-MMS selection of the optimal routing protocol for the case study scenario.

Context Cases	Previous routing protocol	Time (sec)	Current Context		Best settings
			Network size	Mobility (m/s)	I-MMS protocol adapted are
Default	-------	0-320	18	8	AODV
1	AODV	320-960	18	8	GRP
2	GRP	960-1920	18	5	DSR
3	DSR	1920-2880	75	16	OLSR
4	OLSR	2880-3840	25	16	AODV
5	AODV	3840-4800	25	8	AODV

8.5 Results analysis and Comparison

Figure 8.11 through 8.14 shows graphs for the comparisons between six routing protocols (AODV, DSR, OLSR, GRP, TORA, I-MMS) in terms of the four network performance metrics namely; delay, RA, load and throughput, respectively.

8.5.1.1 Delay

The delay graph for the six routing protocols: AODV, DSR, OLSR, GRP, TORA, and I-MMS during the simulation time of 4800 seconds, is shown in Figure 8.11.

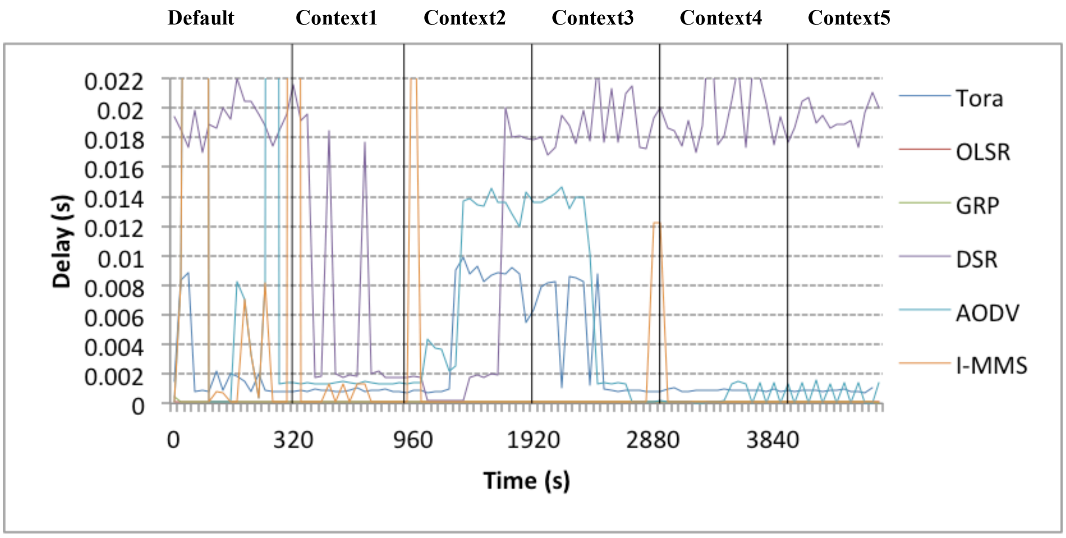


Figure 8.11: The five routing protocols and I-MMS delay.

The figure above shows the comparison between the mentioned six routing protocols in all five context scenarios listed in Table 8. 2. OLSR and GRP have the lowest delay, which are followed by TORA, AODV, and DSR that have the highest delay.

On Demand protocols exhibited higher delay curves due to the *Route discovery* mechanism characteristic exhibited from this category when the source routing table does not obtain the address of the desired destination. As can be noticed from Figure 8.11, between the periods 320s, 960s and 2880s when the network size increased in context 3 to 75 nodes, DSR delay rate increased sharply. The feature that contributed to such an increase is the implementation of DSR's routing cache mechanism (as explained in section 4.2.2.3).

On the other hand, the proactive routing protocols represented by OLSR and GRP, scored the lowest delay performance during the entire simulation time. The reasons for such low delays are as follows:

- ***GRP***: The use of quadrant division that reduces the flooding overhead that effects the network performance.
- ***OLSR***: The use of periodic messages and MPR mechanism for maintaining the node's routing table to be updated.

There is a variation in I_MMS protocol behavior during the simulation time. In the default state from 0s to 320s, the delay curve is observed to be high since the optimisation unit was not activated and AODV was in use as the default routing protocol. GRP was selected after 320s, and the delay decreased. At times 920s and 2880s, there is an increase in the delay due to the broadcast of the decision packet. However, during contexts 2, 3, 4 and 5 the delay curves remained at minimum and approximately constant.

8.5.1.2 RA

Figure 8.12 shows the Retransmission Attempt (RA) for the six routing protocols during the simulation time.

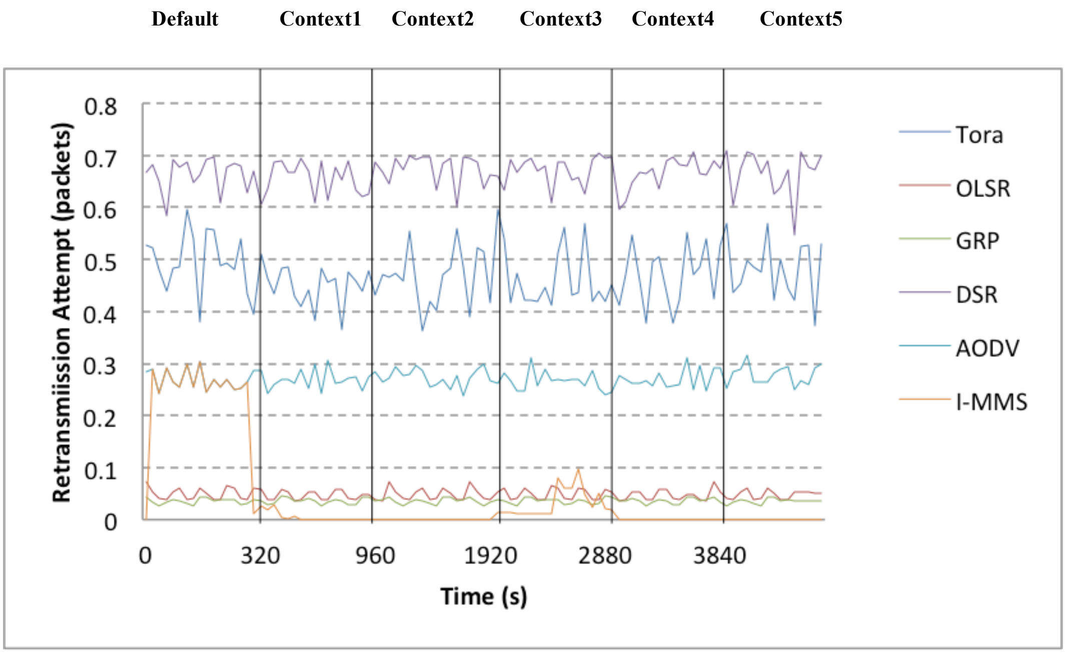


Figure 8.12: The five routing protocols and I-MMS RA.

It is shown in the figure above that I-MMS has the least number of attempts to retransmit packets except from 0s to 320s, as the optimisation unit was not triggered. The second curve peak was between 1920s to 2880s during context 3 with large network size and high mobility when I-MMS lost many packets that needed to be retransmitted. Moreover, as discussed previously, packet buffering is another reason for the slight increase. As for the rest of the simulation duration, I-MMS exhibits more success in packet delivery.

As for the remaining routing protocols, yet again the proactive routing protocols represented in the case study by OLSR and GRP, when compared to both on demand (AODV and DSR) and the hybrid (TORA), proved to be more reliable in terms of delivering packets successfully from the source to the destination.

8.5.1.3 Load

Figure 8.13 illustrates the graph of network load during the operation of the six routing protocols throughout the simulation time.

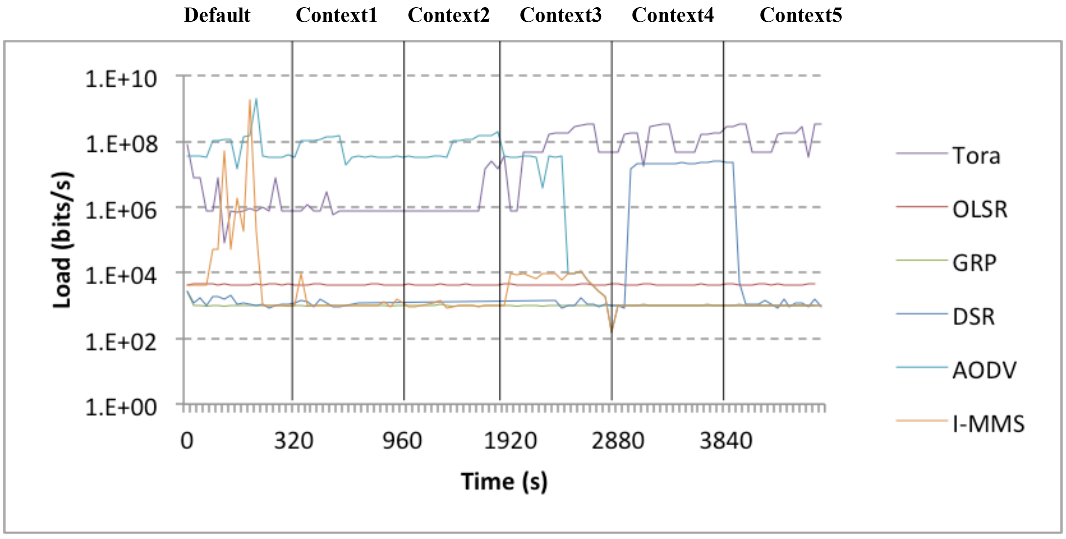


Figure 8.13: The five routing protocols and I-MMS load.

AODV had the highest load from 0s to 2880s but decreased afterwards in contexts 4 and 5 whereas TORA was the worst on contexts 3, 4, and 5 since it works poorly with medium and large network sizes due to the TORA control packets that consume a considerable amount of bandwidth. As TORA is running for each possible destination, the control packets number increases as the number of destinations increases. Moreover, even if one node is transmitting data, the other nodes exchange some control packets that add to the overhead. Likewise, DSR load increases drastically during context 3 and then is followed by a sharp decrease in the following contexts (4 and 5) and attained its minimum level at the first two contexts due to DSR multi-routing path strategy where in case an established route became broken, DSR can search for an alternative route from its route cache. If a ready route to the destination is found in the cache then there is no need for the source to send a new *Route discovery*. GRP and OLSR have the lowest network load due to the same reason explained in section 8.5.1.2.

As for I-MMS showed an acceptable load level after 320s except for the times when the new routing protocols were adopted.

8.5.1.4 Throughput

Figure 8.14 shows the throughput graph for the six routing protocols during the simulation time.

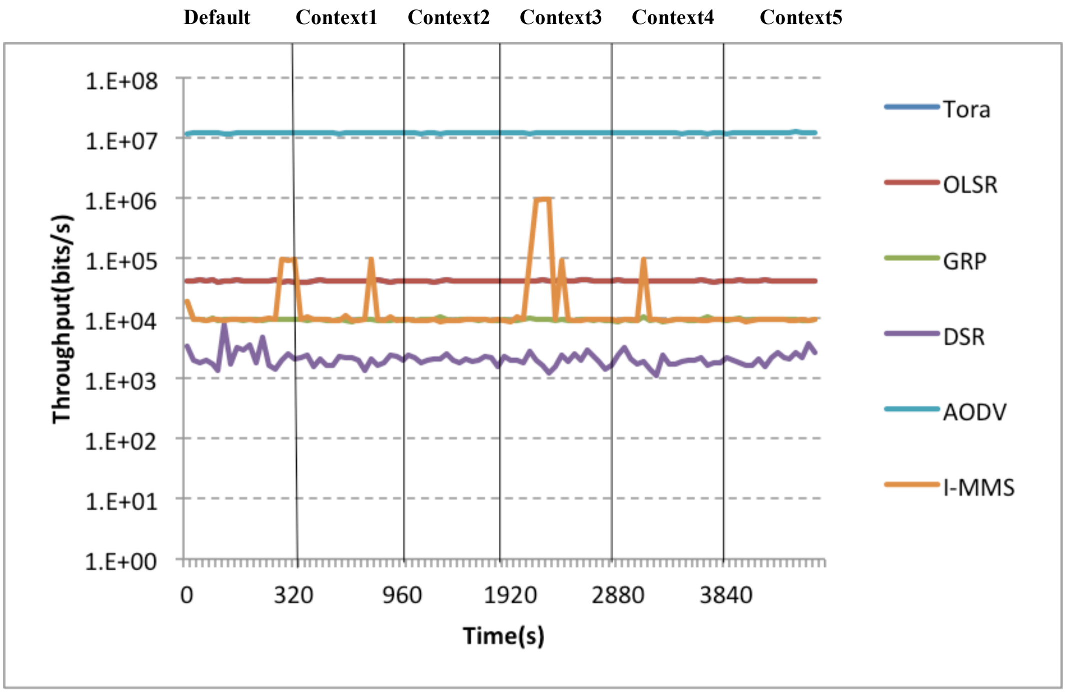


Figure 8.14: The five routing protocols and I-MMS throughput.

The five routing protocols comparison in terms of the performance metric throughput, AODV had the highest throughput throughout the simulation time. The periodic message technique was the factor for the increase, then OLSR was the second highest in throughput because of the periodic updated messages whereas, DSR had the lowest because the protocol does not use a periodic messages technique.

I-MMS at the time instance 320s, 960s, 1920 and 2880, showed an increase in throughput since the decision packet broadcast took place at those moments.

8.6 Summary

In this chapter, the importance of the optimisation unit has been emphasized prior to the I-MMS optimisation system implementation in Opnet^{TM} 17.5 modeller. The smart node was created and embedded with the optimisation unit and received the topology packets from the MANET nodes for the necessary information for network context. Then it works as a predictor to predict the network performance for the current network context by employing five routing protocol (AODV, DSR, OLSR, GRP, and TORA) in order to choose the optimum routing protocol.

The NF modeller modelled the network performance under several network contexts for three applications (FTP, VoIP, and VC). In the case study, only one application was used (VoIP).

The I-MMS was implemented to adopt one of the five routing protocols based on the given network context. The I-MMS adopted four routing protocols in each context of the five context scenarios. OLSR was selected for a dense and high mobility network, while GRP for small and medium mobility levels in the network. DSR was used for small and low mobility levels in the network. However, AODV was chosen twice for high and medium level of mobility in medium sized networks.

The results showed that the proactive routing protocols (OLSR and GRP) have the top results with regard to delay and load, while AODV scored the highest for throughput. I-MMS optimisation system was implemented and operated successfully in Opnet^{TM} 17.5 modeller in an attempt to provide an overall and long term improvement in the network performance. Yet, there are a number of limitations, which will be discussed in Chapter 9.

Chapter 9: Conclusions and Future Work

9.1 Conclusions

This chapter illustrates the main conclusions of this research and reveals the future work potentials. The entire thesis has described research work carried out to achieve the assigned aims and objectives through the conceptual framework summarised in this chapter. The gaps still remaining, and future work required, are pointed out as a continuation of the development of the research. Limitations are focused on as well, to help with overcoming challenges and obstacles in any further study.

The design and implementation of a novel intelligent management system for MANET routing to solve the context-awareness problem was the overall aim of this thesis. MANET routing protocols classification survey based on different networks characteristics, which contributed due to its importance in MANET routing protocol. In this thesis, the use of optimisation techniques in the design of MANET routing protocols was presented. The previous attempts for optimised MANET routing protocols were embedding the optimiser in the routing protocol that creates a new protocol or modified traditional protocol. The only attempt for embedded optimiser in the network node in I-MAN system only three traditional routing protocol were used with raw packet whereas this thesis proposes more scalable optimised system where five routing protocols and three different common applications were utilised. Therefore, the literature review for various classifications and the optimisation techniques utilised in MANET routing protocol have been covered.

Furthermore, five routing protocols were simulated with different network context (network size, mobility level, and application used for data packets) then four networks performance metric were obtained and modelled with the empirical RE technique, ANN, and NF. The resulted models from the three techniques were evaluated to determine the most accurate modelling technique, which is NF. Then three optimisation techniques (GA, SA, and PSO) were evaluated based on the selected NF model to choose the optimum routing protocol based on network performance prediction by the NF model. Then the adopted optimisation technique that produced the least cost function value was PSO. Once all the main components of the proposed optimisation system were studied, the I-MMS was implemented. Even though in our research incorporated the three methods of AI utilised in [3] for three different application (FTP, VoIP, and Videoconferencing) and adding a third optimisation technique that was not included in the previous research in the mentioned reference, both studies concluded that for MANET modelling NF and PSO are the most suited for similar systems.

I-MMS main role in this thesis is to learn from the network's performance and predicted the optimal routing protocol to be used. This system was installed in one node referred to as the smart node. The smart node with the optimisation unit has the responsibility to learn the network node size, mobility, the protocol in operation and the time for its activation. The system demonstrated very promising potential by selecting different routing protocols based on the changing network context and outperformed some of the traditional protocols if they worked individually throughout the simulation time.

Finally, the proposed system implemented in the simulation is not based on individual network nodes performance rather relies on the overall network performance and its cost to decide upon the best-suited routing protocol.

9.2 Achievements

The key aim and achievement of this research is to create a self-optimised MANET assisted by an intelligent heuristic optimised system and utilised by a node in the network called a smart node. The next achievement is modelling MANET performance with artificial intelligent methods that can be used by researchers to develop and compare MANET with different routing protocols. The system flexibility opens the door for adapting to users requirement by adding new MANET performance metric such as data drop or packet delivery rate or considering additional network contexts. Finally, the main contributions mentioned in Chapter 1 have been fulfilled in this thesis.

9.3 Limitations

Every system has limitations and drawbacks as the case of the proposed system in this thesis. The system lacks to include the application being used in the Topology packet due to the type of network simulation that was used to implement the proposed I-MMS. Moreover, the overload and power consumption attributed by the gathered and conveying of topology and decision packets from and to the smart node. The overall delay due to the time required to adopt the new routing protocol. Finally, embedded system in a single node with the computation capability is one of the limitations of the proposed system and the need for a nominee to have similar responsibility in case of the smart node failure and the candidate can step up and become the smart node for the network.

9.4 Future work

The I-MMS routing protocol management system designed and implemented in this thesis demonstrated very promising potential in the case study results and proved successful in predicting the network performance and changing the routing protocol accordingly. Future work definitely can be beneficial for the system to be developed and expanded in order to be utilised in different fields. The factor in which the system can be improved are as follow:

1. In this thesis only one entity mobility model was implemented that is Random Waypoint without a considering the pause time. Different mobility models can be evaluated and compared in their influence on the network performance. Such entities are Random Waypoint with different pause times, Random Walk Mobility, and Random Direction.

2. Adding more network performance metric to the cost function such as data drops, power consumption, latency, jitter, and battery lifetime. Moreover, different data rate can be added as a parameter to test its effect on the overall network performance.
3. Including more routing protocols both the classical and modified routing protocols.
4. The application types used in I-MMS were FTP, VoIP, and VC as a second element to the network context to select for the optimum routing protocol. There are other different application can be added to make the system more robust such as HTTP, and e-mail packets type. In addition, the weighted cost function, which depends on, the application type such as FTP, VoIP, VC, and HTTP etc.…
5. There are two different fields that can utilise the system such as VANET and sensor network and adopt the routing protocols used in such network in the system to be compatible with their networks.
6. Devising a mechanism where a list of smart node nominees to be implemented instead of a single smart node as in our system.
7. In this thesis, different artificial intelligence techniques were employed, the techniques are ANN, NF, GA, SA, and PSO. Other AI candidates are possible and worth investigate such as differential evolution, ant colony, and artificial bee colony.
8. Different network simulation can be considered apart from Opnet such as NetSim, NS2, OMNeT ++, or NS3. However, for more realistic scenarios

a real test bed is considered an ideal choice although it will require a tremendous effort in modification and development.

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