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Enhanced Scheme for Video Transmission over Mobile Ad hoc Networks based on Optimized Link State Routing Protocol

نهج محسن لنقل الفيديو عبر شبكات المحمول الخاصة على أساس بروتوكول توجيه حالة الارتباط الأمثل

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Computer Science

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Authorship Declaration

I, Diaa Eldin Mustafa Ahmed, I confirm that this thesis entitled" **Enhanced Scheme for Video Transmission over Mobile Ad hoc Networks (MANETs) Based on Optimized Link State Routing (OLSR) Protocol "**submitted to Sudan University of Science and Technology, in partial fulfillment of the requirements for the awarding of the Degree of Doctor of Philosophy in Computer Science, and the work presented in it is my achievement. Where I have consulted the published work of others this is always clearly attributed; where I have quoted from the work of others the source is always given. With the exception of such quotations, this dissertation is entirely my own work and represents a record of original and independent research work done by me during the period October 2015 - June 2019; I have acknowledged all main sources of help; If my research follows on from previous work or is part of a larger collaborative research project I have made clear exactly what was done by others and what I have contributed myself; I have read and understood the penalties associated with Academic Misconduct. I also confirm that I have obtained informed consent from all people I have involved in the work in this dissertation following the ethical guidelines.

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Signed

Abstract

A Mobile Ad Hoc Network (MANET) is an infrastructure-less wireless network which allows a group of mobile devices to connect wirelessly without centralized administration. MANETs are useful when rapid deployment in infrastructure-less locations is required, or under emergency situations where communication is not available. Video conferencing over MANET is challenging due to features that characterize this type of network.

This thesis proposed an enhanced scheme based on tuning, modeling, and optimizing the Optimized Link State Routing (OLSR) protocol behavior. The objective is to overcome MANET challenges including Quality of Service (QoS), energy consumption, and security. The novelty of the proposed scheme comes through using an optimal configuration of OLSR protocol which changes the protocol behavior by modifying the HELLO and Topology Control (TC) message intervals to cope with most desirable QoS metrics for transmitting video conferencing traffic over MANET such as (end-to-end delay, Packet Delivery Ratio (PDR%), Jitter, throughput, and WLAN-load). In addition, the proposed scheme provides low energy consumptions compared to conventional OLSR and maintains network QoS when under different security attacks such as black hole attack on the network layer and jamming attack on MAC/PHY layer. Simulation is carried out using OPNET 14.5 to show the impact of the new configuration of OLSR on scalability (network size and nodes density) and mobility speed. Analysis of Variance (ANOVA) and Particle Swarm Optimization (PSO) algorithm were used to model and optimize the OLSR behavior, respectively.

Obtained results showed that the new optimized configuration of OLSR routing protocol compared to conventional OLSR copes with most QoS challenges in terms of E2E-delay and jitter which were decreased by 27%, and 47% respectively, throughput and PDR% increased by 38% and 29% respectively. In addition, when the network enlarges and the mobile density increases the QoS is not degraded. Also, the optimized configuration of the OLSR protocol provides low power consumption due to adaptive behavior in case of network topology changes. The power dissipated for sent/received packets dropped by 40%. The new fine-tuning of OLSR maintained QoS under two popular attacks: black hole and jamming attacks. The proposed scheme is promising for transmitting video conferencing traffic effectively over MANETs.

المستخلص

شبكات الأجهزة المحمولةالخاصة (MANETs) هي شبكات لاسلكية لا تعتمد على بنية أساسية وتسمح لمجموعة من الأجهزة المحمولة بالاتصال ببعضها البعض عن طريق الروابط اللاسلكية دون إدارة مركزية. هذه الشبكات مفيدة للحالات التي تتطلب نشرًا سريعًا في موقع لا تحتوي على بنية تحتية، أو في حالات الطوارئ حيث لا تتوفر الاتصالات. يعتبر عقدمؤتمرات الفيديو عبر MANET أمرًا صعبًا بسبب الخصائص المحددة التي تميز هذا النوع من الشبكات.

في هذه الأطروحة، تم اقتراح مخطط تحسين يعتمد على الضبط والنمذجة وتحسين سلوك بروتوكول توجيه حالة الارتباط الأمثل(OLSR).الهدف هو التغلب على تحديات MANET بما في ذلك جودة الخدمة (QoS) واستهلاك الطاقة والأمن. تأتي حداثة المخطط المقترح من خلال استخدام التهيئة الأمثل لبروتوكول OLSR التيتغير سلوك البروتوكول عن طريق تعديل فترات الفواصل الزمنية لكل من رسائل HELLO والتحكم في الطبلوجيا(TC)للتعامل مع معظم مقاييسجودةالخدمةالمرغوبة لنقل حركة مرور مؤتمرات الفيديو عبر MANET مثل التأخير من طرف الي طرف(E2E delay) ، نسبة تسليم الحزم(PDR%)، الارتعاش(Jitter) ، والإنتاجية(Throughput) ، والحمل في الشبكةWLAN-Load.بالإضافة إلى ذلك، يوفر المخطط المقترح استهلاكًا منخفضًا للطاقة مقارنةً بـالبروتوكولالتقليدي وفي نفس الوقت يحافظ على جودة خدمة الشبكة أثناء الهجمات الأمنيةالمختلفة مثل هجوم الثقب الأسود على طبقة الشبكة وهجوم التشويش على الطبقةالفيزيائيةMAC / PHY. تم تنفيذ المحاكاة باستخدام OPNET 14.5لإظهار تأثير التهيئة الجديدة لـ OLSR علي قابلية التوسع (حجم الشبكة وكثافة العقد) من جهة وسرعة التنقل من جهة أخرى. تم استخدام تحليل التباين (ANOVA) وخوارزميةتحسين سرب الجسيمات (PSO) لنمذجة سلوكيات OLSR وتحسينها على التوالي.

أظهرت النتائج التي تم الحصول عليها أن التهيئة المحسنة الجديدة لبروتوكول التوجيه OLSR مقارنةً بـالبروتوكولالتقليدي تتلاءم مع معظم تحديات جودة الخدمة من حيث التأخيرمن طرف الي طرفوالارتعاش اللذين انخفضا بنسبة 27٪ و 47٪ على التوالي ، وزادت الإنتاجية و معدل تسليم الحزمبنسبة 38٪ و 29٪ على التوالي. بالإضافة إلى ذلك ، عندما توسعت الشبكة وتزايدت كثافة العقد المتنقلة ، لم تتدهور جودة الخدمة. أيضًا ، توفر التهيئة المحسنة لبروتوكول OLSRاستهلاكًا منخفضًا للطاقة بسبب السلوك التكيفي في حالة تغييرات هيكل الشبكة. انخفضت الطاقة المستهلكة للحزم المرسلة / المستلمة بنسبة 40٪. يحافظ الضبط الدقيق الجديد لـ OLSR على جودة خدمة الشبكة أثناء هجومين شائعين: الثقب الأسود وهجمات التشويش. يعتبر المخطط المقترح واعدًا لنقل حركة مؤتمرات الفيديو بشكل فعال عبر.MANETs

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First and foremost, I thank God for my conciliation in this study. I would like to express my deepest gratitude to my supervisor Professor Dr. Othman Omran Khalifa for his excellent guidance, continuous support, and encouragement throughout my PhD study. I am also grateful to him for believing in my potential, this dissertation would not have been possible without his help. His serious and scientific attitude has enlightened my perception and has driven me to understand the physical essence of the work that I have accomplished.

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I am especially thankful to my parents and brothers, who had always, given me the courage, best wishes, and support during my career.

Dedication

This thesis is dedicated to the memory of my father and mother. They instilled in me the inspiration to set high goals and the confidence to achieve them. In addition, this work is dedicated to my brothers, sisters, my small family (Fatima, Mohammed, and Menat Allah), and my colleagues.

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List of Abbreviations

ANOVA	Analysis of Variance
ACO	Ant Colony Optimization
AH	Authentication Header
AODV	Ad hoc On-Demand Distance Vector
AOMDV	Ad hoc On-demand Multipath Distance Vector
AP	Access Point
AQOR	Ad-hoc QoS On-demand Routing
AVC	Advanced Video Coding
BAN	Body Area Network
BE	Best Effort
BTS	Base Station Transceiver
CBR	Constant Bit Rate
CBRP	Cluster-Based Routing Protocol
CDMA	Code Division Multiple Access
CEDAR	Core-Extraction Distributed Ad hoc Routing
CGSR	Cluster-Head Gateway Switch Routing
CHAMP	Caching and Multipath
CI	Computational Intelligence
CLD	Cross Layered Design
CMMBCR	Conditional Max-Min Battery Capacity Routing
DAG	Direct Acyclic Graph
DCF	Distributed Coordination Function
DDR	Distributed Dynamic Routing
DoS	Denial of Service
DREAM	Distance Routing Effect Algorithm for Mobility
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing Protocol
DSSS	Direct-Sequence Spread Spectrum
DYMO	Dynamic MANET On-demand
E2ED	End- to-End Delay
FANET	Flying Ad hoc Network
FHSS	Frequency-hopping spread spectrum
FIFO	First In First Out
FSR	Fisheye State Routing
GA	Genetic Algorithm
GLM	General Linear Model
GPS	Global Positioning System

GPSR	Greedy Perimeter Stateless Routing
GRP	Geographical Routing Protocol
HNA	Host and Network Association
HOPNET	Hybrid ant colony Optimization mobile ad hoc Network
HSR	Hierarchical State Routing
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
iMANET	Internet Based Mobile Ad hoc Networks
InVANET	Intelligent Vehicular Ad hoc Networks
IoT	Internet of Things
IP	Internet Protocol
IPSec	IP Security
IR	Infra Red
ITU	International Telecommunications Union
IWD	Intelligent Water Drop
LANMAR	Landmark Routing
LAR	Location Aided Routing
LEAR	Localized Energy-Aware Routing
LTE	Long Term Evolution
MAC	Medium Access Control
MANET	Mobile Ad hoc Network
MAODV	Multicast Ad hoc On-Demand Distance Vector
MDC	Multiple Description Coding
MDSR	Multipath Dynamic Source Routing
MID	Multiple Interface Declaration
MIMO	Multiple/Input-Multiple/Output
MLRM	Multivariate Linear Regression Modeling
MPR	Multipoint Relays
MRP	Multicast Routing Protocols
MSVS	Multi-Source Video Streaming
MSVS	Multi-Source Video Streaming
NC	Network Coding
NRL	Normalized Routing Load
NS-2	Network Simulator- 2
ODMRP	On-Demand Multicast Routing Protocol
OFDM	Orthogonal Frequency Division Multiplexing
OLSR	Optimized Link State Routing
OMM	Online Max-Min
OPNET	Optimized Network Engineering Tools
OSPF	Open Shortest Path First
PAMAS	Power Aware Multi-Access

PAN	Personal Area Networks
PDA	Personal Digital Assistant
PDR	Packet Delivery Ratio
PDV	Packet Delay Variation
PHY	Physical Layer
PSO	Particle Swarm Optimization
QA-OLSR	QoS Aware OLSR
QoS	Quality of Service
RERR	Route ERRor
RF	Radio Frequency
RFC	Request For Comment
RFID	Radio Frequency Identification
RREP	Route REPly
RREQ	Route REQuest
RT	Real Time
RTS	Request-To-Send
RWP	Random Way Point
SA	Simulated Annealing
SI	Swarm Intelligence
SVC	Scalable Video Coding
TC	Topology Control
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TORA	Temporally-Ordered Routing Algorithm
TTL	Time-To-Live
UDP	User Datagram Protocol
V2I	Vehicles – to – Infrastructure
V2V	Vehicles – to – Vehicles
VANET	Vehicular Ad hoc Network
VC	Video Conferencing
VoIP	Voice over IP
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WSN	Wireless Sensor Network
ZHLS	Zone-based Hierarchical Link State
ZRP	Zone Routing Protocol

Chapter One

Introduction

1 Introduction

Last decades wireless communication has grown and is still an area of interest to numerous scientists and researchers. Mobile Ad hoc Network (MANET) is an autonomous system consisting of a collection of mobile nodes such as (laptops, cell phones, Personal Digital Assistant (PDA) , etc...) connected by wireless links , but has no fixed infrastructure and predefined topology of wireless links. MANET is a type of infrastructure-less network which is self-configurable i.e. each node can move in a random direction and can make an arbitrary network topology [1, 2]. The absence of fixed infrastructure means that the nodes communicate directly with one another in a peer-to-peer fashion. MANET is a special point of focus for industry and academic researchers from all around the globe. This technology has come with its flavors and it is easy to deploy in disaster areas and for emergency operations [3].

1.1 Video Transmission over MANETs Current Issues

Video streaming and interactive video is a well-known topic in Mobile Ad-hoc Networks (MANETs).Video streaming in MANET is an active research area now a day. According to a new report from Cisco [4]:

(1) By 2019, 80% of global internet consumption will be video content.

(2) Traffic from wireless and mobile devices will rise to 66% of all traffic in 4 years.

Video transmission over MANET is one of the most challenging task because it is severely affected by the various properties of the MANET such as mobility, dynamic change in topology, lack of fixed infrastructure, resource constraints, etc .Therefore, it is very important to understand the feasibility of implementing such services over MANET and to know the amount of resources required in order to provide acceptable Quality of Service (QoS) [5].

Streaming is a technique for transferring data in such a way that it can be processed at a steady and continuous stream. Users don't need to wait for the complete media file (audio, video, animation) to be downloaded before playing.

For instance, streaming allows users to watch a movie while they are downloading its later portion, which could take a long time. Also, there are many applications such as distance learning, IP telephony, Video-Conferencing, Telemedicine, live sports games, multi-player games and Video-on-Demand (VoD) that use multimedia streaming. Generally, we can divide streaming applications into three classes [6]:

(1)- Streaming Stored Video (VoD):

– Video is stored at source and transmitted to client when it is requested from the server.

– It begins playing before all data arrives, client can pause, rewind, fast forward, push slide bar and so on.

– Start-up delay is the most important challenge for this type.

(2) - Streaming Live Video:

– Similar to streaming stored video, video contents is sent from a server to a client.

– In such examples, user cannot fast forward but rewind and pause are possible.

(3)- Real-time Interactive Video

– It allows both sender and receiver to transmit data.

– Play-out delay is the most important challenge.

1.2 Thesis Motivations

Recently, the emergence and the innovations of low-cost portable devices such as smart phones has led to an increasing research interest in wireless mobile ad hoc networks (MANETs), where every person, vehicle, and appliance is able to communicate via short-range radio. In addition, the emerging wireless technologies standards such as IEEE 802.11(a, b, e, g, n) have become a popular technology and it has gained a great deal of importance from both research community and industry [7, 8]. These technologies led to a number of wireless services dramatically exploding [9].

Nowadays MANET is such a communication paradigm that offers multiple advantages: lower starting costs, rapid deployment, resilience to disruption, and high bandwidth. However, although MANETs have many advantages, in practice they have not yet reached the envisaged impact in terms of real-world deployment and industrial adoption mostly due to the availability of mobile infrastructure connectivity (e.g., 3G, 4G, 5G networks, Wi-Fi hotspots). Video contents have become a driving force for our daily life, therefore multimedia applications like video streaming, video conferencing and environment monitoring must be made possible in real-time in Mobile Ad hoc Networks. Mobility of nodes, the life of a battery, changes in topology, mobility speeds, network size, security threats, and routing protocols affect the overall performance of MANET. Hence providing good Quality of Service (QoS) for multimedia applications in MANET is a challenge [10, 11]. To provide efficient QoS in MANET, there is a solid need to study the effect of the number of mobile nodes, the network size, mobility speed, and routing protocol behaviors on QoS [12].

However, MANETs do not seem to effectively support live video transmission and multimedia applications [13]. In addition, proposing or developing new MANETs routing protocols from scratch is not an easy task. From this point of view, most of the recent research works are driven towards the improvement of the video transmission performance in terms of enhancing the existing routing protocols or development of new MANETs schemes that copes with the MANETs challenges from one hand and to overcome most of the video constraints from the other hand.

1.3 Problem Statement and its Significance

Despite that MANETs are very versatile and appropriate to be used in many scenarios due to the infrastructure-less and self-organized characteristics, these kind of networks have important limitations, such as being bandwidth-constrained, having variable capacity links, energy-constrained operation and security threats due to different vulnerabilities. These limitations are imposed by the shared nature of the wireless channel, the mutual interference between nearby nodes, the resource-constrained devices, and the absence of infrastructure or centralized administration.

Furthermore, the dynamic topology in these kinds of networks causes frequent link failures and high error rates, which make it even more difficult to maintain a desired degree of Quality of Service (QoS). MANETs are becoming more essential to wireless communication because of increasing popularity of mobile devices.

Currently, MANETs do not support real-time video transmission and multimedia applications effectively [13-15]. Therefore, with the massive demand of video content from mobile devices, it has become very necessary for MANETs to have an efficient routing and QoS mechanisms to support the transmission of multimedia content. As a result, not all routing protocols are capable of providing the same level of QoS that can meet the requirements of video transmission via MANETs [12].

MANET's routing protocols have a different performance in video transmission due to the nature of the protocol or the principles of its work. Moreover, the impact of each protocol is varying with the network contexts such as expansion (scalability or increasing network size), high mobility speed (m/s) and the number of nodes in the network (node density).In addition, to the parameters of the protocol itself and how to configure them. We have found among all literature that there is no super routing protocols that can grantee the desired level of QoS, adapt with scalability and mobility and provide security mechanisms at the same time. Most of the standardized routing protocols for MANETs have been designed to find a feasible route from a source to a destination without taking into account the available resources in the network or specific requirements of an application.

Conventional routing protocols in MANETs do not support QoS, energy-efficient consumption due to sending/receiving packets and acceptable levels of security at once. Each protocol has its own routing strategy, but no such strategy can be effective for all topology conditions. Therefore, the efficient deployment of MANETs might require hybrid approaches. However, MANETs are still not supporting combined techniques for efficient routing, QoS, energy consumption, and security which can guarantee the desired level of QoS for video transmission such as low (E2E-delay, jitter, network load) and high (Packet Delivery Ratio (PDR), throughput). Video transmission may be improved by means of developing enhanced schemes or mechanisms in routing protocols in order to solve or mitigate the limitations of MANETs. It follows that selecting the proper routing protocol for each situation becomes critical.

1.4 Proposed Solution

To overcome the QoS, security, and power efficiency challenges which face the deployment of video transmitting effectively over MANET, enhancement scheme has been proposed in this thesis based on Optimized Link State Routing (OLSR) protocol which is one of the most popular routing protocols . This scheme is primarily focused on changing the behaviors of OLSR through tuning and optimizing their routing parameters. To select the best-fit parameters guarantee the QoS metrics desired for video transmission efficiently, a selection algorithm is proposed to identify and fine tuning the routing parameters values, that in order to cope with QoS level required for video traffic. ANOVA has been used to model the QoS metrics that has great effect on the performance to show the impact of mobility speed and node density when the network become dense and enlarge. Using ANOVA will provides a linear models that represents the relationships between QoS metric and number of nodes (N) and mobility speed (S m/s). PSO has been used as swarm intelligent algorithm to solve the optimization problem to address the OLSR limitation.

1.5 Research Methodology

In this thesis, a research methodology is a quantitative approach based on the simulation and modeling of transmitting video conferencing over MANETs. To conduct this there are fundamental issues that must be addressed such as :

1- Review and study MANETs routing protocols to gain an understanding of issues associated with this field.

2- Investigate which MANETs routing protocols are capable to transmit real-time video contents effectively .
3- Conduct a detailed literature survey to review the current state of the art of video transmission schemes or approaches over MANETs .
4- Explore different classifications of video transmission over MANETs; and furthermore, identify the performance challenges for routing protocols in such networks .
5- Measure and evaluate the performance of desirable MANETs routing protocols such as Ad hoc On-Demand Distance Vector (AODV), OLSR, Temporally-Ordered Routing Algorithm (TORA), Dynamic Source Routing Protocol (DSR), and Geographical Routing Protocol (GRP) for video streaming over MANETs and IEEE802.11g in terms of QoS metrics.
6- Investigate and study optimization techniques with the support of the MATLAB software package and Essential Regression software package, and then select the most appropriate one.
7- Implement (simulate) the proposed and developed scheme for video transmission over wireless networks specifically over MANET.
8- Simulate the designed scenarios using the Optimized Network Engineering Tools (OPNET) simulator.
9- Discuss and interpret the simulation results.
10- Test and evaluate the performance of the proposed scheme.
11- Analyze and compare the obtained results with benchmarks, and validate the simulation scenario results.

1.6 Research Objectives

The main objective of this research is to develop a novel scheme for enhancement of video conferencing QoS metrics over MANET through the fine-tuning configuration of OLSR routing protocol parameters (changing the behavior of the protocol) and this objective requires the following:

1- To develop an algorithm for parameter selection of the desirable MANET routing protocol (changing the behavior of the protocol) based on changing the standard routing parameters in order to find the maximum performance of video streaming metrics (E2E-delay , jitter , PDR , throughput ,network load , retransmission attempts , WLAN-delay) under different MANET network contexts such as (network size , mobility speed and mobile density).
2- To multivariate modeling using Analysis of Variance (ANOVA) to express the QoS metrics as a function of mobility speed (M) , the number of mobile nodes (N) and network model sizes (Z) for different MANET situations.

3- To find the optimal solutions of the QoS metrics models generated by using Particle Swarm Intelligence Optimizations (PSO) and develop a QoS-Aware OLSR (QA-OLSR) routing protocol to maximize the performance of video streaming over MANETs while minimizing the potential clashes for ongoing video traffic and cope with scalability and high mobility .

4- To investigate the impact of OLSR- tuning or the enhanced OLSR configuration on energy consumption and consequently introduce an Energy-Aware OLSR (EA-OLSR) that maximizes the network lifetime and minimizes the power /energy consumption due to routing computations.

5- To investigate the effect of certain routing parameters that have a great role in security issues and introduce Security-Aware OLSR (SA-OLSR) mechanism to overcome the security challenges over MANETs and satisfy the desired security requirements for video streaming over MANETs without adding any significant network overhead .

1.7 Research Questions

In general, the main questions addressed in this thesis are:

(A) How can we find out an optimal routing protocol among a group of MANET protocols that can maximize the overall QoS of transmitted video streams?.

(B) When the MANET network is extended, topology is changed due to high mobility and mobile densities varied, how can we configure the routing protocol control messages so that it can maximize the admitted number of simultaneously transmitted video streams while maintaining high video quality for all the videos?.

(C) What are the optimal configurations of the desirable MANET routing protocol that overcome the security threats such as a black hole and jamming attacks without degrading the QoS provided for video streaming?.

(D) Can the optimal configuration of desirable routing protocol prolong the network lifetime through minimizing the energy consumption due to the entire packet sent/received?

All the above questions can be described in details as follows since the performance of each strategy depends on various network conditions such as:

- **QoS /Routing (**the performance level of a service offered by the network to the application).
- **Question**: Which MANET routing protocol(s) is capable of transmitting video contents and guarantee the requirement of video transmission benchmarks values such as (E2E-delay, jitter, throughput, PDR, etc...)? .

- **Question**: What is the optimal configuration of the desirable protocol(s) that copes with most challenges of MANET?

– **Scalability** (network size, node density).

- **Question**: To what extent can MANET networks grow and how can that be extended while maintaining an acceptable level of performance?.

– **Mobility** (moving speed (m/s) , direction, Mobility model).

- **Question:** Under which mobility model and at which node mobility speed can a high performance for video traffic can be obtained among the above conditions (QoS and Scalability)?
- **Question:** What are the limitations of the mobility speed, and which level can degrade the performance?

– **MAC/PHY parameters** (Data rate (Mbps), Bandwidth, no of channels, buffering, etc...).

- **Question:** What are the optimal configurations of the MAC/PHY layers that meet the requirements of video contents over MANET regarding the cost of technology, their availability, reliability, capacity and extendibility?.

– **Security requirements** (availability, confidentiality, integrity, authentication, and non-repudiation).

- **Question:** How can the security threats or attacks affect the performance of video contents, and how to defend against those attacks? .

– **Energy efficiency** (energy consumption due to packets sent/received) **.**

- **Question:** What are optimal configurations of the routing protocol that meet the requirements to prolong the network lifetime and reduce the total energy consumed?.
- **Question:** To what extent does the network size and under which mobility speed the energy consumption will not degrade the performance?.

1.8 Research Hypothesis

To resolve the research questions proposed above, there are hypotheses for video transmission via each mobile device and MANET. These hypotheses it can be simplified as follows:

(1) Each mobile device is free to move within a network size (small/medium/large) based on Random Way Point (RWP) mobility model.

(2) This study assumes that all nodes are equipped with IEEE 802.11g- MAC layer standard wireless chips because it has been widely adopted and used on many mobile devices.

(3) All mobile nodes use the same routing protocol when they share the transmission medium and they also have similar routing parameters configuration.

(4) If the traffic (mobility speed) /node density is low, we can use long interval values for control messages. That is because the topology change is very limited among the less number of nodes and there is no need for any mobile node to use frequent HELLO and TC messages in order to know their neighbor, which can result in a high network load.

(5) If the traffic / node density is high, we can use short interval values for control messages, because there is a highly dynamic and topology change which requires sending a periodic messages to overcome the topology change. If each node knows its neighbors perfectly this will minimize packet loss and reduce multi-hop communications.

1.9 Research Philosophy

The philosophy behind this work is to develop an enhancement scheme for video transmission over MANET, which has become widespread nowadays. The emerging real-time video applications are becoming the driver of our lives. That can facilitate and improve our lives in different aspects, so any contributions in this area are recommended. The Novelty of our scheme is due to developing a combined scheme based on fine-tuning of MANET routing protocols specifically OLSR through changing the HELLO and TC intervals. Changes in the protocol behaviors aim to fulfill three challenges among transmitting video conferencing over MANETs which are maximizing the performance which leads to high QoS, minimizing the power consumption, routing overhead, and protect the network from popular attacks such as a black hole and jamming attacks.

1.10 Research Scope and Limitations

To limit the direction of the study, several assumptions are made to constrain the research scope. The following points below explain the initial assumptions:

(1) First of all, we assume that each MANET routing protocol has the capability to transmit video streaming, but there are a few of them that are robust and efficient.

(2) There are typical QoS metrics desirable for performance evaluation of video transmission over MANETs such as E2E-delay, jitter, and PDR, and at the same time, there are benchmarking values for these metrics required for efficient and robust transmission of video contents.

(3) To show the feasibility of our scheme, we need to use modeling and optimization techniques such as (ANOVA) and (PSO) respectively to solve our optimization problem in order to find the optimal solution and to show the limitations of our scheme.

(4) We also assume the communication among all the nodes uses a shared channel. This assumption eliminates the channel selection problem and allows us to focus on the suitable routing path in our study.

(5) This study focuses on MANET layers, video conferencing on Middleware and Application Layer, UDP in Transport Layer, (OLSR, AODV, TORA, DSR, and GRP) routing protocols with IPv4 routing in Network Layer, IEEE 802.11/ g in MAC Layer and Orthogonal Frequency-Division Multiplexing (OFDM) in PHY Layer.

(6) We also assume that each wireless node uses a single queue to store the incoming packets and forward the packets based on the First In First Out (FIFO) policy because the basic operation of IEEE 802.11 MAC layer is based on FIFO. Fig. (1.1) summarizes the thesis scope.

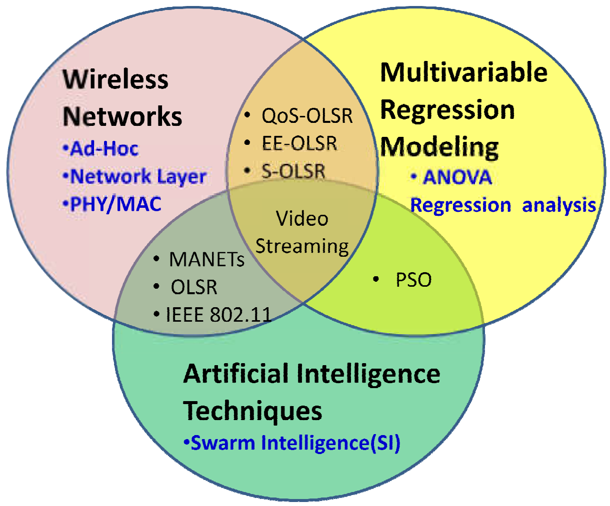


Figure (1.1) Thesis Scope

1.11 Thesis Organization

The rest of this thesis is organized as follows:

Chapter 2 - Mobile Ad-hoc Networks (MANETs): Theoretical background

This chapter presents the historical background of wireless networks, with details of first radio communication; classification of wireless networks, and their standards. It also describes MANET characteristics, issues and applications, routing process, classification of routing protocols, and characteristics of routing protocols, with special attention to the routing protocols related to video transmission over MANET. In addition, an overview of different schemes or approaches used for video transmission over MANET is surveyed.

Chapter 3 - Literature Review and Related Works

This chapter provides a comprehensive report on other works related to the topic of this thesis. It follows, investigates, and reviews the literature related to this thesis specifically in the field of video transmission schemes or approaches over MANET. The feasibility of transmitting video over MANET and the performance evaluation of MANET routing protocols for transmitting real-time video contents are reviewed. There are many approaches proposed in terms of enhancing the video transmission via MANET. The literature surveyed in this chapter focused on the latest efficient proposed solutions and their benefits, advantages, disadvantages, and their limitations through using the OLSR routing protocol to optimize the network performance. Beyond that, the state-of-art in the tuning and optimizing OLSR for video streaming over MANET is reviewed. Also, Swarm intelligence (SI) algorithms are reviewed.

Chapter 4 - Research Methodology

This chapter explains the process of how to identify the suitable MANET routing protocol capable of transmitting video streaming contents via MANETs among a group of routing protocols. Beyond that, this chapter describes main functions and operations of chosen network simulator; clarifies the scenario parameters and chosen mobility model. It investigates the sufficiency of using a network simulator and presents a range of simulators. Simulator environment, network models, scenario environment, and simulation parameters are described. The chapter explains the traffic type for each scenario and performance metrics used for further analysis as well as a comparison between different scenarios in terms of performance metrics.

Chapter 5 – Proposed Scheme for video Conferencing Enhancement over MANETs

Chapter 5 concentrates entirely on the proposed solution part of the thesis; it explains the proposed framework, parameter selection algorithm, simulation setup, and analysis of outcomes. Multivariate Analysis of Variance (ANOVA) and Particle Swarm Optimization techniques (PSO) are described and used for the optimal solution of different network models. Graphical representations of results from all simulations are revealed.

Chapter 6 – This chapter focus on the performance evaluation of the proposed enhancement scheme. Comprehensive simulations performed to compare the overall performance of the enhanced OLSR with the conventional OLSR.

Chapter 7 – Conclusions and Future Works

Concludes of the significant results and analyzes whether the primary set aims and objectives were met. Basically this chapter summarizes the thesis's achievements and findings. The chapter provides some suggestions for future works. Fig. (1.2) shows the organization of the entire thesis.

1.12 Contribution

The main contribution of the work in this thesis is:

1- Comprehensive taxonomy or classification of MANETs routing protocols. The taxonomy listed in this thesis will make the researchers aware of the routing protocol classification available in the area of MANETs. This taxonomy draws an ostensible "big picture" of those available routing protocol classifications that depend on the routing characteristics.

2- Development of a new algorithm for precisely selecting the OLSR routing protocol parameters based on changing the HELLO and TC intervals to cope with most challenging issues such as QoS of video transmission over MANET.

3- Development of a new framework for re-configuring of OLSR routing protocol with the optimal routing parameters.

4- Modeling the OLSR QoS metrics in terms of E2E-delay, Jitter, and PDR using ANOVA to represent each metric as a function of mobility speed (m/s), number of nodes (n), and network size (z).

5- Solving the optimization problem with the three constrained (m, n, and z) to identify the optimal performance of OLSR under these conditions for transmitting video effectively

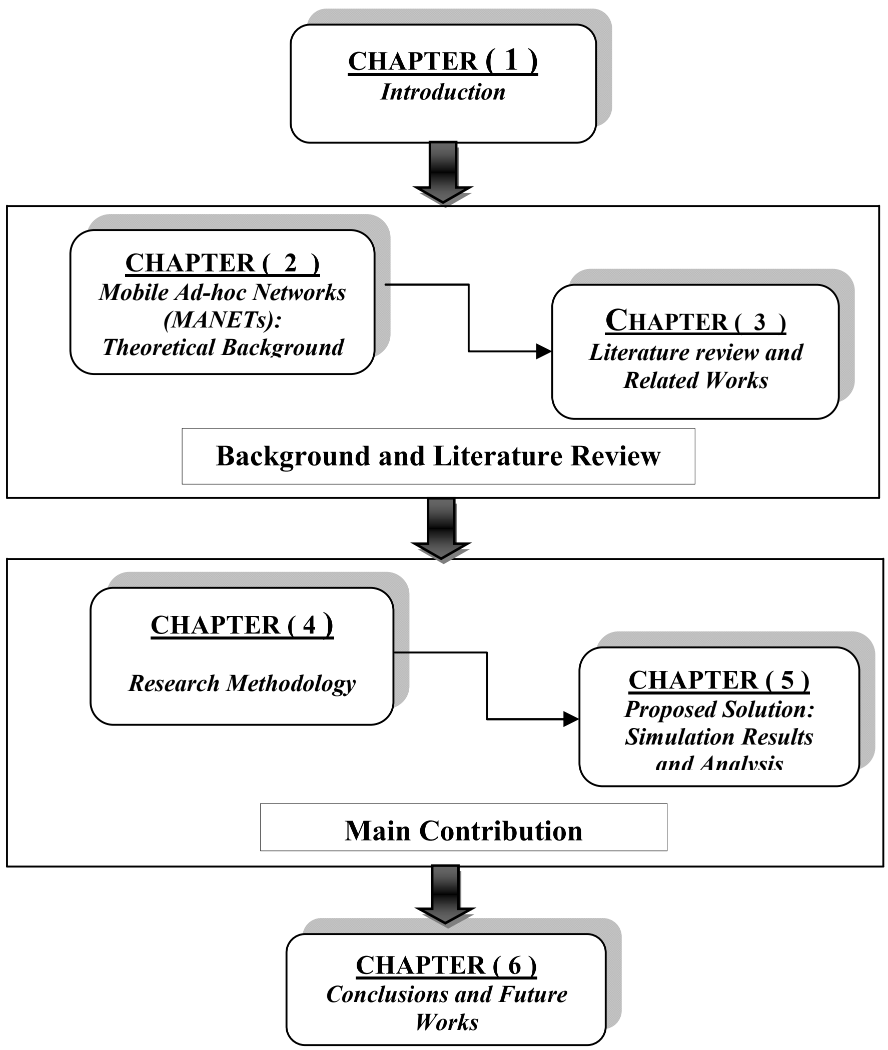


Figure (1.2) Thesis Organization

1.13 List of Publications

1- Jama, Abdirisaq M., Othman O. and Diaa Eldein Mustafa **,"Video Transmission over an Enhancement Approach Of IEEE802. 11e**.“, International Journal of Computer Applications Technology and Research (IJCATR) ,Volume 4 ,Issue 5 ,(2015) ,pp 343 – 350

2- Ahmed, Diaa Eldein Mustafa, Othman O. Khalifa and Jama, Abdirisaq M. "**Video Transmission Over Wireless Networks Review And Recent Advances**.”, International Journal of Computer Applications Technology and Research(IJCTR), Volume(4),Issue(6),(2015), pp 444 – 448.

3- Ahmed, Diaa Eldein Mustafa, and Othman O. Khalifa. ,"**An overview of MANETs: Applications, Characteristics, Challenges and Recent Issues**." International Journal of Engineering and Advanced Technology (IJEAT) –Volume (6), issue (4), (2017): pp 128-133.

4- Ahmed, Diaa Eldein Mustafa, and Othman O. Khalifa., "**A Comprehensive Classification of MANETs Routing Protocols**.“, “International Journal of Computer Applications Technology and Research(IJCTR),volume(6), issue(3) ,(2017): pp 141 – 158.

5- Diaa Eldein Mustafa A. and Khalifa, Othman O.,"**Performance Evaluation of Enhanced MANETs Routing Protocols under Video traffics, for different mobility and scalability models using OPNET**.“, American Journal of Engineering Research (AJER) ,volume(6) , issue (7), (2017) ,pp: 329 - 338 **.**

6- Ahmed, Diaa Eldin Mustafa, et al. "**Performance Evaluation of Ad hoc On-Demand Distance Vector Routing Protocol under Video Streaming**." 2018 7th International Conference on Computer and Communication Engineering (ICCCE). IEEE,(2018): pp: 338-342

7- Khalifa, Othman O., et al. "**Video streaming over Ad hoc on-demand Distance Vector Routing protocol**." Bulletin of Electrical Engineering and Informatics 8.3 (2019): pp: 863-874.

8- Ahmed, Diaa Eldin Mustafa, Othman O. Khalifa, and Hala A. Ebrahim. "**Performance Evaluation of AODV, OLSR, and GRP for Transmitting Video Conferencing over MANETs**." International Journal of Computer Science and Information Security (IJCSIS) ,Vol. 18, No. 4 ,(2020): pp:45-51

Chapter Two

Mobile Ad-hoc Networks (MANETs): Theoretical Background

2 MANETs Background

1.14 Introduction

This chapter presents the background of wireless networks, the classification of wireless networks, and their technologies' standards. In addition, this chapter offers a comprehensive overview of MANET characteristics, applications, and recent issues. Then it describes the routing process in MANET, classification of routing protocols, characteristic of routing protocols, with special attention to the routing protocols related to video transmission over MANET. An overview of different schemes or approaches used for video transmission over MANETs is surveyed.

1.15 Wireless Communications

With recent technological advances in the domain of wireless communications and the emergence of portable computing devices, researchers have turned their attention to improving the function of networks and, in particular, to ensure rapid access to information independent of time or place [16]. In general terms, the expression “wireless communications” refers to “communications involving infrared signals or radio frequencies and allowing the exchange of information and resources between the different entities of a network”. Wireless communications vary according to the range and the type of modulation used. By the nature of the transmission channel used, wireless networks are distinguished from wired networks by a number of characteristics:

– ***An unpredictable environment***: Interference, mobility, changing channels, and variations in the strength of the signal are all factors that make the network extremely variable.

– ***Unreliable medium***. Transmission over a radio channel is prone to errors. Furthermore, interference and the unpredictable quality of links reduce the reliability of the medium. In addition, limited capacity means that the protocols in the transport layer responsible for reliability may not be supported by network nodes.

– ***Limited resources***. In the case of mobile nodes, power is supplied by batteries. For reasons of weight and practicality, these nodes have limited storage capacity and limited processing power. Finally, radio channels are a scarce and costly shared resource for which the usage is governed by restrictive regulations.

– ***Dynamic topology***: Wireless networks are considerably more dynamic in nature than wired networks. This is particularly true in the case of mobile networks. From the moment nodes are able to moves in and out of the range of other nodes, connections within the network can be cut and others can form.

Wireless networks can be categorized using various classifications, according to the size of the zone covered, the architecture of the network, or the technique used for accessing the radio channel. Wireless networks can be broadly categorized into two classes: infrastructure-based wireless networks (Cellular Networks) and infrastructure-less wireless networks (ad hoc wireless networks).

2.2.1 Infrastructure-based (Cellular Networks)

In this type of network, a node can only access the network via a communication infrastructure deployed by the network. This infrastructure could be an Access Point (AP), a wireless bridge, a wireless access router, or a Base Station Transceiver (BTS) as shown in Fig. (2.1).The type of network access infrastructure is dependent on various parameters, including the type of application of the network, the range of the network, the envisaged coverage, and the mobility of the nodes. Examples of infrastructure-based wireless networks are wireless networks set up in airports, offices, homes, and hospitals, where clients connect to the Internet with the help of an access point [17].

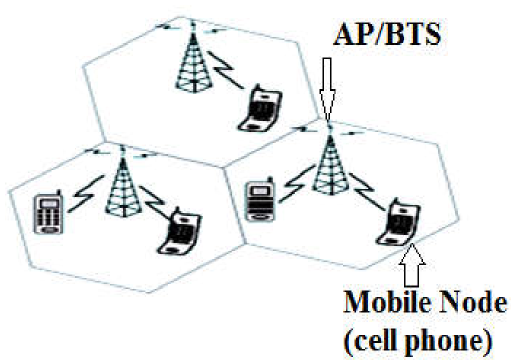


Figure (2.1) Infrastructure Network (Cell phone Network)

Typical types of cellular networks are mobile networks, Wireless Mesh Networks (WMNs) and Wireless Sensors Networks (WSNs) which based on 3G, 4G and Long Term Evolution (LTE) wireless technologies. Fig. (2.2) shown the classification of wireless networks, their basic types, and typical examples of each type. This chapter focuses mainly on MANETs which are under the scope of this thesis.

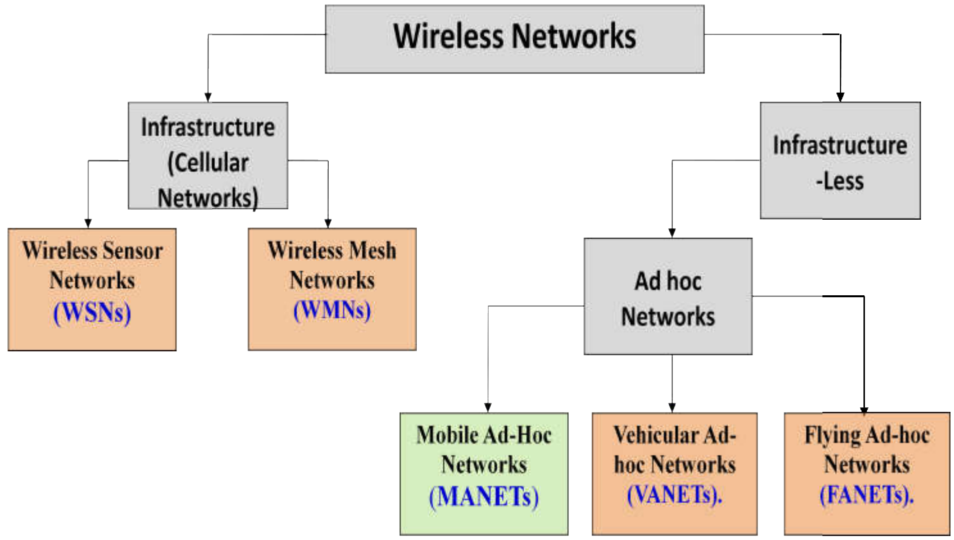


Figure (2.2) Classification of Wireless Networks

2.2.2 Infrastructure-less (Ad-Hoc Networks)

From the Latin meaning "which goes where it must," ad hoc networks are formed dynamically by the cooperation of a random number of independent nodes. The role of each node is not predetermined and nodes make decisions dependant on the situation of the network without having recourse to a preexisting infrastructure. For example, two PCs equipped with wireless network cards can form an ad hoc network each time one comes into the signal range of the other. As no communication infrastructure is used as seen in Fig (2.3), a "hopping" technique is used to access the network. In other words, to communicate with a destination, a mobile node makes use of the other nodes in the network, the message being passed from peer to peer.

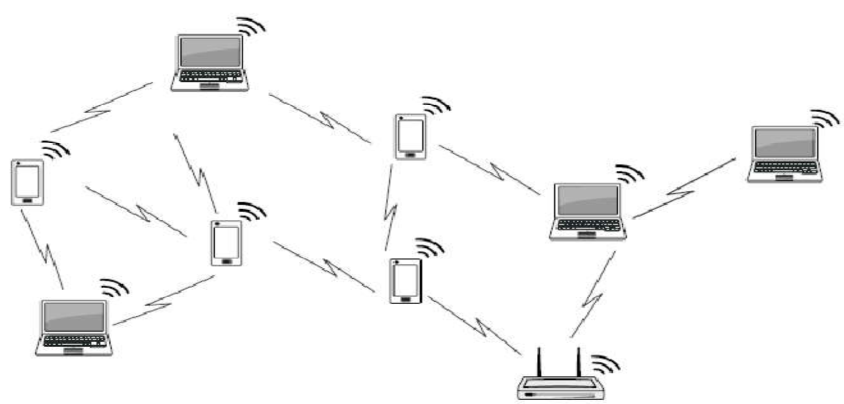


Figure (2.3) Infrastructure-less Network (Ad-Hoc Networks) [18]

There are many types of Ad-Hoc networks such as Mobile Ad hoc Networks (MANETs), Vehicular Ad Hoc Networks (VANET) , Underwater Sensor Networks (UWSN), and Flying Ad Hoc Networks (FANET), which uses the wireless technology IEEE802.x in the MAC layer and such technologies e.g. Direct-Sequence Spread Spectrum (DSSS), Frequency-Hopping Spread Spectrum (FHSS) and Orthogonal Frequency-Division Multiplexing (OFDM) in the PHY layer.

1.16 IEEE802.11- Wireless Local Area Networks (WLANs)

The IEEE 802.11 standard has enjoyed unprecedented success over the past decade. A decade ago, laptops replaced desktop computers as the main driver for 802.11. Smart phones and tablets are now beginning to replace laptops as the key driver for 802.11. The 802.11 standard is the most popular wireless standard to date and possibly the easiest to read. It is also known by the trade name of Wireless Fidelity (or Wi-Fi). The 802.11 wireless LAN is a cost-effective alternative to a wired Ethernet LAN in connecting end-user devices. The IEEE 802.11 standard specifies wireless connectivity for fixed, portable, and moving (mobile) stations in a geographically limited area. The standard is established by the IEEE 802.11 Working Group (WG) [19].

Unlike wired networks, bandwidth can be reused in 802.11 wireless networks. 802.11 has become an increasingly important extension of cellular service. Cellular providers rely on 802.11 to offload voice, data, and video traffic from their crowded and expensive licensed spectrum to a wire line broadband connection. This also benefits users, who do not have to pay more when crossing the bandwidth caps enforced by these providers. Similarly, wire line providers with no cellular service are using 802.11 to expand their broadband service offerings in homes and public areas.

The following paragraphs will provide detailed coverage of 802.11, with an in-depth review of the IEEE 802.x standards and the PHY and MAC technologies associated with each standard. 802.11 deployments have grown significantly in indoor and outdoor access networks, including enterprise wireless LANs, home wireless networks, and large-scale public hotspots. 802.11 technologies have also been deployed in trains, airplanes, parking meters, utility meters, smart-grid meters, and in innovative applications, such as water sprinkler controllers, Radio Frequency Identification (RFID) tags, and sensors. Table (2.1) shows the most popular standards, their technologies, bandwidth, throughput, transmission range, data rate, and PHY /MAC layer technologies. As can be seen in Fig.(2.4), which shows 802.11 data rate evolution, there is near exponential growth in the maximum available data rate since 1997. Table (2.1) shows a comprehensive comparison between the IEEE 802.11 WLAN technologies and their main characteristics including the coverage, capacity, interference and supported data and applications.

Table (2.1): Evolution of IEEE 802.11 Standards

Standard	Year of Released	Specifications						
		Range (m)		RF (GHz)	BW (MHz)	TH (Mbps)	Data Rate (Mbps)	PHY Layer (Modulation)
		In-door	Out-door					
802.11	1997	20	100	2.4	20	0.9	1 , 2	DSSS/FHSS
802.11a	1999	35	120	5	20	2.3	54	OFDM
802.11b	1999	38	140	2.4	20	4.3	11	DSSS
802.11g	2003	38	140	2.4	20	19	54	OFDM
802.11n	2009	70	250	2.4/5	20 /40	390	600	OFDM/MIMO
802.11ac	2013	35		5	20/60/80/160	845	7000	OFDM/MIMO
802.11ad	2013	<5		60	2.16		6760	SC/OFDM
802.11ax	2019			2.4/5	20/40/80/160		10000	OFDM OFDMA

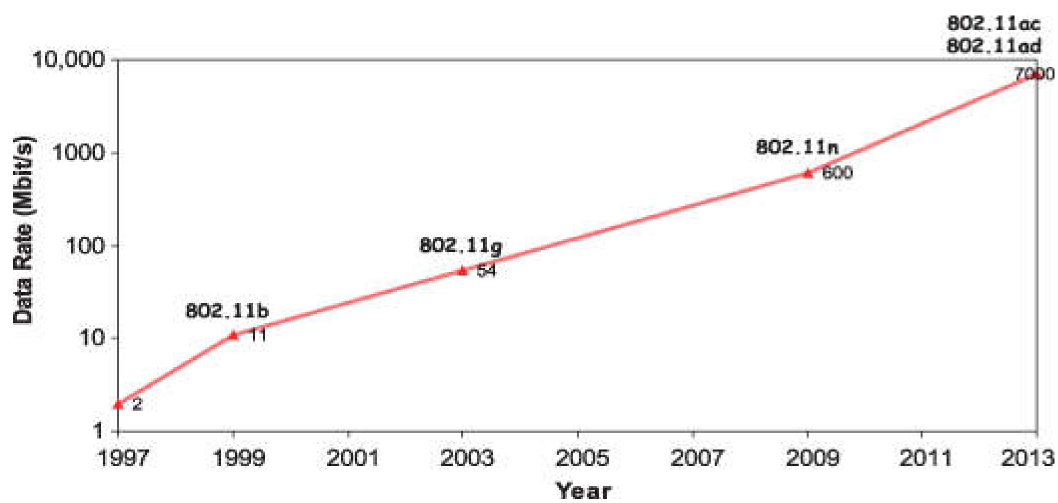


Figure (2.4) IEEE 802.11 Data Rate Evolution

1.17 MANETs: Background

Although initially mobile ad-hoc networks were conceived as a general-purpose network, in terms of real-world deployment and industrial adoption [18] , MANET applications are emerged as specialized networks that are managed by a single authority and tailored to solve specific problems in different areas , for example in military networks, vehicular networks or sensor networks. Additionally, MANETs are expected to become a key component in the 4G architecture, and use most of the important functionality of overall next-generation wireless network technologies.

2.4.1 MANETs: Definition

Last decades wireless communication has grown and is still an area of interest to a large number of scientists and researchers. Mobile ad hoc network (MANET) is an autonomous system consisting of a collection of mobile nodes such as (laptop, cell phones, Personal Digital Assistant (PDA), etc...) connected by wireless links, but has no any fixed infrastructure and predefined topology of wireless links. MANET is a type of infrastructure-less network which is self-configurable in nature i.e. each node is able to move in a random direction and can make an arbitrary network topology [1, 2]. The absence of fixed infrastructure means that the nodes communicate directly with one another in a peer-to-peer fashion. MANET is a special point of focus for industry and academic researchers from all around the globe. This technology has come with its own flavors and it is easy to deploy in disaster areas and for emergency operations [3].

2.4.2 MANETs: Applications

In this section, typical applications scenarios and some of the most illustrative use cases nowadays are described. Table (2.2) illustrates different applications of MANETs through military, civilian and commercialized applications.

Table (2.2): Typical Applications of MANETs

Application	Possible Scenarios
Mobile Conferencing	– Enable mobile conferencing for business users who need to collaborate outside their office where no network infrastructure is available. – Users allow sharing documents, upload and download files, and exchange ideas.
Extended Network Connectivity	– Provides communication between devices or with the Internet in areas with limited infrastructure or intermittent access.
Emergency Services	– Used in disaster situations after disasters or catastrophes, such as flood, earthquake or fire.
Education	– Universities and campus settings. – Virtual class rooms. – Ad hoc communications during meetings or lectures.
Commercial and Civilian Environment	– Used in the E-commerce such as electronic payments anytime and anywhere environments[20]. – Used as road or accident guidance and it is used in transmission of road and weather conditions, taxi cab network, and inter-vehicle networks. – Used in sports stadiums, trade fairs, shopping malls, and airports.
Intelligent Vehicular Ad hoc Networks (InVANETs)	– Main goal of planning InVANETs is to avoid vehicle crash so that passengers are safe.

Tactical Networks	– Support communication and coordination needs between soldiers, military vehicles and information headquarters.
Vehicular Networks (VANETs)	– Vehicles are equipped with wireless interfaces that enable them to communicate with each other Vehicles-to-Vehicles (V2V) or with road-side fixed infrastructure Vehicles-to- Infrastructure (V2I). – V2V communications allow vehicles to participate in vehicle coordination platforms as well as routing of other communications. – V2 I connectivity allow vehicles to obtain information about road conditions, traffic congestion or accident warnings.
Wireless Personal Area Networks (PANs)	– Allows the proximal electronic devices with specific purposes, such as cameras, storage devices, televisions, mobile phones, or laptops, to dynamically share information through an autonomous home network.
Body Area Networks (BANs)	– System of wireless medical sensors located in or around a human body operating as a health monitoring system. – BANs formed by medical sensors are used in telemedicine systems.
Wireless Sensor Networks (WSNs)	– Used to interconnect a set of low-cost and low-power sensor devices deployed in the environment or, alternatively, carried by animals or these devices are usually embedded, for instance, in buildings, bridges, streets, or mountains and they are used for environmental or industrial monitoring and, more generally, to monitor events and phenomena.
Smart Cities	– New scenario of the modern wireless communication where devices communicate via a common platform and can easily be controlled remotely, to provide public services such as smart traffic lights and smart garbage collection.
Internet of Things (IoT)	– Objects of everyday life will be equipped with micro-controllers, and transceivers for digital communication, and suitable protocol stacks that will make them able to communicate with one another and with the users. – It provides easy access and interaction with a wide variety of devices such as, for instance, home appliances, surveillance cameras, monitoring sensors, actuators, displays, vehicles, and so on.
Entertainment	– Multi-user games – Wireless Peer – to – Peer (P2P) networking – Outdoor Internet access – Robotic pets – Theme parks
Internet based Mobile Ad hoc Networks (iMANETs)	– Are ad hoc networks that link mobile nodes and fixed Internet gateway nodes. – The network uses a network-layer routing protocol to link mobile nodes and establish distributed routes and automatically.
Flying Ad hoc Network (FANET)	– Mobile base stations are to mount them on flying vehicles like helicopters, hot air balloons or drones. – In this approach, a subset of the base stations can be equipped with the necessary infrastructure to communicate with the ground base or satellite while the other base stations can simply transfer their data through this subset to the underlying network.

2.4.3 MANETs: Characteristics

Due to the nature of MANET, and their inherit features from the wireless network, MANET has some characteristics that make it popularized everywhere at any time. Consequently we can mention most of the characteristics of MANETs as follows:

– **Infrastructure-less nature**

MANET is formed based on the collaboration between independent peer-to-peer nodes to communicate with other nodes for a particular purpose [21]. No prior base station or organization is defined and all devices have the same role in the network. In addition, there are no pre-set roles such as routers or gateways as the nodes participating in the network are provided, each device can work as a node and router at the same time. That is, it is autonomous in behavior and nodal connectivity is intermittent.

– **Easy and rapid deployment**

MANET includes several advantages over wireless networks, including ease of deployment, speed of deployment, and decreased dependence on a fixed infrastructure. MANET is attractive because it provides an instant network formation without the presence of fixed base stations and system administration [17].

– **Dynamic topology**

MANET nodes are free to move around; thus they could be in and out of the network, constantly changing their links and topology. In addition, the links between nodes could be bi-directional or unidirectional. This feature however causes high user density and large level of user mobility.

– **Bandwidth constraints and variable link capacity**

Wireless links that connect the MANET nodes have much smaller bandwidth than those with wires [21]. Due to the effects of multiple accesses, multipath fading, noise, congestion, fluctuation and signal interference, the capacity of a wireless link can be degraded over time and the effective throughput may be less than the radio's maximum transmission capacity.

– **Multi-hop communication**

Due to signal propagation characteristics of wireless transceivers, MANETs require the support of multi hop communication [22] ; that is, when a destination node for a message is out of the radio range, the MANETs is capable of multi-hop routing for mobile nodes that cannot reach the destination node. A message from source node to destination node goes through multiple nodes because of limited transmission radius. Every node acts as a router and forwards packets from other nodes to facilitate multi-hop routing [23].

– Constrained resources (light-weight terminals)

Most of the MANET devices are small hand-held devices ranging from laptops, smart phones and Personal Digital Assistants (PDA) to cell phones. These devices have limited power (battery operated) processing capabilities and storage capacities.

– Fluctuating link capacity

The nature of high bit-error rates of wireless connection might be more profound in a MANET. One end-to-end path can be shared by several sessions. The channel over which the terminals communicate is subjected to noise, fading, and interference, and has less bandwidth than a wired network. In some scenarios, the path between any pair of users can traverse multiple wireless links and the links themselves can be heterogeneous.

– Limited device security

MANET devices are usually small and portable and are not restricted by location. As a result, these devices can be easily lost, damaged or stolen.

– Limited physical security

Wireless links made MANET more susceptible to physical layer attackers, such as eavesdropping, jamming, spoofing and Denial of Service attack (DoS). However, the decentralized nature of MANET makes them better protected against single failure points. But on the other hand mobile wireless networks are more prone to threats than infrastructure networks. As in MANETs, all the networking functions like routing, packet forwarding are performed by the nodes themselves, because of this reason securing a mobile wireless network is very challenging. The increased possibility of eavesdropping, spoofing and minimization of denial of-service type attacks should be carefully taken into consideration [24]. The distributed nature of operation of security, routing and host configuration causes the absent of a centralized firewall.

– Short range connectivity

MANET depends on Radio Frequency (RF) or Infrared (IR) technology for connectivity, both of which are generally used for short range communications. Therefore, the nodes that wish to communicate directly need to be in close proximity to each other. To overcome this limitation, multi-hop routing techniques are used through intermediate nodes that act as routers to connect distant nodes. Since MANETs can be deployed rapidly without the support of a fixed infrastructure, they can be used in situations where temporary network connectivity is needed.

– Distributed operation

There's no background network for the central control of the network operations, the control of the network is distributed over the list of nodes. The nodes involved in a MANET should cooperate with one another and communicate among themselves, and each node acts as an exchange as needed, to implement specific functions such as routing and security [25].

– Heterogeneity in node and link capabilities

Every node in the network may have one or more different radio interfaces which have varying transmitting and receiving capabilities, which operates on different frequency bands. This variation in node radio capabilities leads to asymmetric links. Each node may also have different processing capabilities because of heterogeneity in software/hardware configuration. For such heterogeneous network, the design of protocols and algorithms is complicated, requiring dynamic adaptation to the changing conditions [24].

2.4.4 MANETs: Challenges and Recent Issues

Regardless of the attractive applications and different characteristics of MANET, we can introduce several challenges and issues that must be studied carefully before a wide commercial deployment can be expected. MANET environment has to overcome these issues and challenges. These challenges represent the open issues and unresolved problems. MANETs have been a popular field of study during the last few years. Almost every aspect of the network has been explored in one way or another at different levels of the problem. The most important challenges and recent research trends of the MANETs are mentioned bellow [11, 19, 20, 26, 27]:

– Limited bandwidth

Wireless links continue to have significantly lower capacity than infrastructure networks. In addition, the realized throughput of wireless communication after accounting for the effect of multiple access, fading, noise, and interference conditions, etc., is often much less than a radio's maximum transmission rate.

– Routing and routing overhead

Routing is a significant point of view for researchers since routing protocols are an essential issue in this field. This is because changes in network topology occur frequently, mobile density varies over time and network size can extend. An efficient and intelligent routing protocol is required to cope with the highly dynamic nature and fulfill of the network conditions. One of the major challenges of MANETs routing protocols is the routing overhead. In MANETs, nodes often change their location and topology within the network. So, some stale routes are generated in the routing table which leads to unnecessarily routing overhead.

– The wireless link characteristics are time-varying in nature

The terminals communicate via a channel which is subjected to fading, noise, interference, path loss and has low bandwidth as compared to wired networks. The scalability, reliability, efficiency, and capacity of wireless links are frequently inferior when the comparison with wired links takes place. This depicts the variable link bandwidth of wireless links.

– Route changes due to mobility

The network topology in an ad hoc wireless network is highly dynamic due to the movement of nodes; hence an on-going session suffers frequent path breaks. This situation often leads to frequent route changes.

– Dynamic topology

Dynamic topology membership may disturb the trust relationship among nodes. The trust may also be disturbed if some nodes are detected as compromised.

– Multiple accesses

A major issue is to develop efficient medium access protocols that optimize spectral reuse, and hence, maximize aggregate channel utilization in MANETs.

– Radio interface

Mobile nodes rely on the radio interface or antenna to transmit packets. Packet forwarding or receiving via radio interface or antenna techniques in MANETs remain useful areas of investigations.

– IP addressing

In MANET every node acts as a router and can forward data packets to other nodes to provide information and data communication among the mobile nodes.

One of the most important issues is the set of IP addresses that are assigned to the MANET network. A difficult and challenging issue is to implement MANET addressing scheme. The MAC address of the device is used in the stand-alone ad hoc network. However, every application is based on TCP/IP and UDP/IP. Today IP addressing and auto configuration address have attracted much attention in MANETs.

– Battery constraints and power management

Devices used in these networks have restrictions on the power source in order to maintain portability, size and weight of the device. A power management approach would help reducing power consumption and hence prolonging the battery life of mobile nodes. Because most devices operate on batteries, power management becomes an important issue.

– Frequent network partitions

The random movement of nodes often leads to partitioning of the network. This mostly affects the intermediate nodes.

– Packet losses due to transmission errors and hidden terminal problem

MANET networks are prone to a much higher packet loss due to factors such increased collisions due to the presence of hidden terminals, presence of interference, unidirectional links, and frequent path breaks due to mobility of nodes. The hidden terminal problem refers to the collision of packets at a receiving node due to the simultaneous transmission of those nodes that are not within the direct transmission range of the sender, but are within the transmission range of the receiver.

– Security threats

The wireless medium is vulnerable .Security is the most important challenge in MANETs because the nodes and the information in MANETs are not secured from threats, for example, Denial of Service (DoS) attacks ,black hole attacks and jamming attacks. Also, mobile devices imply higher security risks compared with fixed operating devices, because portable devices may be stolen or their traffic may insecurely cross wireless links. Eavesdropping, spoofing, and denial of service attacks are the main threats for security.

– Multicasting and geo-casting

Multicast service supports users communicating with other members in a multicast group. Broadcast service supports users communicating with all members on a network.

– Location service

Location information uses the Global Positioning System (GPS) or the network-based geo-location technique to obtain the physical position of a destination.

– Clustering

Clustering is a method to partition the hosts into several clusters and provide a convenient framework for resource management, routing and virtual circuit support.

– QoS/ multimedia

Quality of Service (QoS) and multimedia require high bandwidth, low delay, high packet delivery ratio (PDR) and high reliability. Transmitting real time video contents such as video streaming or video conferencing over MANET is a challenging task, because multimedia applications are delay sensitive and required an acceptable level of QoS to provide multimedia services.

– **Fault tolerance**

This issue involves detecting and correcting faults when network failures occurs. Fault-tolerance techniques are brought in for maintenance when a failure occurs during node movement, joining, or leaving the network.

– **Diffusion hole problem**

The nodes located on boundaries of holes may suffer from excessive energy consumption since the geographic routing tends to deliver data packets along the boundaries by perimeter routing if it needs to bypass the hole. This can enlarge the hole because of the excessive energy consumption of boundary nodes.

– **Device discovery**

Identifying relevant newly moved in nodes and informing about their existence need dynamic update to facilitate automatic optimal route selection.

– **Inter-networking**

In addition to the communication within an ad hoc network, inter-networking between MANET and fixed networks (mainly IP based) is often expected in many cases. The coexistence of routing protocols in such a mobile device is a challenge for the harmonious mobility management.

– **Topology maintenance**

Updating information of dynamic links among nodes in MANETs is a major challenging issue.

– **Robustness and reliability**

Misbehaving nodes and unreliable links can have a severe impact on overall network performance. Due to the lack of centralized monitoring and management mechanisms, these types of misbehaviors cannot be detected and isolated quickly and easily. This increases the design complexity significantly.

2.5 MANETs: Protocol Stack

MANET protocol stack consists of five layers: physical layer, data link layer, network layer, transport layer and application layer as shown in Fig. (2.5), the function of each layer it can be described as follows:

– ***Physical Layer*:** This layer deals with modulation techniques such as (Orthogonal Frequency Division Multiplexing (OFDM), Direct-Sequence Spread Spectrum (DSSS), Multiple/Input-Multiple/Output (MIMO), etc...), and transmission and reception of data from other nodes over the IEEE 802.11. In addition, this layer is concerned with energy management. In this study, we specifically deal with the OFDM modulation technique.

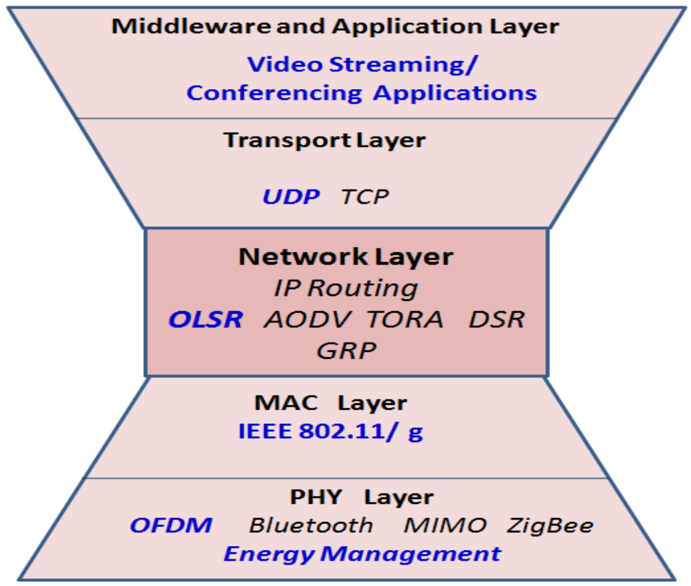


Figure (2.5) Typical MANETs Protocol Stack [28]

– ***Data Link Layer or MAC layer:*** The focus, in this layer, is on the IEEE802.11 MAC protocol, which resolves the problems of medium contention, supports reliable communication, and provides resource reservation. It also minimizes collisions, as well as the time for which the transceiver is turned on. We concentrate in this study on IEEE802.11g, which is a popular standard supported by most mobile devices nowadays. IEEE 802.11g is an improvement for the former IEEE802.11b which has increased the maximum data rate up to 54 Mb/s. Furthermore, it uses the same frequency as 802.11b which is 2.4GHz and it is fully backward compatible with 802.11b hardware which means 802.11g allows interoperability with 802.11b. Moreover, 802.11g uses OFDM as a modulation scheme similar to 802.11a for the data rates 6, 9, 12, 18, 24, 36, 48, and 54 Mb/s. However, at 11 and 5.5 Mb/s, 802.11g reverts to Complementary Code Keying (CCK) modulation scheme the same as 802.11b.

– ***Network Layer:*** This layer primarily deals with routing. In MANET the mobile node works as a host and a router at the same time due to the absence of network infrastructure and centralized administration. However, there are many routing protocols proposed for MANET witch guarantee this feature. We investigate in this study the performance evaluation of five MANET routing protocols: AODV, OLSR, DSR, TORA, and GRP for the video delivery specifically video conferencing. We discuss this issue comprehensively in Chapter (3) and identify which MANET routing protocols are capable of transmitting video effectively.

- ***Transport Layer:*** This layer maintains data flow, controls congestion, and performs several other tasks that are traditionally performed on transport layers in wired networks. In the application presented in this work, the UDP protocol was used in the transport layer.

- ***Application Layer:*** This layer contains application software such as FTP, HTTP, video, audio, and other applications.

2.6 MANETs: Routing Protocols

Routing protocols establish the governing rules and define the set of parameters that indicate how the packets are exchanged between communicating nodes of MANET [29]. Recently, there are different routing protocol algorithms that have been proposed to overcome most of MANET challenges such as dynamic topology changes, limited bandwidth, link failure due to node mobility, limited power on mobile nodes, power consumption due to routing computation and etc.

2.6.1 Challenges facing MANET Routing Protocols Design

MANET works under no fixed infrastructure in which every node works as a router that stores and forwards the packet to the final destination. Routing is one of the most challenging tasks in MANETs. This is due to dynamic topology changes, limited bandwidth, and limited battery power available in each node, frequent link failure, interference, limited resources and etc. Therefore routing discovery and maintenance are critical issues in these networks. Here we will focus on the most popular and important problems facing the development of MANET routing protocols [30]:

- ***Asymmetric links*:** Most of the wired networks rely on symmetric links which are always fixed. But this is not the case with MANETs as the nodes are mobile and constantly changing their position within the network.
- ***Routing Overhead***: In MANETs, nodes often change their location within the network which consequently results in a change in topology. So, some stale routes are generated in the routing table which leads to unnecessary routing overhead.

- ***Interference:*** This is the major problem with MANETs as links come and go depending on the transmission characteristics. One transmission might interfere with another and a node might overhear transmissions of other nodes and can corrupt the total transmission.
- ***Dynamic Topology***: Since nodes are mobile and medium characteristics might change, the topology is not constant. In MANETs, routing tables must somehow reflect these changes in topology and routing algorithms have to be adapted. For example in a fixed network routing table updating takes place every 30sec. This updating frequency might be very low for MANETs.
- ***Distributed operation***: With no central hierarchy of routers, routing must be distributed amongst the participant nodes.
- ***Loop-freedom*****:** Aim to avoid route discovery or maintenance processes from spinning from node to node indefinitely.
- ***Demand-based operation versus Proactive operation*****:** To minimize the control overhead in the network and thus not waste the network resources (bandwidth, battery, memory, etc...) the protocol should be reactive. This means that the protocol should react only when needed and that the protocol should not periodically broadcast control information.
- ***Unidirectional link support*****:** The radio environment can cause the formation of unidirectional links. Utilization of these links and not only the bi-directional links improves the routing protocol performance.
- ***Security:*** Due to the nature of transmission medium, MANET routing protocol is vulnerable to many forms of attacks. They are more prone to security replay transmission, and spoofing threats than other general wired networks because the network structure is not strictly defined. HELLO flood attack are a common attack aims on consuming up the resources of the network like battery power of the nodes . Also a number of nodes keep on getting added as well as deleted from the network making it very easy for a malicious node to enter the network. Then it will be relatively easy for that node to snoop on network traffic, redirect traffic and flood the entire network.
- ***Power conservation*****:** The nodes in the MANETs can be laptops and constraint clients such as PDAs that are limited in battery power and therefore use sleep modes to save the power. It is therefore very important that the routing protocol has support for these sleep modes.

- ***Multiple routes***: To reduce the number of reactions to topological changes and congestion multiple routes can be used. If one route becomes invalid, it is possible that another stored route could still be valid and thus saving the routing protocol from initiating another route discovery procedure.
- ***Quality of Service support***: Most group communication technologies support real-time multimedia applications such as video conferencing, video streaming and distributed gaming. These applications require Quality-of-Service (QoS) aware multicast routing protocols to deliver the same data stream to a predefined group of receivers. Some levels of QoS is necessary to incorporate into the routing protocol.
- ***Scalability***: Routing protocols should be able to scale with the network size. Scalability can be broadly defined as whether the network is able to provide an acceptable level of service even in the presence of a large number of nodes. In MANETs when the network size increases, the number of packets sent by a node also increases. That leads to drainage of limited battery power and network life time reduces and thus scalability is a major challenging issue.
- ***Energy consumption***: In MANETs each node participating in the network acts both as a router and a host and is willing to transfer packets to other nodes. For this purpose, a routing protocol should minimize control traffic. The concept of power as one of the deciding factors in route selection can be crucial in route discovery and route repair phase.

2.6.2 Characteristics of an Ideal Routing Protocols for MANETs

A routing protocol should have the following essential characteristics:

1. Allows fully distributed processing.
2. Adaptive to frequent changes in topology.
3. Transmission should be reliable to reduce message loss.
4. The convergence must be quick, once the network topology becomes stable.
5. Optimal use of bandwidth, computing power, memory and battery power.
6. Provides a certain level of Quality of Service (QoS).
7. Loop free, least control overhead, QoS–aware, energy–aware, location–aware and security–aware.

Consequently the main design criteria for routing protocols in MANETs are as follows:

1. Support scalability and reliability.

2. Support dynamic topology.
3. Support route maintenance and route update.
4. Distributed processing and lightweight computations.
5. Simplicity and ease of implementation.
6. Fault tolerance.

2.7 Classification of MANET Routing Protocols

Routing is a core operation in networks for sending data from one node to another. It has been an area of research since the invention of commercialized mobile Ad-Hoc networks. Several MANET routing protocols have been designed for accurate, fast, reliable, scalable, stable, fair, robust, QoS aware and energy efficient routing protocols for a high volume of changeable network topologies. Such protocols must deal with the typical limitations of changeable network topology, which include high power consumption, low bandwidth, and high error rates. Till to date, number of different routing protocols for mobile ad-hoc networks have been proposed. To establish communication path between nodes, efficient routing protocols are needed.

There are a number of routing protocols currently available in MANETs. There is a need for a general technique to classify available protocols. As shown in Fig.(2.6) MANETs routing protocols can be classified into two general approaches. The first depends on routing strategy and the second is based on network structure .Fig.(2.7) shows the classification according to the routing strategy, where the routing protocols can be categorized as table-driven and source initiated. Fig.(2.8) shows the classification depending on the network structure. These are classified as flat routing, hierarchical routing, geographical (location based) routing, power-aware routing , and multicast routing [31]. In this section we will focus on routing protocols based on network structure because it has gained greet interest from both researchers and the industry.

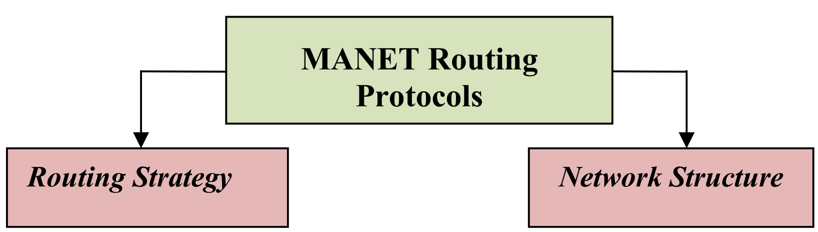


Figure (2.6) MANETs routing protocols (Main Classification)

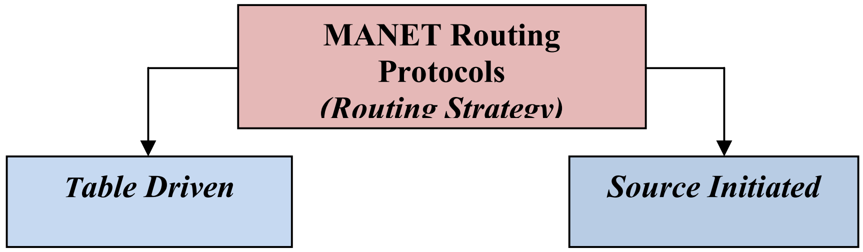


Figure (2.7) MANETs routing classification based on (routing strategy)

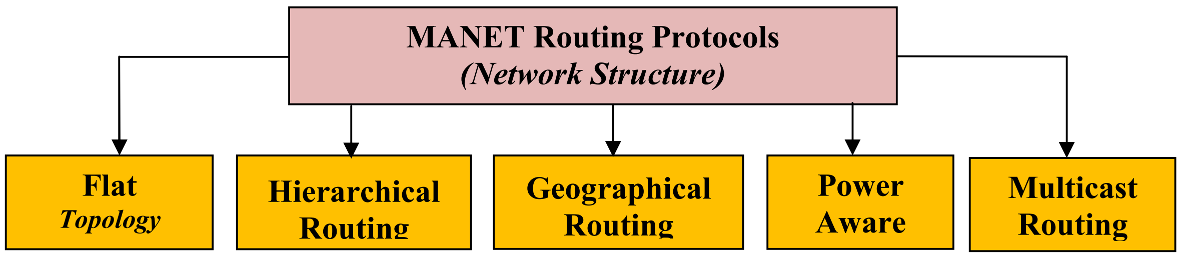


Figure (2.8) MANETs routing classification based on the (Network Structure)

2.7.1 Flat Routing (Uniform) or (Topology Based)

Topology based routing protocols depend on the current topology of the network and cope with the dynamic nature of MANET. The topology-based routing protocols have limited performance compared to geographical (position based) routing protocols which use additional information in order to determine the node location. Topology based routing schemes generally require additional node topology information during the routing decision process. Topology based routing can be further subdivided into ***proactive*** routing protocols (*table-driven*), ***reactive*** routing (on-demand) protocols, and ***hybrid*** routing protocols [32, 33]. Fig.(2.9) shows the detailed taxonomy of Flat routing protocols.

2.7.1.1 Proactive Routing Protocols (Table Driven)

In proactive routing, each node has to maintain one or many tables for storage routing information, and any update in network topology needs to be reflected by propagating changes throughout the network in order to maintain a proportionate network. Examples of proactive protocols are Destination-Sequenced Distance Vector (**DSDV**), Optimized Link-State Routing (**OLSR**), Topology-Based Reverse Path Forwarding (**TBRPF**), and Core-Extraction Distributed Ad hoc Routing (**CEDAR**). We can distinguish between three types of the proactive routing protocols according to the algorithm on which each one is based.

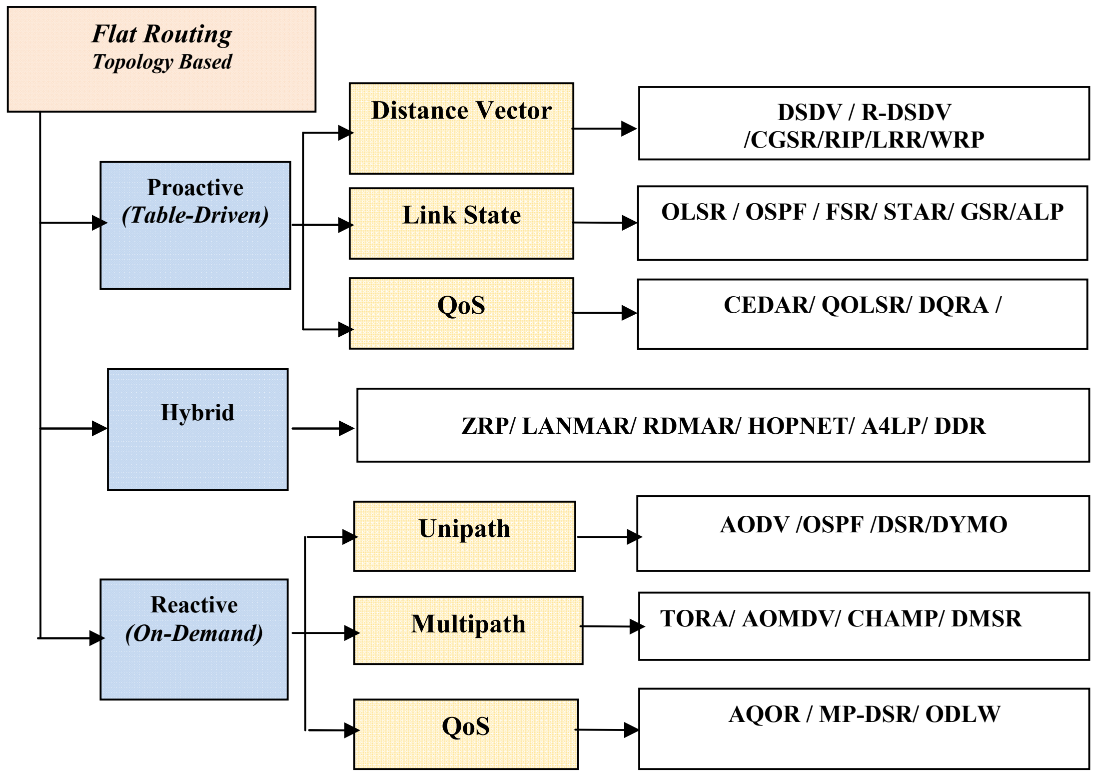


Figure (2.9) Flat Routing (Topology Based) Classification with subdivisions

2.7.1.1.1 Distance Vector Routing

Distant vector protocol is also known as Distributed Bellman-Ford or RIP (Routing Information Protocol). In a distance vector routing protocol, every host maintains a routing table containing the distances from it to possible destinations. In other words, each node contains all available destinations details, the next node to reach to destination and the number of hops to reach the destination [34]. Each routing table entry contains two parts: the next hop to the destination, and the distance to the destination. The distance metric might be the number of hops, the delay, the quality of links along the path, etc. The chosen next hops lead to the shortest path to the destination [35]. Using a distance vector protocol, the router simply forwards the packet to the neighboring host (or destination) with the available shortest path in the routing table and assumes that the receiving router will know how to forward the packet beyond that point [36]. One example of a distance vector routing protocols is Destination Sequenced Distance Vector (DSDV).

DSDV routing protocol is a proactive, hop-by-hop distance-vector routing protocol based on the classical Bellman–Ford routing algorithm proposed by (Charles Perkins and Bhagwatt 1994) [37]. It is a distributed, self-organized, and loop-free routing protocol suitable for dynamic networks [9]. DSDV uses the shortest-path routing algorithm to select a single path to a destination. To avoid routing loops, destination sequence numbers have been introduced [17]. Each node maintains a routing table that contains routing entries for all nodes in the network, and periodically advertises and broadcasts routing updates of their routing information to their neighbors. Each entry in the routing table contains the destination node's address, next-hop node's address, the number of hops to reach the destination, and the sequence number originated by the destination node. Nodes can forward packets to next-hops, and so on all the way to the destination according to their routing tables. The sequence number is used to distinguish stale routes from new ones and thus avoid loop formation. The nodes periodically transmit their routing tables to their immediate neighbors. A node also transmits its routing table if a significant change has occurred in its table from the last update sent. So, the update is both time-driven and event-driven. The routing table updates can be sent in two ways: a "full dump" or an "incremental" update [38].

2.7.1.1.2 Link State Routing

In link state protocols, a router doesn't provide the information about the destination; instead it provides the information about the topology of the network. This usually consist of the network segments and links that are attached to that particular router along with the state of the link i.e., whether the link is in active state or inactive state. This information is flooded throughout the network and then every router in the network builds its own picture of the current state of all the links in the network [36].

Optimized Link State Routing (OLSR) protocol is a proactive (table-driven) and link state routing protocol, has been proposed by (Jacquet et al 1998), where the routes are always immediately available when needed. In OLSR, nodes exchange messages with other nearby nodes of the network on a regular basis to update topology information on each node, as illustrated in Fig. (2.10). Nodes determine their one-hop neighbors, i.e., nodes within their transmission radius, by transmitting HELLO and TC (Topology Control) messages. Based on a selection criterion that will be elaborated upon in the subsequent sections, a set of nodes among the one-hop neighbors is chosen as multipoint relays (MPRs). MPRs nodes have two roles: (a) When the selector sends or forwards a broadcast packet, only its MPRs nodes among all its neighbors forwards the packet, (b) The MPRs nodes periodically broadcast the selector list throughout the MANET (again, by means of MPR flooding). Thus, every node in the network knows which MPR nodes could reach every other node. Only these nodes forward topological information, providing every other node with partial information about the network. Furthermore, only these MPRs will generate link state information to be forwarded throughout the network. By these two optimizations, the amount of retransmission is minimized, thereby reducing overhead as compared to link state routing protocols. Each node will then use this topological information, along with the collected Hello messages, to compute optimal routes to all nodes in the network.

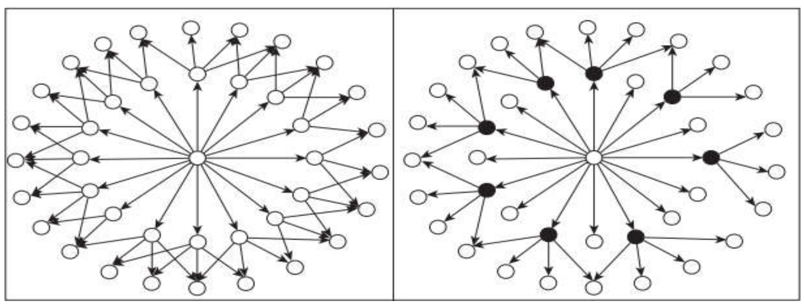


Figure (2.10) OLSR routing mechanism

OLSR is an optimization version of a pure link state protocol in which the topological changes cause the flooding of the topological information to all available hosts in the network. OLSR may optimize the reactivity to topological changes by reducing the maximum time interval for periodic control message transmission. Furthermore, as OLSR continuously maintains routes to all destinations in the network, the protocol is beneficial for traffic patterns where a large subset of nodes are communicating with another large subset of nodes, and where the [source, destination] pairs are changing over time [39].

2.7.1.2 Reactive Routing Protocols (On Demand)

This type of protocols attempts to establish routes between nodes only when they are needed or when routes are no longer valid. Thus, reactive routing protocols such as AODV try to discover routes to a destination only when needed, establish routes only on demand basis and do not take initiative for finding a route. Reactive routing needs less memory and storage capacity than proactive routing protocols. They do not update routing tables constantly. Reactive protocols are also known as (on-demand) routing protocols, and they do not maintain routing information or activity of routing at the network nodes when there is no communication. In this manner, communication overhead is reduced and battery power is conserved as compared to proactive routing protocols. Packets are forwarded throughout the network by the flooding process during the route discovery. The typical examples of reactive or on-demand routing protocols are: AODV, Dynamic MANET On-demand (DYMO), TORA, Ad-hoc QoS On-demand Routing (AQOR) [16].

2.7.1.2.1 Uni-path Routing

Even if several equally good paths are available, the uni-path routing protocols use only one path at a time to a given destination. Such protocols as AODV, Open Shortest Path First (OSPF), DSR, and DYMO operate with this strategy. Most routing protocols are uni path or have a uni-path mode of operation. A commonly used routing protocol called Open Shortest Path First (OSPF) operates in a uni-path mode where equal-cost multipath routing is enabled or turned on in the protocol [12].

Route discovery and route maintenance are the two steps followed by each protocol. In route discovery, the source node first finds a route or several routes to the destination, when it needs to send packets to a destination. This process is called route discovery. But in the route maintenance process, the source node will transmit packets along the route. The route may be broken during the transmission of packets because the node on the route might move away or go down. The broken route will be reconstructed. The process of detecting route breakage and rebuilding the route is called route maintenance.

Ad hoc On-Demand Distance Vector (AODV) [32, 40-42] is a reactive routing protocol that belongs to uni-path routing protocols; (on-demand) routing protocol. Whenever a route from source to destination is required then only it develops a route. AODV is created with the combination of Dynamic Source Routing (DSR) and Destination Sequenced Distance-Vector (DSDV); AODV uses properties of route request (RREQ) and also routes maintenance procedures from DSR and some features like sequence number, periodic updates, hop by hop count from DSDV routing protocol. Every node knows its neighbors and the costs to reach them. In AODV, the source node and the intermediate nodes store the next-hop information corresponding to each flow for data packet transmission. The sequence number of the routing table is used to determine whether the routing information is up-to-date or not and also it is useful to prevent the routing loop problem. When a source requires a route to a destination, it floods the network with a route request (RREQ) packet. On its way through the network, the RREQ packet initiates the creation of temporary route table entries for the reverse path at every node it passes, and when it reaches the destination, a route reply (RREP) packet is uni-cast back along the same path on which the RREQ packet was transmitted. The following information is contained in the packet header for the route request:

- Source node IP address
- Broadcast ID
- Current sequence number for the destination

During a route discovery process as shown in Fig.(2.11), the source node broadcasts a route query packet to its neighbors. If any of the neighbors have a route to the destination, it replies to the query with a route reply packet; otherwise, the neighbors rebroadcast the route query packet. Finally, some query packets reach the destination.

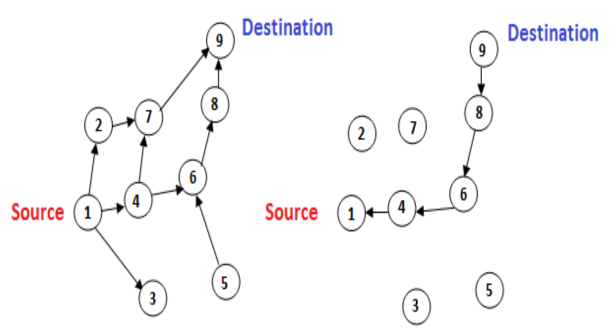


Figure (2.11) AODV route discovery

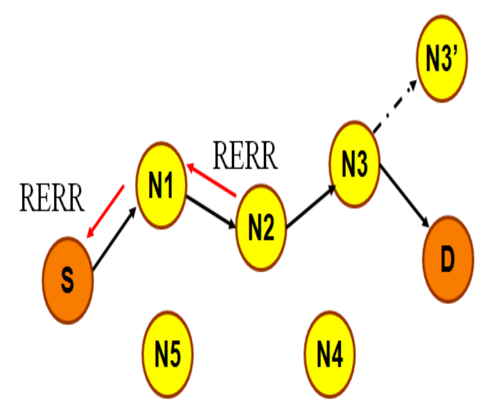


Figure (2.12) AODV route maintenance process

The route maintenance process in AODV is very simple as shown in Fig. (2.12). When the link in the communication path between node S (source node) and node D (Destination node) breaks the upstream node that is affected by the break, in this case, node N2 generates and broadcasts a RERR (Route Error) message. The RERR message eventually ends up in source node S. After receiving the RERR message, node S will generate a new RREQ message. Table (2.3) shows a comparison between two popular proactive routing protocols DSDV and OLSR.

2.7.1.2.2 Multipath Routing

Multipath routing is the process of distributing the data from the source node to the destination node over multiple paths. Multipath algorithms permit traffic multiplexing over multiple paths. Multipath Routing performs better by proper usage of network resources. Multipath routing protocols provide better throughput and reliability than single path protocols. The main goals of multipath routing protocols are to maintain reliable communication, to reduce routing overhead by use of secondary paths, to ensure load balancing, to improve quality of service, and to avoid the additional route discovery overhead [13]. There are several MANET routing protocols, that support multipath techniques such as Temporally Ordered Routing Algorithm (TORA), Ad hoc On-demand Multipath Distance Vector (AOMDV), Caching and Multipath (CHAMP), and Multipath Dynamic Source Routing (MDSR).

Table (2.3): Comparison between proactive protocols DSDV and OLSR

Protocol Properties	**DSDV** Destination Sequenced Distance Vector	**OLSR** Optimized Link State Routing protocol
Proactive type	**Distance Vector**	**Link State- unicast**
Base algorithm	– Bellman-Ford algorithm	– Multipoint Relays (MPRs)
Advantages	– Suitable for dynamic networks. – Less delay in the route setup because of the availability of routes to all destinations at all times. – Maintains only the best path so the amount of space in the routing table is reduced. – Avoid the traffic with incremental updates.	– Does not need a central administrative system to handle its routing process. – Well suited for applications such as (video/audio) which does not allow long delays in the transmission of data packets. – Less end-to-end delay.
Disadvantages	– Heavy control overhead because of the updates due to broken links. – Not suitable for highly dynamic networks. – Inefficient due to the requirement of periodic update transmissions. – To continue an up-to-date view of the network topology at all the nodes, the updates are propagated throughout the network.	– Needs more time to re-discover the broken links. – Requires more power when discovering alternative routes. – Not feasible for highly dynamic networks because of the significant state propagation overhead when the network topology changes. – Consumes more power due to HELLO and TC messages.
	– Does not support multipath routing.	– Wider delay distribution. – Requires for each node to

Limitations		– Difficult to determine a time delay for the advertisement of routes. – Difficult to maintain the routing table's advertisement for larger networks. – The route is decided through the sequence number.	periodically send the updated topology information throughout the entire network, this increases the protocol's bandwidth usage. – Does not support security and QoS. – With unnecessary HELLO and TC control messages, the power consumed will drain the battery life.
Enhanced versions (Extensions)		– Research work to improvements of DSDV is still active. – Many improved protocols based on DSDV have been developed. – These improvements of DSDV include Global State Routing (GSR), Fisheye State Routing (FSR), and (AODV).	– HOLSR and EE-OLSR are proposed based on OLSR with hierarchical architecture and Energy Efficiency. – QOLSR (Support quality of service). – Geo-OLSR (support geographical location information service). – M-OLSR (multipath OLSR), and HOLSR (hierarchical OLSR).
Performance Metrics and QoS Parameters	**Throughpu t**	– Very low when compared to DSR, OLSR, and AODV.	– High when compared with other link-state protocols [43].
	Packet Dropped	– – High.	– Packet loss rate is less because most of the packets sent and received are among the MPR nodes.
	E2ED and jitter	– Low and remains constant as the number of nodes increases in the network.	– Average end to end delay and least compared to DSDV.
	PDR%	– Increases initially then low compared to OLSR.	– Higher packet delivery ratio compared to DSDV.
	Routing Overhead	– Very high for a slight increase in the number of nodes.	– Medium.
	Caching Overhead	– Medium.	– High.

Temporally Ordered Routing Algorithm (TORA) [44] is a source-initiated on-demand routing protocol, which uses a link reversal algorithm and provides loop-free multipath routes to a destination node. In TORA, each node maintains its one-hop local topology information and also has the capability to detect partitions. TORA is proposed to operate in a highly dynamic mobile networking environment. The key design concept of TORA is the location of control messages sent to a very small set of nodes near the occurrence of a topological change. The protocol performs three basic functions:

(1) ***Route creation***: During the route creation phase, the nodes use a height metric, which establishes a Direct Acyclic Graph (DAG) rooted at the destination. Therefore, links are assigned a direction (upstream or downstream) based on the relative height metric of neighboring nodes, as shown in Fig.(2.13).The process for establishing a DAG is similar to the query/reply process in lightweight mobile routing.

(2) ***Route maintenance***: In times of node mobility, the DAG route is broken, and then route maintenance is necessary to reestablish a DAG rooted at the same destination. Timing is an important factor for TORA because the height metric depends on the logical time of link failure. TORA assumes all nodes have synchronized clocks.

(3) ***Route erasure***. In TORA, there is a potential for oscillations to occur, especially when multiple sets of coordinating nodes are concurrently detecting partitions, erasing routes, and building new routes based on each other. Because TORA uses inter nodal coordination, its instability problem is similar to the “count-to-infinity” problem.

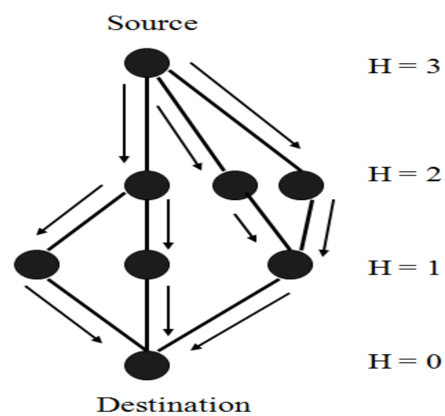


Figure (2.13) TORA routing scheme

2.7.1.2.3 QoS - Reactive Routing Protocols

In any given network, there are two types of flows in general: BE (Best Effort) flows which require the data to be reliably delivered to the destination, and QoS flows such as RT (Real-Time) which apart from reliability, require some additional constraints such as available bandwidth, delay, etc. to be satisfied [45]. Reusing BE routing methods for QoS-aware routing is not feasible since BE routing performs these tasks based on a single measure, usually hop-count while QoS-aware routing, however, must take into account multiple QoS measures and requirements. This section discusses different QoS-aware routing in MANETs from different perspectives including its challenges, classifications, algorithms and comparisons.

Ad hoc QoS On-demand Routing (AQOR): is a resource reservation and signaling algorithm proposed by (Xue and Ganz 2003) [46]. AQOR is a reactive QoS source initiated and hop-by-hop routing protocol that guarantees the smallest end-to-end delay and bandwidth in MANETs [47]. It uses limited flooding to discover the best route available in terms of smallest end-to-end delay with bandwidth guarantee. It is built upon AODV routing and performs exploration of routes only when required. The route discovery mechanism is in on-demand mode, broadcasting the RREQ and RREP packets between the source and destination nodes. The neighboring nodes that satisfy the requirement add a route entry to the source node's routing table and forward the RREQ until it reaches the destination. When the RREQ reaches the destination node, an RREP is sent back along the reverse route, reserving bandwidth at each node. Once the source node receives the RREP, it starts sending data out along the reserved route. AQOR uses timers to detect route breaks and to trigger route recovery. If any node fails to receive a data packet before its reservation expires, a route recovery mechanism is triggered. AQOR uses routing tables for keeping track of its routes. Every time a route failure occurs, AQOR must update its routing table entries, which may sometimes result in inconsistent entries due to the highly dynamic nature of the network topology. To avoid possible loops during route exploration, AQOR uses a route sequence number to indicate the freshness of the control packets for each follow. Table (2.4) shows a comparison between three types of Reactive Routing Protocols: AODV, TORA and AQOR.

2.7.1.3 Hybrid Routing Protocols:

This type is a combination of reactive and proactive routing protocols, as well as a location-assisted routing protocol. These protocols have the advantage of both proactive and reactive routing protocols to balance the delay which is the disadvantage of table-driven protocols and control overhead (in terms of control packets). The main feature of Hybrid Routing Protocols is that the routing is proactive for short distances and reactive for long distances e.g. Zone Routing Protocol (ZRP), Landmark Routing (LANMAR), Hybrid ant colony Optimization mobile ad hoc Network (HOPNET), and Distributed Dynamic Routing (DDR).

2.7.1.3.1 Zone Routing Protocol (ZRP)

As seen before, proactive routing uses excess bandwidth to maintain routing information, while reactive routing involves long route request delays. Reactive routing also inefficiently floods the entire network for route determination [48]. ZRP divides the entire network into overlapping zones of variable sizes where routing inside the zone is performed using a proactive approach and outside the zone is performed using a reactive approach [49]. ZRP provides a hierarchical architecture where each node has to maintain additional topological information, which requires extra memory.

Table (2.4): Comparison between reactive protocols AODV, TORA, and AQOR

Protocol	**AODV**	**TORA**	**AQOR**
Reactive type	**Unipath** (unicast)	**Multipath**	**QoS**
Advantages	– Reliable and offers quick adaptation to dynamic link conditions.	– Failure or removal of any of the nodes quickly resolved without source intervention by switching to an alternate route to improve congestion. – Supports unidirectional links and multiple routing paths.	– Traffic measurements and admission decisions are accurate and provide high channel utilization. – Provide QoS support in terms of bandwidth and end-to-end delay.
Disadvantages	– Routing table entries are purged (deleted) after a certain period of time even if any or some of the links are valid. – Does not discover a route until a flow is initiated.	– Same as on-demand routing protocols. – Not much used since DSR and AODV outperform TORA.	– Initiating a route discovery process each time a route break occurs can lead to high end-to-end delays.
Enhanced versions	– AOMDV (multicast), PAAODV(power-aware), and EAODV(Energy-aware).	– PDTORA.	– N/A.

Limitations		– Requirement on the broadcast medium. – Lacks support for high throughput routing metrics. – It is vulnerable to misuse. – Does not support multiple routing paths. – Large delay caused by the route discovery process.	– Not scalable by any means. – It assumes that all nodes have synchronized clocks. – Oscillations may occur when coordinating nodes currently executing the same operation.	– Every time a route failure occurs, routing table entries must be updated, which may sometimes result in inconsistent entries due to the highly dynamic nature of the network topology.
Base algorithm		– DSDV algorithm.	– Link reversal algorithm and the Directed Acyclic Graph (DAG).	– Resource reservation-based routing and signaling algorithm.
Performance Metrics and QoS parameters	**Throughput**	– Poor for more than 20 Mobiles.	– Better throughput.	– Based on bandwidth and delay only. – Bandwidth utilization: minimum bandwidth. – End to end delay: Maximum end-to-end delay.
	Packet dropped	– Minimum.	– Moderate.	
	Jitter and E2E- delay	– Initially high, but after some time it is very low. – As the number of nodes increases the delay increases.	– High compared to DSR.	
	Packet Delivery Ratio(PDR)	– High.	– High.	
	Routing Overhead	– Less traffic overhead, but high compared to DSDV.	– Low compared to DSR.	
	Caching Overhead	– Low.	– Medium.	

2.7.2 Hierarchical Routing

The idea behind hierarchical routing is to divide the hosts of the self-organized networks into several overlapping or disjointed clusters [50]. Hierarchical-Network is used when the size of the network inside a MANET increases tremendously [33]. Hierarchical routing protocols organize the network as a tree of clusters, where the roles and functions of nodes are different at various levels of the hierarchy. Routes are constructed according to the node's position in the virtual hierarchy [9]. Non-uniform hierarchical routing protocols can be further sorted into three subcategories: *zone-based*, *cluster-based*, and *core-based*. These protocols are categorized according to the organization of the mobile nodes, their respective management and their routing functions. Fig.(2.14) shows the subcategories of MANET hierarchical routing protocols.

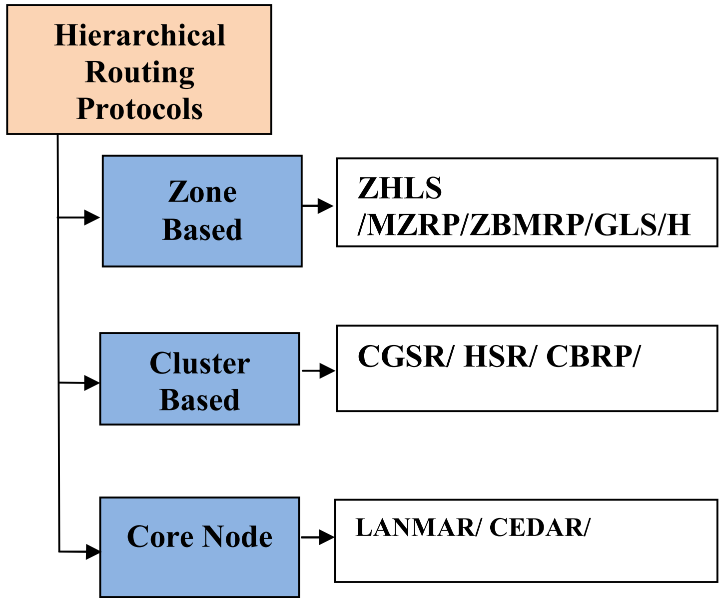


Figure (2.14) Hierarchical Routing Classification

2.7.2.1 Zone- based Routing

With zone-based hybrid routing algorithm techniques each node has a local scope and different routing strategies are used, inside and outside the scope, as communications pass across the overlapping scopes. Given this flexibility, a more efficient overall routing performance can be achieved. Compared to maintaining routing information for all nodes in the whole network, mobile nodes in the same zone know how to reach each other with a smaller cost. In some zone-based routing protocols, specific nodes act as gateway nodes and carry out inter-zone communication. Therefore, the network will contain partitions or several zones. Zone-Based Hierarchical Link State Routing (ZHLS) is a MANET zone-based hierarchical routing protocol [51].

ZHLS (Joa -Ng and Lu 1999) [52] is a zone-based hierarchical protocol that makes use of location information in a novel peer-to-peer hierarchical routing approach [50]. In ZHLS, the network is divided into non-overlapping clusters (zones) as in cellular networks [53] without any masters (zone-heads) as shown in Fig. (2.15).

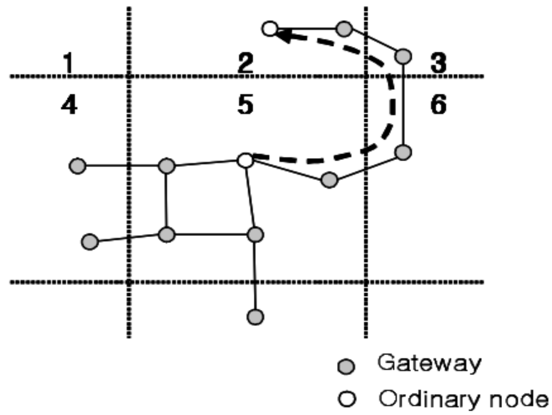


Figure (2.15) ZSLS routing (Zone 5 and 6 are connected but 2 and 5 are not) [54]

In ZHLS, mobile nodes are assumed to know their physical locations with assistance from a locating system like GPS. Each node has its own node ID and a zone ID, which is calculated by using GPS [16]. This topology is made of up to two levels: node level topology and zone level topology. Each node knows the node connectivity within its own zone and the zone connectivity information of the entire network. The link-state routing is performed by employing two levels: node level and global zone level. ZHLS does not have any cluster head in the network like other hierarchical routing protocols.

2.7.2.2 Cluster -based Routing

A cluster-based routing protocol is the most popular hierarchical routing technique. The process of dividing the network into interconnected substructures is called clustering and the interconnected substructures are called clusters. The cluster head (CH) of each cluster act as a coordinator within the substructure. Each CH acts as a temporary base station within its zone or cluster. It also communicates with other CHs [55]. Cluster-based routing provides an answer to address nodes heterogeneity and to limit the amount of routing information that propagates inside the network. A cluster-based routing protocol uses specific clustering algorithms for cluster head election. Mobile nodes are grouped into clusters and cluster heads take the responsibility for membership management and routing functions. Cluster-Head Gateway Switch Routing (CGSR) will be introduced in this section as an example of cluster-based mobile ad hoc network routing protocols. Some cluster-based MANET routing protocols potentially support a multilevel cluster structure, such as Hierarchical State Routing (HSR) [50].

CGSR [56] is a hierarchical routing protocol and clustering scheme that uses a distributed algorithm called the Least Cluster Change (LCC) [57]. CGSR extends DSDV with a cluster framework concept that increases protocol scalability and improves the performance of the routing protocol [58]. CGSR is a multi-channel routing protocol that is generally used in Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA)-based networks. They combine channel assignment and routing functionality. CGSR is a non-uniform hierarchical protocol, which is based on forming clusters among nodes and selecting a cluster head to control routing to outside the cluster area [59].

Selecting a cluster head is a very important task because frequently changing cluster heads will have an adverse effect on the resource allocation algorithms that depends on it. Thus cluster stability is of primary importance in this scheme. CGSR is an effective way to channel allocation within different clusters by enhancing spatial reuse. The explicit requirement of CGSR on the link layer and MAC scheme is as follows: (1) each cluster is defined with a unique CDMA code and hence each cluster is required to utilize spatial reuse of codes. (2) Within each cluster, TDMA is used with token passing. Gateway nodes are defined as those nodes which are members of more than one cluster and therefore need to be communicating using different CDMA codes based on their respective cluster heads [60].

In CGSR, when forwarding a packet, a node firstly checks both its cluster member table and routing table and tries to find the nearest cluster-head along the routing path. As shown in Fig. (2.16), when sending a packet, the source (node 1) transmits the packet to its cluster-head (node 2). From the cluster-head node 2, the packet is sent to the gateway node (node 3) that is connected to this cluster-head and the next cluster-head (node 4) along the route to the destination (node 8). The gateway node (node 6) sends the packet to the next cluster-head (node 7), i.e. the destination cluster-head. The destination cluster-head (node 7) then transmits the packet to the destination (node 8).

2.7.2.3 Core Node -based Routing

In core node-based routing protocols, critical nodes are dynamically selected to compose a "backbone" for the network. The “backbone” nodes carry out special functions, such as the construction of routing paths and propagation of control/data packets. Optimized Link State Routing (OLSR) and Core Extraction Distributed Ad hoc Routing (CEDAR) protocols are typical core node-based MANET routing protocols [51].

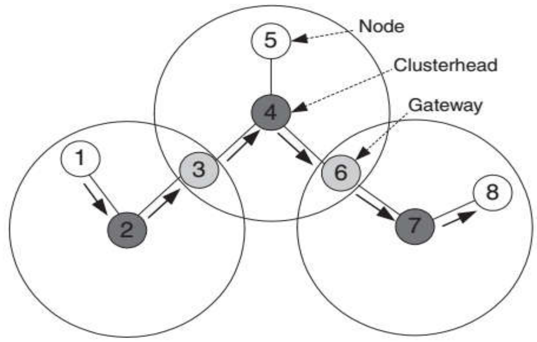


Figure (2.16) Cluster Structure in CGSR [56]

Landmark Ad Hoc Routing (LANMAR):

In the Fisheye State Routing protocol (FSR) (Pei et al 2000a) [61], every node in the network needs to maintain the whole network topology information. This strictly limits its scalability. The LANMAR (Pei et al 2000b) [62] is proposed as a modification of FSR and aims to gain better scalability. In contrast to FSR, LANMAR belongs to the non-uniform routing category of mobile ad hoc networks.

In LANMAR, mobile nodes are divided into predefined logical subnets according to their mobility patterns, i.e., all nodes in a subnet are prone to move as a group. A landmark node is pre-specified for every logic subset to keep track of the subnet. Using LANMAR; every mobile node has a hierarchical address that includes its subnet identifier. A node maintains the topology information of its neighbors and all landmark nodes, which represent logical subnets. Similar to FSR, neighboring nodes in LANMAR periodically exchange topology information and the distance vector of landmark nodes. When a source sends packets to the destination inside its neighboring scope (i.e., the source and the destination belong to the same subnet), desired routing information can be found from the source's routing table. Otherwise, the subnet identified in the destination node's address will be searched. Then, according to the distance vector, the packets will be routed towards the landmark node of the logical subset. Compared to FSR, LANMAR is more efficient because the need to exchange topology information is reduced substantially.

Table (2.4): Comparison of Hierarchical protocols ZHLS, CGSR and LANMAR

Protocol	**ZHLS**	**CGSR**	**LANMAR**
Hierarchical type	**Zone Based**	**Cluster Based**	**Core Node**
Advantages	– The network is geographically divided into non-overlapping zones – Assumes that each node has a location system such as GPS and the geographical information is well known. – Defines two levels of topologies node level and zone level. – Single point of failure and traffic bottlenecks can be avoided.	– Multi-channel routing protocol is generally used in TDMA or CDMA-based networks. – Non-uniform hierarchical protocol. – Forming clusters among nodes and selecting a cluster head to control routing outside the cluster area. – Uses a sequence number scheme to reduce stale routing table entries and gain loop-free routes. – Simpler addressing scheme.	– Distributive, adaptive, hierarchical routing. – Robust in rapid topological change. – Mobile nodes are divided into predefined logical subnets according to their mobility patterns. – Guarantees the shortest path from a source to a destination if the destination is located within the scope of the source.
Disadvantages	– Does not have any cluster head in the network like other hierarchical routing protocols. – All nodes must have a preprogrammed static zone map in order to function or in other words static zone map is required.	– Highly dynamic environment can adversely affect protocol performance. – Frequently changing cluster heads will have an adverse effect on the resource allocation algorithms that depends on it. – Since additional time is required to perform cluster head reselection, time to recover from link failure is higher than DSDV and WRP.	– Assumes that nodes are grouped into subsets according to their movement patterns and the membership of each subnet remains unchanged during the lifetime of the network, so it is only suitable for specific application scenarios. – Assumption of group mobility. Nodes may not have the best route to distant destinations.
Routing Table/Overhead	– Large communication overhead in the network, because all network nodes construct two routing tables, and intra-zone	– Reduces the size of the routing table as well as the size of routing update messages. – Since each node only maintains routes to its	– Reduces both routing table size and control overhead for large MANETs.

	routing table and an inter-zone routing table.	cluster head, routing overhead is lower compared to DSDV and WRP.	
Limitations	– Take time to search a new route when routes are disconnected because it searches only one route. In particular, the real-time application is severely-impacted by this delay.	– Both cluster members and routing tables need to be updated. – Uses DSDV as an underlying routing scheme.	– It is only suitable for specific mobile applications.
Base algorithm	– ZHLS algorithm.	– Clustering algorithm based on the lowest identifier or the highest connectivity. – Least Cluster Change (LCC).	– Scoped routing algorithm (e.g., FSR). – Binding algorithm.
Cluster structure	– No masters. – Multiple gateways between clusters.	– Single gateway.	– Group mobility is assumed so that the relative relationship among mobile nodes in a group doesn't change over time and it results in a natural clustering.
Scalability	– Support high scalability	– High scalability.	– Improves routing scalability for large MANETs with the assumption that nodes under a LANDMAR move in groups.

However, LANMAR assumes that nodes are grouped into subsets according to their movement patterns and the membership of each subnet remains unchanged during the lifetime of the network, so it is only suitable for specific application scenarios. Table (2.4) illustrates a comparison between three major Hierarchical protocols ZHLS, CGSR and LANMAR.

2.7.3 Geographic Position (Information Assisted)

Geographic routing (also called geo-routing or position-based routing) is a routing principle that relies on the geographic position information. Geographical routing protocols are topological independent, developed for large and distributed network operations. Generally, in traditional MANETs, the nodes are addressed only with their IP addresses [53]. But, in the case of location-aware routing mechanisms, the nodes are often aware of their exact physical locations in the three-dimensional world within the network. The proactive zones act as collectors of packets, which forward the packets efficiently to the destination, once the packets reach any node at the zone vicinity [53].

Fig (2.17) shows the basic subdivisions of the geographic position routing protocols. The Global Positioning System (GPSs), which are embedded in nodes, it is used to update information in tables in position-based algorithms. That makes position-based algorithms different from the table-driven and on-demand algorithms [63].This type of protocol is mainly proposed for mobile wireless networks and based on the idea that the source sends a message to the geographic location of the destination instead of using the network address. Geographic routing is a technique to deliver a message to a node in a network over multiple hops by means of position information [31]. Nodes use broadcast to know the location of one-hop neighbors. Due to this, position-based routing requires minimal routing overhead and also avoids delay and latency due to localized forwarding.

Routing decisions are not based on network addresses and routing tables; instead, messages are routed towards a destination location. Geographic Position Information assisted protocols are used to eliminate the limitations of topology-based routing by using additional information. It gives better performance in dynamic topologies because packets are forwarded to the destination with respect to its position.

Each node determines its own position and for determining the position of the network node the different positioning schemes are used such as GPS, GPRS etc. Location-aware routing does not require route establishment and maintenance. No routing information is stored. Typically, a node selects the next hop for packet forwarding by using the physical position of its one-hop neighbors and the physical position of the destination node; positioning information of the networks' nodes are usually obtained via queries offered through some location service [58].

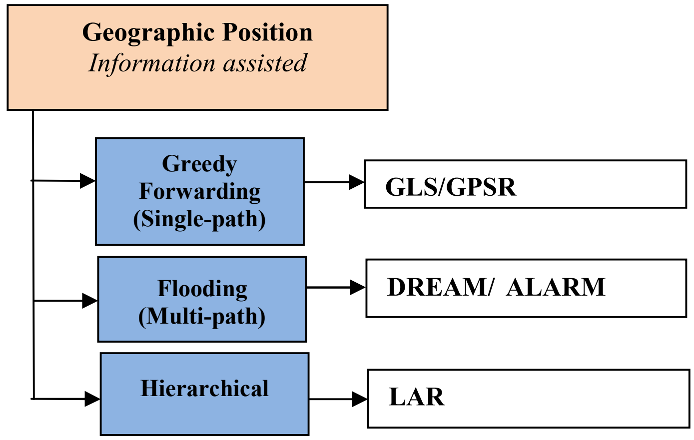


Figure (2.17) Geographic Position Routing Classification

Fig (2.17) shows the different categories of the location aware or geographical position routing technique. Generally this type is subdivided into three main approaches with respect to path strategy and packet forwarding : greedy (single-path), flooding (multi-path) and hierarchical [64, 65]. In the next section we will discuss and explain each category aided with examples of protocols such as Greedy Perimeter Stateless Routing (GPSR), Distance Routing Effect Algorithm for Mobility (DREAM) and Location Aided Routing (LAR).

2.7.3.1 Greedy Forwarding (Single-path)

The shortest path route is an example of a single-path strategy, where one copy of the message is in the network at any time. Most single-path strategies rely on two techniques: greedy forwarding and face routing. Greedy forwarding tries to bring the message closer to the destination in each step using only local information. Greedy forwarding is used when the message is able to advance from source towards the destination (Fig. 2.18-a). It does not imply route establishment or maintenance and the next hop [65].

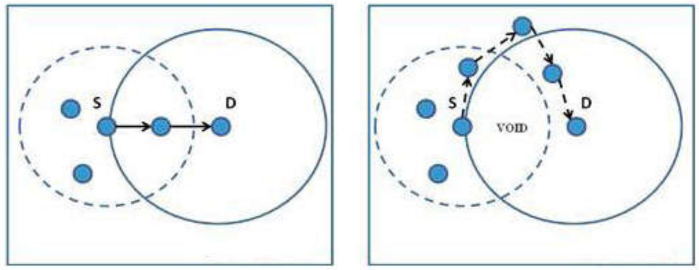


Figure (2.18) (a) Greedy (b) Greedy Failure at node S Forwarding

Thus, each node forwards the message to the neighbor that is most suitable from a local point of view. The most suitable neighbor can be the one who minimizes the distance to the destination in each step (Greedy). The decision is made according to the optimization criteria of the algorithm and does not guarantee that a packet reaches its destination. Metrics can be hop count, geographic distance, progress to destination, direction, power, cost, delay, a combination of these, etc. If the message has reached a node which has no closer neighbors to the destination (a void or hole), a recovery procedure is necessary (Fig. 2.18-b) making the forwarding method a hybrid. Recovery from such a concave node can be done through flooding or perimeter (face) forwarding.

Karp and Kung [66] proposed Greedy Perimeter Stateless Routing protocol (GPSR) routing protocol which uses the location of nodes to selectively forward the packets on the basis of distance. The packets are forwarded on a greedy basis by selecting the node closest to the destination. The best path was also calculated through a node which was farther in geometric distance from the destination. This process continues until the destination is reached. In some cases the best path may be through a node which is farther in distance from the destination node. In such scenario right hand rule is applied to forward around the obstacle and resume the greedy forwarding as soon as possible [67, 68].

2.7.3.2 Flooding-based (Multi-path)

In flooding-based approaches, messages are flooded through the whole network area or portion of the area. A simple flooding geo-cast algorithm works as follows: A node broadcasts a received packet to all neighbors as shown in Fig. (2.19) provided that this packet was not already received before in order to avoid loops and endless flooding. A node delivers a packet if the own location is within the specified destination region, which is included in each geo-cast packet. This is a simple and robust but not an efficient approach, since location information is not used for forwarding in order to reduce the number of packets [69].

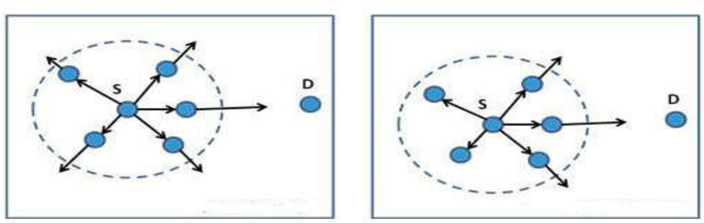


Figure (2.19) (a) Flooding (b) Restricted Flooding

Distance Routing Effect Algorithm for Mobility (DREAM) (Basing et al., 1998) [70] provides location service for position-based routing. In this framework, each node maintains a position database that stores position information about other nodes in the network. It can therefore be classified as an all-for-all approach, which means all nodes work as the location service providers, and each node contains all other nodes location information. An entry in the position database includes a node identifier, the direction and distance to the node, together with the time-stamp of entry creation. Each node regularly floods packets to update the position information maintained by the other nodes. Since the accuracy of the position information in the database depends on its age, a node can control the accuracy of its position information available to other nodes by adjusting the frequency of sending.

2.7.3.3 Hierarchical Approaches

The third forwarding strategy is to form a hierarchy in order to scale to a large number of mobile nodes. Some strategies combine the nodes location and hierarchical network structures by using the zone based routing. Others use the dominating set routing. Some others present a two level hierarchy within them; if the destination is close to the sender (in number of hops), packets will be routed based on a proactive distance vector. Greedy routing is used in long distance routing [67].

In [71, 72] , a **Location Aided Routing (LAR)** is presented which utilizes location information to minimize the search space for route discovery towards the destination node [67]. LAR is a reactive unicast routing protocol which is based on DSR. LAR aims to reduce the routing overhead for the route discovery and it uses Global Positioning System (GPS) to obtain the location information of a node. LAR essentially describes how location information GPS can be used to reduce the routing overhead in an ad hoc network and ensure maximum connectivity. Location-Aided Routing is an example of restricted directional flooding routing protocols; however, partial flooding is used in LAR for path discovery purposes. Hence, LAR proposes the use of position information to enhance the route discovery phase of reactive Ad-Hoc routing approaches. Table (2.5) comprises between the three geographic position protocols GPSR, DREAM and LAR**.**

2.7.4 Power-Aware Routing Protocols

As MANETs lack of fixed infrastructure and mobile nodes in MANET are battery driven, in such environment energy efficiency is an important consideration to increase the network lifetime [73] .Since the nodes in MANETs are mobile, routing and power management become critical issue [74] .Several power aware routing schemes have been proposed for MANET networks as shown in Fig.(2.20). The main objective of power aware routing schemes is to minimize the power consumption and maximize the network lifetime. The network lifetime is defined up to the moment when a node runs out of its own battery power for the first time [75].This classification of protocols is based on the consumption of energy during transmission, i.e., energy required to transmit a signal is approximately proportional to dX, where d is distance and is the attenuation factor or path loss exponent, which depends on the transmission medium. When X=2, which is the optimal case, transmitting a signal half of the distance requires one fourth of the energy and if the node is in the middle, will spend another fourth of the energy for the second half. Thus data is transmitted with half of the energy than through direct transmission.

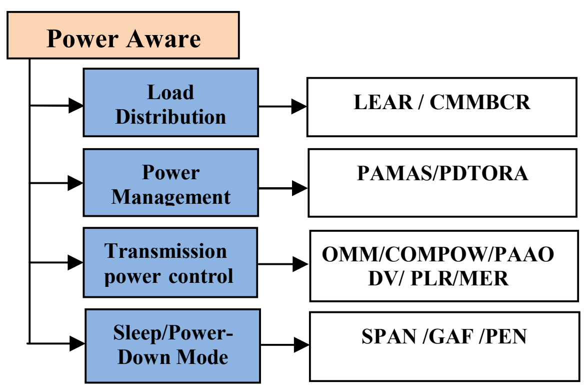


Figure (2.20) Power and Energy-aware subdivisions

2.7.4.1 Load Distribution

This approach is also based on active communication energy. The main goal of this approach is to balance the amount of energy usage among all mobile nodes and to maximize the lifetime of the network by avoiding over-utilized nodes when selecting a routing path. The protocol selects underutilized nodes rather than the shortest route. This may result in longer routes, but packets are routed only through energy-rich intermediate nodes. Protocols based on this approach do not only provide routes with the lowest energy, but prevent certain nodes from being overloaded, and thus increases the network lifetime. The most popular examples of this approach are Localized Energy-Aware Routing (LEAR), and Conditional Max-Min Battery Capacity Routing protocols (CMMBCR).

Table (2.5): Comparison between Geo-protocols GPSR, DREAM, and LAR

Protocol	**GPSR**	**DREAM**	**LAR**
Geographic Position Type	**Greedy Forwarding**	**Flooding**	**Hierarchical**
Advantages	– Guarantees a good PDR. – Especially in the high density of nodes. – Data forwarding overhead is low. – Increased efficiency when more nodes are added to the network. – Local maxima can be found easily.	– Packet loss is higher than GPSR. – No delay in routing discovery methods.	– Localized route discovery – Restricted directional flooding. – Reduces routing overhead. – Reduce the number of nodes to which the route request is propagated.
Disadvantages	– Impossible to find the optimal path. – Scalability occurs when increasing in-network diameter and mobility. – Delay increases at high mobility. – Generates a large number of control packets for high speeds.	– Requires GPS. – Flooding can influence the performance of the basic algorithm. – A recovery method is necessary when the destination node is not in the given direction.	– Based on source routing, flooding is used if no location information is available. – Low performance when various optimization techniques are not implemented like the alternative definition of request zone, another adaptation of request zone, and so on.
Energy consumption	– Low.	– High.	– High.
Routing metric	– Closest distance.	– Shortest Path.	– Shortest Path.
Packets Delivery Ratio (PDR)	– High.	– Low.	– Low.
Jitter and end to end delay	– Lower delay.	– Long delay	– Long delay
Routing/Communication Overhead	– High	– Minimizes routing overhead.	– Reduces overhead by limiting the search to requested zone only. – Reduces traffic, no need of HELLO messages.

The **Localized Energy-Aware Routing (LEAR)** protocol (Woo et al. 2001) [76] directly controls energy consumption. In particular, it achieves balanced energy consumption among all participating mobile nodes. The LEAR protocol is based on DSR, where the route discovery requires flooding of route-request messages. When a routing path is searched, each mobile node relies on local information of remaining battery level to decide whether or not to participate in the selection process of a routing path. An energy-hungry node can conserve its battery power by not forwarding data packets on behalf of others. Decision -making process in LEAR is distributed to all relevant nodes, and the destination node does not need to wait or block its order to find the most energy-efficient path.

Upon receiving a route -request message, each mobile node has the choice to determine whether or not to accept and forward the route -request message depending on its remaining battery power ***(E_r).*** When it is higher than a threshold value ***(Th_r)***, the route-request message is forwarded; otherwise, the message is dropped. The destination will receive a route-request message only when all intermediate nodes along the route have good battery levels. Thus, the first arriving message is considered to follow an energy-efficient as well as a reasonably short path.

2.7.4.2 Power Management

Power management technique is used to reduce the energy consumed in the MANET interface of battery-powered mobile devices. The design of best possible power management policies needs to explicitly account for the dissimilar performance requirements posed by different application scenarios such as latency, throughput and other performance metrics [77]. Power management techniques have been studied comprehensively in the context of CPU, memory and disk management in the past. The main idea is to switch devices to the low-power state in periods of inactivity. As compared with traditional techniques in operating systems, power management in communication devices requires distributed coordination between two (or multiple) communicating entities, as all the entities have to be in the active mode for successful communication.

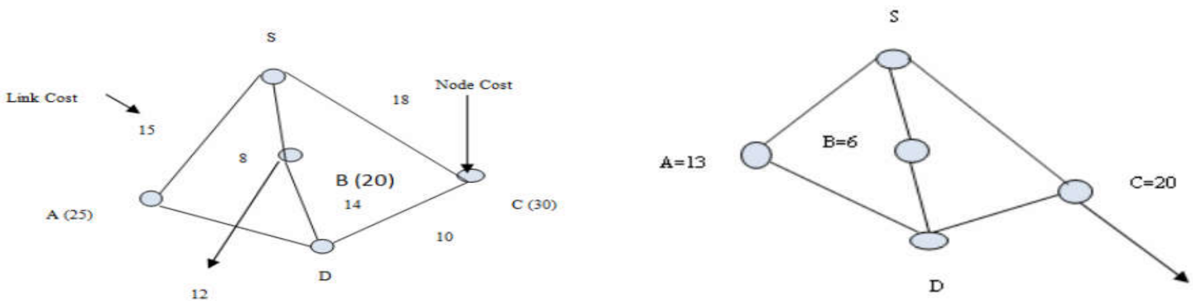
Power Aware Multi-Access (PAMAS) [78] routing protocol is an extension to the AODV protocol. It uses a routing cost model to discourage the use of nodes running low on battery power. The lifetime of the network is improved significantly. This routing protocol saves energy by turning off radios when the nodes are not in use. Although it was implemented on the

AODV protocol, the technique used is very standard and can be used with any on-demand protocol. The energy aware protocol works only in the routing layer. Advantage of PAMAS protocol is that this protocol saves 40-70% of battery power by intelligently turning off radios when they cannot transmit or cannot receive packets. This protocol tends to increase the throughput of the network as compared to other power aware routing protocols. One of the disadvantages of PAMAS protocol is a broadcasting problem. In this protocol, a broadcast may collide with another transmission at some receiver [73].

2.7.4.3 Transmission Power Control

Transmission power control approach can be achieved with the help of topology control of a MANET [23]. The transmission power determines the range over which the signal can be coherently received, and is therefore crucial in determining the performance of the network (throughput, delay, and power consumption) [24]. Power-aware routing protocols based on transmission power control finds the best route that minimizes the total transmission power between a source and destination. It is equivalent to a graph optimization problem, where each link is weighted with the link cost corresponding to the required transmission power. Finding the most power-efficient (min-power) route from source to destination is equivalent to finding the least cost path in the weighted graph. A routing algorithm essentially involves finding an optimal route on a given network graph where a vertex represents a mobile node and an edge represents a wireless link between two end nodes that are within each other's radio transmission range.

Online Max-Min Routing Protocol (OMM) is a power-aware routing protocol for MANET networks dispersed over large geographical areas to support applications where the message sequence is not known. This protocol uses two different metrics of the nodes in the network to optimize the lifetime of the network as well as the lifetime of individual nodes by maximizing the minimal residual power (max-min), which helps to prevent the occurrence of overloaded nodes, the other metric is minimizing power consumption (min-power). In most applications that involve MANETs, power management is a real challenge and can be done at two complementary levels (1) during communication and (2) during idle time. The OMM protocol maximizes the lifetime of the network without knowing the data generation rate in advance. The metrics developed showed that OMM had a good empirical competitive ratio to the optimal online algorithm that knows the message sequence and the max-min achieves over 80% of the optimal node lifetime for most instances and over 90% of the optimal node lifetime for many problem instances. OMM protocol uses Dijkstra's algorithm to find the optimal path between source-destination pairs. This min-power path consumes minimal power ($\boldsymbol{P}_{\mathbf{min}}$). In order to optimize the second metric, the OMM protocol obtains multiple near-optimal min-power paths that do not deviate much from the optimal value (i.e., less than $z\boldsymbol{P}_{\mathbf{min}}$ where $z \geq 1$) and selects the best path that optimizes the max-min metric. Fig.(2.21) shows an example of the algorithm for a given source and destination pair. In Fig.(2.21) - (a), S $\rightarrow B \rightarrow D$ is the min-power path as it consumes the minimal energy ($\boldsymbol{P}_{\mathbf{min}}$ =22) i.e. path cost is 22. If z = 2, alternative paths S$\rightarrow A \rightarrow D$ (path cost=27) and S $\rightarrow C \rightarrow D$ (path cost=28) can be considered since their path costs are within the tolerance range ($z\boldsymbol{P}_{\mathbf{min}}$ = 44) [79, 80].



(a) Min-power path (b) Max-min path

Figure (2.21) Min-power path and max-min path in the OMM protocol [44]

2.7.4.4 Sleep/Power-Down Mode

This approach is based on saving the energy during inactivity; when the node is idle. Nodes can save the energy during inactivity by switching into sleep/power-down mode when there is no data to transmit or receive. This leads to considerable energy savings, especially when the network environment is characterized with low duty cycle of communication activities. However, it requires a well-designed routing protocol to guarantee data delivery even if most of the nodes sleep and do not forward packets for other nodes.

SPAN protocol is a power saving mechanism that reduces power consumption of nodes by retaining the capacity and coordinating with the underlying MAC layer. SPAN protocol operates between the routing layer and the MAC layer [81]. SPAN coordinates the "stay-awake and sleep" cycle of the nodes and also performs multi-hop packet routing within the ad hoc network. Meanwhile, other nodes remain in the power saving mode and periodically check if they should remain awaken and become a coordinator. SPAN adaptively elects coordinators by allowing each node to use a random back-off delay to decide whether to become a coordinator in the network and rotates them in time. This technique not only preserves network connectivity, it also preserves capacity, decreases latency and provides significant energy saving. Other advantage of the SPAN protocol is that the master nodes play an important role in routing by providing a routing backbone and control traffic as well as reducing channel contention. The disadvantage of SPAN protocol is that the amount of power saving decreases slightly as density increases.

2.7.5 Multicast Routing Protocols

Multicast is the delivery of information to a group of destinations simultaneously, using the most efficient strategy to deliver the messages over each link of the network only once, creating copies only when the links to the destinations split. Multicast routing protocols for MANET use both multicast and unicast for data transmission [53].In recent years, a number of multicast protocols for ad hoc networks have been proposed. Based on the routing structure, they can broadly be classified into two categories: tree-based protocols and mesh-based protocols [82]. Fig. (2.22) illustrate the basic subdivisions of the multicast routing protocols.

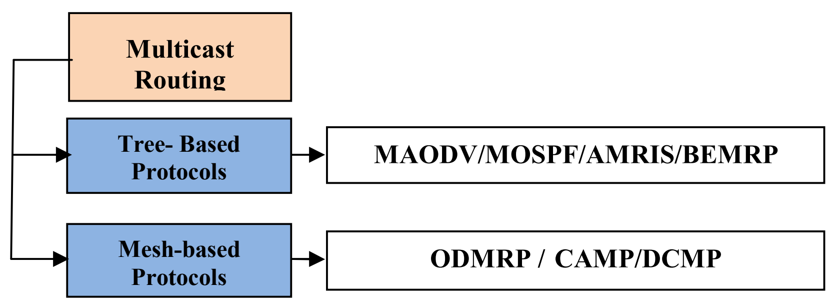


Figure (2.22) Multicast subdivisions based on the Network structure

2.7.5.1 Tree Based Multicast Routing Protocols

In tree-based protocols, there exists a single path between any sender-receiver pair. Tree-based protocols have the advantage of high multicast efficiency (which is defined as the ratio of the total number of data packets received by all receivers to the total number of data packets transmitted or retransmitted by senders or intermediate nodes). However, tree-based protocols are not robust against frequent topology changes and the packet delivery ratio (which is defined as the ratio of the number of data packets delivered to all receivers to the number of data packets supposed to be received by all receivers) drops at high mobility.

Multicast Ad Hoc On-Demand Distance Vector (MAODV) routing protocol was proposed by (Elizabeth Royer and Perkins) [83] witch discovers multicast routes on demand using a broadcast route-discovery mechanism. A mobile node originates a Route Request (RREQ) message when it wishes to join a multicast group, or when it has data to send to a multicast group but it does not have a route to that group. Only a member of the desired multicast group may respond to a join RREQ. If the RREQ is not a join request, any node with a fresh enough route (based on group sequence number) to the multicast group may respond. If an intermediate node receives a join RREQ for a multicast group of which it is not a member, or if it receives a RREQ and it does not have a route to that group, it rebroadcasts the RREQ to its neighbors. As the RREQ is broadcast across the network, nodes set up pointers to establish the reverse route in their route tables. A node receiving a RREQ first updates its route table to record the sequence number and the next hop information for the source node. This reverse route entry may later be used to relay a response back to the source.

For join RREQs, an additional entry is added to the multicast route table. This entry is not activated unless the route is selected to be part of the multicast tree. If a node receives a join RREQ for a multicast group, it may reply if it is a member for the multicast group's tree and its recorded sequence number for the multicast group is at least as great as that contained in the RREQ. The responding node updates its route and multicast route tables by placing the requesting node's next hop information in the tables, and then unicasts a Request Response (RREP) back to the source node. As nodes along the path to the source node receive the RREP, they add both a route table and a multicast route table entry for the node from which they received the RREP, thereby creating the forward path, as shown in Fig. (2.23).

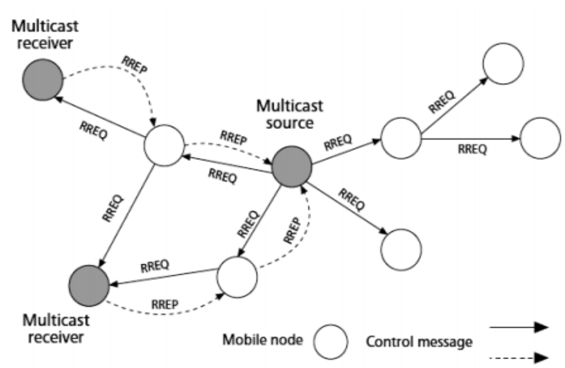


Figure (2.23) MOADV route discovery mechanism[84]

2.7.5.2 Mesh-based Protocols

Mesh-based protocols provide redundant routes for maintaining connectivity to group members. The low alleviated due to redundant routes. Mesh-based protocols are robust to node mobility. However, redundant routes cause low multicast efficiency.

On-demand Multicast Routing Protocol (ODMRP) [85] is mesh-based and uses a forwarding group concept (only a subset of nodes forwards the multicast packets). A soft-state approach is taken in ODMRP to maintain multicast group members. No explicit control message is required to leave the group. In ODMRP, group membership and multicast routes are established and updated by the source on demand. When a multicast source has packets to send, but no route to the multicast group, it broadcasts a Join-Query control packet to the entire network. This Join-Query packet is periodically broadcast to refresh the membership information and update routes.

When an intermediate node receives the Join-Query packet, it stores the source ID and the sequence number in its message cache to detect any potential duplicates. The routing table is updated with the appropriate node ID (i.e. backward learning) from which the message was received for the reverse path back to the source node. If the message is not a duplicate and the Time-To-Live (TTL) is greater than zero, it is rebroadcast. When the Join-Query packet reaches a multicast receiver, it creates and broadcasts a “Join Reply” to its neighbors. When a node receives a Join Reply, it checks if the next-hop node ID of one of the entries matches its own ID. If it does, the node realizes that it is on the path to the source and thus is part of the forwarding group and sets the FG_FLAG (Forwarding Group Flag). It then broadcasts its own Join Table built upon matched entries. The next-hop node ID field is filled by extracting information from its routing table. In this way, each forward group member propagates the Join Reply until it reaches the multicast source via the selected path (shortest). This whole process constructs (or updates) the routes from sources to receivers and builds a mesh of nodes, the forwarding group.

In Table (2.6) we show a novel comprehensive comparison between different MANET routing protocols. The comparison included examples of all the routing protocol types discussed in this chapter.

Table (2.6): Comparison between different MANETs routing approaches

Protocol	Structure /Route Computation	#Routes	Stored Information	Update Period	Update Information	Update Dest.
Flat Routing (Topology Based) ---- Reactive (On-Demand)						
AODV	Flat –reactive/ Broadcast query	Multiple	Next hops for desired dest.	Event-driven rm	Route-error	Source
TORA	Flat-Reactive/ broadcast QUERY	Multiple(DAG)	Neighbors' heights	Event-driven	Node's height	Neighbors
AQOR	Flat-reactive/ limited query	Multiple	Bandwidth and end to-end delay	Periodical	Bandwidth ,end to-end delay, signaling	Neighbors
DSR	Flat-Reactive/ broadcast QUERY	Multiple	Routes to desired Dest.	Event-driven RM	ROUTE-ERROR	Source
Flat routing (topology based) --- proactive (table driven)						
OLSR	Flat-proactive/ Distributed	Multiple	Mpr nodes, link load, delay, bandwidth	Periodical	Hello and tc messages	Neighbors
DSDV	Flat-Proactive/ distributed	Single	Distance vector	Hybrid	Distance vector	Neighbors
FSR	Flat-Proactive/ distributed	Single or multiple	Entire topology , closer nodes	Periodicals(dif. Freq.)	Link state of fisheye scope ,distant nodes	Neighbors
WRP	Flat-Proactive/ distributed	Single	Dist./routing/link-cost table, MRL	Hybrid	Dist. Vec., List of Resp.	Neighbors
GSR	Flat-Proactive/ distributed	Single or multiple	Entire topology	Periodical	All nodes link state	Neighbors
	Flat- Routing --- Hybrid routing Protocols					
ZRP	Flat-hybrid Proactive(intra)/reactive(inter)	Single or multiple	Local (within zone), topology	Periodical	Link state of nodes in the zone	Neighbors
ZHLS	Hierarchy-hybrid/ Proactive/reactive (hier. Addr.)	Multiple	Local(inter zone) , (intra zone) topology	Period./event-driven	Node/zone , link state	Zone/all Nodes
Hierarchical protocols						
CSGR	Hierarchy-cluster-Proactive/ distributed	Single	Cluster. Member. Table, Dist.Vec.	Periodical	Cluster. Member. Table, Dist.Vec.	Neigh.&Clus Head
LANMAR	Hierarchy-Core node	Single or multiple	Entire topology, dist.Vec. Of landmark nodes.	Periodical	Landmark distance vector, Next Hop Address, sender's LMDV	Next Hop /Destination
CEDAR	Hierarchy-Proactive/ core broadcast QUERY	Single	Core/other nodes: global/local	Period./Event-driven	Dynamic/stable Link state	Neigh./Core Nodes
Geographic Position (Information assisted) Routing Protocols						
GPSR	Geographic- greedy forwarding/	Single	Greedy mode(provides all nodes with their neighbors' positions)	Periodic beaconing	Perimeter mode (beacon to the broadcast mac address, ip, position.)	Greedily /neighbors

DREAM	Geographic-flooding / distributed	Multiple	Position info., about other nodes in the network	Periodical	Distances separating nodes	Dest., node, neighbor node.
LAR	Geographic-reactive	Multiple	Location of the destination, distance to define the requested zone.	Periodic update of beacons	Expected zone of the destination	Request zone
Power-Aware , Energy –Efficiency routing Protocols						
LEAR	Power-aware	Multiple	Battery Power (Er) and threshold value (Thr)	Periodical	Energy efficient, shortest path	Destination
PAMAS	Power-aware/ RTS-CTS message exchange	Multiple	Await Packet, Idle ,wait CTS,BEB	Periodical	CTS or Busy Tone	Neighbors
SPAN	Power-aware/ broadcast QUERY	Multiple	Routing backbone and control traffic	Periodical		Neighbors
OMM	Power-aware/ Min-power , and max-min	Multiple	Link cost, Node cost, tolerance range, graph optimization algorithm	Periodical	Zpmin , Pmin, link costs	Dest., Neighbors
Multicast routing protocols						
MAODV	Multicast	Multiple	Requesting node's ,next hop	Periodically	RREP , forward path	Next hop
ODMRP	Multicast	Multiple	Source ID ,sequence number in its message cache	Periodically	Group membership and multicast routes	Neighbors

2.8 Video Transmission Schemes over MANETs

There are many techniques proposed for video transmission over MANETs. These techniques focus on efficient transmission taking in consideration most challenges facing video communication via MANETs. Generally, we classified them into three main categories as shown in Fig.(2. 24) below.

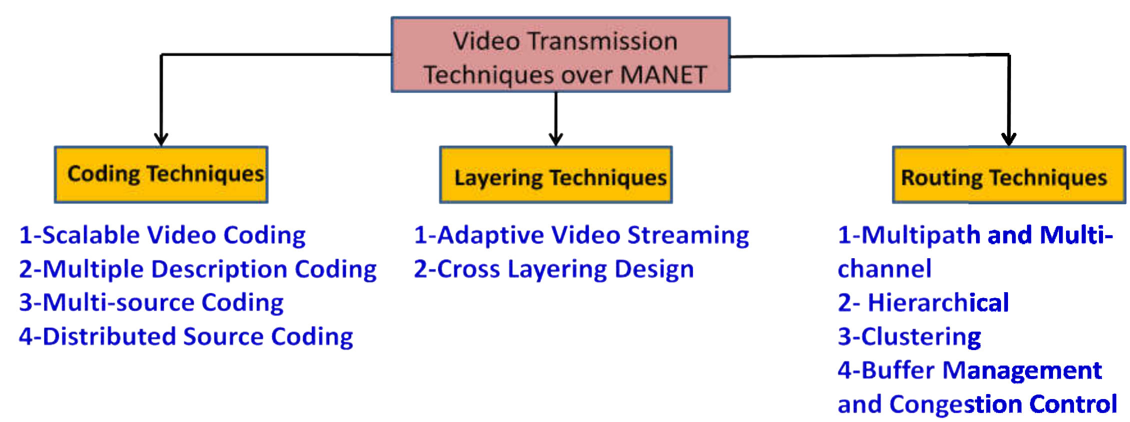


Figure (2.24) Classification and state-of-art of video transmission over MANET

2.8.1 Coding Techniques

Video streaming over mobile ad-hoc networks is becoming a highly important application for reliably delivering the content between the user and the content storage node. The key challenge is, hence, to address the impact of user mobility on the quality of the delivered video. Accordingly, the pioneering concept of Network Coding (NC) emerges as a promising approach for improving the video transmission quality mainly in a multicast mobile environment. The following coding techniques represent the different coding techniques used for efficient video transmission over MANETs.

2.8.1.1 Scalable Video Coding (SVC)

Scalable Video Coding (SVC) (Schwarz et al., 2007) [86], is an extension of H.264/MPEG-4 Advanced Video Coding (AVC). Is a video coding technology that encodes the video at the highest resolution, and allows the bit-stream to be adapted to provide various lower resolutions. This technique decomposes video into multiple layers of prioritized importance. In SVC layers are coded into base and enhancement bit-streams and progressively combine one or more bit-streams to produce different levels of video quality.

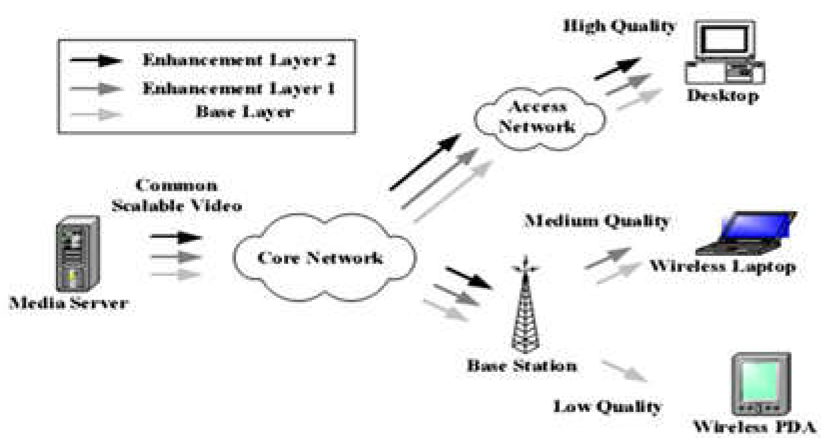


Figure (2.25) Scalable Video Coding (SVC) technique

Fig. (2. 25) shows a typical example of SVC with one base and two enhancement layers. It can produce three different qualities:

1. Base layer
2. Base + Enh1 layers
3. Base + Enh1 + Enh2 layers

This technique has the following advantages:

1. Adapting to different bandwidths or client resources such as spatial or temporal resolution or computational power.
2. Facilitates error-resilience by explicitly identifying the most important and less important bits.
3. Scalable encoded video data enables a decoder to decode selectively only a part of the coded bit stream.
4. The main idea behind the scalable video is to create a compressed bit-stream which can be used by different users according to their needs.

2.8.1.2 Multiple Description Coding (MDC)

Multiple Description Coding (MDC), has been proposed as a source coding technique that is robust to channel errors for video transmission. MDC has emerged as an alternative way to improve the performance of streaming video in both P2P streaming and over ad hoc networks. MDC encodes a media source into two or more sub-bit-streams. The sub-streams, also called descriptions have equal importance in the sense that each received description alone can guarantee a basic level of reconstruction quality and additional description can further improve the quality. MDC has the following characteristics and advantages:

1. The loss of one description does not influence other descriptions; a lost packet in any path does not need to be retransmitted.
2. MDC splits video streams into two or more versions or descriptions that are sent over multiple paths.
3. Each description can serve to reconstruct the video but if more than one description is received the quality can be enhanced by combining the descriptions.
4. MDC differs from layered video coding because in the latter the base layer must be received in order to reconstruct the video for display.
5. MDC provides graceful video quality degradation without the need for retransmission.
6. If packet loss or delay occurs on one of the paths then this can be compensated for by the encoded bit-stream from other paths.
7. MDC also may reduce the bandwidth requirement for anyone route through an ad hoc network, at a cost in increased coding redundancy.

2.8.1.3 Multi-Source Video Streaming (MSVS)

In MANETs, each node operates as an intermediate mobile node (forwarding data), regular data-consuming node, data-generating node (source node), and as a router. There are two major problems with multisource video streaming:

1- Multipath discovery, which finds multiple independent paths.

2- Rate allocation, which determines the sending rate for each source of the path.

The multi-source mobile video streaming client can obtain video data from multiple sources: remote video servers, local hotspot caches that pre-fetch video data, and neighboring devices.

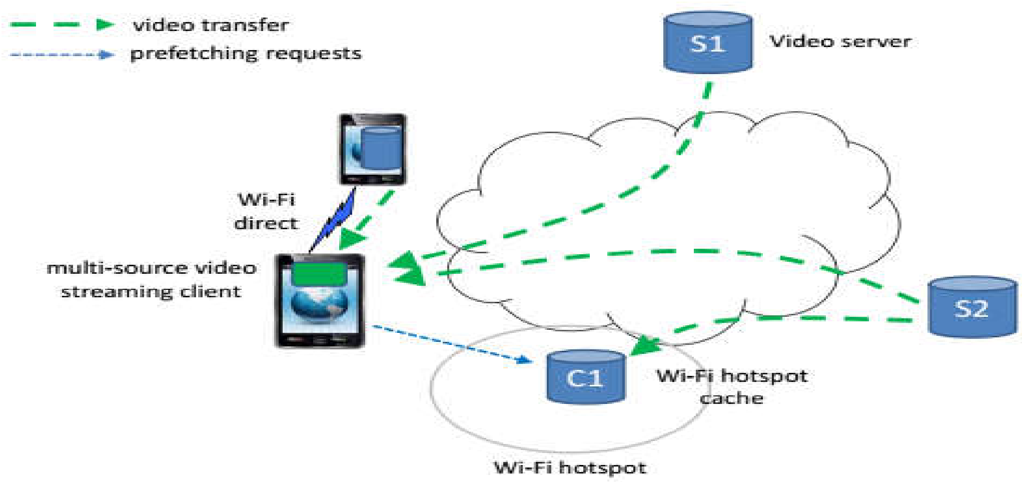


Figure (2.26) Multi-source Video Streaming technique

The multi-source mobile video streaming client as shown in Fig.(2.26) contains all the intelligence for downloading parts of a video file from multiple servers. In particular, the video streaming client implements the following three procedures:

- ***Load balancing***: the client measures the throughput that it receives from different video servers, and adjusts the number of video chunks that it requests from each server based on the measured throughput.
- ***Fault tolerance***: the client can detect when a server or the path from a server is down, and request video chunks from another available server.
- ***Enhanced offloading with pre-fetching***: the client exploits mobility and throughput prediction to send to local caches in hotspots that it will encounter requests to pre-fetch parts of the video so that they are immediately available when the mobile device connects to these hotspots.

2.8.1.4 Distributed Source Coding (DSC)

DSC is a new paradigm for video compression, based on Slepian , Wolf's ,and Wyner - Ziv's information-theoretic results. DSC allows a many-to-one video coding paradigm that effectively swaps encoder-decoder complexity with respect to conventional (one-to-many) video coding, thereby representing a fundamental conceptual shift in video processing [87, 88].

DSC enables low-complexity video encoding where the bulk of the computation is shifted to the decoder. Since the inter-frame dependence of the video sequence is exploited only at the decoder, an intra-frame encoder can be combined with an inter-frame decoder. The rate-distortion performance is superior to conventional intra-frame coding, but there is still a gap relative to conventional motion-compensated inter-frame coding. Wyner–Ziv coding is naturally robust against transmission errors and can be used for joint source-channel coding. A Wyner–Ziv MPEG encoder that protects the video waveform rather than the compressed bit stream achieves graceful degradation under deteriorating channel conditions without a layered signal representation. Fig.(2.27) shows the conceptual framework of DSC for a distributed compression of two statistically dependent random processes X and Y . The decoder jointly decodes X and Y and, thus, may exploit their mutual dependence.

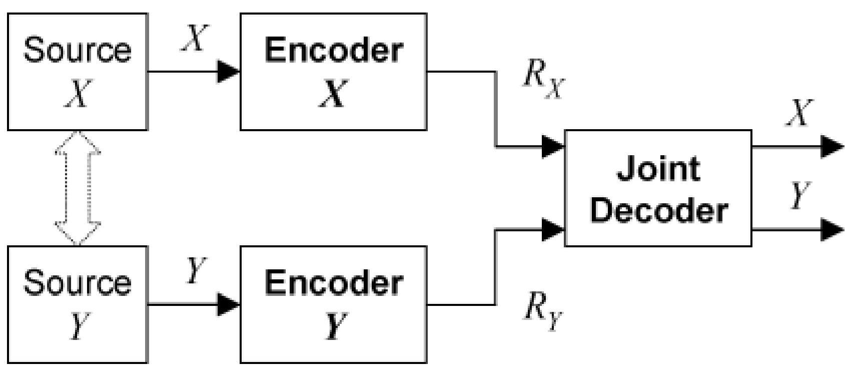


Figure (2.27) Multi-source Video Streaming technique

2.8.2 Layering Techniques

2.8.2.1 Adaptive Video Streaming

Adaptive bit-rate streaming is a technique used in streaming multimedia over a computer networks. As shown in Fig.(2.28) video is transmitted by means of maintaining a constant transmission rate and sending the information of all layers. Other scheme incorporates an adaptive model in which the source of traffic eliminates layers from SVC stream in order to adapt to the available bandwidth as .It works by detecting a user's bandwidth and CPU capacity in real time and adjusting the quality of a video stream accordingly. Trans-coding Stream Switching and splitting.

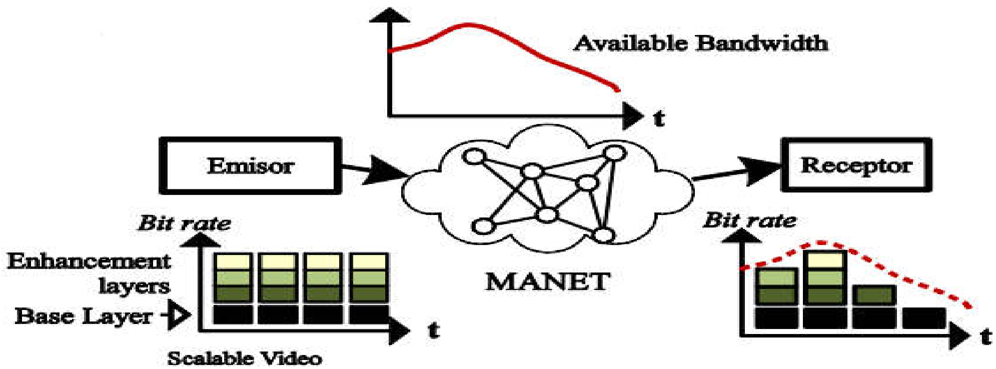


Figure (2.28) Adaptive Video Streaming in MANETs

2.8.2.2 Cross Layering Design (CLD)

CLD is a layered architecture, like the seven –layer OSI model that divides the overall operation of the network into layers and defines a hierarchy of services to be provided by the individual layers. In cross-layer architecture, layers exchange information and jointly optimize in order to improve the overall performance.

Cross-layer design (CLD) as in Fig.(2.29) exploits layer dependencies and therefore allows us to propagate required parameters throughout the protocol stack. It allows making better use of network resources by optimizing across the boundaries of traditional network layers. It is especially well suited to video streaming application over MANET where the characteristics vary over time. The following represents the main characteristics of CLD:

– Different CLDs focuses on different optimization purposes and different QoS metrics, which are delay, priority handling, resource constraint, etc.

– The CLD provide an individual solution for flow-control, admission control, link failure, routing overhead, power conservation, energy minimization, and congestion control.

– There is no complete and combined solution for the above issues for wireless multimedia applications.

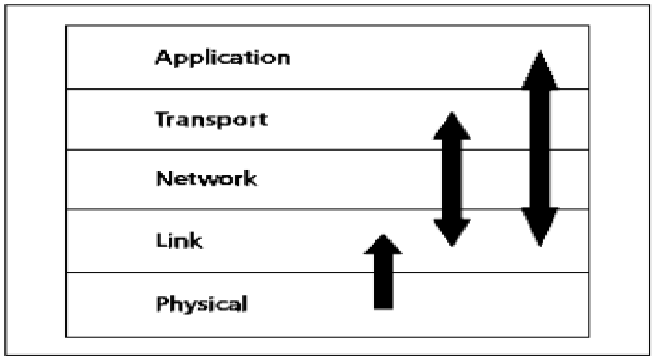


Figure (2.29) Cross-Layered Design

- **CLD advantages**

– Sharing the information between non -adjacent layers.
– Estimating the dynamic wireless conditions.
– Adapting to the network condition.
– Power efficiency and robustness to errors.
– Efficient network utilization.
– Multi-services support.

- **CLD limitations**

– Include security issues.
– Problems with non-conformant routers (misbehavior of network routers).
– Processing efficiency (additional costs of the routers' hardware associated with cross-layer information processing).

2.8.3 Routing Techniques

2.8.3.1 Multipath and Multi-channel

This techniques working by splitting up streams of multimedia into several sub-streams and sending these sub-streams along different paths from source to destination, and reassembling them again at the destination. This improves the quality of the received stream as compared to the single –description, single-path case.

Multipath routing can improves QoS by providing:

1. Accumulation of bandwidth and delay: breaking the capacity of more than one route.
2. Route load balancing: balances the traffic load in higher number of nodes.

3. Fault tolerance: by adding redundancy, to reduce the effect of network failures onto affected video quality.
4. Enhance error resilience during the transmission.

2.8.3.2 Hierarchical Routing

Bandwidth constraints and node mobility are portrayed as the major causes that prevent good quality of service and smooth video playback. Hierarchical routing means hierarchical arrangement of network nodes which may reduce packet interference as well as offer a structured architecture that reduces control traffic overhead. Particularly, the proposed hierarchical routing protocols aims at providing scalability when the number of nodes grows, while maintaining complexity as low as possible. The resulting reduction in packet losses and video playback interruptions finally enhances the quality of received video streams.

2.8.3.3 Cluster-Based Routing Protocols (CBRP)

CBRP proposed for real-time multimedia streaming in MANET networks to:

1. Improve the stability of cluster-heads, cluster formation, in consideration of the node mobility and connectivity.
2. Link-broken detection mechanism is designed, which is able to distinguish whether packet loss is due to mobility or congestion, and to make proper reaction.
3. Reduce route overhead, and to increase the decodable ratio of video frame at the application layer as well.
4. Quality of real-time multimedia streaming is improved significantly, in terms of decodable frame ratio, delay and delay jitter.

2.8.3.4 Multicast Routing Protocols (MRP’s):

Multicast communication improves the network performance in terms of bandwidth consumption, battery power and routing overhead as compared to unicast for same volume of data communication. Congestion control adaptive multicasting routing protocol are proposed to achieve load balancing and avoid congestion in MANETs. Multicast based group communication demands dynamic construction of efficient and reliable route for multimedia data communication during high node mobility, contention, routing and channel overhead.

2.8.3.5 Buffer Management and Congestion Control

- Congestion is a situation in communication networks in which too many packets are present in a part of the subnet.
- Congestion may occurs when the load on the network (number of packets send to the network) is greater than the capacity of the network (number of packets a network can handle).
- Congestion leads to long delay, more packet loss, bandwidth degradation, high network load and waste time and energy on congestion recovery.
- If many mobile nodes attempt to communicate at the same time, many collisions will occur which will lower the available bandwidth and possibly lead to congestive collapse.
- Congestion control is necessary in avoiding congestion and/or improving performance after congestion.
- Congestion control schemes are usually composed of three components: congestion detection, congestion feedback, and sending-rate control.
- Congestion control technique is the method by which the network bandwidth is distributed across multiple end to end connections.
- Congestion control means controlling the traffic.
- One of the techniques to control the congestion is through effective queue management.
- RTS/CTS (RTS request to send / Clear to send) are used for collision avoidance method.

2.9 MANETs Security Attacks and Vulnerabilities

MANETs is characterized as a multi-hop, self-configured, self-administration and infrastructure less network. Due to this nature, MANETs becomes vulnerable and are susceptible to different security attacks, which have a damageable effect on the overall performance of the network. These attacks can appear in different layers of MANETs protocol stack. Attacks in MANETs are often categorized based on the behavior of the attack i.e. **Passive** or **Active attack**. Because almost all currently known attacks are Active, except eavesdropping, such a classification is not useful. Attacks can be also classified as **external** or **internal** [89] A node “inside” the system must perform an attack that sends authenticated data, while an external attacker can perform a jamming attack. However, as this classification is more theoretical than real (e.g., an internal attacker can also perform a jamming attack, and an external attacker can execute an impersonation attack), we again conclude that the external versus internal classification does not provide considerably discriminative information about attacks. Fig. (2.30) show the security attacks classification in MANETs based on passive or active attacks and from then internal or external attack.

Passive attacks: In the case of passive attacks, the data transmitted within the network is not altered. But it involves unauthorized "listening" to the network traffic or accumulation of data from it. It does not disrupt the operation of a routing protocol but attempts to discover important information from the routed traffic.

Active attacks: Active attacks can be either internal or external, hindering the message flow between the nodes. Active external attacks are initiated by outside sources that do not belong to the network. Internal attacks are from malicious nodes that are a part of the network and are hard to detect when compared to the external attacks. These attacks

support unauthorized access in the network letting the attacker make changes such as modification of packets, DoS, congestion, etc [90].

External attacks: Are nodes that are not part of the network. In this case, the implementation of cryptographic mechanisms can solve the problem: only nodes with the necessary permissions can access the network or decrypt the content.

Internal attacks: Are nodes that are a legitimate part of the network. These nodes have the authorizations and cryptographic material necessary to belong to the network and other nodes make them a priori confidence.

Generally, we will focus on our study here in this section into the active part of the security attacks in MANET. More specifically we study the jamming attack as an external attack on the PHY layer from one side and from the other side we studying the impact of black hole attack at the network layer as an internal attack. Table (2.7) show the description of the most common attacks in MANETs ordered in the table according to the layers of MANETs protocol stack. The following are a detailed description of two attacks studied in our thesis in order to show their impact on the performance of the new configured SA-OLSR when under the attack and when under the normal traffic(without attack).

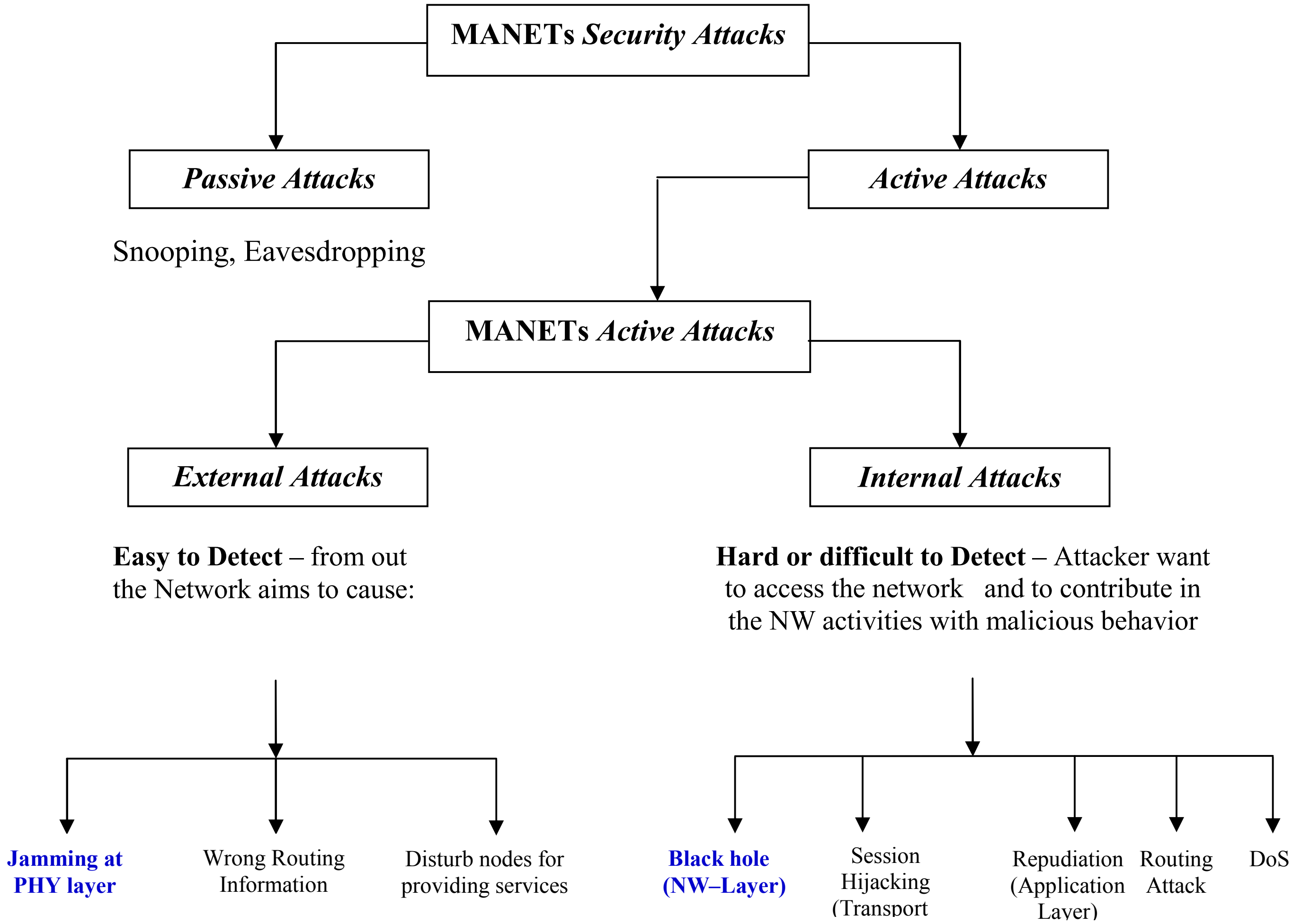


Figure (2.30) Classification of MANETs security attacks

Table (2.7): MANETs Security Attacks based on the protocol stack

Layer	Attack	Target	Description
Physical	Jamming	Availability	A particular class of DoS attacks. It is easily delivered by emitting continuous signal injecting dummy packets into the shared medium causing interference with existing communications or in some cases abusing the MAC (Medium Access Control) layer of other nodes within a range.
	Eaves-dropping	Privacy Confidentiality	The node simply observes the confidential information. This information can be later used by the malicious node. The secret information like location, public key, private key, password etc. can be fetched by eavesdropper.
Link/MAC	MAC misbehavior	Availability	Generate denial o f service
	Selfish	Availability	Malicious node doing a routing misbehavior in the route discovery packets of the routing protocol to advertise itself as having the shortest path to the node whose packets it wants to intercept.
Network	Black hole	Availability	Sending fake routing information that claims an optimum route to make other nodes relay data packets through the malicious node. In a second step, this node could drop or discard traffic.
	Wormhole	Availability	Two colluding attackers record packets at one location and replay them at another using a private high-speed link.
	Gray hole Attack	Confidentiality Availability Integrity	In the first one, the attacker drops the packets coming from some nodes but forwards all the other packets. In the second, the malicious node attacks the network for some time, and then behaves as a normal node for other period of time.
Transport	Session hijacking	Integrity Authorization Privacy	The malicious node hides its IP address and uses another IP address in the network.
Application	Malicious code	Availability	Viruses, Spywares, Worms
	Repudiation attack	Authentication Non-repudiation	Rejection of nodes partially or totally

(A) Jamming Attack

The jamming attack is an active and external attack on the PHY layer. Jamming attack it's a kind of DoS attack, the attacker jams the network by sending fake or dummy messages to the destination nodes as illustrated in Fig.(2.31). When the communication medium of the network is being jammed then the network resources became overwhelmed. In this way, the legitimate users are stopped from doing the useful work by either jamming the network or by flooding the network with messages. In this way, a part of the total network is not available to the legitimate users and it certainly affects the efficiency and performance of the network. Jamming attacks would reduce the performance of the network.

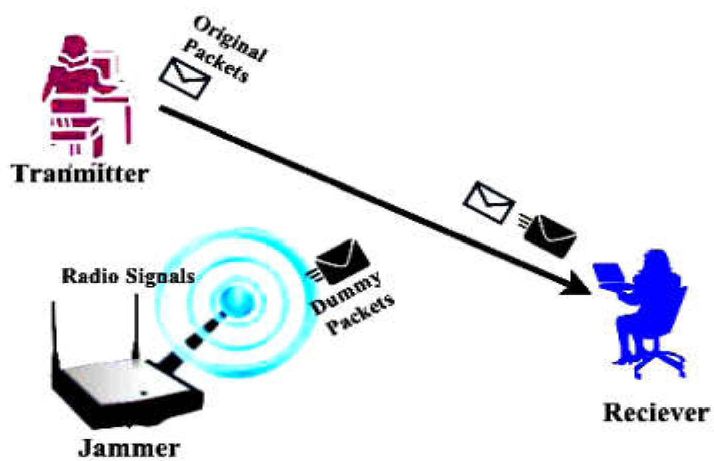


Figure (2.31) Jamming Attack Mechanism

MANETs do not have base stations or access points, and due to this nature, MANET networks are susceptible to jamming attack which is the most common attacks. Indirect jamming is an attack in which a compromised OLSR node is, by its actions, causing legitimate nodes to generate inordinate amounts of control traffic, thereby increasing both channel occupation and the overhead incurred in each node for processing this control traffic. This control traffic will be originated from legitimate nodes; thus, to the wider network, the malicious device may remain undetected. The general mechanism whereby a malicious node (jammer) can cause indirect jamming is for it to participate in the protocol by generating plausible control traffic and to tune this control traffic to in turn trigger receiving nodes to generate additional traffic.

(B) Black-hole attack

Black-hole attack is a very destructive packet drop attack in which the malicious node on receiving a RREQ packet replies with a fake RREP packet that contains small hop count and a destination sequence number, making the source believes that RREP packet sent by attacking node is genuine and that node really has the most optimal path to that particular destination even though that attacking node has no route to that destination. When the source node actually transmits a data packet through that black-hole node, the black-hole node drops that packet and does not forward it further.

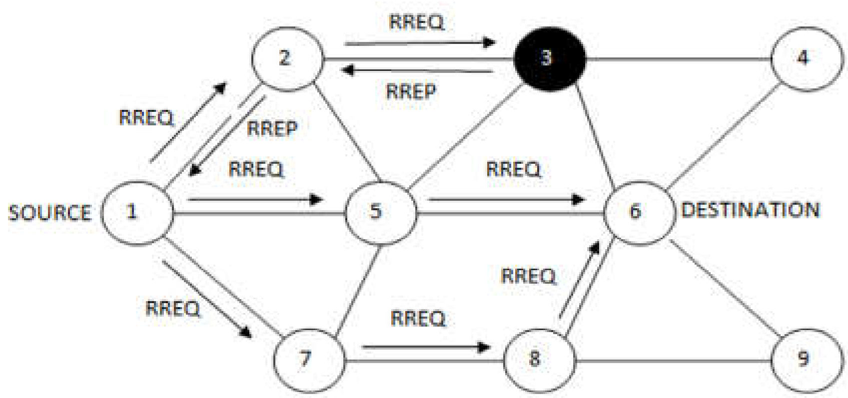


Figure (2.32) Node 3 acting as Black hole by sending fake RREP [91]

In Fig. (2.32), the scenario of a black-hole attack is illustrated. In the above illustration, node 3 is the attacking node, node 1 is the originator of the RREQ packet and it initiates a route discovery mechanism to establish a path to the destination node 6. Node 3, which is a black-hole node, on receiving the RREQ packet generates fake RREP packet with a relatively smaller hop count and a destination sequence number that is a little higher than the destination sequence number placed in the field of RREQ packet last known to the source. On receiving the RREP packet generated by node 3, the source node 1 gets assured that this path is the optimal one. But, when node 1, sends a data packet to the destination node 6, then node 3 on receiving the data packet drops it and does not forward it any further.

The black-hole attack drastically drops the packet delivery ratio and if no countermeasure is taken against this attack, it can almost shut down the communication in virtually any network. The true form of black-hole attack in which the malicious attacking node drops all the packets does not exist as it is quite easy to detect such form in which no packet is delivered or forwarded in some defined interval of time.

2.10 Robust Secure Routing Protocol for MANETs

Routing Protocols for mobile ad hoc networks suffer from the malicious action of the nodes in the network when sending the packet from source through intermediate nodes to destination, so the security in the network layer is the most important issues to countermeasure various types of attacks in MANETs. Many researchers investigate secure routing protocol to protect data communication and provide a more reliable route between nodes in the whole network.

These secure routing protocols are designed either as an extension to the existing routing protocol for MANET or a standalone to be applicable to some types of routing protocols. The main goal of security MANETs is to provide more security services, as possible, to prevent a large number of attacks that may launch to the network. This part of our research aims to investigate the adding of security services by using IPSec protocol to the existing unsecured OLSR protocol for MANET and analyze the efficiency of both secure and unsecured protocols on the overall performance of the ad hoc network. On the other hand, we investigate the modified or the fine-tuned OLSR which is called SA-OLSR after adding IPSec and PCF services on the network layer and PHY layer respectively and compare the results with/without the security attacks at network layers and PHY/MAC layer. The only attacks will be investigated are a black hole and jamming attacks.

2.10.1 IPSec Protocol

IP Security (IPSec) is a collection of protocols designed by the Internet Engineering Task Force (IETF) to provide security for a packet at the network level. IP Security can be an appropriate choice for the MANET network layer to protect both routing information and data message [92]. As a solution to the security of MANETs problems, the IPSec protocol is proposed. IPSec is a protocol suite that works on the Internet layer of the TCP/IP stack. Not only does it encrypt the packet data, but it can also encrypt the header information [93].

Although the use of IPSec is optional in IPv4, the usage of IPSec protocol is made mandatory in IPv6 whereby using 128-bit address in IPv6 enables easy deployment of the IPSec [94]. Through applying IPSec, communication endpoints are able to **authenticate**, **encrypt**, and check the **integrity** of messages using standardized and established IPv6 mechanisms. It has two modes of operation, namely the Transport mode and Tunnel mode. In transport mode, authentication and encryption only occur at the payload of the IP packet. Meanwhile, the tunnel mode provides authentication and encryption of the entire IP packet. It is an open standard protocol that contains several subsequent components. The Authentication Header (AH) provides data authentication and integrity for IP packets that are passed between two systems but does not provide data confidentiality (encryption) of packets. Whereas the Encapsulating Security Payload (ESP) is a security protocol that provides encryption of the IP packet where it authenticates the inner IP packet and ESP header. Security Associations (SA) provides the necessary data and algorithm for the AH and ESP operations. Fig,(2.33) below shows the AH and ESP in the Transport mode [89].

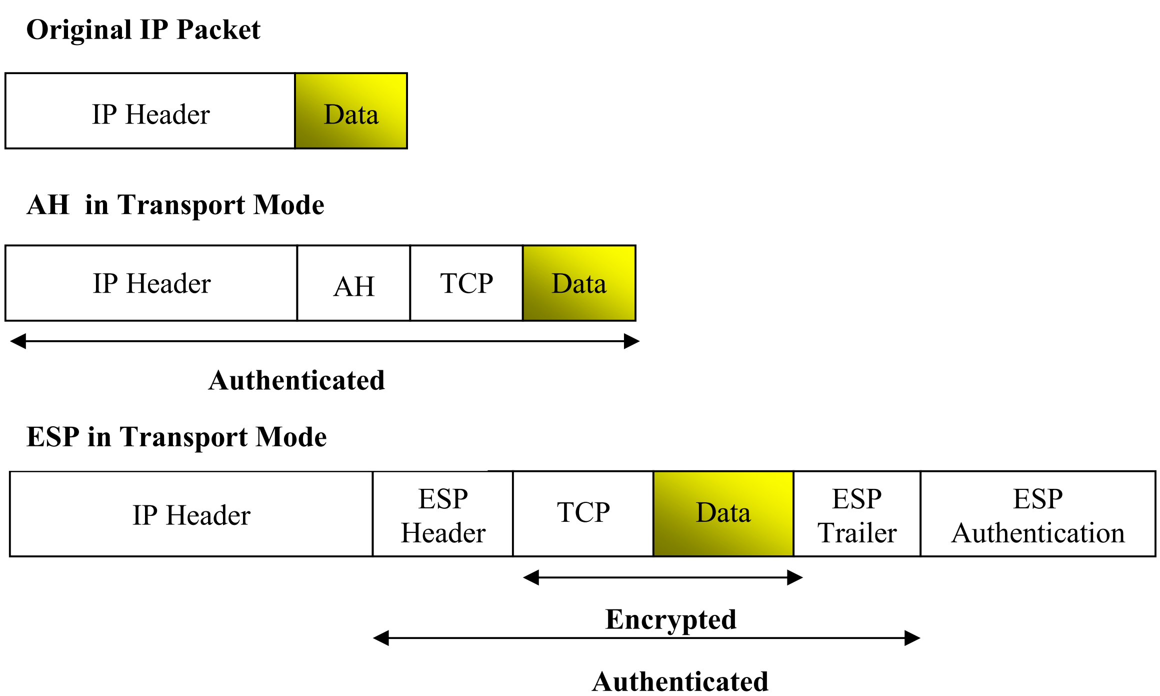


Figure (2.33) AH and ESP in Transport Mode for IPSec protocol

Since many ad hoc networks employed IP based routing, they should be protected and communication between nodes should be secured. We aim in this section in our thesis to investigate the performance of MANET with the application of IPSec protocol and to see the effectiveness of IPSec protocol in providing security when the MANET is under black hole and jamming attack. In our study, OPNET simulator is used to simulate a comparison of mobile nodes with and without IPSec, using Optimized Link State Routing (OLSR).

2.10.2 Point Coordination Function (PCF)

Distributed Coordination Function (DCF) and Point Coordination Function (PCF) are the two different Media Access Control (MAC) mechanisms which are specified by the IEEE 802.11 standard. DCF is the basic MAC mechanism whereas PCF is built on top of DCF and provides contention-free media access. PCF can achieve higher throughput than the contention based DCF due to the nature of contention-free, and PCF provide guaranteed service which is important for ***real-time*** applications and PCF could also be used for non real-time services which will be an attractive option for future wireless networks. In our simulation work we configured the MAC to use the PCF in order to achieved high performance which is desired for video conferencing.

2.11 Chapter Summary

This chapter has presented a comprehensive overview of MANETs. In the literature most of the authors classified MANETs routing protocols into: proactive, reactive and hybrid. However this classification is not covering other important routing mechanisms in MANETs such as Hierarchical Routing (HR), Geographical Routing (GR), Power Aware (PA) and Multicast Routing (MR). In this chapter, several existing routing protocols for MANET networks were described. One example for each category of routing strategy was discussed. In this survey we found that AODV, OLSR and TORA from the Flat–routing approach are powerful, highly adaptive, efficient and scalable distributed routing algorithms. These protocols are efficient and adaptable for different applications specifically real time applications such as video streaming and video conferencing. From the hierarchical approach have been found that ZHLS, LANMAR, and CGSR are highly scalable and on the other hand have least communication overhead, meaning that these protocols are capable for delay sensitive applications and also compatible for tactical scenarios where the nodes are spread out on a huge coverage area. Geographic routing protocols such as GRP, GPSR, DREAM, and LAR scale better for MANETs mainly for two reasons: 1) there is no necessity to keep routing tables up-to-date, and 2) no need to have a global view of the network topology and its changes. The power aware and multicast routing protocols provide low communication overhead and benefits in large scale MANETs and are feasible for some applications such as VANET, iMANET, FANETS , smart cities, and IoT.

Chapter Three

Literature Review and Related Works

3 Literature Review and Related Works

3.1 Introduction

Mobile ad hoc networks (MANETs) are characterized by infrastructure-less, dynamic topology, without any centralized administration, and limited resources which make more difficult streaming of multimedia applications over these networks. Providing an acceptable level of Quality of Service (QoS) for video streaming is an important challenge. In addition, supporting security protection or defense from most of the security attacks and at the same time prolongs the network lifetime by reducing the power consumption due to data communications is a challenging issue in MANETs. In this chapter, initially, many approaches or technique concerning video transmission over MANETs, and different routing techniques recently proposed for video streaming over MANET has been reviewed. In addition, five routing protocols (AODV, OLSR, DSR, TORA and GRP) have been proposed to study it in order to evaluate which of them can improve QoS for real-time multimedia applications.

3.2 Feasibility of Video Streaming over MANET

This section discusses the various kinds of literature that are reviewed during the whole research work concerning the feasibility of video streaming over MANET networks.

Shiwen Mao et al. (2003) in [95] to further verify the feasibility of video transport over ad hoc networks, they implemented an ad hoc multipath video streaming test-bed using four notebook computers. Their tests show that acceptable quality streaming video is achievable with both LC with ARQ and MDMC, in the range of video bit rate, background traffic, and motion speed examined. Together with simulation results using the Markov path model and the OPNET models, their studies demonstrate the viability of video transport over ad hoc networks using multipath transport and multi-stream coding.

Magnus E. H. *et al*. (2008) [96] they conclude that the most limiting factor of video streaming performance in MANETs appears to be the CPU of the client, so conservation of CPU time must be a priority when designing a streaming solution for MANETs. We also found that the bit rate of the video stream is the main parameter affecting the performance of all nodes in the path, and see that the MANET must be able to handle peak bandwidth requirements that are much higher than the video bit rate. On the client node, both resolution and encoding also have a large effect on resource consumption.

Martin Fleury *et al*. (2011) [85] they started from the fact that video streaming and multimedia applications in general have become an engine of growth in wireless networking. They discuss how video streaming can take place in this challenging environment. Their works in that paper focus on the feasibility of video streaming within a MANET and VANET. Error resilience and path diversity are presented as the key to robust streaming. Their study shows that simplified forms of multiple description coding are a practical route to take, with redundant frames in the temporal domain or Flexible Macroblock Ordering in the spatial domain can offering preferred solutions. They consider that exploitation of path diversity over a MANET and a VANET. Path diversity allows the merging of the peer-to-peer concept with ad hoc networks.

In [29] **Gokul Bhat, Janise McNair** (2014) they focuse on providing low end-to-end delay while streaming video with TCP as the transport layer. To that end, a random linear coding-based set of enhancements to TCP's flow control called ”Variable Bucket Size Network Coding (VBNC)” are proposed and the impact of those modifications across different routing protocols are studied for mobile ad-hoc networks (MANETs). The VBNC enhancements to TCP address the issue of TCP's agnostic flow control with respect to the arriving traffic at the source and also handle the conservative approach towards flow control. The proposed algorithm has been implemented in NS-3 and the system performance is compared from the perspective of congestion window evolution, video end-to-end delay and video goodput. Their evaluation shows that without significant changes in the network stack, their algorithm is compatible with the currently widely used OLSR and AODV routing protocols and offers almost a 100% improvement in video good-put over TCP New Reno.

3.3 Enhancement of QoS for Video Streaming over MANET

Several research works have addressed the enhancement of QoS of video transmission over MANETs and proposing different approaches to overcome most of the recent challenges facing the video transmission over MANETs effectively and efficiently. The following section reviewed the important studies in this domain.

V. Saritha and P. Venkata Krishna (2018) had been proposed a multipath routing protocol which is based on Quality of Service (QoS) parameters in their paper [83]. The QoS parameters considered are delay, bandwidth and hop count. They used different types of traffic such as real-time traffic and non-real-time traffic. In order to improve reliability by reducing the number of retransmissions, an additional packet is generated in the case of non-real-time traffic and multiple description coding is used in the case of real-time traffic. The proposed algorithm, MRQ was simulated using NS-2 and compared with the existing competing schemes – QAMR and RA-MDC. Simulation results proved that the performance of their scheme is better in terms of End-to-End delay, packet delivery ratio, Peak Signal Noise Ratio (PSNR) and retransmissions ratio metrics.

Asha and G . Mahadevan (2016) [97] in order to overcome the issue of the QoS in MANET they propose a cross-layer design technology to improve the overall performance of the Mobile Ad-Hoc Network. Their proposed cross-layer design optimized the video transmission rate, end-to-end delay and resource utilization for improved performance of MANET. Their proposed algorithm shows less interference by utilizing spectrum sensing and sharing method. Their simulation results showed that the proposed algorithm is an efficient method to improve the QoS in terms of overall throughput of the network.

Mahadev A. Gawas *et al*.(2016) [98] due to the fact that routing protocol is responsible for the successful packet delivery and QoS Support. The conventional single scalar routing protocols are not suitable for high traffic QoS sensitive multimedia traffic load on Mobile ad Hoc Networks (MANETs). They proposed a Cross-layer Multi-metric link disjoint Multipath Routing (CMMR) protocol based on distinct QoS constraints. They used in their work cross-layer communications to consider multiple-layer metrics like MAC queue utilization, node density degree, and mobility factor to achieve channel state awareness and keep the up to date status of the route in terms of QoS proficiency at each intermediate node. Their proposed algorithm is validated with an extensive simulation with high real-time traffic using NS-3. Their results showed significant improvement of CMMR in terms of packet delivery and end-to-end delay.

Ramakant Chandrakar *et al*.(2015) [99] their proposed work is about to provide effective video transmission in case of a congested network. Their simulation has been done for 50 nodes using NS-2.35 in an area of size 1000 m x 1000 m. The QoS performance metrics such as packet delivery ratio, end to end delay and throughput are evaluated against time for both

AODV and DSR routing protocols. They found through their simulation study that, DSR has the all-round performance better than AODV protocol and it is the ideal choice for communication to happen under UDP and TCP protocol. However, the packet delivery ratio in their work does not exceed 14% in case of AODV and approximately 47% in case of DSR, which is not acceptable for delay-sensitive applications such as video conferencing or video streaming. From this point of view, both AODV and DSR are not the best choice for transmitting real-time contents over MANET.

Sumitra Ranjan Sinha et al. (2015) [100] , Ad-hoc on-demand Distance Vector Multipath routing (AOMDV) protocol is used on Mac layer or network layer for frequent and constant streaming of audio, video and text type of data. This work proposes a new approach to data compression with (AOMDV) to enhance the QoS of the network. Simulations were carried out by NS2 and measure the effective minimization of end to end delay and improvement of throughput of the network and results were compared with existing techniques. Results clearly exhibit the performance of the proposed approach over the existing protocols.

N.Gomathi et al. (2012) [30] proposed a novel method for enhancing the QoS of multimedia applications in MANETs by using Multipath and Multi Description Coding. Their enhancement was achieved by implementing the Multi Description Coding (MDC) at application layer along with Connectionless Light Weight Protocol (UDPLite) in transport layer and multipath at network layer. The proposed approach has been examined using ns2 simulator. This approach achieves an increase of 12.75% in Peak Signal to Noise Ratio (PSNR) which is an improvement in PSNR as compared to the conventional methods.

N.Gomathi et al. (2011) in their paper [67] proposed a novel method for enhancing the Quality of Service (QoS) of multimedia applications in wireless ad-hoc networks. Their enhancement is achieved by implementing the Connectionless Light Weight Protocol (UDPLite) in transport layer that supports multimedia applications. In addition to implementing the transport layer protocol, parameters of MAC layer have also been considered to propose an approach that achieves a reduction in delay, jitter and increase in Peak Signal to Noise Ratio (PSNR). Their proposed method achieves 9% improvement in reduction of delay and 5% improvement in PSNR as compared to the conventional UDP Protocol.

Naveen Chilamkurti *et al.*(2010) [101] in this paper the authors proposed a cross-layer mapping algorithm to improve the video quality of H.264 video transmission over IEEE 802.11e wireless networks. They proposed a cross-layer approach involves exploiting information from both the Application layer and the MAC layer. Improved video quality is obtained by allowing the Application layer to pass its stream along with their requirements by using the hierarchical characteristics of video slices. They give priority to the most significant video packets to protect the most important video data in the presence of network congestion. During network congestion, less important video packets are dropped earlier than the most important video packets. Their proposed approach dynamically allocates different video packets to the most appropriate access categories in the IEEE 802.11e MAC layer. This adaptive mapping algorithm successfully enhances the video transmission quality. They demonstrate that they obtained much better performance with their proposed scheme compared to IEEE 802.11e EDCA (i.e., all video flows mapped to just one class of EDCA) using performance metrics such as PSNR, frame/slice loss, and the visual video quality. Their performance results demonstrate that their proposed scheme with cross-layer support and provides improves of video quality performance compared to the traditional EDCA approach.

VC Frías in his a PhD thesis (2010) [68] he developed a framework suitable to success in the issue of the provision of QoS to video-streaming services over MANETs. In addition, he developed a new routing protocol named MMDSR (Multipath Multimedia Dynamic Source Routing). It is a multipath routing extension of the well-known DSR (Dynamic Source Routing) protocol for MANETs. MMDSR is capable of maintaining more than one active path simultaneously between the source and destination nodes involved in a video-streaming session. It has been designed according to a cross-layer architecture which gathers information of the different levels of the stack protocols and takes the most proper configuration decisions to maximize the final performance. Special control packets have been designed to be sent periodically to monitor the status of the network. The objective is to be able to identify which are the most reliable and stable paths, which are going to be used for the multimedia transmission.

R. Pandian *et al*.(2006) [102] design and implement an enhanced AODV for transmitting video over MANETs. In their paper, an enhanced ad hoc on demand distance vector routing protocol(EAODV) was been suggested, which determines more stable routes by including the signal power received from all other neighboring nodes as an association stability factor along with the conventional route identifying parameters. The proposed routing protocol is implemented using network simulator NS-2 and its performance analysis has been carried out which shows better performance for various mobility models. Hence an enhancement has been suggested to AODV routing protocol, by adding Association Stability as metric in identifying a stable route. The enhanced routing algorithm based on stability of the route is found to perform well with increase in the number of video packets delivered which improves the quality of video. The packet delivery ratio is found to increase by 20% when compared to AODV at lower pause time and almost equals performance by 98% at low mobility with a lesser end-to-end delay.

3.4 Performance Evaluation of Video Transmission over MANETs

Many works have been done in the area of routing protocols in MANETs. Different protocols had been evaluated using a different kind of simulators such as NS-2, OPNET, OMNet++ and other simulation tools. The performance evaluation performed to investigate the feasibility, reliability and the quality of service (QoS). The following paragraph showed the state of art and most important studies done recently:

H. Redwan *et al*. (2018) in their research paper [103] they analysis the performance of four MANETs routing protocols (AODV, DSR , GRP , and OLSR) for UAVs communication based on scenarios with varying data rates supported IEEE 802.11p. Their simulation results shown that varying data rates has an impact in the delay performance of all protocols. In terms of load, AODV shown a least load followed by DSR and GRP while in terms of routing overhead OLSR has a highest routing overhead traffic followed by GRP and AODV. The lowest delay observed for OLSR followed by AODV and GRP. However their study and simulation works not considered the high mobility and scalability, they used mobility speed 20m/s and node density 50 nodes.

Hazzaa *et al*.(2017) [64] evaluated the performance of AODV for different traffics (FTP, Voice, Video Conference) in terms of delay , throughput , network load , retransmission attempts as QoS parameters for MANET network , and they used route discovery time , routing traffic received, routing traffic sent as QoS parameters for the AODV protocol. Their simulation works implemented in the environment of OPNET modular and show that there are significant differences between the three types of traffics .They conclude that the impact of traffic type on MANET depend on the QoS requirements for each type of traffics.

Kushwaha *et al*. (2016) [104] compared between three MNETs routing protocols DSDV, DSR and AODV for CBR traffic using OPNET simulator .They carried out from the simulation that in all three protocols, DSDV is showing better performance than AODV and DSR, however, in exponential traffic AODV has better performance than DSDV. In addition, after analyzing all three protocols it can be observed that there are optimal values of packet size and offered load for which value of throughput and PDR values are optimal, after that their values are decreased or become constant.

Ramakant *et al*.(2015) in their research paper [105] performed a simulation of three MANETs routing protocols AODV, DSR and DSDV on the basis of three performance parameters packet delivery ratio (PDR),end-to-end delay and throughput via using NS-2 simulator. Their observations from the simulation works show that DSR is better for small number of nodes but for large number of nodes, DSDV is superior. Also their study show that AODV is better throughput compared to other protocols DSR and DSDV. The main disadvantages of their works they don't mentioned the simulation duration time and data rate among coverage WLAN protocol IEEE802.11. However in that study the authors can use any hybrid routing protocol such as ZRP or DDR to comparing it with reactive and proactive routing protocols used in that study.

PN Sadigale *et al.* (2015) in their article [106] were studied and analysis the performance of two routing protocols PUMA and OLSR on the basis of various performance metrics like throughput, PDR, end to end delay and energy consumption for multicasting multimedia data content .They were found in their study that PUMA performs better in networks considering terms of packet delivery ratio, throughput and energy consumption parameters, OLSR gives better results for end to end delay and in overall performance PUMA is better used for multimedia streaming. One disadvantage of their works is the shortest simulation time. However OLSR can perform better after a long time.

Alqaysi *et al.* (2015) in their paper [3] analyzed and compared two MAN ETs routing protocols AODV and OLSR with transmitting video streaming application in terms of end-to-end average delay, load, retransmission attempts, and throughput using OPNET .They found that the proactive protocol OLSR is verified to be very efficient and effective routing protocol for MANETs for real-time data transmission such as video streaming or video conferencing. The main disadvantages of their simulation work are the fixed number of mobile nodes (60) which can't represent the real live scenario in this case.

Wardaku *et al.* (2014) in their research paper [107] ,they analyzed the performance of multimedia traffic in MANETs with various mobile subscriber speed by using CBR and Voice over IP (VoIP) connection using Qualnet 6.1 simulator in terms of throughput, end to end delay, and total data received. They concluded that the overall performance of routing protocol for CBR and VoIP at 0 to 10 mbps is better than CBR and VoIP at 0 to 20 mbps. The disadvantage of their study is they don't show at what data rate in the PHY/IEEE 802.11/n protocol they simulate the multimedia traffics.

Gagangeet. *et al.* (2013) in [108] demonstrated a comprehensive investigation of the MANETs routing protocols AODV, DSR, TORA, OLSR and GRP using OPNET 14.5 modular simulator. The performance evaluation done based on the quantitative metrics throughput, delay, load and data dropped. Their simulation shown that AODV is best suited protocol for video conferencing for lower number of nodes and OLSR is can be used as a replacement as its performance degrades for high number of nodes, and OLSR suits better for high number of nodes.

J. K. Joshi *et al*. in (2013) [109] analyzed ZRP, AODV, AOMDV and DDIFF MANETs routing protocols on the basis of average throughput, average end-to-end delay and packet delivery fraction to propose the most suitable protocol that will improve the quality of video streaming over MANETs .Their simulation works performed in NS-2 simulator and concluded that the overall performance of DDIFF and ZRP is better in term of packet delivery fraction as well as average end-to-end delay among other used protocols. While, in term of average throughput AODV and DDIFF has produced better results with compare to others. They found that DDIFF is comparatively better to providing quality in video streaming over different used routing protocols on MANETs.

Salman Nasser *et al.* (2012) in [69] were performed a performance comparison of MANETs routing protocols AODV, OLSR and TORA on real-time video traffic using OPNET simulation. In their study, they conclude that OLSR outperforms AODV and TORA routing protocols in terms of higher network load and minimal delay. End-to-end delay of AODV was 35% greater in comparison with protocol OLSR. The main disadvantage of their study is the form of network structure in the simulation model. They used server in the middle of the network and all other nodes where in the coverage area of the server. That structure is not really representing the idea of MANETs network. However the authors in their study they used an important metrics to evaluate the routing performance, but they don't mentioned the simulation time and mobility model used.

Muhammad Shaffatul Islam *et al.(*2012) in [110] another study on comparing MANETs routing protocols on video streaming was done .The authors they concluded that it is possible to launch video streaming with acceptable quality and throughput over MANETs. The simulation results in their study show that the performances of a routing protocol vary depending on the network scenario as well as types of video traffic used. They conclude that the overall performance of TORA is the best for all QoS parameters; also the performance of AODV is poor compared to OLSR and GRP but better than DSR. However their study doesn't mentioned a concrete conclusion for which protocol performed best among the set of the protocols under the study.

George Adam *et al.* (2011) in [111] evaluated and compared the performance of the most well-known routing protocols AODV, DSR and OLSR in terms of the performance metrics packet delivery ratio, end-to-end delay, packet delay variation (jitter) and the routing overhead for multimedia data transmission under NS-2 simulator environment. In their study the simulation show that DSR outperformed both AODV and OLSR, in terms of end-to-end delay and packet delay variation and seemed to be the most efficient in the simulated environment. The authors show that the low jitter delay and the adequate packet delivery ratio values suggested DSR as a serious proposal for multimedia data transmission in wireless ad hoc networks. However, in that study the researchers used most of the IETF quantitative metrics, but their study not mentioned the data rate used among coverage WLAN protocol IEEE802.11/g.

S. Baraković *et al.* (2010) in [112], they compared the performance of three MANETs routing protocols AODV, DSDV and OLSR on constant bit rate (CBR) traffic using NS-2 simulator in term of packet delivery ratio(PDR) ,end-to-end delay and normalized routing load. Their simulation results show that all three protocols react in a similar way in terms of end-to-end delay in low load scenarios, while with increasing load the protocol DSDV outperforms AODV and DSR routing protocols. The authors they don't mention at which data rate on the WLAN IEEE 802.11 protocol performed the simulation. However their study is limited because they used a constant number of mobile nodes which can not reflect the scalability effect.

Gupta *et al*. (2010) in their paper [113] evaluated the performance of three MANETs routing protocols AODV, DSR and TORA on the basis of tow performance metrics: average end-to-end delay and packet delivery ratio. They conclude that AODV outperformed DSR and TORA. Founded that AODV has minimum overhead that makes it suitable for low bandwidth and low power network and TORA is suitable for operation in large mobile networks having dense population of nodes.

Jamali *et al.*(2009) demonstrated in [65] a comparative analysis of the throughput percentages through using OPNET modular to set of protocols (AODV, DSR, OLSR, TORA, and GRP) for multimedia streaming under different environments and nodes density. The objective of their study is to observe the QoS performance of those protocols. The simulation show that the protocols OLSR and GRP perform better than the other routing protocols in all simulated cases particularly in the case of network with great size and the great number of nodes. However in their study they used a single performance metric (throughput) which is not quite enough to measure the performance of MANETs routing protocols under multimedia applications, there are important metrics such as end-to-end delay, routing overhead, delay variation, packet delivery ratio and etc… were not used. The main disadvantages of that study is that using a client/server architecture through choosing one node as (server) to streams videos to others nodes , which is not required in MANETs since the processing is decentralized and distributed and all the nodes in the network structure are acts as sender/receiver in the same time.

However from the previous works we can observe that there is a great attention with video transmission via MANETs in the last decades. Most of the latest studies used OPNET modular which is the popular and optimized simulator. The performance metrics that the authors were used in their studies is sufficient in most cases but in some cases the authors they used a little metrics. Two MANETs routing protocols (AODV and OLSR) only has a better performance among different routing protocols such as DSR, DSDV, TORA, FSR and GRP. Table (3.1) shows summery of the related works.

Table (3.1) Summery of related works of performance evaluations

Reference Publishing Date	Routing Protocols	Mobility Model/ Node Speed	Type of Application	Simulation Area in (m2) + No. of nodes	Coverage WLAN Protocol+ Data rate Mb/s	Performance metrics	Simulator + Simulation time (sec)
[103]-2018	AODV ,DSR,GRP ,OLSR	Random Waypoint	HTTP traffic	800x800 50 nodes	IEEE802.11p 4,5,9,18 and 27	Routing traffic Delay Load Throughput	OPNET 3600 sec
[64]- 2017	AODV	Random Waypoint	FTP, voice, Video-Conference	1000*1000 50 nodes	IEEE802.11 11	Retransmission Att. Route discovery time Routing traffic received Routing traffic sent	OPNET 3600 sec

[104]-2016	DSDV, DSR, AODV	Random Waypoint	CBR/UDP Video traffic	800x800 40 nodes	IEEE802.11b NM	— Throughput, — Packet Delivery Ratio (PDR)	OPNET 900 sec
[105]-2015	AODV, DSR, DSDV	RWP 5m/s,10m/s,20m/s	CBR Video Transmission	200, 400, 600, 800, 1000 100 to 500	IEEE802.11 NM	— Packet Delivery Ratio — End-to-End delay — Throughput	NS-2 NM
[106]-2015	OLSR,PUMA	Random Waypoint Model 0-100 m/s	Multimedia Data Content (MPEG4)	1000×1000 5,10,15,20,25	IEEE802.11 11	— Throughput — PDR — End to End delay — Energy consumption	NS-2 15 sec
[3]-2015	AODV, OLSR	Random Waypoint Model 5 m/s	Video application	1000×1000 60	IEEE802.11g 5.5	— End-to-end delay — Retransmission Attempts — Load — Throughput	OPNET 600sec
[107]-2014	AODV, OLSRv2, FSR	Random way point 0 to 20 m/s	CBR and VOIP	1500x1500 50 and 100	IEEE802.11n NM	— Throughput — End-to-end delay — Total data received	Qualnet 6.1 500 sec
[109]-2013	ZRP,AODV, AOMDV and DDIFF	Random way point	Video Streaming	1000x750 25 , 75	IEEE802.11 NM	— Throughput, — End-to-end delay — PDF	NS-2.35 100 sec
[108]-2013	AODV,DSR, TORA,OLSR and GRP	Random Waypoint	Video Conferencing (High resolution video) and e-mail (High load)	1000 x 1000 30, 60 and 90	IEEE802.11 11	— Throughput, — Delay — Load and — Data Dropped	OPNET 600 sec
[69]-2012	AODV,OLSR and TORA	NM	Video Conferencing	500x500 24 clients and one server	IEEE 802.11 11	— Throughput — End-to-end delay — Network Load	OPNET NM
[110]-2012	AODV,DSR, TORA,OLSR,GRP	5 m/s and 10m/s	Video Streaming	800x800 1600x1600 25,85	IEEE802.11a 54	— Throughput — End-to-end — Packet delay variation	OPNET 10
[111]-2011	AODV, DSR and OLSR	Manhattan city model 0 – 20 m/sec	Video Transmissions	500 x 500 50	IEEE802.11g NM	— Packet delivery ratio — End-to-end delay — (jitter) — Routing overhead	NS-2 900 sec
[112]-2010	AODV, DSDV and DSR	Random Waypoint 10 m/s , 20m/s .50m/s	CBR traffic with 20 kbps	500x500 50	IEEE 802.11 NM	— Packet delivery ratio — End-to-end delay — NR- load	NS-2 100 sec
[113]-2010	AODV, DSR and TORA	Random waypoint	CBR (UDP)	500 x 500 50	IEEE802.11g NM	— End-to-End delay — Packet delivery ratio	NS-2 200 sec
[65]-2009	AODV, DSR, OLSR, TORA ,GRP.	NM	Video Streaming	800x800 I600xl 600 25 and 81	IEEE802.11g 11 .54	— Throughput	OPNET NM

*NM: Not Mentioned

3.5 Efficient Routing Protocols for Transmitting Video over MANET

Providing and proposing MANETs routing protocols capable of transmitting video efficiently is an open research area and a wealth of literature exists in this area. **Jahir, Yasmin, et al (2019)** [108] the main objective and goal of an efficient MANETs routing protocols is to ensure reliable, energy efficient communication which is susceptible to mobility and topology changes in the different MANETs applications. The purpose is to improve delay, reduce overhead, minimize energy used, sustain movement and increase bandwidth for multimedia applications.

V. Saritha et al. (2019) in [83] proposed a multipath routing protocol which is based on Quality of Service parameters. The QoS parameters considered are delay, bandwidth and hop count. Different types of traffic such as real- time traffic and non-real-time traffic are considered. In order to improve reliability by reducing number of retransmissions, an additional packet is generated in the case of non-real time traffic and multiple description coding is used in the case of real-time traffic. They proposed MRQ algorithm, was simulated using NS-2 and compared with the existing competing schemes - QAMR and RA-MDC. Their Simulation results proved that the performance of their scheme is better in terms of End-to-End delay, packet delivery ratio (PDR), Peak Signal Noise Ratio (PSNR) and retransmissions ratio metrics.

Ismail Bennis et al. (2018) [114] proposed a cross-layer scheme to handle video streaming over wireless sensor networks. Their starting point is to provide a carrier sense aware disjoint multi-path routing protocol able to transmit efficiently video and regular data from many sources to a unique base station (BS). This protocol will cooperate with the application layer in order to provide a frame-aware solution to assign high priority to the most important frames and low priority for the least important ones. This priority concerns mainly the path that will be used by the frames and the queuing policy that will be applied. Our queuing policy involves en-queuing, de-queuing and congestion solving function in order to reduce video latency and enhance the reliability. Our scheme is explained through a theoretical study with illustrative examples. Many simulations have been conducted, they demonstrate improvements of some performance indicators such as packet data rate, delay, loss packet rate and user experience.

In [107] **Liu, Jianpo et al. (2018)** based on the fact that routing technology which can meet the requirements of QoS technology can be realized in the process of multimedia video transmission. Due to the deviation in the process of network information transmission and the role of network dynamic topology, QoS routing in Ad Hoc is provided in the complex process of video transmission. They proposed application of multipath routing protocol based on Ad Hoc to improve the throughput of the network information data and to enhance the stability of data transmission. They aiming at the problem of choosing the interference path with different height, a multi-path routing protocol based on Ad Hoc network routing technology.

3.6 Video Streaming based on OLSR Routing Protocol

OLSR routing protocol present in many research works as the best and suitable protocol for transmitting video streaming /conferencing over MANETs because it’s proactive, low latency, highest throughput and meet to most of the required QoS for video traffics. The following are the latest research works related to video transmission over MANET based on OLSR routing protocol.

Haque Nawaz , Husnain Mansoor Ali (2018) in [115] experimental test bed scenarios developed and OLSR routing protocol implemented by using the Wireless LAN physical characteristics 1EEE 802.11g standard using OPNET modeler 14.5 version simulator tool. Their scenarios designed with 10 and 20 nodes density and configured each node with video streaming application. However, in that study the network performance and features of OLSR evaluated by altering the number of nodes using same parameters. In this paper, the OLSR protocol implemented and evaluated in terms of OLSR HELLO Traffic Sent, OLSR TC Traffic Sent, OLSR Routing Traffic Sent, OLSR Routing Traffic Received, Data Dropped, Network Delay, Network Load, Media Access Delay and Wireless LAN Throughput. They found that the node density has great impact on the performance of OLSR routing protocol. It has been observed that all parameters have the greater values with respect to greater node density.

Syeda Tasmiya et al. (2016) [116] proposed a novel approach for appraising the performance of multimedia traffic for OLSR routing protocol in MANET. They used in their simulation work performance parameters like throughput, average end to end latency, and data carrier delivery rate using NS2.They conclude that Ad-hoc on demand distance vector (AODV) protocol works well for constant bit rate (CBR) where as Optimized link state (OLSR) protocol works well in case of TCP . Since there is huge TCP or multimedia traffic is being transmitted in MANETs, it is concluded that OLSR is the best routing protocol from all the perspective for transferring the TCP.

Abdelali Boushabawe et al. (2014) [117, 118] they proposed an extension of MP-OLSR (Multipath Optimized Link State Routing Protocol),named FQ-MP-OLSR (Fuzzy based Quality of service MP-OLSR), which integrates two fuzzy systems. The first receives as inputs three links Quality of Service (QoS) metrics: delay, throughput and Signal to Interference plus Noise Ratio (SINR) and return as output multi-constrained QoS metric used to find the best paths. The second fuzzy system was applied to adapt cost functions used to penalize paths previously computed by Dijkstra's algorithm. The authors scheduled multimedia traffic among heterogeneous multiple paths, FQ-MP-OLSR integrates also the Weighted Round-Robin (WRR) scheduling algorithm, where the path weights, needed for scheduling, are computed using the multi-constrained QoS metric provided by the first fuzzy system. These mechanisms allow FQ-MPOLSR to improve video QoS and QoE (Quality of Experiment), against the MPOLSR that uses classical mechanisms such as hop count as single metric, cost functions without adaptation and Round-Robin (RR) as scheduling algorithm. Implementation and simulation experiments performed with Network Simulator NS2 are presented in order to validate our proposed approach. Their results show that FQMP-OLSR achieves a significant improvement of the video streaming quality in term of QoS and QoE.

Taiki Honda et al. (2013) in [119] they investigated the performance of OLSR protocol for video streaming application. Their simulations were conducted in urban environment in two scenarios with and without buildings. They consider 802.11p standard and send multiple video streaming flows over UDP. They use throughput, delay and jitter as evaluation metrics. Based on their simulation results, they found that OLSR can create links when buildings are not considered, but when buildings are considered some islands are created in the network and there are a lot of disconnections.

3.6.1 OLSR Fine Tuning Routing Parameters

The unique character of OLSR is that it minimizes the size of control messages and rebroadcasting by using the MRP. OLSR does not give the satisfactory performance with existing values of parameters. Therefore it is necessary to modify OLSR parameters for better performance [73].

Elizabeth Serena Bentley et al. (2018) [120] while decreasing the HELLO packet interval has been shown to improve the network performance for certain environments in simulations, it had not been verified with the use of actual radios in environments/scenarios that prove to be challenging to communications. By decreasing the HELLO packet interval, we can achieve an improved network performance with higher packet delivery ratios and lower packet delays in scenarios where there is a fast-moving advantaged node. A smaller HELLO packet interval allows the UAV to assign frequencies and (re)establish links with ground nodes quickly when within range, as well as bring links to the UAV down immediately after the UAV flies out of range. Experiments using real WNaN radios on the ground and mounted on an octocopter circling above validated results that had previously only been demonstrated in simulation environments, verifying the benefits of lowering the HELLO packet interval without disrupting network stability.

Dhriti Sharma, Harpreet Kaur (2016) in their research paper [84] studying the performance of two MANETs routing protocols OLSR and TORA. The protocols are evaluated on the base of delay, network load and throughput after altering of control interval values done for OLSR for its unsurpassed performance. This relative study confirms that enhanced OLSR outperforms among all concerned protocols in terms of network load and throughput.

Gautami et al. (2016) [121] a hybrid GA-SA(Genetic Algorithm – Simulating Annealing) which are a meta-heuristic approaches are used to enhance the performance of OLSR protocol by tuning the OLSR parameters leading to better Quality of service and communication efficiency. The proposed algorithm reduces NRL to 15%, reduce E2ED delay to less than 2 ms and increase PDR to 100%.

Bandi and Chandrashekhar (2015) [80] GA (Genetic Algorithm) and PSO(Particle Swarm Optimization) are used to fine-tune few OLSR parameters. The two algorithms are compared using QoS. The simulation results show that the fine-tuned OSLR protocol behaves better than the original routing protocol with intelligence and optimization configuration.

J. Gupta and A. Verma (2013) in [122] they study the impact of HELLO and Topology Control (TC) messages on the performance of OLSR in term of load, delay and throughput using OPNET. Their simulation study has shown that the HELLO interval in OLSR has great impact on the performance of various factors such as load, delay and throughput. They found that the throughput decreased as the value of HELLO interval increases.

3.6.2 OLSR Routing Parameters Optimization

A number of studies in the literature adjusted routing configurations making it suitable and easily applied into different kinds of network. In addition, studies tried to improve routing efficiency mainly in terms of network connectivity or available bandwidth by using multi-objective optimization strategy[123, 124].

Pushp Sra, Satish Chand (2019) in their work [110], a novel heuristic called Advanced-Optimized Link State Routing (A-OLSR) protocol is designed to provide QoS. It functions by enhancing the connectivity of nodes and establishing more stable routes as compared to standard best-effort Optimized Link State Routing (OLSR) protocol. The simulation results show that A-OLSR provides lower delay, reduces energy consumption and achieves higher throughput without introducing any additional routing overhead as compared to the standard OLSR and its variants-A′-OLSR and A″-OLSR. Their results also show that A-OLSR provides scalability since its performance remains consistent with the increasing size of network.

Nassir Harrag et al. (2018) [125] in this paper the authors describes their work to solve the difficulties of automatic selection process of the routing protocol parameters through using a multi-objective genetic .The realized experiments showed the effectiveness of the proposed NGSA-II-OLSR compared to the original OLSR. In case of low node mobility, the proposed NSGA-II-OLSR improves the PLR between 8.59 and 33.17%; the E2ED between 18.17 and 27.56%; and the NRL between 35.18 and 36.60%. While in case of high mobility node, it improves the PLR between 3.47 and 9.94%; the E2ED between 1.47 and 9.40%; and the NRL between 0.14 and 2.34%. In addition, the algorithm can adapt the ad hoc network to each topology change which makes it adaptive to any environment changing.

Felipe Jovel et al. (2017) [126] they present their results of an experimental study that was designed to understand the impact of neighbor discovery (ND) message hold times on the performance of mobile ad hoc networks. Experiments were conducted on a physical test bed of pseudo-mobile nodes and an NS-3 based simulator. The results of these experiments indicate that setting the ND message hold time 25% to 100% larger than the ND message interval provides favorable performance; or 2 s larger on an absolute scale. In particular, that hold time provides the best trade-off between two sources of packet loss induced by the neighbor discovery process: misrouting and neighbor-flapping. The precise absolute value required is system dependent and therefore we discuss how to derive it in general. To nearly eliminate neighbor-flapping, the ND message hold time needs to be set to slightly greater than twice the value of the ND message interval (i.e., > 100% larger) to protect against the occurrence of a single isolated lost ND message.

Kanika Gupta et al. (2016) [127] discuss the impact of HELLO messages on the performance of OLSR in term of packet delivery ratio, delay and throughput. The objective of their research is to study the impact of tuning on the performance of mobile routing protocol OLSR, which is a proactive routing protocol. Their experiments are conducted by NS-2.34 by using tool command language. A basic framework is employed to analyze the performance of routing protocol OLSR by tuning its parameters. Firstly they evaluated the performance in terms of QoS by applying an optimization strategy that obtains automatically efficient OLSR parameter configurations by coupling two different stages: an optimization procedure and a simulation stage. Was observed that tuned-OLSR outperformed OLSR. The three basic parameters are tuned by applying Genetic (GA), Simulate Annealing (SA) and particle swarm (PSO) algorithms. These optimization techniques show a considerable increase in throughput, packet delivery ratio and a substantial decrease in delay as compared to the respective performance of OLSR. The optimization methodology presented in their work (coupling meta-heuristics and a simulator), offers the possibility of automatically and efficiently customizing any protocol for any MANET and VANET scenarios.

Yangcheng Huang et al, (2006) [128] in this paper, the authors investigate the different impacts of tuning refresh interval timers on OLSR performance under various scenarios (varying node density and node speed). Based on the simulation results with NS2, they found that although reducing refresh intervals could improve OLSR’s performance, the intervals for some message types (HELLO messages) have a bigger impact on OLSR performance than for other message types. They found that the impact of the interval timer grows with increased network mobility and node density.

3.7 Swarm Intelligence (SI) Optimization for Video over MANET

Computational intelligence provides an adaptive mechanism that induces intelligent behavior in a dynamic and complex environment like MANETs, WSNs, and VANETs. In recent years, with the quick expansion of CI techniques, routing protocols based on ant colony optimization, fuzzy logic, particle swarm optimization, artificial bee colony, evolutionary algorithms, reinforcement learning, and bee mating optimization have been widely adopted to ensure application specific QoS guarantee in the resource-constrained MANETs[129].

M. Usha , B. Ramakrishnan (2019) [105] in order to utilized the channel and the bandwidth effectively, to achieve this, they proposed an enhanced Optimal Link State Routing Protocol (MMPR-OLSR) with the GSA-PSO (Gravitational Search-Particle Swarm

Optimization) scheme in combination with the cognitive radio technique. Their technique can be applied to the Vehicular Sensor Networks. MMPR-OLSR with GSA-PSO optimization facilitates the MMPR-OLSR protocol to select the suitable member nodes using an optimal searching technique. The GSA-PSO optimization not only helps in choosing the appropriate MMPR nodes, but also helps in reducing the unnecessary overheads due to the propagation of the control packets. By selecting the appropriate MMPR nodes, it is also possible to minimize the number of relay selector nodes used in transmission. The optimization technique also focuses on assigning the channels among all the network users. A group of nodes are selected before the start of the actual transmission. These vehicular nodes within the communication range are used as relays in the transmission. These nodes are categorized as Multi Point Relays. Cognitive radio plays an active role by identifying the idle channels, thus enabling the usage of the unused channels. Their proposed approach works efficiently in achieving the objective of effective channel utilization combined with efficient transmission. Their proposed approach is simulated using the NS2 platform and is evaluated based on important network metrics. Their proposed method shows a sharp decrease in delay and a high packet delivery ratio in addition to high channel utilization. The proposed GSA-PSO approach decreases the delay associated with packet transmission and delivery in VANETs and also ensures a good PDR due to the effective channel utilization.

Toutouh and Alba (2017) in their article [79] analyzed the use of two parallel multi-objective soft computing algorithms to automatically search for high-quality settings of the AODV routing protocol for vehicular networks. These methods are based on an evolutionary algorithm and on a swarm intelligence approach. Their experimental analysis demonstrates that the configurations computed by their optimization algorithms outperform other state-of-the-art optimized ones. In turn, the computational efficiency achieved by all the parallel versions is greater than 87%.

Gupta and Kohli (2016) [127] GA, PSO and SA algorithms are applied to tune OLSR parameters routing protocol. Proposed protocol is firstly evaluated in terms of QoS by applying an optimization strategy by coupling two different stages: an optimization procedure and a simulation stage. Proposed protocol shows considerable increase in throughput, packet delivery ratio and a substantial decrease in delay as compared to the respective performance of standard OLSR.

Lobiyala et al. (2015) [130] PSO is used for the selection of the optimal combination of AODV routing protocol parameters to improve QoS. Experimental results show that the developed algorithm reduces the packet delivery ratio (1.96%), the network routing load (37.07%) and the average end-to-end delay (80.65%).

Gunasekar and Hinduja (2014) [54] Intelligent Water Drop (IWD) algorithm is applied to tune the OLSR parameters leading to the optimal paths and provides an effective multi-path data transmission to obtain reliable communications in the case of dense networks. The proposed algorithm can control the overhead generated and improved packet delivery ratio.

3.8 Security Enhancement of OLSR over MANET

The optimized link state routing (OLSR) protocol is an efficient proactive routing protocol which is very suitable for such dense and large-scale MANET. However, in both data plane and routing plane, OLSR-based MANET suffers from many serious security threats which are difficult to resist via traditional mechanisms. Security of the private information is becomes necessity in MANET network. The dynamic nature of mobile nodes of MANETs is mostly affected by security problems which reduce data forwarding rate in multimedia sources. Due to the rapid growth of wireless applications, the different multitalented routing protocols are proposed in recent years. But the recent protocols are not efficient for multimedia applications, till now, specific security aware routing protocols are not proposed for multimedia data transfers [113].

Schweitzer, Nadav, et al. (2019) [131] without adding overhead on the network ,they proposed a method that ensures finding such bottleneck nodes that all data must pass through it (assuming one exists) in OLSR based MANET, with linear cost. To accomplish this task, experimented and compared, using network simulation tools, multiple types of attackers over a diverse set of topologies.

Kamel Saddiki et al. (2018) [132] presented the vulnerability of OLSR protocol versus a smart cooperative misbehaviors nodes. After that, they proposed a new optimized scheme called Neighbors-Trust-Based. Their main idea is to build collaboration between neighbors to detect misbehaviors nodes. They demonstrate the feasibility of their scheme through a detailed simulation using NS2.

R. Bhuvaneswari, R. Ramachandran (2018) [104] based on Elliptic Curve Cryptography (ECC) based prevention in case of MANET, they proposed a methodology particularly focuses and analyses the implementation of ECC in the presence and absence of attacks and various parameters like Throughput, Delay, Packet Delivery Ratio, and Average Delay. Their results show that even in the presence of attacks when the message is encrypted with ECC, the confidential information is secured and it cannot be read by the intruder. Also, ECC is more appropriate to be used in small gadgets like mobile phones and to protect the information at the time of emergency rescue operations. As it is strongly based on specialized mathematics on elliptic curves it is harder to break and provides security to wireless devices in an efficient manner. OLSR is proven to be the best-suited protocol not only for MANETs but also is being experimented in case of FANETs, UANETs and so on. In this paper, the authors had compared the performance of OLSR-ECC in the presence and absence of DoS attacks with a minimum number of nodes. The various improvements in OLSR-ECC based on several applications and devices with more precision for achieving better security in case of highly mobile and more scalable environment can also be considered for the future research.

Prateek Kumar Singh, Koushik Kar (2018) [133] examined routing attacks on OLSR protocol executed through control message manipulation. Specifically, we consider three different implementations of control message based black hole attacks on OLSR namely TC-Black hole attack, HELLO Black hole attack and TC-HELLO-Black hole attack. Malicious nodes can deliberately attract messages of other nodes towards itself and therefore, pose a great threat to the functioning and security of the network. The proposed mechanism utilizes a Reputation Routing Model (RRM) to mitigate the effect of the mentioned three black hole attacks. Performance of our model is evaluated against the TC, HELLO and TC-HELLO-Black hole attack on OLSR protocol for static as well as mobile scenarios. The emulation results establish that proposed solution can significantly mitigate the impact of mentioned three black hole attacks on OLSR in terms of packet delivery performance for static, low and high mobility scenarios. In these scenarios, our proposed model is able to isolate and steer away packets from paths with malicious nodes. Performance evaluation of RRM in presence of link reliability (retransmissions) and a larger fraction of malicious nodes will be investigated in future work.

R. Bhuvaneswari, R. Ramachandran (2018) [134] focused on the active denial of service (DoS) attacks in the network layer routing protocol OLSR. Wormhole, black hole, and grey whole attacks are implemented. Malicious intruders nodes are duly identified through their false HELLO messages and the fictitious node based verification of the TC messages within regular intervals. Fictitious node based detection of DoS attacks are proposed by varying the number of fictitious nodes for particular number of network nodes and the parameters throughput, delay, packet delivery ratio and average delay are evaluated using network simulator NS2 and the results are compared. The number of fictitious nodes required for the maximum throughput of the given network is finally evaluated. They found that as the network size increases, the overhead that is added by increasing the number fictitious node becomes negligible and the OLSR protocol's advantage that this protocol is suitable for the large as well as dense networks is still enhanced with security measures.

3.9 Energy Aware OLSR

Mobile Ad Hoc networks (MANET) allow a set of wireless hosts to exchange information without any special infrastructure. Limited battery power is one of the most important issues in mobile ad-hoc network by that efficient utilization of battery power or energy is must in routing process. Among the various factors which cause disorder in such a network and routing process the problem of broken links is occur due to the lack of energy is the most important ones[135]. In MANET networks, a mobile device has a limited battery and a considerable amount of energy is consumed in wireless interfaces. These characteristics limit the network lifetime of the wireless ad hoc networks. Therefore, many power management schemes have been proposed to reduce the power consumption in the wireless interfaces and thereby increase the network lifetime in the MAC layer using 802.11 standards [136] . Optimized Link State Routing (OLSR) has been accepted as one of the distinguished and dominant routing protocols for Mobile Ad Hoc Networks [137] .

OLSR uses a concept of the Multipoint Relay (MPR) selection mechanism to reduce the broadcast packet during a flooding process. In OLSR protocol, MPR nodes use more energy than non MPR nodes. Due to this MPR nodes run out their energy.

Santiago González et al. (2016) [138] they performed a simulation and analysis regarding energy optimization in MANET and proposed a new routing approach based on the OLSR protocol .Their simulation parameters include Mac protocol 802.11g , data rate 54 Mbps and video Bit rate (Average) 300kbps. Their approach aims at decreasing the power consumption on nodes with higher amount of neighbors, since they are likely to be the most strategic nodes to maintain the whole network connectivity. The evaluation performed on the simulation environment shows clear changes in the pattern of energy expenditure using S-OLSR. The most significant difference is achieved on the zone with higher node density. Specifically, results show a reduction in the energy consumption of 6% and 11% in comparison with the ER-OLSR mechanism and the standard OLSR protocol, respectively.

Teerapat Sanguankotchakorn (2015) [139] proposed a game theoretic method to reduce the control overhead while maintaining the throughput of OLSR and also reducing the power consumption. His proposed method is called Game Theoretical OLSR (gOLSR). He also investigate the effect of gOLSR on power consumption of nodes based on IEEE 802.11 MAC and Sensor Medium Access Control (SMAC) protocol used in mobile sensor network. OLSR is modified in such a way that every node in the system has to play the game when HELLO and TC interval are expired. Each node will choose its strategy to *"Update"* or *"Not Updat*e" the HELLO and TC messages in each round of game.

Ahmed Loutfi et al. (2013) [140] proposed a novel energy aware clustering algorithm for the optimized link state routing (OLSR) routing protocol. This algorithm takes into account the node density and mobility and gives major improvements regarding the number of elected cluster heads. Their objective is to elect a reasonable number of cluster heads that will serve for hierarchical routing based on OLSR. The proposed algorithm aims to increase the network lifetime by considering the ad hoc residual energy while taking routing decisions. It also optimizes the delay of carried flows by adopting a selective forwarding approach based on a hierarchical routing model.

Thomas Kunz (2008) [141] studied the impact of different OLSR protocol modifications that aim to increase node lifetime and network performance. OLSR evaluated under a range of different scenarios, varying traffic load and mobility pattern. For static networks, all protocol variants achieve relatively similar performance. Across all mobility scenarios, Modified Routing performed best, clearly outperforming Default OLSR as the mobility rate increased (delivering up to 30% more data packets). In that work was assumed for the implementation that all nodes have complete and accurate access to residual energy levels. While this is feasible in a simulator, and was done to focus on the effect of energy-efficient mechanisms within OLSR, this is unrealistic in real networks/for real deployments.

3.10 Chapter Summary

In this chapter, we reviewed a variety of research works including the performance evaluations of MANETs routing protocols, we found that there is a great deal of attention to the QoS of video streaming based AODV, DSDV, DSR, OLSR, TORA, and GPR routing protocols. Multi-path, multi-path with QoS, hierarchical, MDC, cross-layered approaches is proposed as efficient routing techniques for transmitting video streaming over MANETs. However, multipath routing may expand the complexity of MANETs as it involves appropriate strategies for fragmentation and defragmentation of multimedia video streaming routed over multiple paths. In addition, part of these techniques it's easily to implement through simulation test bed, but it's impractical on MANET environment. Obviously from the reviewed literature that the Computational Intelligence (CI) techniques such as PSO, GA, SA, TS, ACO, and other bio-inspired techniques are used as routing optimization techniques recently , because they has a good impact on the overall performance of the routing protocols.

However, most of recent studies in literature succeeded somewhat in enhancing the routing performance for one or two features, but it also loses other features or part of its routing efficiency. This is because of the limitation capacity of MANETs routing protocols.

Chapter Four

Research Methodology

4 Research Methodology

4.1 Introduction

The research methodology that it had been used in this thesis consists of both qualitative and quantitative study. The qualitative part has a detailed literature review, which is covered comprehensively in Chapter (3), and the quantitative part consist of a simulation study with an experimental setup. This chapter explains and provides the quantitative approach which is consist of identifying the desired MANET routing protocols under the investigation of transmitting video conferencing. The simulation tool, the routing protocol parameters, and QoS metrics are explained in details with the focuses of its importance and how it mathematically calculated. Beyond that, in this chapter, the proposed scheme for enhancement video transmission over MANET on the bases of OLSR routing protocol is also described, including the fine-tuning algorithm and the enhancement framework. The ANOVA and PSO are explained in details as a modeling and optimization techniques respectively.

4.2 Performance Evaluation of Video Transmission over MANET

Here we investigate the efficient MANETs routing protocols that can provide a high QoS for video conferencing and video streaming over MANETs through simulation experiments varies in network sizes and density of mobile nodes (number of mobile nodes). The simulation was carried out using OPNET 14.5 simulation modular. The routing protocols under investigation are:

(a) Reactive routing protocols (AODV, DSR)

(b) Proactive routing protocols (OLSR ,TORA)

(c) Hybrid or position-based routing protocol GPR

The simulation aims to evaluate the performance of the above routing protocols for video conferencing over MANET in order to identify which MANET routing protocols guarantee the required QoS metrics desirable for transmitting real-time video applications.

4.3 QoS Metrics for Video Transmission

There are different kinds of parameters for the performance evaluation of the routing protocols. These have different behaviors of the overall network performance. In this study, ten parameters had been evaluated for the comparison of the overall network performance. In case of video traffic, three metrics had been evaluated which have a great impact on the QoS of video traffics end-to-end delay (E2E-delay (sec)), packet delay variation (Jitter (sec)), and packet delivery ratio (PDR %). For the WLAN network performance , average end-to-end delay (sec), throughput (bits/sec), retransmission attempts (packets), WLAN-load (bits/sec), total packets dropped (packets/sec), routing overhead (bits/sec), and network load (bits/sec) are been evaluated. These parameters as shown in Table (4.1) are important in the consideration of evaluation of the routing protocols in a communication network. These protocols need to be checked against certain parameters for their performance.

Table (4.1): QoS metrics desirable for video traffic

Video Traffic	**Wireless LAN (WLAN)**
Packets End-to-End Delay (sec)	Average End –to-End delay (sec)
Packets Delay Variation (Jitter sec)	Throughput (bits/sec)
Packets delivery Ratio (PDR %)	Retransmission Attempts (packets)
	WLAN-Load (bits/sec)
	Total packets dropped (packets/sec)
	Routing overhead (bits/sec)
	Network load(bits/sec)

To check protocol effectiveness in finding a route towards the destination had been observed how much control messages does the source send. It indicates the routing protocol internal algorithm's efficiency. These parameters have great influence in the selection of an efficient routing protocol in any communication network specifically with video streaming and conferencing which are delay-sensitive applications.

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Table (4.2): End-user performance expectative – video services

Parameters	**Video Traffic Type**	
	Video Streaming	Video Conferencing
E2ED	4 ~ 5 sec allowable	≤ 150 ms of one-way latency from mouth to ear (per the ITU G.114 standard).
Jitter	No significant jitter requirements	≤ 30 ms
PDR %	< 2%	≤ 1%
Bandwidth Required	Depends on the encoding and the rate of the video stream.	Minimum bandwidth guarantee is videoconferencing session + 20 percent. For example, a 384-kbps videoconferencing session requires 460 kbps guaranteed priority bandwidth

There are restricted QoS requirements for multimedia services based on international standards [45] that can be applied as either a one-to-one capability or a multipoint conference, and these restrictions are described by the International Telecommunications Union - Telecommunications Standardization Sector (ITU-T). Table (4.2) shows the standard QoS parameters of the video traffics required to transmit it efficiently

4.3.1 Packets - End –to-End delay (E2ED)

The packet end-to-end delay is the time from the generation of a packet by the source up to the destination reception. So this is the time that a packet takes to go across the network. This time is expressed in seconds. There have been several kinds of delays which are processing delay (D_{proc}), queuing delay (D_{queue}), transmission delay (D_{trans}), and propagation delay (D_{prop}). E2ED represented mathematically as shown in Equation (4.1). A routing protocol with minimum delay increases the efficiency of the network. This metric is important in delay-sensitive applications such as video traffic and voice transmission.

$$D_{E2E_i} = \left[D_{RDD_i} + D_{queue_i} + D_{RTD_i} + D_{proc_i} + D_{prop_i} + D_{trans_i}\ \right] = (R_i - S_i) \qquad (4.1)$$

$$AV_{E2E_i} = \frac{1}{N}\sum_{i=1}^{n}(R_i - S_i)$$

Where:

D_{RDD_i} : *Route Discovery Delay*
D_{queue_i} : *Queuing Delay*
D_{RTD_i} : *Retransmission Delay at the MAC layer*
D_{proc_i} : *Processing Delay*
D_{prop_i} : *Propogation Delay*
D_{trans_i} : *Transmission Delay*

4.3.2 Packet Delivery Ratio (PDR)

PDR is an important metric in networks and is defined as the ratio between all the received packets at the destinations and the number of data packets sent by all the sources as illustrated in Equation (4.2). A high PDR is desired for real-time multimedia applications.

$$PDR = \frac{data\ packets\ recived\ at\ destination}{data\ packets\ sent\ by\ sources} * 100 \qquad (4.2)$$

4.3.3 Packets Delay Variation (PDV)

Packet Delay Variation (PDV) or Jitter (sec) is the variation in time between arrivals of packets or in other words, is the difference in end-to-end one-way delay between selected packets in a flow with any lost packets being ignored as in Fig.(4.1) and Equation (4.3). Low jitter is especially an important metric for real-time applications requiring timely delivery e.g. video-conferencing, VoIP etc.

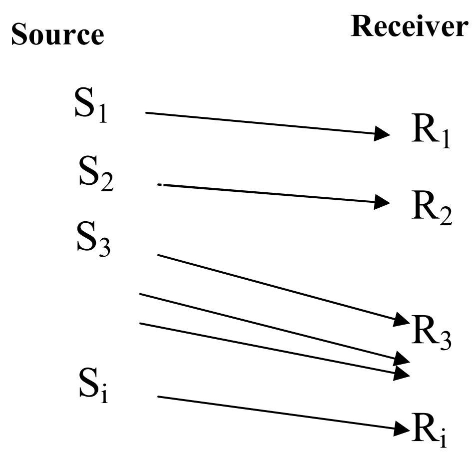


Figure (4.1) PDV (Jitter) between the Source and Receiver

$$D_i = (R_i - S_i) - (R_{i-1} - S_{i-1}) = (R_i - R_{i-1}) - (S_i - S_{i-1})$$

$$jitter = \frac{\sum_i^n |D_i|}{n} \quad (4.3)$$

Where:

S_i : i^{th} *packet send by source*

R_i : i^{th} *packet recived by receiver*

D_i : i^{th} *packet delay*

n : *number of packets*

4.3.4 WLAN-E2E-Delay

(E2ED) determines the average time that packets require from the source to the application layer at the destination node. It is expressed in seconds.

4.3.5 Throughput

Throughput is defined as; the ratio of the total data that reaches a receiver from the sender. The time it takes by the receiver to receive the last message is called throughput. Throughput is expressed as bytes or bits per sec (byte/sec or bit/sec). Some factors affect the throughput as; topology changes in the network, unreliable communication between nodes, limited bandwidth available and limited energy. High throughput is an absolute choice in every network. Throughput can be represented mathematically as in Equation (4.4). In MANETs throughput is considered as an important parameter to measure the robustness of the network.

$$Throughput = \frac{(No\ of\ bytes\ Received \times 8)}{(Simulation\ Time \times 1000)}\, kbps \qquad (4.4)$$

4.3.6 Retransmission Attempt

The total number of retransmission attempts by all WLAN MACs in the network until either a packet is successfully transmitted or it is discarded as a result of reaching short or long retry limit. For real-time multimedia application is required very few retransmission attempts are desired, at it has an impact on the packet loss.

4.3.7 WLAN –Load

Network load represents the total load (in bits/sec) submitted to wireless LAN layers by all higher layers in all WLAN nodes of the network or can be measured directly by calculating the amount of traffic the nodes generate and forward as stated in Equation (4.5). Network overloading occurs when more traffic enters the network, and it is difficult for the network to handle this traffic. The load is desirable to be less for efficient and reliable communication. Efficient networks can easily cope with a large amount of traffic.

$$NRL = \frac{\sum_{m=1}^{n} RPgen}{\sum_{m=1}^{n} recvs} \qquad (4.5)$$

Where:

RPgen : *Routing Packets generated (Packets Sent by the sources*

recvs : *Packets received*

n : *number of packets*

4.3.8 Total Packets Dropped (PD)

This metric is important for video streaming applications because they are sensitive for packets dropped or lost which can affect the quality of the video. Mathematically it is computed by Equation (4.6), in MANET networks PD occurs because wireless links are subject to transmission errors or due to the existence of malicious nodes as in the case of black hole attack.

$$PD = Total\ Packets\ Sent - Total\ Packets\ Recived \qquad (4.6)$$

4.3.9 Routing Overhead

To keep up-to-date information about network routes, routing algorithms generate small-sized packets, called routing packets. One example of such packets is a HELLO packet, which is used to check whether the neighbor node is active. Equation (4.7) shows how to calculate the routing overhead, routing overhead is less for reactive routing protocols (On-demand), but is very high for proactive (table-driven). Note that routing packets do not carry any application content as data packets do. Both, routing and data packets have to share the same network bandwidth most of the time, and hence, routing packets are considered to be an overhead in the network. This overhead is called routing overhead. A good routing protocol should incur lesser routing overhead.

$$Routing\ Overhead = \frac{Total\ routing\ Packets\ Sent}{Total\ Data\ Packets\ Recieved} \qquad (4.7)$$

4.4 Simulation Tool

There are different simulation platforms for MANETs such as NS-2, NS-3, GloMoSim, QualNet, OMNet++, and OPNET. In this research OPNET 14.5 (Optimized Network Engineering Tool version 14.5) was used to perform the modeling, simulation and performance analysis of MANET routing protocols for transmitting real-time video contents. OPNET Modeler is the industry's leading high-level event-based network simulation and development tool, which is a network modeler through which one can design any kind of network model and then can simulate it. Moreover, it provides a very attractive virtual network environment that is prominent for research studies, network modeling, research and development R&D, network operations and performance analysis of routing protocols.

To choose between OPNET and NS-3, a number of proven functionalities were taken into account. Firstly OPNET supports most of the effective MANET protocols; it's a Discrete Event Simulator (DES) which supports parallel processing. OPNET has a number of core elements with a huge amount of documentation available for general purpose uses. Core components include model library, model documentation, and tutorials.

Table (4.3): Comparison between network simulators

Name	Granularity	Metropolitan mobility	Parallelism	Interface	License
NS-2	Finest	Support	No	C++/OTCL	Open source
DIANEmu	Application-level	No	No	Java	Free
GloMosim	Fine	Support	SMP/beowulf	Parsec (C-based)	Open source
GTNets	Fine	No	SMP/beowulf	C++	Open source
J-Sim	Fine	Support	RMI-based	Java	Open source
Jane	Application-level	Native	No	Java	Free
NAB	Medium	Native	No	OCaml	Open source
OMNet++	Medium	No	MPI/PVM	C++	Free for academic and educational use
OPNET	**Fine**	**Support**	**Yes**	**C/C++**	Commercial
QualNet	Finer	Support	SMP/beowulf	Parsec (C-based)	Commercial
SWANS	Medium	-	No	Java	Open source

OPNET is a commercial network R&D system which can be integrated with various events - driven models available in its library. But network modeling in OPNET is sometimes more expensive than other simulators which are open source and available free of cost functioning similar processes. But OPNET uses Windows platform and it has a user-friendly graphical user interface with a number of supported protocols. OPNET has excellent tools to analyze and visualize results obtained from the simulation. Table (4.3) shows a detailed comparison of different network simulators.

4.5 OPNET-Based Simulation Set up parameter and network models

To evaluate the above mentioned QoS metrics mentioned above for MANET routing protocols AODV, OLSR, DSR, TORA, and GRP, simulation has been performed for three different models called small Scale, Medium Scale and Large Scale based on the network size in m2 and the density of mobile nodes as shown in Table (4.4) below. We focus here to show the impact of the scalability on the QoS of video conferencing and which routing protocol copes with scalability challenges. The number of scenarios performed is equal to the number of different mobile densities times the number of routing protocols.

Table (4.4): MANET network simulation models

Network Model	Network Size (m2)	Number of Nodes	No. of Scenarios
Small Scale	500X500	5,10,15,20,25,30,35	7X5=35
Medium Scale	1000X1000	40,50,60,70	4X5=20
Large Scale	1500X1500	80,90,100	3X5=15

4.5.1 WLAN- Simulation Parameters

As a consequence, the WLAN simulation parameters have been selected and determined in order to identify the specifications of mobile nodes as target elements. Their mobility speed also specified which is in the range [0-10] m/s for low speed and [10-20] m/s for medium/high speed. In addition, the MAC layer IEEE 802.11g protocol and its parameters required to simulate a WLAN network are specified as shown in Table (4.5).

Table (4.5): WLAN- network simulation parameters

Parameter	Value
Network Area(Size) (m^2)	SZ 500x500 MZ 1000x1000 LZ 1500x1500
Wireless Nodes	LD(5,10,15,20 ,25,30,35) MD (40,50,60,70) HD (80,90,100)
Node Speed (m/s)	[0 , 10] and [10,25]
MAC Layer Protocol	PHY IEEE 802.11g
Data Rate (Mbps)	54
Channel Settings	Auto Assigned
Buffer Size (bits)	256000=32 KB
Transmit Power (Watt)	0.005
Transmission Range (m)	250
Packet Reception Power Threshold(dBm)	-95
Link Delay Threshold (sec)	0.1
MANETs routing Protocols	AODV OLSR, DSR ,TORA and GRP
Simulation Time(sec)	800
Addressing Mode	IPv4
Simulator	OPNET 14.5

4.5.2 Random Waypoint (RWP) Mobility Model Parameters

The mobility of nodes is the key attribute of MANETs, and the performance of MANETs needs to be studied in presence of mobility [142]. The position and the direction of nodes can change with time as it moves with random velocity and acceleration. There are several proposed mobility models which simulate the movement of the nodes in MANETs. The effect of routing protocols combined with the mobility model is examined in this simulation.

4.5.2.1 OPNET Implementation of (RWP)

The generation of the node trace model of (RWP) using OPNET can be set and implemented as follows:

(1) - When the simulation starts, each mobile node randomly chooses one location in the finite continuous plane (simulation area) as the destination coordinates.

(2) - The mobile node starts to move from its current position towards the destination with constant velocity selected uniformly and randomly from the interval [V_{min} ,V_{max}], where V_{min} denotes the minimum speed ($V_{min} > 0$) and the parameter V_{max} denotes the maximum allowed velocity of each mobile node.

(3) - When the simulation starts, each mobile node randomly chooses one location in the finite continuous plane (simulation area) as the destination coordinates.

4.5.2.2 Characteristics of (RWP)

1) V_{max} and T_{pause} are the two key parameters that determine the mobility behavior of nodes.

2) $$\text{Topology of MANET is Stable} = if \begin{cases} V_{\max} & Low \\ T_{Pause} & Long \end{cases}$$

3) $$\text{Topology of MANET is (HD)} = if \begin{cases} V_{\max} & High \\ T_{Pause} & Short \end{cases}$$

Where:

HD: *Highly Dynamic*

T_{Pause}: *Pause time*, when ($T_{pause}=0$) *second, nodes are in continuous motion.*

4.5.2.3 Limitations of (RWP) Model

Although the RWP mobility model has been widely used in MANET simulations, it is insufficient to capture the following mobility characteristics:

A. ***Temporal Dependency of Velocity***: The velocity of a mobile node will change continuously due to physical constraints of the mobile, which causes the velocities at two different time slots to be independent.

B. ***Spatial Dependency of Velocity*****:** The movement pattern of a mobile node in RWPM may be influenced by and correlated with nodes in its neighborhood, but each mobile node of this model moves independently of others.

C. ***Geographic Restrictions of Movement:*** The movement of a mobile node in the RWPM mobility model may be restricted along the street or a freeway while a geographic map may define these boundaries.

4.6 Proposed Enhancements Related to the MANETs Protocol Stack

Research concerning MANETs is currently of great interest. The performance of MANET is related to the efficiency of the routing protocols in adapting to frequently changing network topology and link status [143]. Because of the importance of routing protocols in the dynamic multi-hop networks, a number of routing protocols have been proposed in the last few years; concurrently, a great deal of research work is being undertaken by researchers to improve their performances.

Dass et al. (2018) overviewed in [144] numerous studies have analyzed the performances of routing protocols in mobile Ad-hoc networks (MANETs); most of these studies vary in at most one or two parameters in experiments and do not study the interactions among these parameters. Furthermore, efficient mathematical modeling of the performances has not been investigated; such models can be useful for performance analysis, optimization, and prediction.

In OLSR, maintaining an up-to-date routing table for the entire network calls for excessive communication between the nodes as periodic control messages updates are flooded throughout the network. Hence OLSR generates a large amount of control overhead which consumes valuable bandwidth that should have been employed by user data traffic instead of sensing topological changes in the network. Therefore, excessive control overhead in OLSR is detrimental to its overall performance in data forwarding, which has been analyzed for improvement in [63]. The approach presented in this thesis aims to improve the QoS of OLSR to guarantee the requirements of transmitting video traffic effectively by improving other parameters like end-to-end delay, jitter, PDR, and throughput.

The novelty of that approach comes due to developing an integrated scheme that fulfills three challenges among transmitting video conferencing over MANETs through tuning and optimization of OLSR routing parameters. The contributions can be shown into the following enhancements:

1) QoS enhancement in terms of (E2E delay, jitter, throughput, PDR, Network Load, etc...) which cope with QoS requirements desired for video traffic delivery.
2) Enhancement of a security scheme in order to defense and prevent MANET network from the security challenges that can degrade the performance in to two different network layers (black hole attack at network layer, and jamming attack at MAC/PHY layer).
3) Enhancing the power efficiency (reducing power consumption) due to data exchange (control or information messages) and prolong the network lifetime, in addition, not influence the overall performance.

All these enhancements are oriented to different layers in MANETs protocol stack. Fig.(4.2) shown all works on the MANETs protocol stack that should have been proposed. Basically, would have been focus on **five** different network layers:

1) **Application Layer*:*** One of the delays sensitive applications which are video conferencing application to transmit over MANET network was been choose.
2) In the **Transport Layer**: The UDP protocol is selected as transport layer protocol with CBR traffic which is relevant to video streaming contents. High quality real-time video streaming requires a huge bandwidth and a highly reliable transmission medium. However, wireless mobile networks still have difficulties in achieving the required reliability. Streaming with the UDP protocol has less overhead than TCP packets, which have a greater overhead due to packet acknowledgements. This makes UDP a suitable choice for real time video streaming.
3) **UDP** is a protocol used to carry data over IP networks. One of the principles of UDP is that it assumes that all sent packets are received by the other party (or such kind of control is executed at a different layer, for example by the application itself). Erion Çano (2019) [145] states that using CBR for comparison purposes is important in order to get fair results. Varying traffic (i.e. TCP) could make the load unpredictable and corrupt the simulation results.

4) **Network Layer**: in Chapter (5), comprehensive simulations are performed among different MANET routing protocols and we found that OLSR is the best suitable protocol for transmitting video effectively over dense MANET networks. In this layer we investigate the influence or the impact of the tuned and optimized configuration of OLSR routing protocol on the QoS of transmitting video conferencing in terms of (E2E, jitter, PDR, throughput, Network Load… etc). The proposed algorithm for selecting OLSR routing parameters (tuning OLSR) is evaluated and the performance of the QoS-OLSR (Quality of Service OLSR) is compared to ordinary OLSR. On the other hand how the tuned or optimized configurations of the modified OLSR provides a defense from one of the popular attacks in this layer such as black hole attack.

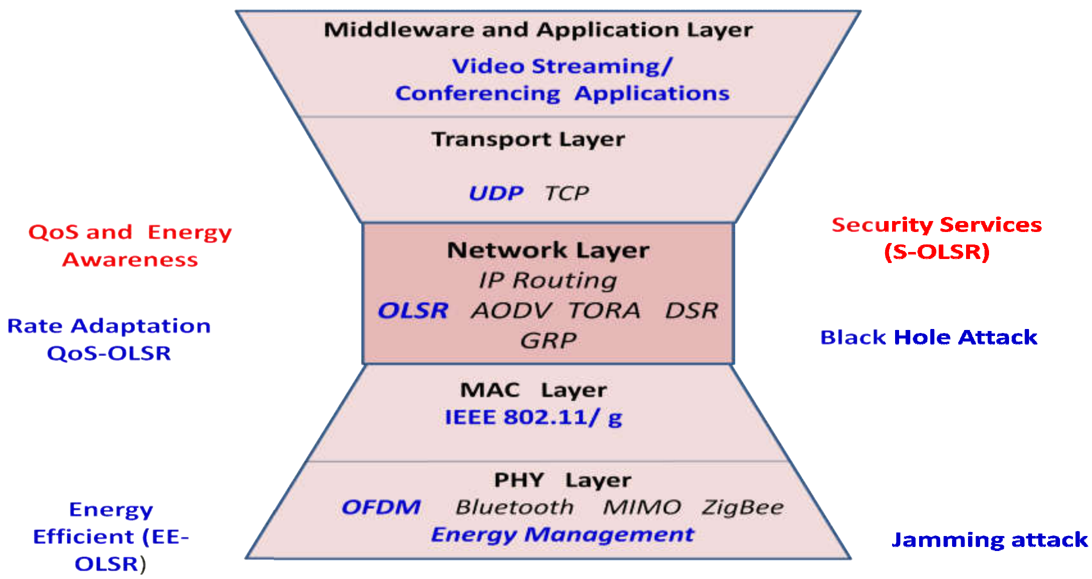


Figure (4.2) QoS, Security and Energy –OLSR enhancements [28]

5) **MAC/PHY Layer**: IEEE802.11g is used as WLAN technology standard due to its characteristics mentioned in Chapter (2).The security attacks involved in this layer and energy consumptions due to send/receive operations are centric issues on which we focus. We investigate the impact of the optimized configuration of OLSR on the power consumption and the network lifetime. In addition, we evaluate the impact of the optimized configuration on defending MANET from jamming attacks, which is one of the most important attacks in the MAC/PHY layer that has a great impact on the QoS of video streaming.

4.7 Multivariate Linear Regression Modeling (MLRM)

The usual expression of the General Linear Model (GLM) conception is that data may be accommodated in terms of a model plus error as mentioned in Equation (4.1).

$$Data = Model + Error \qquad (4.1)$$

In simple linear regression, we attempt to model the relationship between two variables, for example, X and Y. For a linear relationship, we can use a model of the form shown in Equation (4.2):

$$y = \beta_0 + \beta_1 x + \varepsilon \qquad (4.2)$$

Where $\boldsymbol{y}$ is the dependent or (***response***) variable and $\boldsymbol{x}$ is the independent or (***predictor)*** variable. The random variable ε is the error term in the model. In this context, error does not mean mistake but is a statistical term representing random fluctuations, measurement errors, or the effect of factors outside of our control.

The linearity of the model in (4.2) is an assumption. We typically add other assumptions about the distribution of the error terms, independence of the observed values of $\boldsymbol{y}$, and so on. Using observed values of $\boldsymbol{x}$ and $\boldsymbol{y}$, we estimate β_0 and β_1 and make inferences such as confidence intervals and tests of hypotheses for β_0 and β_1. We may also use the estimated model to forecast or predict the value of y for a particular value of $\boldsymbol{x}$, in which case a measure of predictive accuracy may also be of interest.

Multiple linear regressions is a generalization of simple linear regression to the case of more than one independent variable, and a special case of general linear models, restricted to one dependent variable. The basic model for multiple linear regressions is given by formula (4.3).

For x_1, x2, x3,… , x_n, be a set of n predictors believed to be related to a response variable y , the linear regression model for the jth sample unit has the form:

$$Y_j = \beta_0 + \beta_1 x_{j_1} + \beta_2 x_{j_2} + \cdots + \beta_n x_{j_n} + \varepsilon_j \qquad (4.3)$$

Where:

β_0 : Constant coefficient (is the intercept)

$\beta_{i\ ,\ i=0,1,2,\ldots,n}$: are unknown (and fixed) regression coefficients.

ε : Is the random error

We assume that: $E(\varepsilon_j) = 0$, $\mathrm{Var}(\varepsilon_j) = \sigma^2$, $\mathrm{Cov}(\varepsilon_j, \varepsilon_k) = 0 \quad \forall j \neq i$

Regression analysis is a statistical approach used to predict the value of one or more responses from a set of predictors. It can also be used to estimate the linear association between the predictors and responses. Predictors can be continuous or categorical or a mixture of both. We first revisit the multiple linear regression models for one dependent variable and then move on to the case where more than one response is measured in each sample unit [146, 147].

Now we extend the regression model mentioned as in Equation (4.3) to the situation where we have measured ***m*** responses $y_1, y_2, y_3, \ldots, y_m$, e.g (jitter, E2ED, PDR, etc..) and the same set of ***n*** predictors $x_1, x_2, x_3, \ldots, x_n$,(# nodes, speed, HELLO, TC, data rate, etc...) on each sample unit. Then each response follows its own regression model as in Equation (4.4):

$$\begin{aligned} y_1 &= \beta_{01} + \beta_{11}x_1 + \cdots + \beta_{n1}x_n + \varepsilon_1 \\ y_2 &= \beta_{02} + \beta_{12}x_1 + \cdots + \beta_{n2}Z_n + \varepsilon_2 \\ &\;\vdots \\ y_m &= \beta_{0m} + \beta_{1m}x_1 + \cdots + \beta_{nm}x_n + \varepsilon_m \end{aligned} \tag{4.4}$$

Or more generally as in Equation (4.5):

$$y_j = \sum_{i=0}^{n} \beta_{ij}x_i + \varepsilon_j \tag{4.5}$$

Sums of squares

We can partition variability in ***y*** into variability due to changes in predictors and variability due to random noise (effects other than the predictors). The sum of squares decomposition is given by Equation (4.6) and Equation (4.7):

$$\sum_{j=1}^{n} \left(y_j - \bar{y} \right)^2 = \sum_{j=1}^{n} (\hat{y} - \bar{y})^2 + \sum_{j=1}^{n} \hat{\varepsilon} \tag{4.6}$$

Or symbolically:

$$SST^2 = SSR^2 + SSE^2 \tag{4.7}$$

Where:

SST: **T**otal **S**um of **S**quares differences between original value of y which is y_j and the average value of y which is $\bar{y}$, and this is given by:

$$\boldsymbol{SST} = \sum_{j=1}^{n} \left(y_j - \bar{y} \right)^2 \qquad (4.8)$$

SSR: **S**um of **S**quares **R**egression differences between the predicted value of y which is y_j and the average value of y which is $\bar{y}$, and this is given by:

$$\boldsymbol{SSR} = \sum_{j=1}^{n} (\hat{y} - \bar{y})^2 \qquad (4.9)$$

SSE: Sum of Square Error, and is given by**:**

$$\boldsymbol{SS}E = \sum_{j=1}^{n} (\hat{\varepsilon})^2 \qquad (4.10)$$

The coefficient of multiple determinations is:

$$\boldsymbol{R^2} = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \qquad (4.11)$$

Thus $\boldsymbol{R^2}$ in Equation (4.11) gives the proportion of variation in **y** that is explained by the model or, equivalently, accounted for by regression on $\boldsymbol{x}$. The $\boldsymbol{R^2}$ value is a measure of how well the model explains the data. It is an example of a ***goodness-of-fit*** statistic. The value of $\mathbf{R^2}$ is desired max for the ***goodness-of-fit*** for any model, from Equation (4.11) that mean ($SSR \cong SST$) or by another way $SSE = SST$) .

Multivariate Linear Regression Modeling (MLRM) is used in our thesis to model most of the QoS metrics (jitter, E2E-delay, PDR, ..) desired for transmitting real-time video content such as video conferencing over MANETs efficiently. We will discuss these concepts comprehensively in section (4.8).

4.8 Analysis of Variance (ANOVA)

ANOVA attempts to explain data (the dependent variable scores) in terms of the experimental conditions (the model) and an error component [148]. In analysis-of-variance (ANOVA) models, we are interested in comparing several populations or several conditions in a study. ANOVA is an analysis tool used in statistics that splits an observed aggregate variability found inside a data set into two parts: systematic factors and random factors. The systematic factors have a statistical influence on the given data set, while the random factors do not. Analysts use the ANOVA test to determine the influence that independent variables have on the dependent variable in a regression study. To study the influence of some parameters on the overall performance of any MANET routing protocol based on internal factors (configuration of the protocol itself, QoS required, power consumptions) and external (mobility speed, density of nodes, network coverage area), we must use an analysis tool to show the variability and correlation between the responses and predictors.

The computed ***F*** statistic (also called the ***F*-ratio**) given by Equation (4.9), allows for the analysis of multiple groups of data to determine the variability between samples and within samples.

$$\boldsymbol{F} = \frac{MST}{MSE} \tag{4.9}$$

Where:

$\boldsymbol{F}$: ANOVA coefficient

MST : Mean sum of squares due to treatment

MSE : Mean sum of squares due to error

The null hypothesis for an ANOVA is that there is no significant difference among the groups; the result of the ANOVA's ***F-ratio*** statistic will be close to **1**. The alternative hypothesis assumes that there is at least one significant difference among the groups. After cleaning the data, the researcher must test the assumptions of ANOVA. They must then calculate the ***F*-ratio** and the associated probability value (***p*-value**). In general, if the ***p*-value** associated with the ***F*** is smaller than **.05 ($p<0.05$)**, then the null hypothesis is rejected and the alternative hypothesis is supported. If the null hypothesis is rejected, one concludes that the means of all the groups are not equal. Post-hoc tests tell the researcher which groups are different from each other.

The ANOVA test allows a comparison of more than two groups at the same time to determine whether a relationship exists between them. Fluctuations in its sampling will likely follow the Fisher ***F*** distribution.

4.9 Routing Protocols Optimization

Optimization is a scientific discipline that deals with the detection of optimal solutions for a problem, among alternatives. The optimality of solutions is based on one or several criteria that are usually problem and user-dependent. Optimization is the procedure of detecting attributes, configurations or parameters of a system, to produce desirable responses. In computer science, one is interested in designing high-performance computer systems at the lowest cost [149].

In the case of routing protocols, the desired high performance is a complex task due to different factors affecting the required performance. Due to MANETs characteristics, there are many factors that influence performance such as mobility speed , node density , data rate , bandwidth , link failure , environmental factors , link capacity , and so on. Due to the unpredictable and changing topology of MANETs, communication protocols usually rely on some parameters that adapt their behavior to the current circumstances. The performance of the protocol is highly sensitive to small changes in the set of those configuration parameters. Therefore, fine tuning them for optimally configuring a communication protocol is a complex and critical task. Additionally, due to the drawbacks present in MANETs there is not a single goal to be satisfied but several such as network resources, QoS, energy used, and so forth [150].

This type of problem can be scientifically resolved through modeling and optimization. Modeling offers a translation of the original problem (MANET environment, routing protocol parameters, topology change parameters, etc.) to a mathematical structure that can be handled through algorithmic optimization procedures. The model is responsible for the proper representation of all key features of the original system and its accurate simulation. Concurrently, it offers a mathematical means of identifying and modifying the system's properties to produce the most desirable outcome without requiring its actual construction, thereby saving time and cost.

The produced models are usually formulated as functions, called ***objective functions***, in one or several variables that correspond to adaptable parameters of the system. The model is built in such a way that, based on the particular optimality criteria per case, the most desirable system configurations correspond to the extreme values of the objective function. Thus, the original system optimization problem is transformed to an equivalent function minimization or maximization problem. The difficulty in solving this problem is heavily depending on the form and mathematical properties of the objective function. Constraints can be posed by the user or the problem itself, thereby reducing the number of prospective solutions. If a solution fulfills all constraints, it is called a feasible solution. Some of the most interesting and significant subfields, with respect to the form of the objective function, are:

1. **Linear optimization** (or linear programming): It studies cases where the objective function and constraints are linear.
2. **Nonlinear optimization** (or nonlinear programming): It deals with cases where at least one nonlinear function is involved in the optimization problem.
3. **Convex optimization**: It studies problems with convex objective functions and convex feasible sets.
4**. Quadratic optimization** (or quadratic programming): It involves the minimization of quadratic objective functions and linear constraints.
5. **Stochastic optimization**: It refers to minimization in the presence of randomness, which is introduced either as noise in function evaluations or as probabilistic selection of problem variables and parameters, based on statistical distributions.

4.9.1 Taxonomy of the Optimization Process

In this section, we present the basic classification or taxonomy of optimization techniques that use nature inspired algorithms for solving some of the recent challenges in MANETs such as QoS, security, energy efficiency, Routing, and others. We classify them in terms of execution mode, information needed, and platform executing the algorithm. The literature reveals two different approaches when applying meta-heuristics for solving problems in MANETs: online and offline techniques. The main difference between them lies in the moment when the optimization algorithm is applied.

(A) Online meta-heuristics approaches: Are used for correcting behaviors or making decisions during runtime, trying to find the best next step. They can be implemented either in the (constrained) network node(s) or in a central unit, but usually require intensive computation. However, the second option contradicts ad hoc networks and therefore MANETs essence. However it is not relevant to MANETs because they are decentralized and there is no central unit to optimize the whole system and use global knowledge such as the position and energy level.

(B) Offline meta-heuristics approaches: The main goal is to find the best possible configuration, settings, and decisions, and these findings will later be used during runtime. The algorithm stops after performing a predefined number of generations or when the optimal value is found (in case it is known). The quality of the solutions found is usually tested by simulation, thus, it directly depends on the modeling of the system. However, there is compromise between the accuracy of the model and the optimization time. These offline met-heuristic approaches are useful when the system does not need to adapt to changes during runtime. This approach is suitable for MANETs only when using the local knowledge. For this reason in this thesis we use this approach to attempt to mitigate most of MNAETs challenges such as QoS, security, and energy efficiency.

6.9.2 Swarm Intelligence (SI)

Many complex optimization problems are effectively addressed using Swarm Intelligence (SI) which is a sub field of Computational Intelligence [151]. SI is mainly defined as the behavior of natural or artificial self-organized, decentralized systems. Swarms interact locally with each other or with external agents i.e. environment and can be in the form of bird flocks, ants, bees etc. It is the property of a system whereby the collective behavior of (unsophisticated) agents interacting locally with their environment causes coherent functional global patterns to emerge. SI provides a basis with which it is possible to explore collective (or distributed) problem solving without centralized control or the provision of a global model.

SI based approaches are nature and bio-inspired. Swarms are abundantly found in nature. In the nature animals form into swarms to search food, build nests, to hunt and avoid being hunted etc. Each individual swarm has simple rules of access to a limited amount of information via its immediate neighbors or local environment. Some SI approaches are: Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and honeybee paradigms [152]. The population of the potential solution is called as swarm and each individual in the swarm is defined as particle. The particles fly in the swarm to search their best solution based on experience of their own and the other particles of the same swarm. The (SI) based approaches are more promising from other conventional techniques for optimization problems, due to the nature, architecture, topology and functionality of ad hoc networks. (SI) approaches are more suitable for the routing and energy resources optimization related issues in MANETs. Bio inspired, SI approaches are more promising for Ad-hoc networks due to the prominent aspects such as locality of interactions , availability of multiple paths ,self organizing, failure backup, and ability to adapt in a quick and robust way to topological and traffic changes and component failures.

4.9.3 Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) was developed by Kennedy and Eberhart in 1995, which uses equations to simulate the swarming characteristics of birds and fish. PSO is a computational intelligence oriented, population-based stochastic optimization technique. The use of the PSO algorithm is used to determine an optimum solution. In the PSO algorithm, an optimal solution is found from the social behavior of bird flocking. the aim is discovering patterns that govern the ability of birds to fly synchronously and to suddenly change direction with regrouping in an optimal formation [153].

PSO consist of a group of individuals called particles. The particles fly through a multidimensional search space looking for the best solution. The effective solution can be obtained by using common information of the group and information owned by particles themselves. For better performance, each particle adjusts its velocity time to a time based on its current velocity with respect to its previous best position and also the position of the current best particle in the population. For solving the optimization problems and combinatorial problems PSO algorithm is most useful.

In PSO the population is called the **swarm**. Each particle in the swarm represents a **solution** in a high-dimensional space with five vectors as mentioned in Equations (4.10) – (4.15):

Swarm vector is defined as a set:

$$\boldsymbol{S} = \{\boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_N\} \tag{4.10}$$

N : number of particles (candidate solutions)

Solution vector is subset of the search space **A:**

$$\boldsymbol{x}_i = (\boldsymbol{x}_{i1}, \boldsymbol{x}_{i1}, \ldots, \boldsymbol{x}_{in})^T \in \boldsymbol{A}, i = 1, 2, \ldots, N \tag{4.11}$$

The particles are assumed to move within the search space, *A*, iteratively. This is possible by adjusting their *position* using a proper position shift, called ***velocity***, and denoted as:

Velocity vector:

$$\boldsymbol{v}_i = (\boldsymbol{v}_{i1}, \boldsymbol{v}_{i1}, \ldots, \boldsymbol{v}_{in})^T \in \boldsymbol{A}, i = 1, 2, \ldots, N \tag{4.12}$$

Velocity is updated based on information obtained in previous steps of the algorithm. This is implemented in terms of a memory, where each particle can store the ***best position*** it has ever visited during its search. For this purpose, besides the swarm, **S**, which contains the current positions of the particles, PSO maintains also a ***memory*** set:

$$\boldsymbol{P} = \{\boldsymbol{p}_1, \boldsymbol{p}_2, \ldots, \boldsymbol{p}_N\} \tag{4.13}$$

P contains the ***best positions***

Current position and **updated position:**

$$\boldsymbol{x}^i_{k+1} = \boldsymbol{x}^i_k + \boldsymbol{v}^i_{k+1} \tag{4.14}$$

Updated velocity

$$\boldsymbol{v}^i_{k+1} = \boldsymbol{v}^i_k + \boldsymbol{c_1}\,\boldsymbol{r_1}(\boldsymbol{p}^i_k - \boldsymbol{x}^i_k) + \boldsymbol{c_2}\,\boldsymbol{r_2}(\boldsymbol{p}^G_k - \boldsymbol{x}^i_k) \tag{4.15}$$

Where:

$\boldsymbol{c_1}, \boldsymbol{c_2}$ **:** Cognitive parameter and social parameter, respectively

$\boldsymbol{r_1}, \boldsymbol{r_2}$**:** Random values between [0 , 1]

The PSO detailed operation and simple operation pseudocode, operation flow chart is shown in Table (4.6) , (4.7) and respectively.

Table (4.6) Pseudocode of the detailed operations of PSO

Input	$N; x; c_1; c_1; x_{min}; x_{max}; ; f(x)$ $(objective\ function)$
	$\boldsymbol{Set}\ t \leftarrow 0$
	$\boldsymbol{Initialize}\ x_i(t), v_i(t), p_i(t), i = 1, 2, \ldots, N$
	$\boldsymbol{Evaluate}\ f(x_i(t)), i = 1, 2, \ldots, N$
	$\boldsymbol{Update}$ indices , G_i , of the best particles
	$\boldsymbol{While}\ (stoping\ condition\ not\ met)$
	$\boldsymbol{Update}\ velocites, v_i(t+1)\ and\ particles,\ x_i(t+1), i = 1, 2, \ldots, N$
	$\boldsymbol{Constrain}\ particles\ within\ bounds\ [x_{min}, x_{max}]$
	$\boldsymbol{Evaluate}\ f(x_i(t+1)), i = 1, 2, \ldots, N$
	$\boldsymbol{Update}\ best\ position\ p_i(t+1)\ and\ indices\ G_i$
	$\boldsymbol{If}\ (local\ search\ is\ applied)\ \boldsymbol{then}$
	$\boldsymbol{Choose}\ a\ position\ p_q(t+1),\ q \in \{i = 1, 2, \ldots, N\}$
	$\boldsymbol{Apply}\ local\ search\ on\ p_q(t+1)\ and\ obtain\ a\ solution\ \boldsymbol{y}$
	$\boldsymbol{If}\ (f(y) < f(p_q(t+1))\ \boldsymbol{then}\ p_q(t+1) \leftarrow \boldsymbol{y}$
	$\boldsymbol{Endif}$
	$\boldsymbol{Set}\ t \leftarrow t + 1$
	$\boldsymbol{End\ While}$

Table (4.7) Pseudocode of the simple operations of PSO

Input	Number of particles **N**; swarm **S** ; best position **P**
	$\boldsymbol{Set}\ t \leftarrow 0$
	$\boldsymbol{Initialize}\ \boldsymbol{S}\ and\ Set\ \boldsymbol{P} = \boldsymbol{S}$
	$\boldsymbol{Evaluate}\ \boldsymbol{S}\ and\ \boldsymbol{P}, and\ define\ index\ \boldsymbol{G}\ for\ the\ best\ position$
	$\boldsymbol{While}\ (termination\ criterion\ not\ met)$
	$\boldsymbol{Update}\ \boldsymbol{S}\ using\ Eq. (5.14)\ and\ (5.15)$
	$\boldsymbol{Evaluate}\ \boldsymbol{S}$
	$\boldsymbol{Update}\ \boldsymbol{P}\ and\ redefine\ index\ \boldsymbol{G}$
	$\boldsymbol{Set}\ t \leftarrow t + 1$
	$\boldsymbol{End\ While}$
	$\boldsymbol{Print}\ best\ position\ found$

4.10 Proposed Scheme for QoS Enhancements of OLSR

The proposed scheme is based on three integrated approaches: **a)** simulation, **b)** modeling and performance evaluation of the OLSR, and **c)** optimization. The optimization is used to find efficient OLSR parameter configurations .Fig. (4.3) shows the proposed scheme for enhancing the QoS of OLSR routing protocol for transmitting video conferencing content over MANETs. The major objective is to change the behavior of OLSR such that the modified OLSR copes with critical challenges requirements related to video transmission in bases of minimum (jitter, E2E-delay, retransmission) , highest (PDR, throughput) , less (routing overhead, network load), and adaptive in case of the topology change due to increasing or decreasing the node density and mobility speed. Our work is divided into five integrated phases or steps as illustrated in Fig.(5:

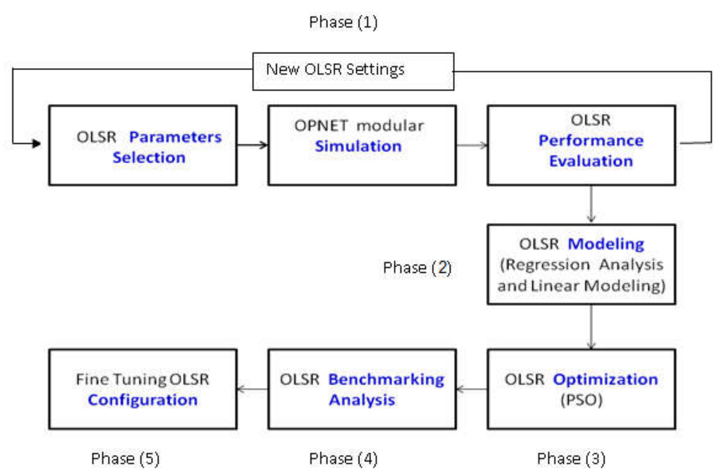


Figure (4.3) Proposed framework for OLSR behavior enhancement

1- ***Simulation of OLSR and parameters selection:*** this stage aims to identify the optimal behavior of OLSR configuration using the proposed algorithm for OLSR parameters selection as shown in the flow chart in Fig. (4.4). Basically, this algorithm is proposed for selecting the OLSR parameters (HELLO, TC... etc) starting with the default values of conventional OLSR (RFC) and then simulating these values via OPNET modular. The QoS metrics such as (E2E delay, jitter, PDR, throughput… etc) are evaluated, analyzed and compared to benchmark values (OLSR-RFC). This process is repeated with precise changes in the behavior of the routing protocol with taking in considerations the ***node density***, ***node speed*** and ***network size*** by changing (increasing or decreasing) control message intervals of the ordinary OLSR routing parameters shown in Table (4.8). At each simulation run, the results are saved and compared to the previous one.

The default value of parameters used in OLSR (RFC 3626) offers moderate QoS. Therefore, considering the impact of the value of parameters on the network performance, we try to discover an optimal value of parameters for OLSR before deployment. There are **eight** parameters (except **ADDRESSING_MODE**) used in OLSR tuning as mentioned in Table (4.8). It can be seen from Table (4.8) that the number of possible combinations of the value of parameters is very large. Further, testing of each set of values of parameters on OPNET individually is impractical. This motivates us to use the meta-heuristic that is capable to solve the combinatorial optimization. The ranges of parameters given in Table (4.8) are considered based on the restrictions posed in modified OLSR.

Table (4.8) Main OLSR parameters and RFC 3626 specified values

Parameter	Standard value (RFC 3626)	Range
WILLINGNESS	3	Z ∈ [0, 7]
HELLO_INTERVAL	2.0 sec	R ∈ [2.0, 15.0]
REFRESH_INTERAL	2.0 sec	R ∈ [2.0, 15.0]
TC_INTERVAL	5.0 sec	R ∈ [4.0, 35.0]
NEIGHB_HOLD_TIME	3×HELLO INTERVAL	R ∈ [5.5, 45.0]
TOPOLOGY_HOLD_TIME	3× TC_INTERVAL	R ∈ [10.5, 90.0]
MID_HOLD_TIME	3× TC_INTERVAL	R ∈ [10.5, 90.0]
DUBLICATE_MESSAGE_HT	30.0 sec	R ∈ [10.5, 90.0]
ADDRESSING_MODE	IPV4	

To analyze the different sets of values of parameters (solutions), we have used three well known QoS parameters which are defined in Chapter (4) and mentioned with Equations from (4.1) throughout (4.5) for the E2E delay, PDR, jitter, throughput, and NRL respectively.

2- ***OLSR- QoS modeling:*** we obtained from the previous phase the QoS metrics observed such as (E2E, jitter, PDR, throughput) of the optimal OLSR parameters. We created from phase (1) a Multivariate Linear Regression Models (MLRM) for each metric using the Analysis of Variances (ANOVA). Each model is a linear equation, where the E2E delay, jitter, PDR, throughput are responses (dependent variables) and the number of mobile nodes (***n***), mobility speed (***s***) and network size(***z***) are predictors (independent variables). When using these models shown in Equation (4.16) throughout Equation (4.19), we can estimate or predict the QoS metrics at any given state of the network.

$$\mathrm{E2E}_{\mathrm{dely}} = f_1\,(n\,,s\,,z) \tag{4.16}$$

$$\text{Jitter} = f_2(n\,,s\,,z) \tag{4.17}$$

$$\text{PDR} = f_3(n\,,s\,,z) \tag{4.18}$$

$$\text{Throughput} = f_4(n\,,s\,,z) \tag{4.19}$$

Each metric (response) mentioned above can be expressed as a linear equation as we have expressed above in the above mentioned Equation (4.3).

3- ***PSO optimization for QoS :*** We used the Particle Swarm Optimization (PSO) as one of the Bio-inspired techniques to find the best solution to overcome the problem of predicting QoS of any network under certain conditions to satisfy specific metrics values (min (delay, jitter), max (PDR, throughput), and so on). We constructed for each metric a linear model of an objective function or what is called fitness function. The objective function may be minimized in case of (E2E delay, jitter) or may be maximized in case of (PDR, throughput). The PSO technique finds the optimum solution required to satisfy certain conditions after complex iterations. Table (4.6) and Table (4.7) show the basic ideas of PSO. The objective function can be of the form in Equation (4.20).

$$QoS_{max}(E2ED, jitter\,, PDR) = \alpha \cdot f_1 + \beta \cdot f_2 + \gamma \cdot f_3 + \delta \cdot f_4 \tag{4.20}$$

4- ***OLSR QoS Benchmarking Analysis:*** when we are going through the literature of optimizing or tuning OLSR routing parameters under certain network conditions based on the number of nodes, node speed, and network size .There are remarkable contributions in this area of research since video transmission over MANETs has become an interested area of research to both the academic and industry communities. In this phase, we compared our new findings to the most recent contributions related to the improvement of the QoS of OLSR for transmitting video contents over MANETs.

5- ***Fine tuning of OLSR:*** in this phase, we used the results obtained to configure OLSR using the fine-tuning parameters to cope with video transmission over MANETs which requires a restricted level of QoS. For this purpose, we created a design criterion scheme for MANETs networks structured randomly to overcome the QoS, power management and security challenges.

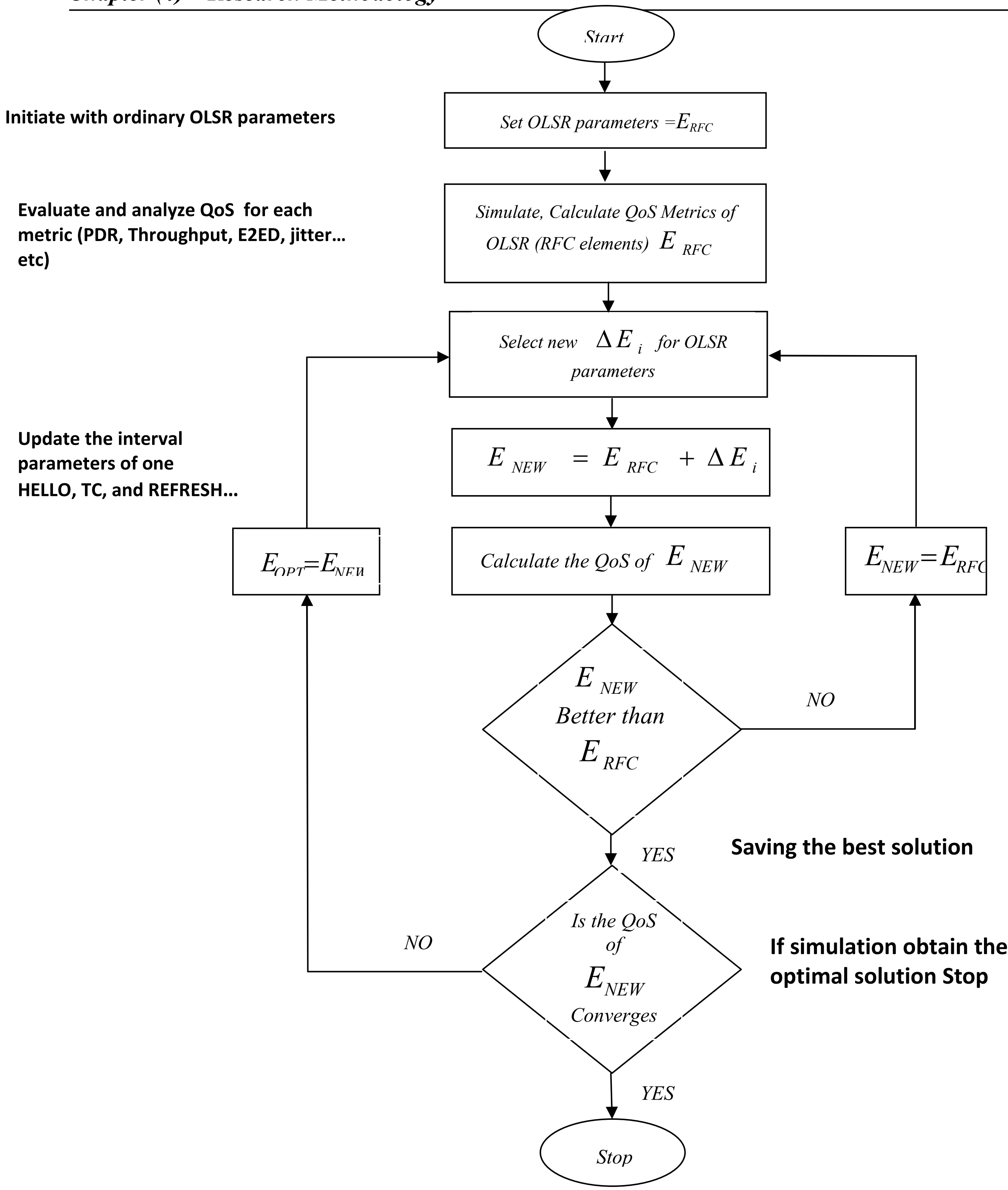


Figure (4.4) Proposed algorithm for OLSR parameters selection

The proposed framework model is restricted to enhancing the QoS of video streaming over MANETs based on OLSR routing protocols and is shown in Fig.(4.5). At the beginning we simulate different scenarios of MANET networks for transmitting video conferencing based on conventional OLSR. Our implemented scheme consists of coupling two parts, one is an optimization algorithm using PSO swarm intelligence and other is solution evaluation using network simulator OPNET as shown in Fig. (4.5). By using PSO as an optimization algorithm, our scheme has the ability to generate solution vectors which are called a population. Each population represents a set of HELLO interval values for nodes used for network deployment. By using OPNET simulator, each population is evaluated and produces global information about the network such as jitter, PDR, throughput, E2E-delay, and Network Routing Load (NRL). This information is used to compute the fitness function as follows:

$$Fitness_{function(1)} = w_1 \times jitter + w_2 \times \text{E2Edelay} - w_3 \times PDR \qquad (4.21)$$

The above fitness function shown in Equation (4.21) is aggregative minimizing function and his goal is minimizing both ***jitter*** and ***E2Edelay***, in other hand, maximizing ***PDR***. For this reason PDR was formulated with a negative sign. The factors w_1, w_2 and w_3 are weights used to give the importance of each metric on the resultant fitness value. Since the goal of our scheme is to enhance the routing effectiveness without damaging communication efficiency, we decided to initialize w_1, w_2, w_3 with values 0.3, 0.2 and 0.5 respectively [154, 155].

Another fitness function is proposed as a maximizing function mentioned in Equation (4.22) and its goal is to maximize the ***throughput*** and PDR***,*** and on the other hand minimized the Normalize Routing Load (***NRL***). Those metrics are desired for any optimum performance of MANET networks.

$$Fitness_{function(2)} = w_1 \times NRL - w_2 \times throughput - w_3 \times PDR \qquad (4.22)$$

However, most of the recent research works focused on the model mentioned in Equation (5.21), i.e. solving a single fitness function instead of multi-functions. The originality of our work is to solve a multi-constraint fitness functions to show the impact of the tuned OLSR in different QoS metrics.

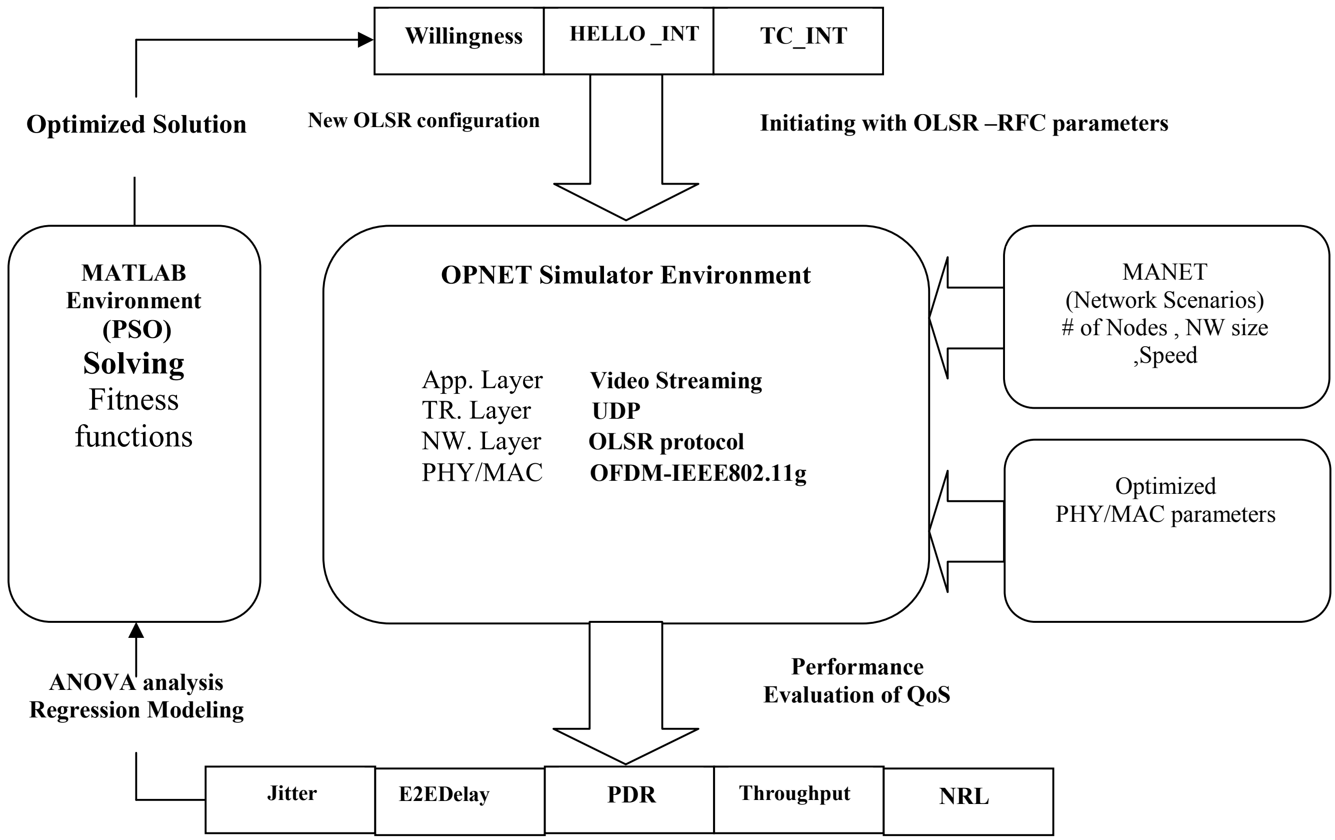


Figure (4.5) Optimization framework proposed for QoS-OLSR configuration

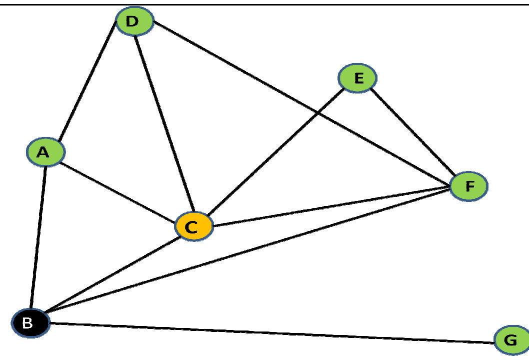
4.10.1 OLSR Tuning Algorithm

Optimized Link State Routing (OLSR) is a proactive link state routing protocol specifically designed for ad hoc networks with low bandwidth and high mobility. OLSR uses a subset of special nodes of the network that act as multipoint relays (MPRs) to periodically broadcast the routing control information. This way, it reduces the number of required transmissions, and therefore, the network workload. The core functionality of this protocol mainly consists of two processes: neighborhood discovery and topology dissemination that exchange four different types of messages. Fig. (4.6) and Table (4.9) show the concept of MPRs selection and the control messages used in OLSR protocol.

Table (4.9) OLSR control messages and their functionality

Control Message	Functionality
HELLO	Periodically exchanged between neighbor nodes (1-hop distance) to obtain the neighborhood information and MPR selection signaling.
TC (Topology Control)	Generated and retransmitted for flooding topological information in the whole network only through mprs nodes

MID (Multiple Interface Declaration)	Generated and sent by the OLSR nodes to report information about their network interfaces employed to participate in the network.
HNA (Host and Network Association)	Provides the external routing information by giving the possibility for routing to the external addresses.



Node	1- Hop Neighbor	2 -Hop Neighbor	MPR selected
B	A, C, F, G	D, E	C

Figure (4.6) OLSR : 1-hop and 2-hop communication

OLSR has several features that makes it suitable for highly dynamic MANET networks:

1- It is well suited for high-density networks, with concentrated communication between large numbers of nodes.
2- It is useful for applications requiring short delays in the data transmission, as most of the warning information in MANETs.
3- The protocol information can be extended with data to allow the hosts to know in advance the quality of the routes.
4- It permits an easy integration into existing operating systems and devices, including smart-phones, embedded systems, without changing the header of the IP messages.
5- It manages multiple interface addresses for the same host, allowing MANETs nodes to use different network interfaces such as Wi-Fi and Bluetooth.

Adapting or tuning the OLSR routing protocol behavior has recently gained a lot of attention research works. The key messages in OLSR are HELLO and TC messages. HELLO messages are periodically exchanged to inform nodes about their neighbors and their neighbors and are 1-hop broadcast messages [125]. The 2-hop neighborhood information is then used locally by each node to determine MPRs. In contrast, TC messages are flooded through the network to inform all nodes about the (partial) network topology. At a minimum, TC messages contain information about MPRs and their MPR selectors. There are few parameters in OLSR which can control the efficiency of OLSR.

The Hello-interval parameter represents the frequency of generating a HELLO message. Increasing the frequency of generating Hello messages leads to more frequent updates about the neighborhood and hence a more accurate view of the network and results in additional overhead. The TC-interval parameters represent the frequency of generating a TC message and are used for topology discovery. If the frequency of TC messages is increased then nodes have more recent information about topology, as nodes leave and enter the network very frequently. The MPR-coverage parameter allows a node to select redundant MPRs. The number of MPRs should be a minimum as it introduces overhead in the network. But the more MPRs the more is the reachability.

The TC-redundancy parameter specifies, for the local node, the amount of information that may be included in the TC message. The TC-redundancy parameter affects the overhead by affecting the number of links being advertised as well as the number of nodes advertising links. Through the exchange of OLSR control messages, each node accumulates information about the network. This information is stored according to the OLSR specifications. Timestamp with each data point and modify the control messages and local repositories accordingly. For better efficiency of OLSR state information such as residual energy level of each node, bandwidth, queue length, etc should be available while making routing decisions. Incorrect information may lead to degradation in the efficiency of OLSR. As state information in OLSR is collected by Periodic Exchange of above-mentioned messages, this information may not be up to date as topology changes very fast. The residual energy level of the nodes changes rapidly and the node with less energy level must not be selected in route. The main focus here is the effect of residual energy levels on protocol efficiency. The main thing is how nodes can collect accurate energy level information about other nodes by OLSR control messages. Traffic load can be one factor that can affect the inaccuracy of energy level information.

However, there is importance to adjust the OLSR routing parameters to reasonable values which can guarantee the QoS of different applications especially video conferencing. Our assumptions go into the following steps:

(1)- In the case of low mobile density and slow mobile nodes, there is no rapid change in topology. Therefore, frequent HELLO and TC will result in a routing overhead and from then congested network. So the HELLO and TC intervals must be greater than the standard value in order to avoid packet loss and low PDR.

(2)- In the case of middle/high mobile density and high-speed mobility, there is a great and rapid topology change. Increasing the mobility and the scalability will increase the traffic load that will cause degradation on the QoS. We need to change the HELLO and TC intervals by decreasing its interval times to values that can provide an adequate sense for topological changes and at the same time that can maximize the overall performance and QoS without increasing the network load.

We analyzed the impact of sending more frequent Hello and TC messages (by reducing Hello and TC intervals) as well as more redundant topology information (by increasing TC redundancy and MPR-coverage parameters). Choosing very small values for Hello and TC intervals will significantly increase the protocol overheads, in particular for TC messages that are flooded throughout the network. While this may be beneficial to the accuracy of the collected state information, the increased control message overhead would be quite detrimental to the data traffic and consume a non-trivial amount of energy. We, therefore, explored neither very small Hello message intervals (less than 1 s) nor small TC message intervals (less than 3 s).Our finds when implementing the OLSR tuning algorithm provides a new configuration for the OLSR routing protocols. The new or modified parameters enhanced the overall performance of OLSR.

4.11 Chapter Summary

A comprehensive study of the QoS metrics required for video transmission effectively and efficiently are been discussed in this chapter. The RWP mobility model and it is limitations are explained, since it is one of the most important mobility models, . In addition, the network simulation models are identified with it is parameters.

The proposed solution frame works, the OLSR parameters selection, and tuned parameters desired to optimize it are also explained. ANOVA and PSO are modeling and optimization techniques respectively, their roles in modeling the QoS metrics and optimize MANET considering the mobility speed and node density was described.

Chapter Five

Simulation Results of Video Conferencing over MANET

5 Simulation Results of Video Conferencing over MANET

5.1 Introduction

In the previous chapter, a detail routing techniques for MANET were discussed and some examples were presented. This chapter analyzes the key issues and limitations for the provision of video conferencing services over MANET. In particular, the performance evaluation of the QoS of MANETs routing protocols such as reactive routing protocols (AODV and DSR), proactive (OLSR and TORA), and hybrid protocols such as GRP in terms of end-to-end delay, jitter, packet delivery ratio (PDR %), throughput, and other QoS parameters. The performance analysis has been focusing on identifying which MANET routing protocols grantee the QoS of video streaming over MANET and cope with the scalability and mobility challenges. These routing protocols are studied through simulation experiments under OPNET 14.5 modular, which allow understanding the reasons for the quality degradation incurred during the video transmission over MANET and under which conditions the QoS will remain acceptable.

5.2 RWP Simulation Setup

The Random Waypoint (RWP) model proposed by (Johnson and Maltz 1996) [156]**.** Become one of the most popular mobility models or a 'benchmark' mobility model to evaluate the performance of MANET routing protocols under their mobility pattern, because of its simplicity, availability and straightforward stochastic model. Most of the simulation tools supported by (RWP), in this simulation RWP has been modeled by the OPNET 14.5 modular and their parameters explained in Table (5.1).

Table (5.1): RWP simulation parameters in OPNET

Parameter	**Value**
x_max (meters)	500
y_max (meters)	500
Speed meters/seconds)	uniform_int (0, 10) for low mobility and, uniform(10,25) for high mobility
Pause Time (seconds)	constant (100) for low mobility and constant(0) for high mobility
Start Time (seconds)	constant (100)
Stop Time(seconds)	End of Simulation

5.3 MANETs Traffic parameters and Video Traffic parameters

Tables (5.2) and (5.3) illustrate the MANET traffic generation parameters and video conferencing parameters respectively.

Table (5.2): MANET Traffic Generation Parameters

Parameter	Value
Start Time (seconds)	100
Packet Inter-arrival Time (sec)	Exponential 1
Packet Size (bits)	Exponential 1024
Destination IP Address	Random
Stop Time (sec)	End of Simulation

Table (5.3): Video conferencing Parameters

Parameter	Value
Application	High Resolution Video Streaming
Frame Size Information (bytes)	128X240 pixels
Frame inter-arrival time	15 frames/sec
Type of Service	Best effort(0)
Application Segment Size	64.000 or 32.000
Frame Size	256
Maximum available bandwidth (MHz)	10

5.4 AODV, OLSR, TORA, DSR, and GRP Protocols Parameters

The simulation was performed and implemented to the conventional or the (RFC) values of each protocol. Table (5.4) shows all the required parameters for MANET routing protocols under investigation.

Table (5.4): AODV, OLSR, TORA, DSR, and GRP protocols parameters

Parameter	Value
AODV	
Active Route Timeout (sec)	3
HELLO Interval(sec)	uniform (1, 1.1)
Allowed HELLO Loss(sec)	2
Net Diameter	35
Node Traversal Time(sec)	0.04
Route Request Retries	5
Route Request Rate Limit (pkts/sec)	10
Route Error Rate Limit (pkts/sec)	10
Timeout Buffer(sec)	2
OLSR	
Willingness	Default=3

HELLO Interval (sec)	2.0
TC Interval (sec)	5.0
Neighbor Hold Time (sec)	6.0
Topology Hold Time (sec)	15.0
Duplicate Message Hold Time (sec)	30.0
TORA	
OPT Transmit Interval (seconds)	300
IP Packet Discard Timeout (seconds)	10
Max Retries (number of attempts)	3
Beacon Period (seconds)	20
Max Beacon Timer (seconds)	60
DSR	
Route Expiry Timer (seconds)	300
Expiry Timer (seconds)	30
Request Table Size (nodes)	64
Maximum Request Period (seconds)	10
Initial Request Period (seconds)	0.5
Maximum Buffer Size (packets)	50
Maintenance Hold off Time (seconds)	0.25
Maximum Maintenance(Retransmissions)	2
Maintenance Acknowledgement Timer (seconds)	0.5
Broadcast Jitter (seconds)	uniform (0, 0.01)

5.5 Implementation and Analysis

The simulation has been implemented among three different MANETs network models in order to show the impact of the scalability (node density per network size) and mobility speed on the performance of the desired routing protocols (AODV, OLSR, TORA, DSR, and GRP).

5.5.1 Network Model: Small Scale - Low Density

This section presents the experimental results along with the analysis of the simulations, where the most significant routing protocol metrics (E2ED, jitter; PDR, AE2ED, throughput, retransmission attempts, WLAN-load, total packets dropped, routing overhead and network load) are measured.

5.5.1.1 Video Conferencing –End-to-End Delay (E2ED)

To measure performance of video conferencing in MANET we follow E2ED delay that includes all possible delays caused by buffering during route discovery latency as mentioned in section 4.3. E2ED is an important metric for evaluating the QoS of video conferencing over MANET and it is desirable to be very low. Results depicted in Table (5.5), and Fig. (5.1) show the E2ED of the network for video conferencing traffic; the E2ED is low and very low with respect to AODV and OLSR respectively. AODV protocol cannot set up the node connection quickly and it creates larger delays in the network. Due to the reactive approach nature of the AODV protocol, it is highly possible that the data packets wait in the buffers, till it discovers a route on its way to the destination node.

Table (5.5): Small Scale: E2ED Vs Node Density

# Nodes	AODV	OLSR	DSR	TORA	GRP
5	0.027023984	0.102900154	0.242462174	0.131182642	0.126678348
10	0.121174083	0.018528821	0.142327023	0.127100544	0.094956645
15	0.145199836	0.025819977	0.053152581	0.072346479	0.112618485
20	0.082804194	0.019055225	0.564481955	0.060341974	0.179601287
25	0.024227272	0.01861592	0.831847103	0.333630066	0.333630066
30	0.001296534	0.299272659	1.327509406	1.718714252	0.734189205
35	1.50658914	0.517147411	0.987810222	2.681859901	0.899918134

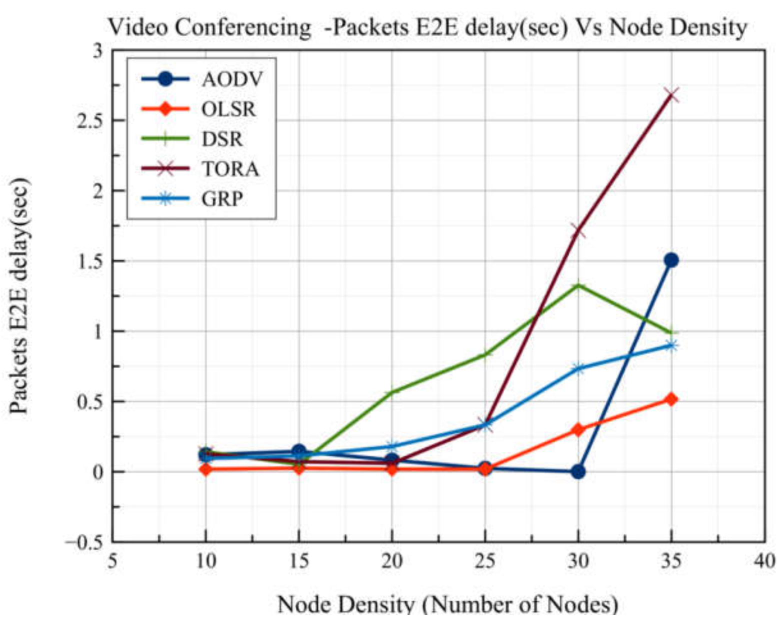


Figure (5.1) Small Scale: VC- E2ED (sec) Vs Node Density

In time a RREQ packet is transmitted for the purpose of route discovery, the destination node replies back to all nodes for the same route request packet that it receives, thus, they need larger time to determine the lowest congested route.

For the real-time traffic due to the larger size of video packets, it needs more time to be transmitted through the route, therefore the video traffic delay increases steadily with increasing congestion in the network, since nodes are only allowed to transmit when the available bandwidth is enough. On the other hand, OLSR protocol set up quick connections between network nodes without creating major delays for real time traffic. This is because that the OLSR protocol does not need much time in a route discovery mechanism. Also we can observe that the E2ED is very high in case of TORA and DSR and moderate in case of GRP. However we can say that OLSR has better performance in terms of E2ED.

5.5.1.2 Video Conferencing –Packets Delay Variation (jitter)

Delay variation (jitter) is a result of network congestions and network interference. Jitter is important to determine the size of play out buffers for applications requiring the regular delivery of packets like voice or video play out. Jitter is a critical metric for evaluating the QoS of video conferencing as mentioned in Table (4.2).From our simulation results as shown in Table (5.6) we found that AODV and OLSR perform better than the other routing protocols, for the low density of mobile nodes [5~25], OLSR achieving *very low* values of jitter [0~3 ms] but AODV achieving low values [0.1 ~235 ms], while AODV is better if the number of nodes increase.

Table (5.6): Small Scale: Delay Variation (Jitter (sec)) Vs Node Density

# Nodes	AODV	OLSR	DSR	TORA	GRP
5	0.000183423	0.003448025	0.094246255	0.06550923	0.006080237
10	0.019962437	4.79E-06	0.096633919	0.322217691	0.004004765
15	0.235917532	3.46E-05	0.064230991	0.055537842	0.006836796
20	0.041478442	9.27E-06	0.069878844	0.001751031	0.007883454
25	0.000128296	5.07E-06	1.929608963	0.031555488	0.031555488
30	0	0.027467944	1.093092086	8.832856764	0.148378692
35	0	0.102887391	0.389130904	9.899823159	0.200358767

TORA sends more updated packets, whereas an acknowledgment of the retransmitted update packet might not be received, resulting in a serious congestion of the network. TORA and DSR are the worst protocols in terms of jitter as shown in Fig. (5.2), when the number of mobile nodes increases the jitter will increase specifically in case of TORA and this is due to the routing protocol structure. GRP goes after OLSR and AODV because it position-based routing, where position accuracy determines whether the correct routes are selected.

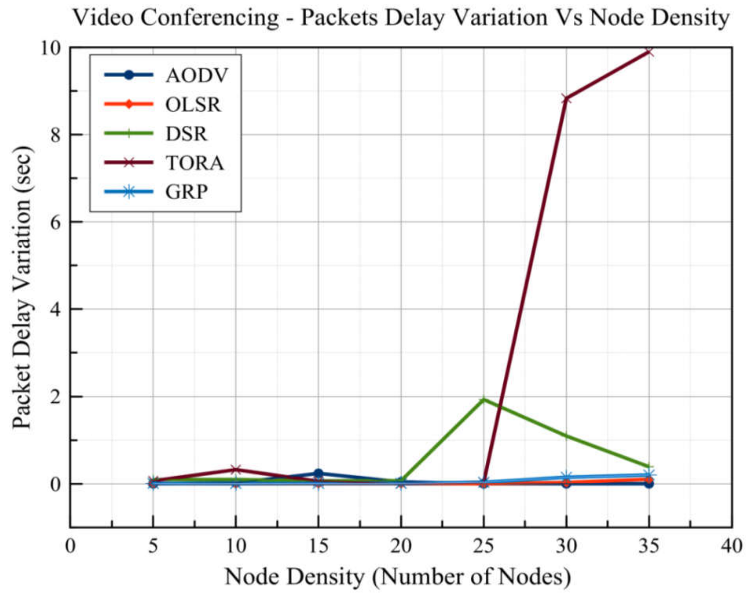


Figure (5.2) Small Scale: VC -Jitter (sec) Vs Node Density

5.5.1.3 Video Conferencing –Packets Delivery Ratio (PDR %)

PDR represents the reliability of the network. For video traffic over MANET ,this metric is desired very high (100%), but practically can't be reached this value due to the packet dropped in case of buffer overflow, MAC congestion, link failure , and exceeding retransmission timeout. Based on ITU-T and Internet Engineering Task Force (IETF) recommendations, PDR% must not exceed 2% as illustrated in Table (4.2).

In the investigation of which MANET routing protocol has high reliability, simulation showed that OLSR and AODV have efficient performance in terms of PDR%.

Table (5.7): Small Scale: Video Conferencing PDR % Vs Mobile Density

# Nodes	AODV	OLSR	DSR	TORA	GRP
5	99.44	32.81	24.28	19.20	32.96
10	31.75	99.99	19.50	24.84	28.86
15	41.20	99.94	56.43	44.75	20.38
20	39.55	99.98	4.42	59.21	15.27
25	25.00	99.99	0.93	24.90	11.12
30	0.00	15.70	0.05	1.25	0.49
35	0.00	3.33	0.03	0.80	0.33

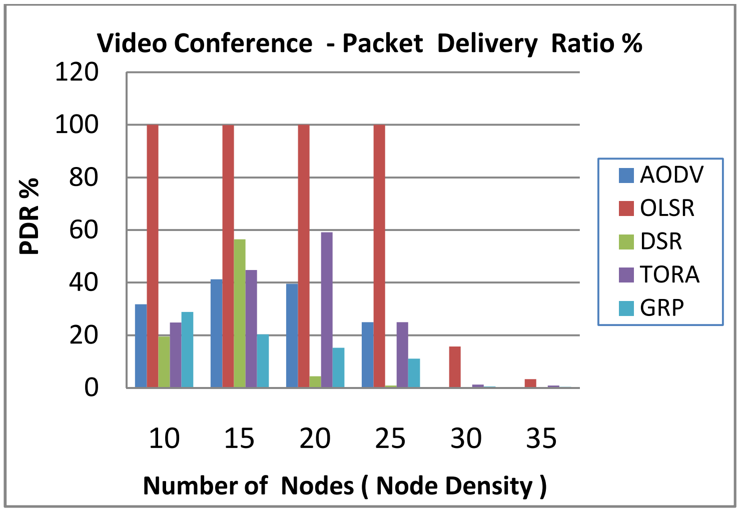


Figure (5.3) Small Scale: VC –PDR% Vs Node Density

As shown in Table (5.7), and Fig. (5.3) OLSR outperforms all of the routing protocols when the number of nodes into the range [10~25 nodes]. PDR% is drastically dropped to an unacceptable value (15%) when the number of nodes increased. However, there is a great impact of the mobile density on the PDR%, when MANET is extended (scalable) and becomes highly dynamic, this will cause packet loss which leads to low PDR%.

5.5.1.4 Video Conferencing –Throughput (bits/sec)

Throughput measures the robustness of the network; it is observed from the simulations that when the number of mobile nodes is small, the optimum throughput can be achieved. The effectiveness of a routing protocol is measured through the throughput measurement which is the number of packets received by the receiver within certain time interval. Table (5.8) shows the measurement of throughput among all of the routing protocols under investigation. Two different routing protocols perform better in terms of throughput; AODV and GRP have the highest throughput in all mobile densities.

As shown in Fig.(5.4), AODV throughput decreases moderately as number of nodes increase, but the worst impact is observed in OLSR where throughput declines appreciably as network size increases. DSR and TORA have similar performance in terms of throughput. TORA performs better with higher throughput than DSR and OLSR, because TORA makes a Direct Allocation Graph (DAG) of all the nodes first then start sending packets. Since it does not engage in the route discovery again and again and already have a DAG of all the nodes in the network, the performance metrics of TORA clearly dominate the other two routing protocols OLSR and DSR.

Table (5.8): Small Scale: Throughput (bits/sec) measurements Vs Mobile Density

# Nodes	AODV	OLSR	DSR	TORA	GRP
5	14,911,729.88	15,321,766.68	14,419,082.97	15,072,761.32	15,366,614.61
10	15,043,999.11	4,822,244.91	14,417,720.04	15,044,561.23	15,428,837.63
15	15,200,325.89	9,823,902.79	15,296,109.59	15,020,931.40	15,308,320.83
20	15,641,737.51	9,991,742.13	14,514,779.91	15,145,664.97	15,273,946.50
25	15,501,561.74	9,848,324.22	8,985,975.63	14,052,295.39	14,052,295.39
30	14,345,297.52	14,026,820.01	11,242,515.40	10,060,791.80	12,582,702.96
35	12,948,772.48	13,409,211.34	10,404,867.13	8,844,707.04	12,131,597.77

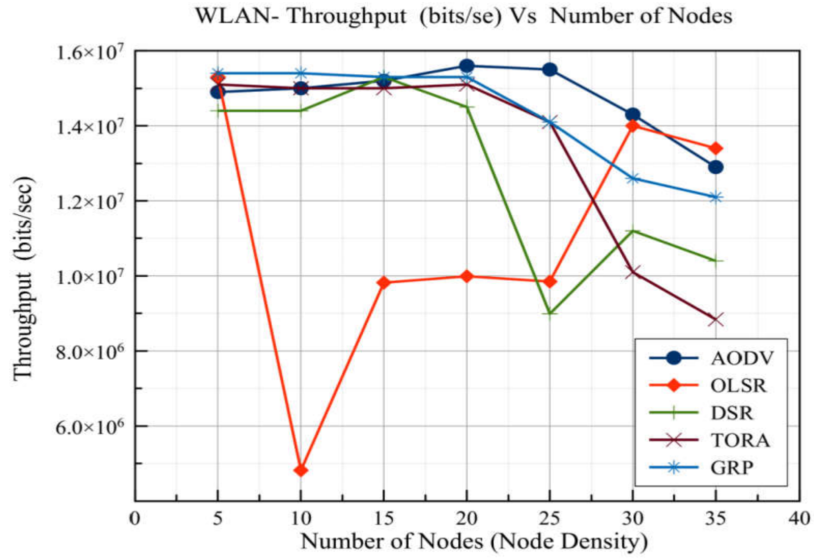


Figure (5.4) Small Scale: Throughput Vs Node Density

5.5.1.5 Video Conferencing- Data Dropped (bits/sec)

When a packet arrives at the network layer, the routing protocol forwards the packet if a valid route to the destination is known. Otherwise, the packet is buffered until a route is available. A packet is dropped in two cases:

a) The buffer is full when the packet needs to be buffered.
b) The time that the packet has been buffered exceeds the limit.

As illustrated in Table (5.9) and Fig. (5.5) founded that OLSR is outperforms other protocols in all mobile densities and has a capability to transmit real-time data which is sensitive to information loss.

Table (5.9): Small Scale: Data Dropped (bits/sec) vs Mobile Density

# Nodes	AODV	OLSR	DSR	TORA	GRP
5	0	1,361.62	1,853.15	1,453.49	1,622.39
10	15,355.98	0	1,944.97	1,472.06	979.5953756
15	19,024.89	0	92.73296246	746.9526012	1,621.69
20	13,439.24	2.161564504	2,267.07	792.93	2,140.15
25	23,951.35	0	29,343.32	17,540.11	17,540.11
30	39,699.74	11,879.76	65,551.24	37,619.67	68,389.20
35	42,167.44	39,979.05	125,667.77	54,293.68	108,936.50

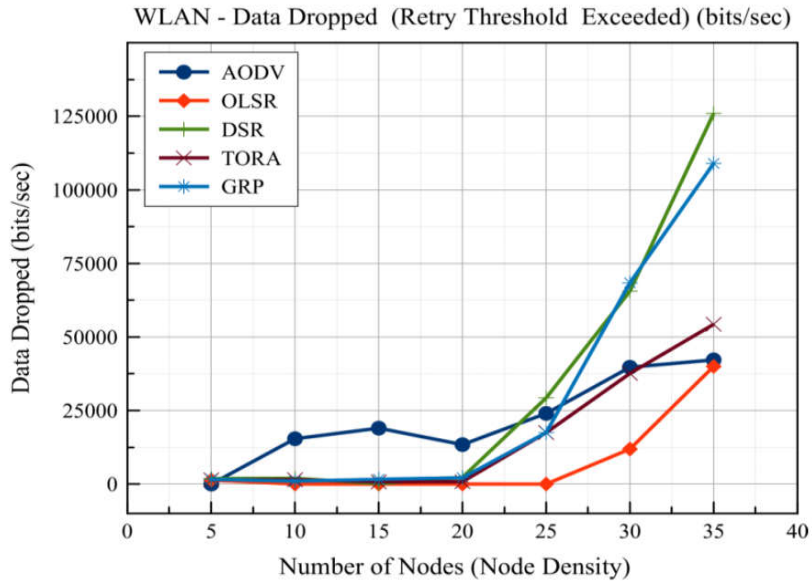


Figure (5.5) Small Scale: Packets Dropped Vs Mobile Density

5.5.1.6 Video Conferencing – Routing Overhead (packets/sec)

In MANETs the nodes are continuously moving, this mobility of nodes causes continuous link breakage due to which frequent path failure occurs and route discoveries are required. The fundamental mechanism for route discoveries is broadcasting in which the receiver node blindly rebroadcasts the first received route request packet unless it has a route to the destination.

This mechanism incurs retransmission which causes overhead and decrease the PDR and increase the E2ED, which cannot be avoided. MANET routing protocols (e.g. AODV, OLSR, etc..) have to cope with dynamic topology by continuously monitoring topology changes and disseminating such information over the whole network. Proactive protocols provide fast response to topology change but at the price of increased overhead of control traffic. As shown in Table (5.10) and Fig. (5.6) the proactive protocols (OLSR and TORA) have less routing overhead in small-scale model, because the topology change is rare and mobility speed is low. The worst protocol in all cases is DSR.

Table (5.10): Small Scale: Routing overhead Vs Mobile Density

# Nodes	AODV	OLSR	DSR	TORA	GRP
5	1,222.13	920.5537764	36,216.60	160.3489	540.9412
10	2,616.36	640.8329579	31,221.20	1,601.59	1,169.09
15	3,530.80	638.6566909	24,940.26	2,517.53	1,789.98
20	4,596.76	2,168.63	22,558.87	3,053.22	3,002.11
25	6,278.08	2,174.93	178,294.33	0	4,430.17
30	11,919.51	4,884.96	50,048.63	25,022.69	6,061.62
35	52,948.65	8,387.73	53,198.57	22,955.15	7,823.57

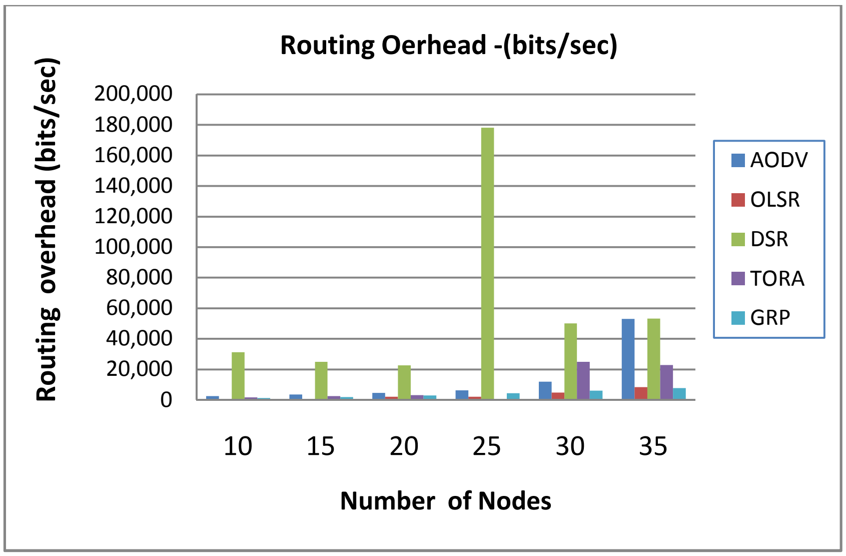


Figure (5.6) Small Scale: Routing Overhead Vs Mobile Density

5.5.1.7 Summary Results of the Small-Scale Model

From the previous comprehensive performance evaluation of MANETs routing protocols AODV, OLSR, TORA, DSR and GRP for small-scale network model we conclude that:

A. OLSR outperform the other routing protocols as shown in Table (5.11) specially in desirable metrics for video conferencing over MANET such as :

— Packet E2E delay (ms)

— Packet Delay Variation (Jitter)

— Packet Delivery Ratio (PDR %)

Also OLSR maintains a performance among IEEE802.11g- WLAN in terms of:

— Throughput (bits/sec)

— Network Load (bits/sec)

— Retransmission Attempts (packets)

B. AODV and GRP routing protocols are effective and capable for video transmission over MANTs.

C. DSR is the worst in all QoS metrics and this was due to DSR algorithm that uses source routing and route caches. Sending of traffic onto stale routes causes retransmissions and leads to excessive delays and also maintains multiple routes per destination which increases the routing overhead.

D. TORA suffers higher delay in case of video streaming. One of the factors responsible for the poor performance of TORA is related to its formation of temporary loops within the network and collisions held, thus the links to neighbor nodes are broken. Besides, in response to link failures, TORA sends more updated packets, whereas an acknowledgment of the retransmitted update packet might not be received, resulting in a serious congestion of the network [51].

E. DSR and TORA routing protocols, are the poorest in performance compared to AODV, OLSR and GRP in small -scale network model. Therefore we can conclude that both of them are not capable for real–time video transmission, and they are discarded in the next scenario for investigating the feasibility of video transmission over MANETs in (large-scale/high dense nodes/ high mobility).

Table (5.11): Small Scale: Summery Results

Metrics	Protocols				
	AODV	OLSR	TORA	DSR	GRP
Packet E2E delay (ms)	Low	V. Low	High	V. High	Low
Packet Delay Variation(Jitter/ms)	Low	V. Low	V. High	High	V. Low
Packet Delivery Ratio (PDR %)	V. Low	High	Low	V. Low	Low
WLAN-End-to-End Delay (sec)	Low	V. Low	High	V. High	Low
Throughput (bits/sec)	V. High	Low	High	Low	High
Retransmission Attempts(packets)	Less	V. Less	Moderate	Moderate	Moderate
Network Load (bits/sec)	Low	V. Low	Moderate	V. High	High
Total Packets Dropped (packets)	High	V. Less	High	V. High	V. High
Routing Overhead (packets/sec)	Low	V. Low	Low	V. High	Low

5.5.2 Network Model: Medium /Large scale - High density:

Further results are collected for a large network. As shown in the first scenario (Small-Scale) have been founded that OLSR, AODV, and GRP are capable for transmitting real-time video traffic such as video conferencing and video streaming contents. In this part we simulate the three routing protocols under two network sizes (1000x1000 m^2 and 1500x1500 m^2) with mobility density between (40 ~ 100 nodes) and node speed between (20 ~ 35 m/s) respectively. The following is the results gained from our simulation:

5.5.2.1 Video Conferencing –E2E Delay

Reactive protocols (On-demand) need time for route discovery, therefore, the communication latency or E2ED increases. During route discovery AODV protocol produces a large amount of routing traffic by blindly flooding the entire network with RREQ packet which increases the E2ED and the routing overhead. As shown in Table (5.12), and Fig. (5.7), the reactive protocol AODV has a very high E2ED in medium and high density of mobile nodes. OLSR has a high E2ED when compared to GRP which is position based routing protocol and also classified as proactive routing protocol. In GRP each mobile node is assisted with Global Positioning System (GPS) which is used to determine and mark the location of the node and flooding will be optimized by quadrants.

Table (5.12): Middle – Large Scale: E2ED Vs Mobile Density

Node Density	AODV	OLSR	GRP
40	0.453699	0.630912	0.586034
50	0.385387	0.264429	0.344123
60	0.445169	0.116587	0.489687
70	0.342405	0.168401	0.308636
80	0.065558	0.852037	0.605469
90	2.145617	1.049566	0.512508
100	2.620332	1.179383	0.443905

Therefore the E2ED is very low in case of GRP and it's clear that it has a capability to transmit video traffic in dense network. According to the ITU-T standards mentioned in Table (4.2) for the allowed E2ED in seconds we can say the fact that all the three routing protocols are in the range [4~5 sec] for video streaming. OLSR outperforms AODV and GRP in the mobile densities between [50~70 nodes], while GRP outperforms in the case of high density of nodes and large scale network model. However, it is feasible to use geographical or position based routing protocols for video transmission in case of dense networks.

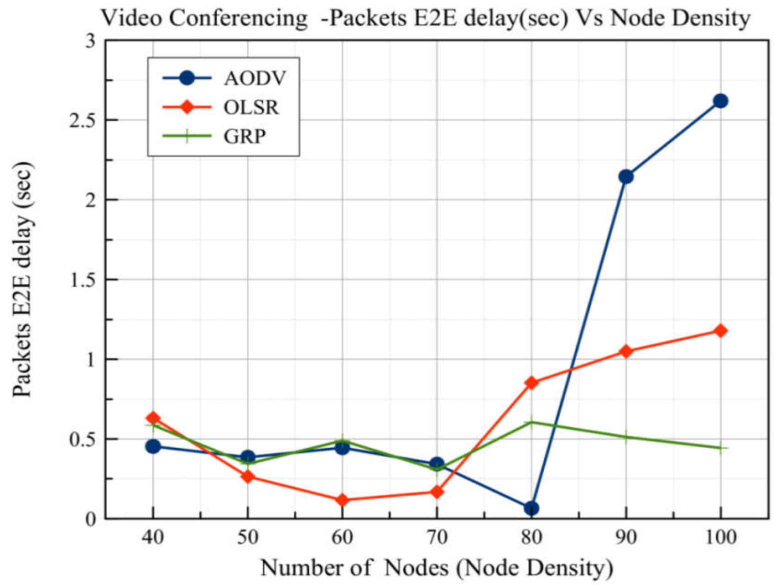


Figure (5.7) Middle – Large Scale: E2ED (sec) Vs Mobile Density

5.5.2.2 Video Conferencing – Jitter (sec)

As shown in Table (5.13) and Fig. (5.8), as the number of nodes starts to increase jitter in AODV increases (97.42 sec with 60 mobile nodes), which is not acceptable compared with desired values according to table (4.2).

Table (5.13): Middle – Large Scale: Jitter (sec) Vs Mobile Density

Node Density	AODV	OLSR	GRP
40	33.27422687	3.487836598	0.411030016
50	59.3276473	1.553671049	0.169847542
60	97.42771037	0.188368214	0.281619867
70	7.728666843	0.595700226	0.168644812
80	45.63733141	3.428668972	2.060207478
90	60.12627752	5.268830537	1.684856999
100	40.20718261	20.42955231	0.463333032

Therefore AODV is very poor and worst in terms of jitter because AODV is generally a demand based routing protocol. Geographical protocols take advantage of nodes location information to compute routes and this will improve scalability and reduce the network traffic. GRP outperform AODV and OLSR in terms of jitter due to its accuracy in determining the position and computing the path between the source and destination and at the same time maintain the link breakage efficiently. The jitter value in case of GRP is out of range [169 ms at

50nodes~2sec at 80 nodes], but if we reconfigure it with suitable parameters we will enhance its performance in terms of jitter.

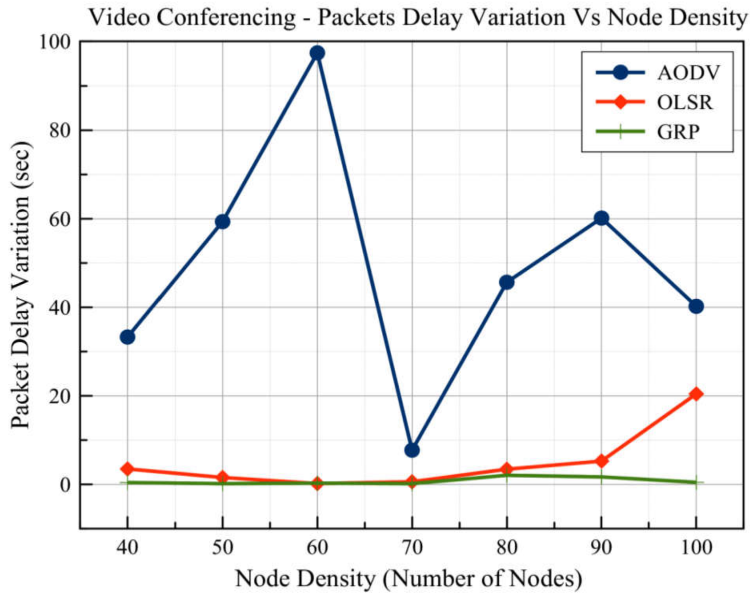


Figure (5.8) Middle – Large Scale: E2ED (sec) Vs Mobile Density

5.5.2.3 Video Conferencing –WLAN-E2ED (sec)

It is evident that in case of media access delay or WLAN-E2ED, AODV does not perform better in medium/large scale within dense and high mobility as shown in Table (5.14). The highest E2E delay occurs in case of AODV because the protocol searches for the new routes only when they are needed. This strategy usually generates less control traffic. But at the same time, it increases the overall delay in the network since packets remain waiting at buffers until they are transmitted through the new routes. OLSR has a minimum media access delay when the number of mobile nodes less than 70, but when the number of nodes increases the media access delay also increases. OLSR and GRP have similar behaviors in terms of E2E delay.

Overall observation depicted in Fig. (5.9) shows that media access delay or WLAN-E2ED is very less and less in the case of proactive (OLSR) and hybrid routing protocol (GRP), respectively while increase when the number of nodes increases in the case of reactive protocol (AODV).

Table (5.14): Middle – Large Scale: WLAN – E2ED (sec) Vs Mobile Density

Node Density	AODV	OLSR	GRP
40	4.138442	1.139627	0.955532
50	3.595707	0.588795	0.63185
60	5.260362	0.454113	0.634154
70	2.573877	0.522414	0.862136
80	6.66714	2.389701	1.40558
90	8.718186	2.545673	1.210629
100	17.18072	2.270639	1.393037

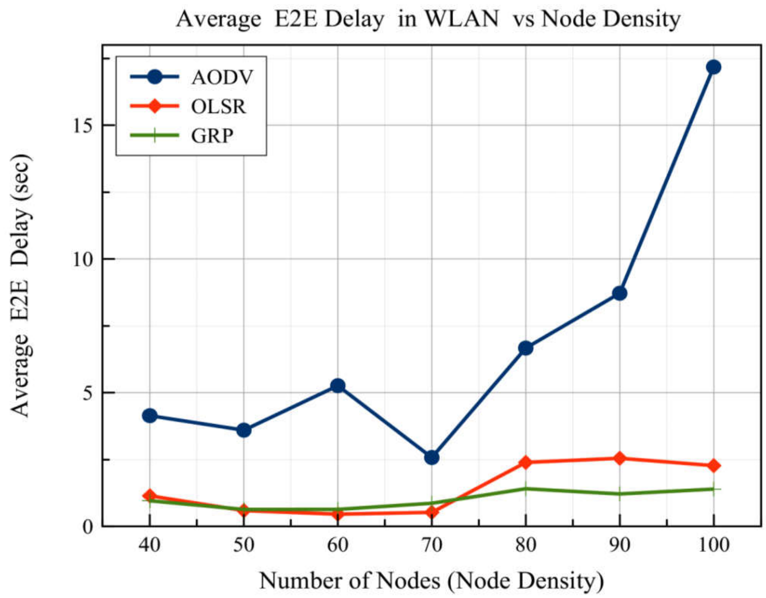


Figure (5.9) Middle – Large Scale: WLAN – E2ED (sec) Vs Mobile Density

5.5.2.4 WLAN –Throughput

The observation of throughput at Middle-Large scale network model as noticed from Table (5.15) and Fig. (5.10) explains that AODV gives the lowest throughput out of the three protocols while OLSR attains the highest value. In proactive protocols, every node already knows its destination, since OLSR protocol is proactive (table driven) and uses multi-point relay (MPR) broadcast, so it provides better throughput.

OLSR has shown has a good performance than the other two protocols because of its proactive nature, all the routes from a node to another node are known in advance, so OLSR has not faced any problem to deliver data packets from source to destination in this Middle-Large network model, and that is why OLSR has maximum throughput compared to AODV and GRP. OLSR throughput rises from 12Mbps to 15 Mbps .It is also observed that GRP throughput is slightly greater than AODV and this is due to its position based nature.

Table (5.15): Middle – Large Scale: WLAN – Throughput Vs Mobile Density

Node Density	AODV	OLSR	GRP
40	1.11E+07	1.24E+07	1.20E+07
50	1.06E+07	1.44E+07	1.30E+07
60	9.95E+06	1.34E+07	1.29E+07
70	1.21E+07	1.31E+07	1.23E+07
80	9.57E+06	1.41E+07	1.18E+07
90	1.26E+07	1.42E+07	1.22E+07
100	1.29E+07	1.48E+07	1.14E+07

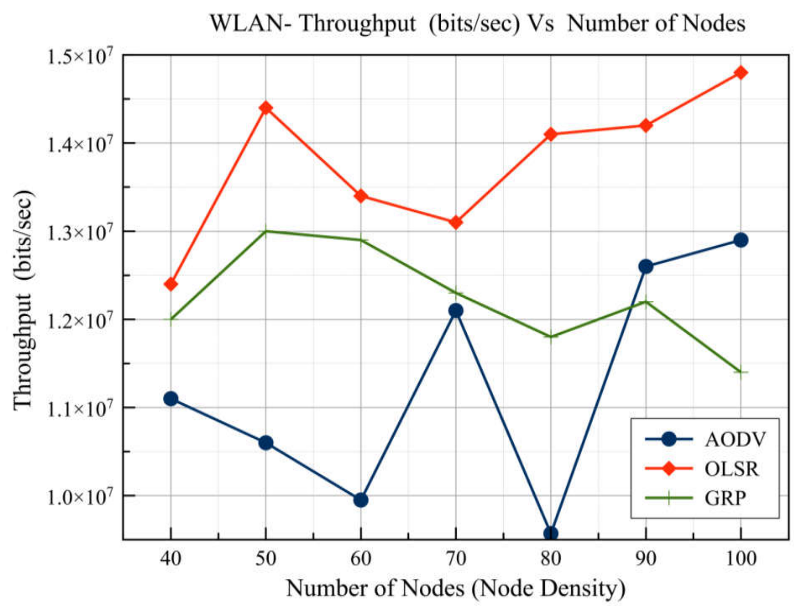


Figure (5.10) Middle – Large Scale: WLAN – Throughput Vs Mobile Density

5.5.2.5 WLAN –Load Analysis:

WLAN- load of all the protocols is shown in Table (5.16) and Fig. (5.11). OLSR has shown maximum load and GRP has shown moderate results with consistent load, whereas AODV has minimum load on the network and outperformed OLSR and GRP.

OLSR has maximum network load because it delivers more data packets, the nodes have high mobility which in tern results in periodic broadcast of HELLO messages and Topology Control (TC) messages in order to discover neighborhood nodes. In addition, OLSR is a link state protocol which uses a table driven approach. Therefore, OLSR generates more communication overhead and takes more maintenance time which adds to the overall load in the network.

Table (5.16): Middle – Large Scale: WLAN – Load Vs Mobile Density

Node Density	AODV	OLSR	GRP
40	1.00E+07	1.23E+07	1.24E+07
50	9.38E+06	1.43E+07	1.34E+07
60	8.06E+06	1.34E+07	1.32E+07
70	9.25E+06	1.28E+07	1.26E+07
80	5.83E+06	1.12E+07	1.24E+07
90	6.84E+06	1.12E+07	1.27E+07
100	6.99E+06	1.15E+07	1.20E+07

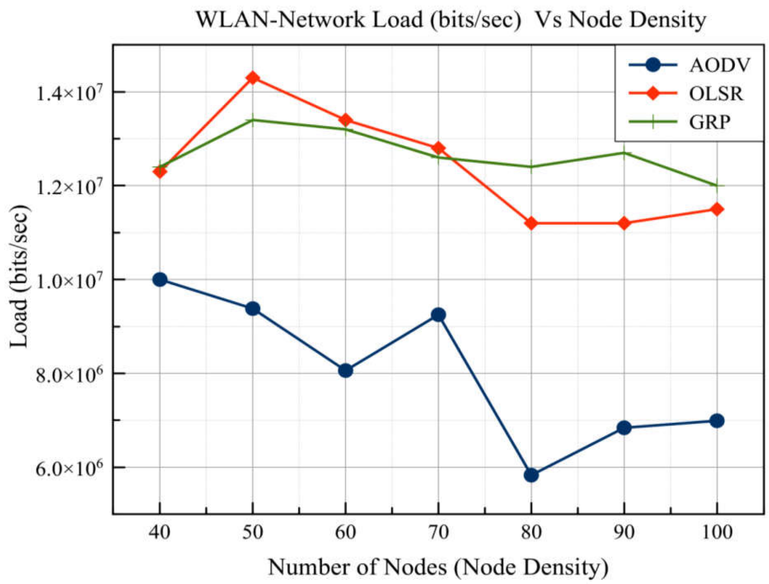


Figure (5.11) Middle – Large Scale: WLAN – Load Vs Mobile Density

5.5.2.6 Summary Results of the (Middle/Large) -Scale Model

As shown on Table (5.17) and from the previous comprehensive performance evaluation of MANET routing protocols AODV, OLSR, and GRP for transmitting video streaming into two different network models with variable node density and variable mobility speed we conclude that:

1. OLSR achieved high performance compared to AODV and GRP especially for medium network size in terms of:
   a) Video conferencing – packet E2E delay
   b) Video conferencing – packet delay variation (jitter)
   c) Throughput

d) WLAN – Retransmission attempts

e) WLAN – E2E delay

f) WLAN – Network load

Table (5.17): Middle/ Large Scale: Summery Results

Metrics	Protocols		
	AODV	**OLSR**	**GRP**
V.C. Packet E2E delay (msec)	Low	Low	Low
V.C Packet Delay Variation(Jitter)	High	V.Low	V.Low
Packet Delivery Ratio (PDR %)	V.Low	High	V.Low
End-to-End Delay (seconds)	V.High	V.Low	V.Low
Throughput (bits/sec)	V.Low	High	Low
Retransmission Attempts(packets)	Low	V.Low	Low
Network Load (bits/sec)	V.Low	High	High
Total Packets Dropped (packets)	High	Low	V.High
Routing Overhead (packets/sec)	Low	High	Low

2. GRP outperforms OLSR and AODV in the large network size, because geographic routing protocols scale better for MANETs mainly for two reasons: 1) is that there is no necessity to keep routing tables up-to-date and , 2) is that there is no need to have a global view of the network topology and its changes.

3. The previous metrics are desirable QoS parameters for transmitting video over MANETs , but at the same time OLSR has drawbacks like not very high Packet Delivery Ratio (PDR%) , low throughput(bits/sec) in the small scale MANET network model.

4. In medium and large network models, AODV not capable for transmitting video traffic over MANETs.

5. OLSR outperform AODV and GRP in the medium network model, but GRP is better in the large model, as it performs better with the high density of nodes.

6. So we need to develop a technique that can enhance or improve the overall performance of OLSR in order to guarantees the QoS parameters required and to cope with MANET challenges such as efficient- energy consumption and security.

5.6 Chapter Summary

This chapter explains our research methodology which is a quantitative approach. We implemented a comprehensive performance evaluation for different MANET routing protocols to investigate which MANET routing protocols are capable to transmit real-time video contents effectively within different network sizes and under different mobile densities with variable mobility speed. Initially, we investigated the performance of five popular MANET routing protocols which are reactive (AODV, DSR), proactive (OLSR, TORA) and hybrid or position-based GRP protocol. Each one of them has pros and cons in transmitting real-time video contents.

In this study, have been observed some shortcomings in existing MANET routing protocols:

1. No existence of a super protocol that can guarantee all required QoS parameters such as minimum E2ED, minimum packet delay variation (jitter), maximum or highest PDR, maximum throughput and minimum network load for transmitting real-time video content effectively.
2. The results showed that there is no routing protocol in the current stage that can provide efficient routing to any size of network without modifications, regardless of the number of nodes and the network load and mobility.
3. Most existing routing protocols send a HELLO message or acknowledgment between the nodes, which increases the load and delay on the network.
4. They have not covered all routing problems, such as reducing network load, data drop, and delay, in some scenarios.
5. They find the shortest path from the source to the destination, but for the worst-case scenario, when the shortest path is congested, a different path that might be longer but may be more efficient is used.
6. Only the primary route is defined; however, if, for some reason, the primary route fails, then the protocol needs to rediscover the route, which will consume extra time and power.
7. They are not concerned with link reliability, such as the available data rate (bandwidth), delay, node battery life, and node selfishness, and thus, the path is not guaranteed to deliver the data from the source to the destination.

8. Most existing MANET routing protocols find any path from source to destination, but it is not necessarily the optimum path. Such paths are not efficient for different applications.

In view of the above shortcomings, we have drawn up a list of should-have features when should have been decided to enhance existing routing protocols for MANETs to transmit video streaming efficiently. To achieve this enhancement in case of OLSR routing protocol, it should have the following features and requirements:

1. To enhance the QoS of OLSR have been need to achieve a minimum E2ED, maximum PDR, minimum jitter, high throughput and low network load, these requirements can't be achieved without modifying the routing protocol's behaviors.
2. Not all of the proactive protocols address the security vulnerabilities that are inherited from wireless networks. The proper function of these protocols is based on an assumption that all the nodes exist and operate in a secure environment where link- and physical-layer security mechanisms are in place. Although security is a major concern in wireless communications, it is found that the security mechanisms will increase processing time, power consumption, and latency. So we need to enhancement OLSR in terms of security services without degradation of QoS. Note that proactive routing protocols already suffer from high latency in case of dense networks.
3. To establish a route to the destination without affecting the performance, energy should be conserved for critical nodes. The ultimate goal is to conserve energy of the nodes. So we need to enhance the power consumptions in OLSR routing protocol, in order to increase the network lifetime.
4. Having a minimum control message overhead due to changes in the routing information when topology changes occur.

Chapter Six

Performance Evaluation of Enhanced Video Conferencing Scheme

6 Performance Evaluation of Enhanced Video Conferencing Scheme

6.1 Introduction

As mentioned in the previous chapter, there is no existence of a super protocol that can meet the QoS requirements for video streaming over MANET. In this chapter, we explain the proposed scheme for enhancing video streaming over MANETs effectively based on the OLSR routing protocol. Moreover, the proposed framework of tuning OLSR routing parameters and OLSR tuning algorithm are explained in details. The Multivariate Linear Regression Modeling (MLRM) method and Analysis of Variance (ANOVA) technique are described as the methods for representing the QoS metrics of the tuned OLSR behaviors in a linear model form. Particle Swarm Optimization algorithm (PSO) is introduced as an optimization technique that will be used for optimizing the modified version of OLSR protocol outcomes. In addition, a performance evaluation of the modified OLSR protocol is performed and compared with OLSR-RFC in terms of QoS, security attacks, and power consumptions. In the end, all results are drawn and a summary of our findings is analyzed.

6. 2 Performance Analysis of Enhanced QoS -OLSR

After performing a comprehensive simulation for the modified (tuned) parameters of OLSR, we found that the overall performance and the behavior of OLSR are improved on the bases of QoS for transmitting video conferencing. The modified version of OLSR is named QoS-OLSR for this reason. The performance of QoS-OLSR is evaluated using a set of qualitative parameters for a set of quantitative parameters: Jitter (ms), packet delivery ratio (PDR %), average E2ED (sec), throughput (bits/sec), routing overhead in %, and routing protocol performance (Total HELLO message sent/received, routing table calculations, MPRs calculation). In each case, the simulations were carried out 20 times for a number of nodes (10 -70 nodes) by changing a set of data rates, a set of maximum node speeds and a set of transmission ranges. The results were averaged for each case and simulations were performed under worst-case scenarios with a maximum number of connections and the existence of traffic throughout the simulation.

(A)– Average E2E- Delay Analysis

In the case of low mobile density (10 – 25 node) as shown in Fig.(6.1)- (a) , there is no significant difference between QoS-OLSR and OLSR in terms of E2E-delay . This is due to network stability and less topology change. Using long HELLO and TC intervals in QoS-OLSR, also doesn't cause a great difference in E2E-delay. E2E-delay is computed from the queuing delay which is not affected when the number of nodes is small and the network is not congested. Most of the delay in low density is due to processing delay. There is an improvement in the E2E-delay when the mobile nodes are between (30 – 60 nodes), where the E2E-delay dropped by 44%, 74%, 21%, 5% at 30, 40, 50, and 60 nodes respectively. It is obvious that QoS-OLSR outperforms OLSR in terms of E2E-delay specifically when the number of nodes are between (30 -50).

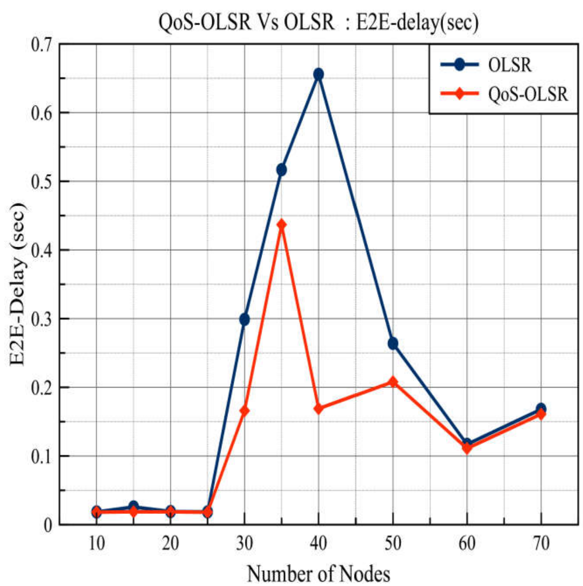
(B) – Packet Delay Variation (jitter) Analysis

In Fig. (6.1)- (b), had been provided additional evidence that the effect of tuning OLSR has an impact on one of the important metrics related to video transmission which is jitter. QoS-OLSR and OLSR are approximately similar in behavior with low mobile density (10 nodes); both achieved (0.004 ms) which is theoretically and practically accepted according to ITU-standards mentioned in Chapter(4) Table (4.2). QoS-OLSR achieves better jitter in mobile density (35-70) which is between (12.7 ms) and (173 ms) as the worst value at 70 nodes with an average of (94 ms) over all the densities. Form Table (6.1), the average jitter drop percentage in QoS-OLSR compared to OLSR is 47%.

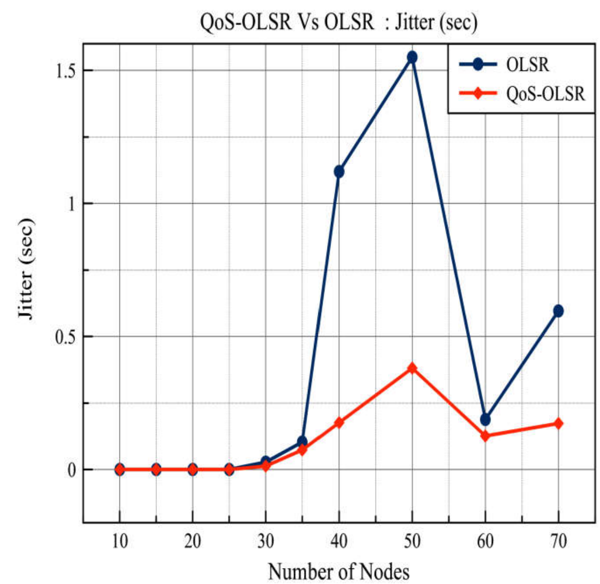
Table (6.1): QoS metrics :QoS-OLSR compared to OLSR

E2E-delay			Drop %	Jitter		Drop %	Throughput		Incr. %	PDR%		Incr. %
# Nodes	OLSR	QoS-OLSR		OLSR	QoS-OLSR		OLSR	QoS-OLSR		OLSR	QoS-OLSR	
10	0.0185	0.0182	2	0.0000047	0.0000047	0	4.82E+06	4.93E+06	2	97.37	100.0	3
15	0.0258	0.0187	28	0.0000346	0.0000069	80	9.82E+06	9.94E+06	1	96.68	100.0	3
20	0.0191	0.0187	2	0.0000092	0.0000063	32	9.99E+06	9.95E+06	0	95.48	100.0	5
25	0.0186	0.0181	3	0.0000050	0.0000043	14	9.85E+06	5.01E+06	(-49)	90.39	98.34	9
30	0.299	0.166	44	0.0275	0.0127	54	1.40E+07	1.46E+07	4	88.67	97.09	9
35	0.517	0.437	15	0.103	0.0733	29	1.34E+07	1.32E+07	(-1)	79.52	95.45	20
40	0.656	0.169	74	1.12	0.176	84	1.24E+07	3.77E+07	204	70.19	93.49	33
50	0.264	0.208	21	1.55	0.381	75	1.44E+07	3.41E+07	137	63.26	89.36	41
60	0.117	0.111	5	0.188	0.126	33	1.34E+07	2.44E+07	82	48.77	86.17	77
70	0.168	0.161	71	0.596	0.173	71	4.82E+06	4.93E+06	2	44.82	84.12	88
Average			**27%**			**47%**			**38%**			**29%**

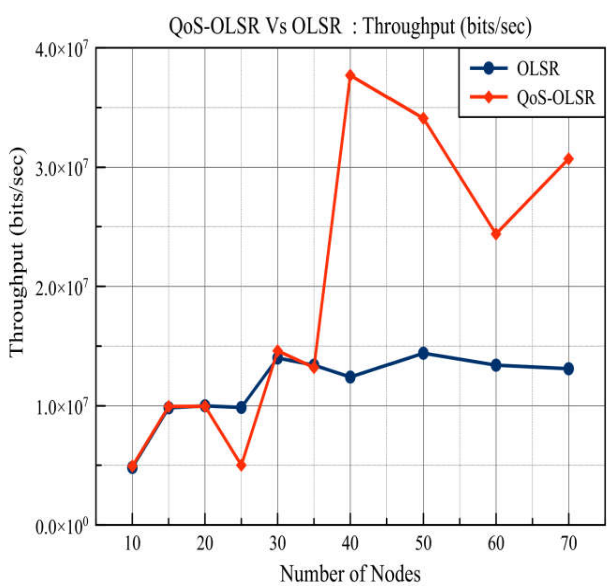
Generally, QoS-OLSR outperforms OLSR in the middle/large scale network size and shown in the Table (6.1). Under the modified configuration of QoS-OLSR the jitter decreases when the number of nodes increases, while the jitter increases when the number of nodes increases in the case of OLSR.



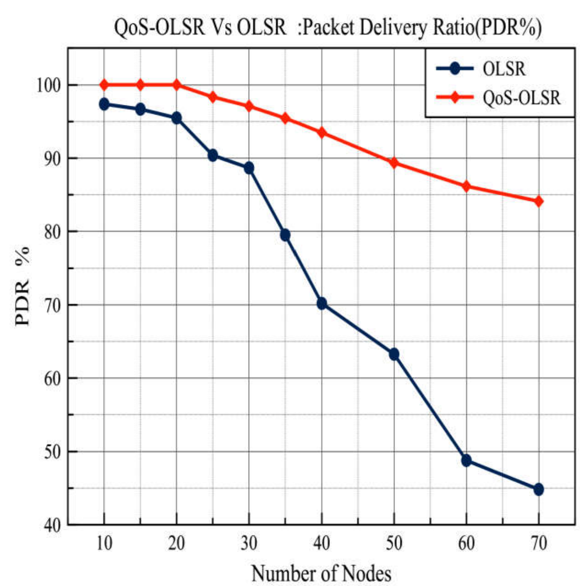
(a) E2E- Delay (sec)



(b) Jitter (ms)



(c) Throughput



(d) Packet Delivery Ratio (PDR%)

Figure (6.1) QoS metrics evaluation vs density: QoS-OLSR compared to OLSR

(C) - Throughput Analysis

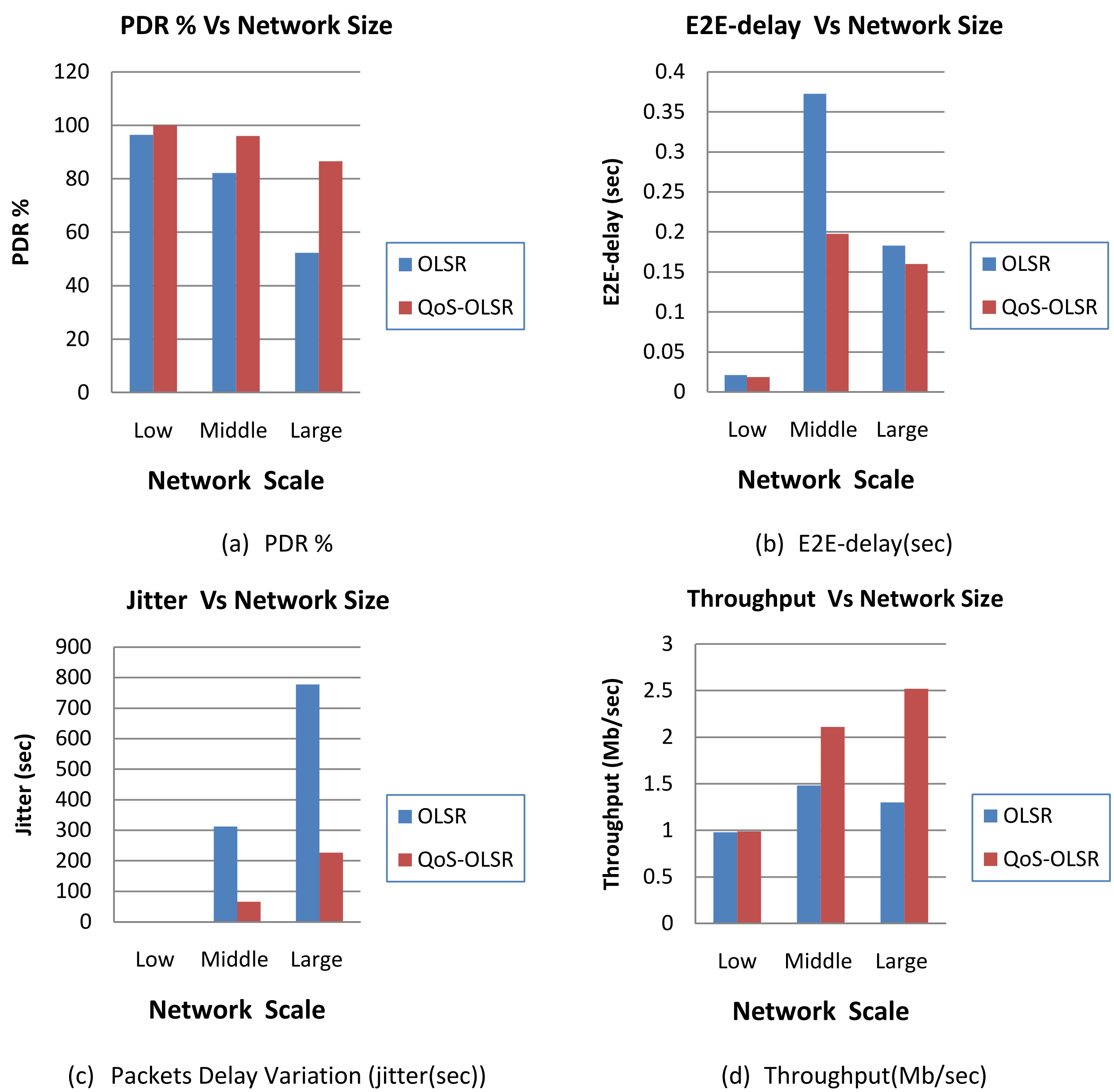
Throughput is one of several important parameter of network performance as it reflects the usage degree of the network resources for the typical routing protocol. Here the basic aim is to achieve the maximum throughput. Fig. (6.1) - (c), illustrates the performance of a network in terms of throughput by varying the number of nodes and pause time. Throughout is directly related to the packet drops. Packet drops typically happen because of network congestion or for lack of route. The throughput comparison shows that the QoS-OLSR and OLSR performance margins are very close under the traffic load of 10 to 20 nodes in MANET scenario and have large margins when the number of nodes increases to 70 nodes. The throughput is increased when the number of nodes increased. OLSR on the other hand has difficulties in finding routes when the number of nodes increases, which is clear from the figure, where the throughput drops slightly with densities smaller than 50. The peak values are shown in the figure at 40 mobile nodes in the case of QoS-OLSR (3.77E+07 bits/s), while the peak value in case of OLSR is (1.44E+07 bits/s) at 50 nodes. QoS-OLSR has a higher throughput compared to OLSR and the overall average increment percentage is 38%. During large traffic, the rate of collision count increases which further affects the throughput of the system. Our attempt to increase throughput is successful when we set the value of HELLO interval to 0.5. The throughput shows the enormous increase, when the value of HELLO interval is 0.5 , as shown in fig.(6.1) - (c).

(D) - Packet Delivery Ratio (PDR%) Analysis

Fig. (6.1) - (d) shows a comparison of packet delivery ratio (PDR%) on the basis of node densities. For the increased number of nodes, the PDR% is not satisfactory. Buffer lengths and low transmission ranges are the causes for the low packet delivery ratios in all the cases. Moreover, node densities have much impact on the packet delivery ratios. When node density increased the PDR% decreased, because in a sparse network there are not enough intermediate nodes to route the packets. At low densities QoS-OLSR achieves 100% PDR with increased rate between (3-5) percent compared to OLSR. Transmission of videoconferencing traffic over MANETs requires high packet delivery ratios. We observed that QoS-OLSR has distinguished values of PDR% starting from 98.34% at 25 nodes and decreasing softly to reach 84.12% at 70 nodes.

6.3 Impact of Scalability on the Performance of QoS-OLSR

Table (6.2) and Fig.(6.2) illustrate the summery of our findings based on QoS metrics PDR%, E2E-delay (sec), jitter(sec), and throughput (Mbps). From the simulation results it is clear that when the number of nodes is very high speed (sparse topology), the performance is poor (low throughput, high packet loss) because there are less number of connections due to sparse nature of topology.



(a) PDR %

(b) E2E-delay(sec)

(c) Packets Delay Variation (jitter(sec))

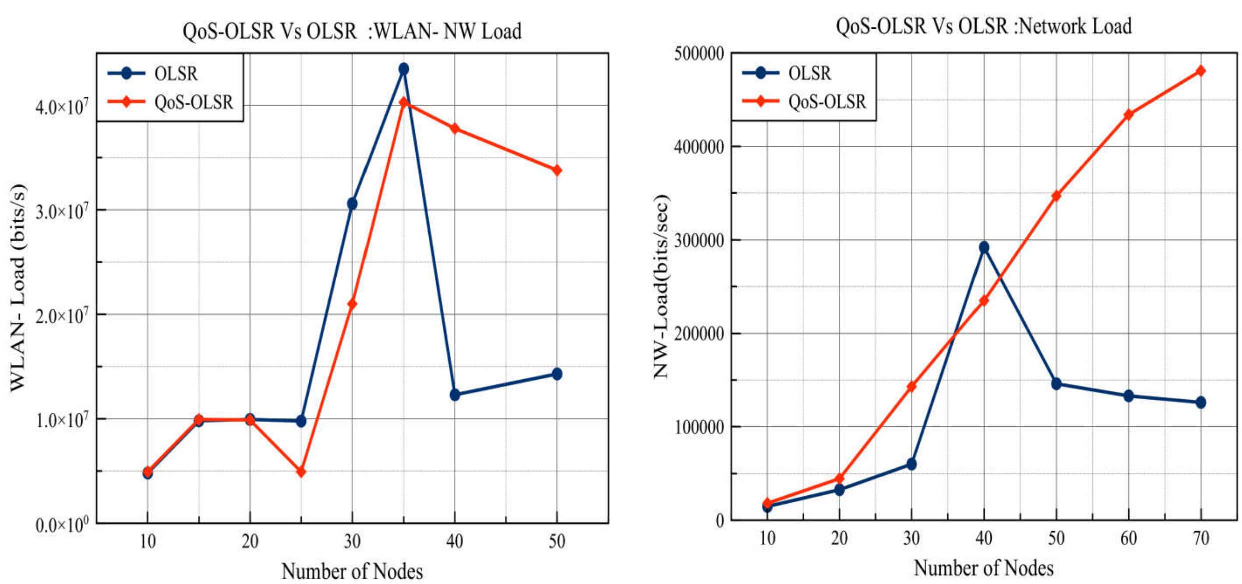
(d) Throughput(Mb/sec)

Figure (6.2) QoS metrics evaluation vs scalability : QoS-OLSR Vs OLSR

Table (6.2): Average QoS metrics: QoS-OLSR vs OLSR

Metric	OLSR			QoS-OLSR		
	Low	Middle	Large	Low	Middle	Large
PDR %	96.51	82.19	52.28	**100.0**	**96.09**	**86.55**
E2ED(sec)	0.0211	0.3727	0.183	**0.0185**	**0.1975**	**0.1600**
Jitter(ms)	0.01617	312.626	778.0	**0.00597**	**65.501**	**226.666**
Throughput(Mb/sec)	0.98	1.48	1.30	**0.99**	**2.11**	**2.52**

As the number of nodes is increased the performance becomes more or less constant but if density is too large, more and more nodes try to access the common medium, thus the number of collisions increases thereby increasing packet loss and decreasing the throughput. It is clearly revealed that QoS-OLSR outperforms OLSR in all these metrics specifically in Middle and Large network scales. In Low network scale, both protocols have similar characteristics and behaviors and are not found to vary much. However there is great feasibility of transmitting video conferencing over the modified QoS-OLSR.



(a) WLAN – Load (b) Network Load

Figure (6.3) QoS-OLSR Vs OLSR in terms of Load

One of the drawbacks of what had been assumed in this study is the network load. Using short HELLO and TC intervals in dense and sparse network will increase the network load. Redundant control messages among scalable network add routing traffic overhead which increases to some extend the throughput and latency. In this study the network load of conventional OLSR is less than QoS-OLSR, but this defect did not influence the QoS metrics as a tradeoff. Figure (6.3) (a) and (b) shows the characteristics of OLSR and QoS-OLSR in terms of WLAN-Load and NW-Load.

Table (6.3): Current QoS values and Optimal QoS values

QoS Parameters	Current Setup (Average)	Optimal Expected Values
Latency (E2E-delay)	$\leq 230\ ms$	$\leq 140\ ms$
Packet Delay Variation (Jitter)	$\leq 75\ ms$	$\leq 40\ ms$
Packet Loss %	≤ 5 %	≤ 1%

6. 4 Impact of Mobility Speeds on the Performance of QoS-OLSR

This section, primarily focus on the impact of mobility speeds on the performance of MANET enhanced routing protocol QoS-OLSR. Observations and discussion aim to study the effect of various mobility speeds for the nodes on the performance of QoS-OLSR. Has been considers the problem from a different perspective, using the simulation have been modeled the dynamic network size into (Small, Middle, Large) with varying number of movement speeds (slow, medium, high) at an invariable pause time which should be zero under weakest case because a longer pause time of the node may be insignificant for mobile Ad-hoc network with frequently and vastly moving nodes. The number of nodes may be another varying parameter as it plays an important role in performance. The simulation evaluates various performance parameters versus node density and mobility speeds. Different QoS metrics (E2E delay, jitter, PDR %, Network load, and routing overhead) have been tested to show the system scalability and mobility.

The simulation was tested using three different scenarios based on network size, mobility speeds, and node density as shown in Table (6.4). Data was collected among 24 different scenarios with number of turn 10 times for each scenario to validate the computed values.

Table (6.4): Scalability and mobility simulation parameters

Network Model(Scale)	Network Size (m^2)	Mobility Speeds m/s	Number of Nodes	No. Of Scenarios
Small	500X500	Slow (5-10)	5-25	5x2=10
Medium	1000X1000	Medium (15-20)	30-45	4x2=8
Large	1500X1500	High (25-30)	50-70	3x2=6

(A)- Packet Delivery Ratio (PDR%) Results Analysis

Fig. (6.4) illustrates the performance of the average PDR% under various mobility speeds which ranged from 5 m/s to 30 m/s. It is obvious that when the mobile node moves with greater speed there are more chances for link breakage resulting in less packet delivery ratio. As shown in the figure, QoS-OLSR attains nearly 100% PDR when the node density is low such as 10-20 nodes. This is because QoS-OLSR maintains updated routes for all nodes in the network at all the times. Thus, the routes are available even in high mobility. In addition, mobility speed has no impact on PDR% when the mobile density is low, and is 100% for 10 and 20 nodes under different mobility speeds. This is due to using a long HELLO interval among stable topology, which means that QoS-OLSR still performs better at low mobile density with a small scale network size.

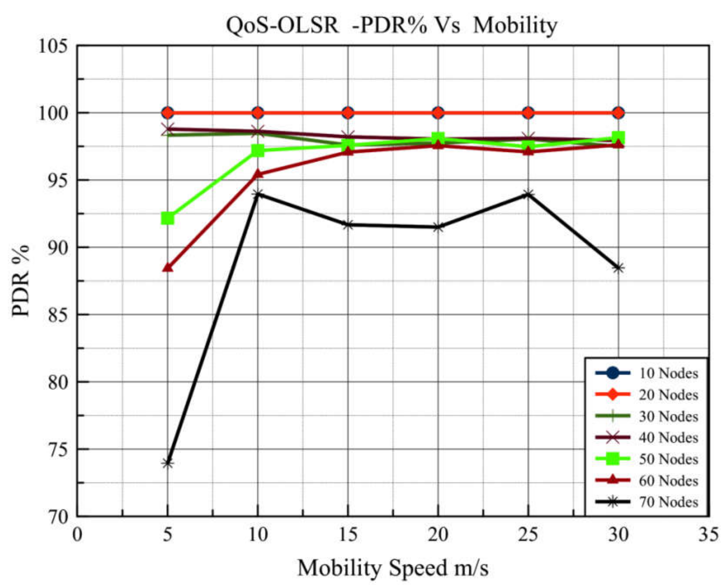


Figure (6.4) QoS-OLSR : PDR% under scalability and mobility

As number of nodes start to increase, the PDR% starts to decrease due to link failure and the network becoming sparse. It is obvious that, when the number of nodes is between (50-70) node, the initial values of PDR% at slow speed are less and start to increases at the medium mobility speed because of the nodes succeed in maintaining a route from source to destination. Also, the tuned values of HELLO and TC messages facilitate each node to discover its neighborhood quickly without causing packet loss which is reflected on high packet delivery ratio. In case of 70 nodes, the PDR% drastically decreased at highest speeds (25- 30 m/s) due to the congestion occurring in the network due to the huge amount of packets sent/received by the communicating nodes.

(B) E2E- delay Simulation Results Analysis

Although OLSR has been designed for large network configuration, we examine the E2E-delay of QoS-OLSR performance over (Small –Middle –Large) configuration. Fig.(6.5) shows that the E2E-delay increases as the node density increases. Higher mobility causes more links broken and frequent re-routing and thus causes larger E2E- delay. QoS-OLSR has stable E2E-dealy in low mobile densities with different mobility speeds such as 20, 30, and 40 nodes. From the simulation results it appears that the E2E-delay is high at 10 nodes with different mobility speeds because the network is unstable with high dynamicity which results in MPRs' redundancy which expands routing updates dissemination throughout the network.

For QoS-OLSR, the routing delay increases at the cost of throughput, because routing exchange messages at shorter intervals meaning that QoS-OLSR is more suitable to maintain accurate value of MPRs. On the other hand, quick link breakage detection which is made possible due to shorter HELLO interval ultimately provides more convergence. Therefore, QoS-OLSR achieves high efficiency in terms of E2E-delay and there is less significant effect of the mobility in E2E-delay.

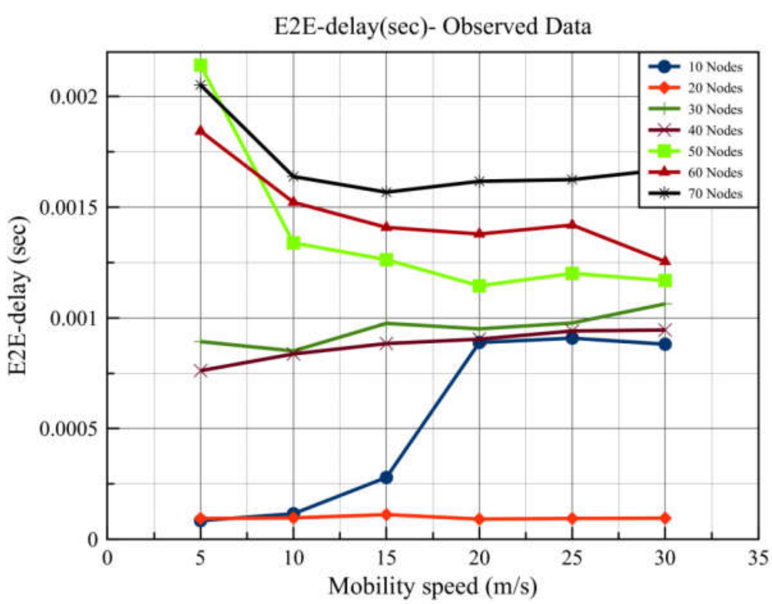


Figure (6.5) QoS-OLSR : E2E-delay under scalability and mobility

(C) Throughput simulation Results Analysis

As showing in Fig.(6.6), in general, throughput increases when density increasing , this is clearly on the Small/Middle network size with mobility speeds between (5 -20 m/s) , while in the high density (60 -70 nodes) , the throughput decreases when node density increases. The QoS-OLSR has a high throughput in 20m/s speed for all densities except 40 nodes, as it continuously updates all available routes in its routing table. With the increase in speed, it shows a little decrement in throughput.

6.5 Impact of tuned parameters on the protocol performance

In this section, the experimental results demonstrate a comparison between OLSR and QoS-OLSR based on the routing protocols performance. The optimal parameters selected for QoS-OLSR enhanced the performance of the protocol itself before enhancing the QoS metrics which is discussed in the next section. The whole behavior of QoS-OLSR can be shown through different routing metrics such as the HELLO messages sent/received, total TC messages forwarded, MPRs count, and route table calculations. These calculations can show how the routing protocol performance was improved.

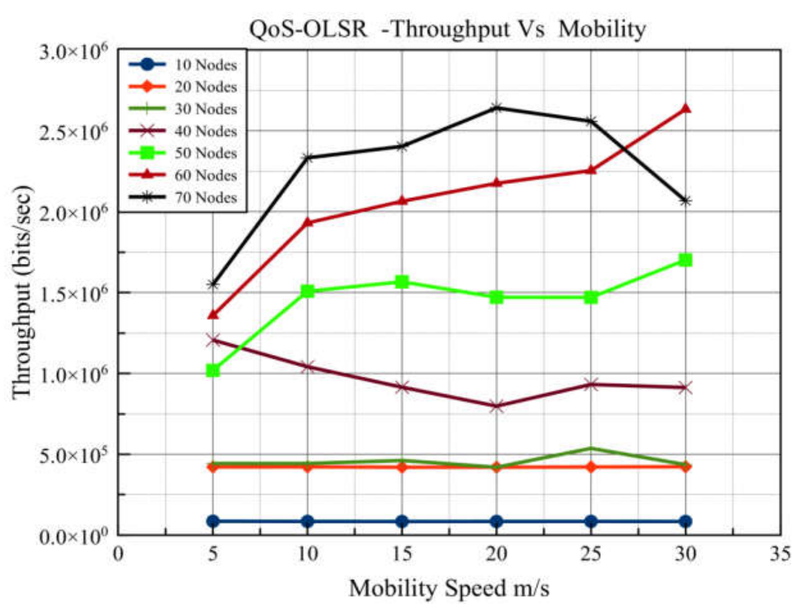


Figure (6.6) QoS-OLSR - Throughput (bits/sec) under different mobility speeds

(A) – Total HELLO messages received

HELLO messages traffic is specified by the time interval between two consecutive HELLO messages within one-hop neighborhood to obtain the neighborhood information. Less frequent HELLO messages is required to achieve highest QoS in the case of slow speed and low scalability. But in the case of dense and sparse network topology we need more frequent HELLO messages via shortening their intervals to discover the neighborhood. Fig.(6.7) – (a) shows the total HELLO messages calculated.

Within the low density the QoS-OLSR HELLO traffic is less than OLSR that is because we use a long HELLO interval which results in less HELLO traffic. In the middle and high density as shown in the figure the QoS-OLSR has a relatively high traffic than OLSR due to shortening the HELLO interval.

(B) - MPRs count (calculation)

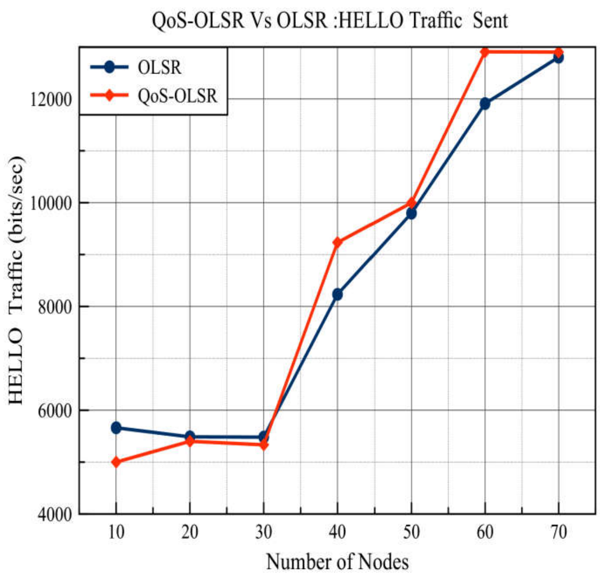
The goal of introducing the MPR is to minimize the number of re-transmitters. Thus, the number of selected MPR per node should be as low as possible. MPRs are calculated so that a node can reach all its symmetric 2- hop neighbors via one of its MPRs. MPR calculation is based on willingness announced by neighbors. MPR calculation is based on the information from: (1) the neighbor set, (2) the link set, and (3) the 2-hop neighbor set. We computed the average MPR count as shown in Figure (6.7) – (b). In the Small / Middle network size with Slow /Medium mobility speed, QoS-OLSR almost has fewer MPRs compared to OLSR. But the MPRs count increases instantly after exceeding 40 nodes.

(C)- TC – Messages Forwarded

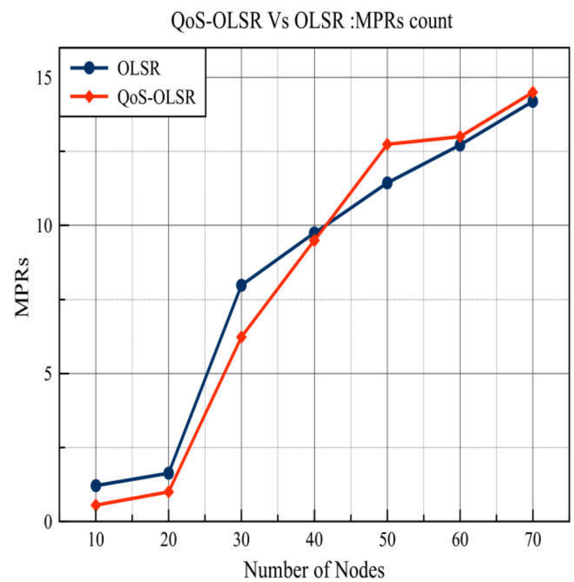
In order to examine the effects of tuning the TC interval on the performance of QoS-OLSR, the TC interval is decreased from 5sec by$\Delta t = 0.2s$. The value of the state holding timer intervals is adjusted correspondingly. The higher the TC packets sent rate in network; the more frequent the network topology changes. As a result, more fresh routs are available in network for better routing. Fig.(6.7) – (c) shows the total Topology Control (TC) traffic sent (bit/s).

(D)- Retransmission Attempts

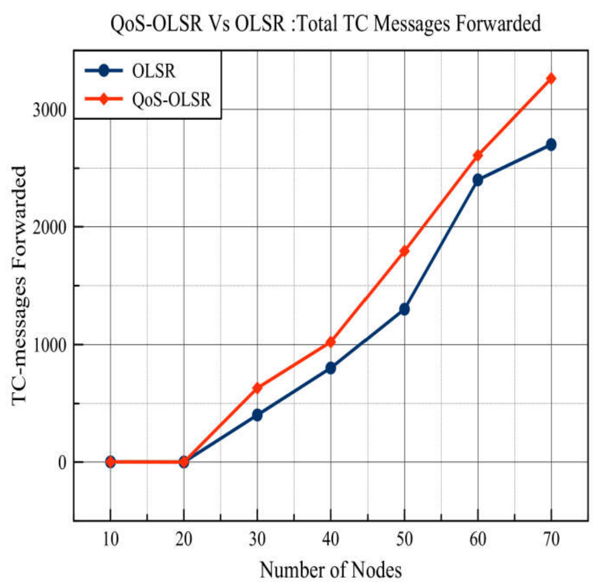
In MANET, high speed of mobility or continuously changing network topology, and scalability cause link breakage and invalidation of end-to-end route. The link failure is indicated by the absence of HELLO message. To reduce the link failure the messages are retransmitted. By retransmitting the messages the routes or system consumes more energy and the system life time will be less. Fig.(6.7) – (d) compares retransmission between QoS-OLSR and OLSR. Less retransmission is achieved by QoS-OLSR restrictedly when the number of nodes is between (35-70) nodes. This proves that QoS-OLSR performs better on high density, and the tuned parameters have a great impact on the protocol performance in terms of retransmission attempts.



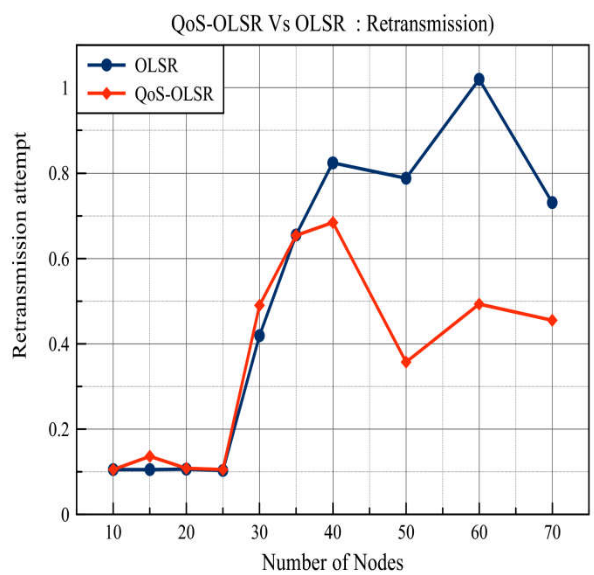
(a) HELLO traffic sent



(b) MPRs count



(c) TC –Messages Forwarded



(d) Retransmission attempt

Figure (6.7) QoS-OLSR routing performance

However, from the above performance metrics for the modified QoS-OLSR we conclude from Fig.(6.7)- (a) to (d) the following:

1- Reducing the HELLO interval improved QoS-OLSR's performance mainly in the Middle network size.

2- The impact of tuning the HELLO interval increases with increased node speed. When the network is relatively stable with less mobility, tuning HELLO interval has smaller impact than with high mobility.

3- The impact of tuning the HELLO interval has no obvious relationship with network density, specifically low density (10-30) nodes.

From Fig.(6.3) – (a) and (b) we can see:

4- The performance improvement introduced by reducing the HELLO interval is at the expense of increased overhead consequently network load, this is one of the drawbacks of tuning OLSR.

5- The overhead grows with node density; that is, the overhead in a high-density network is much larger than that in a low-density network.

6.6 (MLRM) to the QoS Metrics of QoS-OLSR

This section, aims to use and implement the MLRM technique as previously mentioned to construct a linear models for QoS metrics obtained for QoS-OLSR under variable mobile density and mobility speed. This step is important to show the influence of the mobility speed and node density on each metric. In addition, each model can provide statistical approach for predicting the responses such as E2E-delay, jitter, PDR%, and throughput when we know the speed and density. The following is the analysis of the linear models representing the QoS metrics mentioned above.

(A) E2E- delay modeling

Fig.(6.5) in section 6.4 and subsection (B)- demonstrate the observed E2E-delay from the simulation data. Now the aim is to create a linear model of the E2E-dealy as a response variable, while the number of nodes and node density as predictors as mentioned in Equation (4.3). The objective is to build a linear combination between the E2E-delay and both node density and mobility speed. Also we use ANOVA analysis to show the impact of dach factor (speed, density) on the E2E-delay.

Fig. (6.8) represent the predicted E2E-delay, while Equation (6.1) represents the estimated linear model. Table (6.5) shows the MLRM report for predicting E2ED with $\mathbf{R^2=0.7141}$.

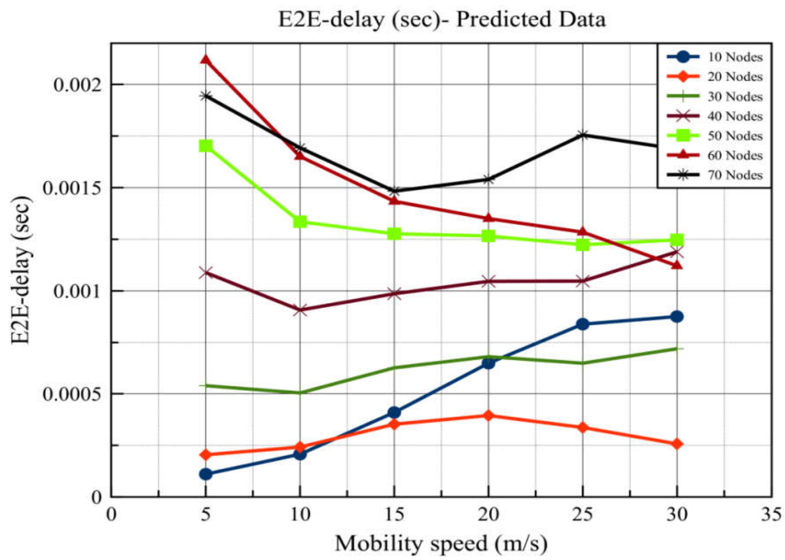


Figure (6.8) QoS-OLSR : predicted E2E-delay

Table (6.5): Multiple Regression and ANOVA Report for E2E-delay

Run Summary

Response (Y)	**E2ED**
Fixed Factor(s)	Speed, Nodes
Covariate(s)	Speed, Nodes
Model	Speed + Nodes

Parameter	**Value**	**Rows**	**Value**
R²	**0.7141**	Rows Processed	42
Adj R²	0.6995	Rows Filtered Out	0
Coefficient of Variation	0.3135	Rows with Y Missing	0
Mean Square Error	9.813446E-08	Rows with X's Missing	0
Square Root of MSE	0.0003132642	Rows Used in Estimation	42
Ave Abs Pct Error	86.311	Completion Status	Normal Completion
Error Degrees of Freedom		39	

Descriptive Statistics

Variable	**Count**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Speed	42	17.5	8.642634	5	30
Node	42	40	20.24243	10	70
E2ED	42	0.0009993338	0.0005714487	8.39737E-05	0.002141397

Analysis of Variance (ANOVA)

Source	DF	Sum of Squares	Mean Square	F-Ratio	P-Value	Significant at 5%?
Model	2	9.561456E-06	4.780728E-06	48.716	0.0000	Yes
Speed	1	2.788743E-09	2.788743E-09	0.028	**0.8670**	No
Nodes	1	9.558667E-06	9.558667E-06	**97.404**	0.0000	Yes
Error	39	3.827244E-06	9.813446E-08			
Total(Adjusted)	41	1.33887E-05	3.265536E-07			

(MLRM) - Model Coefficient T-Tests

Independent Variable	Model Coefficient b(i)	Standard Error Sb(i)	T-Statistic to Test H0: β(i)=0	P-Value	Reject H0 at 5%?
Intercept	**6.191112E-05**	0.0001466156	0.422	0.6751	No
Speed	**-9.542589E-07**	5.660734E-06	-0.169	0.8670	No
Nodes	**2.385306E-05**	2.416886E-06	9.869	0.0000	Yes

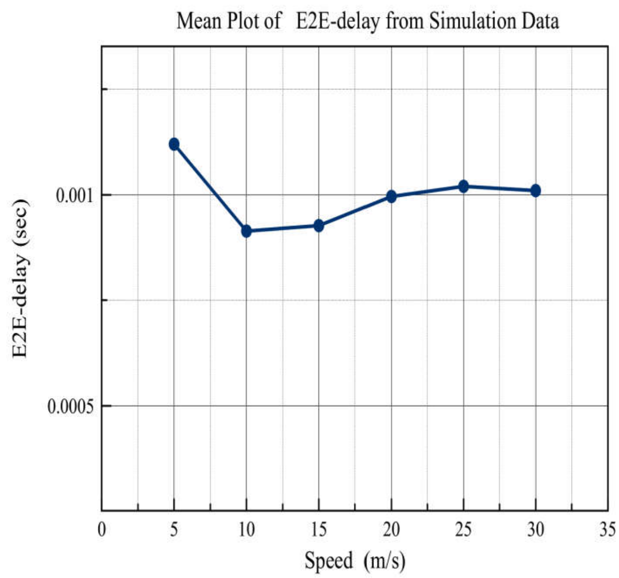
Therefore from the Model Coefficients **b(i)** Confidence Intervals we can construct the E2ED estimation equation as follows:

$$\text{E2ED} = 0.000061 - 0.00000095 * \text{Speed} + 0.000023 * \text{Node} \qquad (6.1)$$

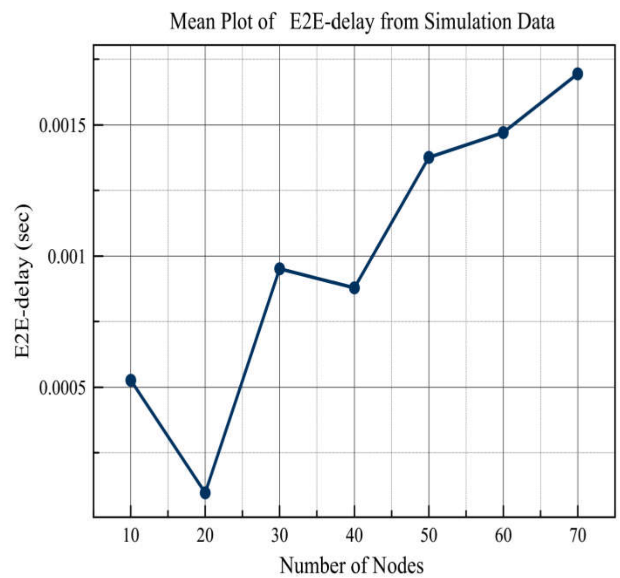
The effect of mobility speed (m/s) and node density on the E2ED from the ANOVA analysis is shown in Fig. (6.9). It's clear that from Fig.(6.9) - (a) and (b) that the mobility speed has a less impact on the E2E-delay (**F-Ratio=0.028**). When the mobility increases there is no significant change on the E2E-dely, while the node density has a great impact on the E2E-delay **(F-Ratio =97.404)**, as the number of nodes increases the E2E-delay starts to increase. In other words, the mobility speed does not affect the new configuration QoS-OLSR and the performance in terms of E2E-delay is affected by the scalability.

From Equation (6.1) the optimum E2E-delay is desired to be minimum, the speed factor has (-ve) sign, but nodes factor has (+ ve) sign. That means if the number of nodes is increased this will add E2E-delay and will not become optimum.

Fig.(6.10) – (a) and (b) show the 3D-surface plot for E2E-delay from simulation data, and the predicted E2E-delay, respectively.

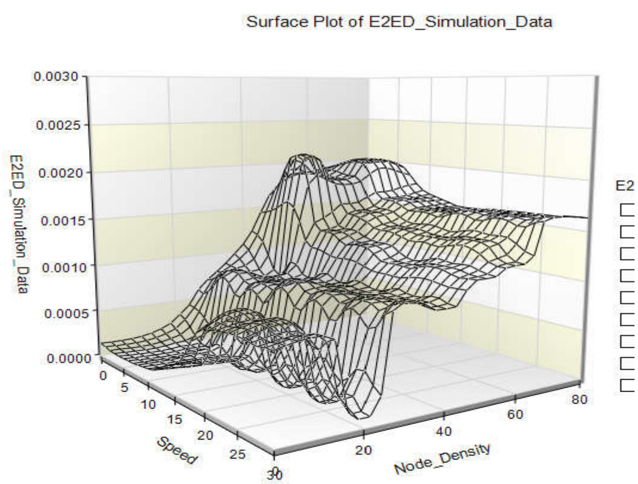


(a) **E2E-delay Vs Speed**

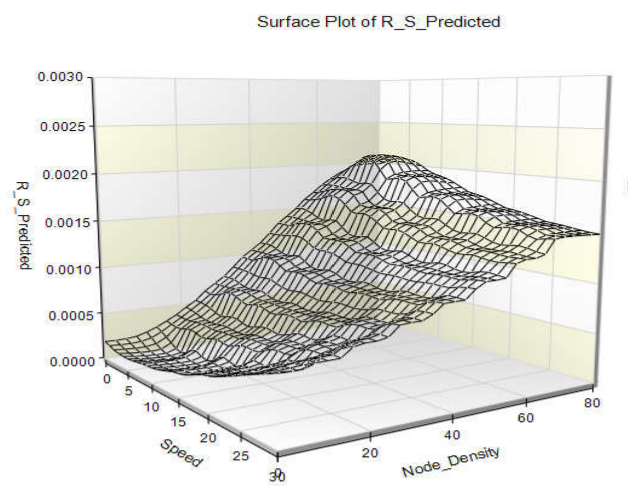


(b) **E2E-dely Vs Node Density**

Figure (6.9) E2E-delay: ANOVA mean plotted simulation data



(a)



(b)

Figure (6.10) E2E-delay surface plot: (a) original simulation , (b) predicted

(B) PDR% modeling

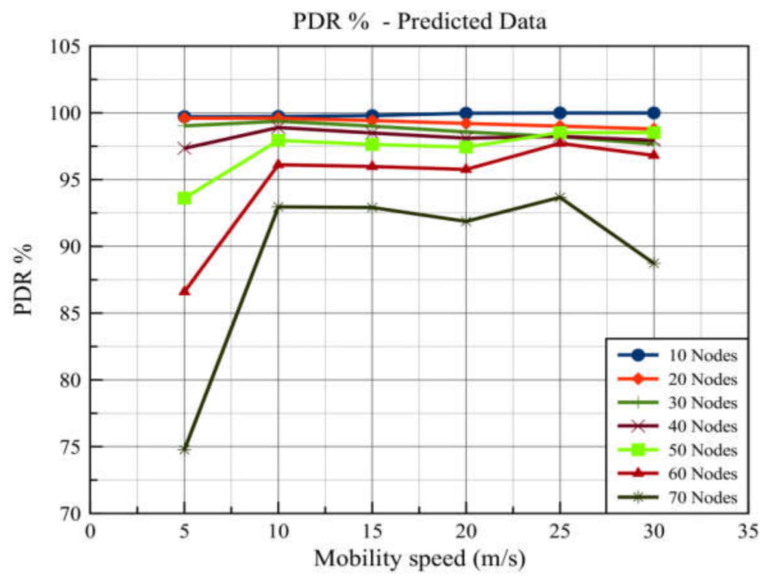


Figure (6.11) PDR % : Predicted data

Fig. (6.4) in the previous section showed the PDR % data gathered from the successive simulation of QoS-OLSR under variable mobility speeds and number of nodes. Fig (6.11) and Table (6.6) shows the predicted PDR% after using the MLRM and ANOVA analysis respectively.

Table (6.6): Multiple Regression and ANOVA Report for PDR %

Run Summary

Response (Y)	**PDR%**
Fixed Factor(s)	Speed, Nodes
Covariate(s)	Speed, Nodes
Model	Speed + Nodes

Parameter	**Value**	**Rows**	**Value**
R^2	0.4905	Rows Processed	42
Adj R^2	**0.4644**	Rows Filtered Out	0
Coefficient of Variation	0.0356	Rows with Y Missing	0
Mean Square Error	11.84813	Rows with X's Missing	0
Square Root of MSE	3.442111	Rows Used in Estimation	42
Ave Abs Pct Error	2.311	Completion Status	Normal Completion
Error Degrees of Freedom		39	

Descriptive Statistics

Variable	Count	Mean	Standard Deviation	Minimum	Maximum
Speed	42	17.5	8.642634	5	30
Nodes	42	40	20.24243	10	70
PDR	42	96.78189	4.703408	**73.94828**	**100**

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F-Ratio	P-Value	Significant at 5%?
Model	2	444.9268	222.4634	18.776	0.0000	Yes
Speed	1	42.17594	42.17594	**3.560**	**0.0667**	**No**
Nodes	1	402.7509	402.7509	33.993	0.0000	Yes
Error	39	462.077	11.84813			
Total(Adjusted)	41	907.0038	22.12205			

Model Coefficient T-Tests

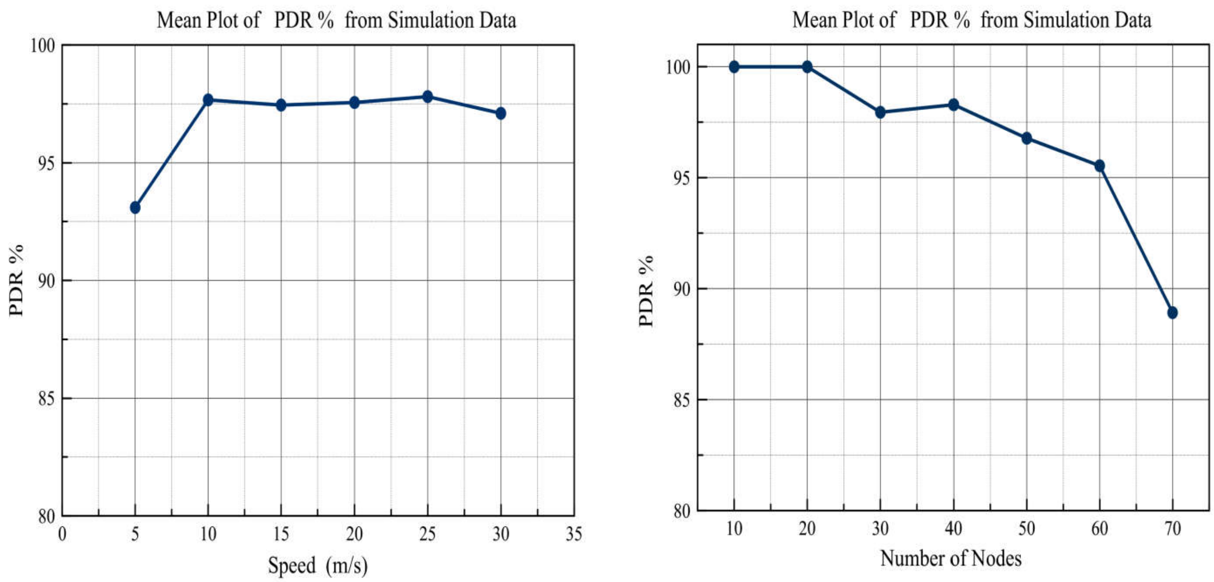
Independent Variable	Model Coefficient b(i)	Standard Error Sb(i)	T-Statistic to Test H0: β(i)=0	P-Value	Reject H0 at 5%?
Intercept	**100.9215**	1.610995	62.645	0.0000	Yes
Speed	**0.117353**	0.06219949	1.887	**0.0667**	**No**
Nodes	**-0.154833**	0.02655646	-5.830	0.0000	Yes

The estimated PDR% from the model coefficients is represented by Equation (5.24)

$$\mathrm{PDR} = 100.92 + 0.117 \ast \mathrm{Speed} - 0.154 \ast \mathrm{Node} \qquad (6.2)$$

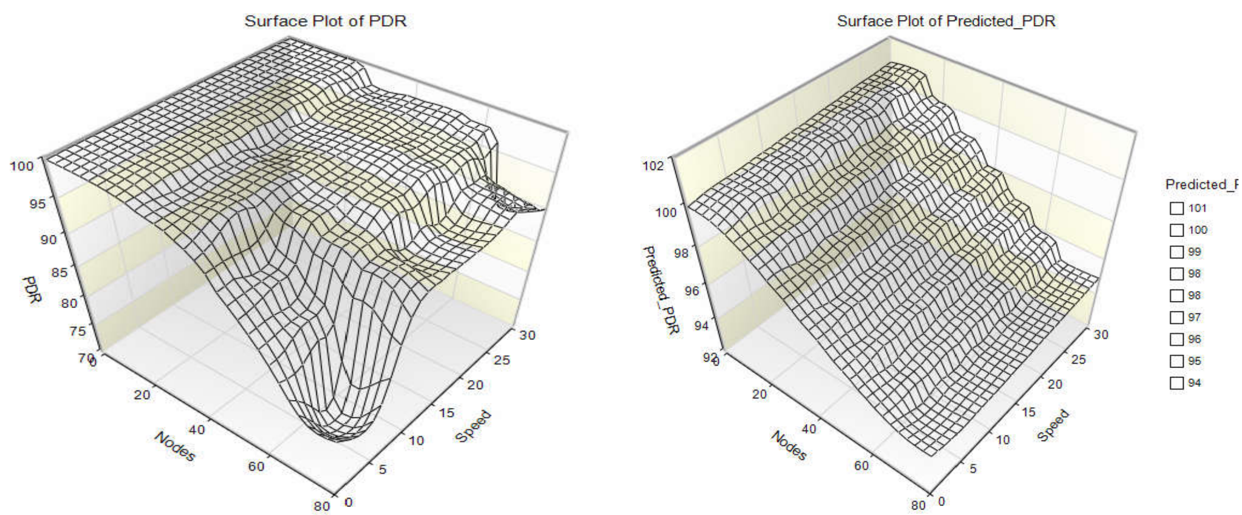
For the second time as illustrated in the case of E2E-delay, the mobility did not have an effect on the PDR%, but the node density has a great impact as shown in Fig. (6.12) – (a) and (b). Fig.(6.13) –(a) , (b) show the surface plot of the original simulation data and the estimated PDR% respectively.

The slow mobility speed has a noticeable effect on PDR% rather than the high mobility specifically in the high density. That is because link breakage and packet loss occurs while QoS-OLSR builds and maintains consistent paths resulting in low PDR% when the network become sparse and dense as shown in Fig.(6.14). However, QoS-OLSR had a consistent PDR% and suffered from less PDR % as the network grew larger but speed did not have profound effects on the performance



(a)PDR % vs Speed (b)PDR % vs Node Density

Figure (6.12) PDR % :ANOVA mean plotted simulation data



(a) (b)

Figure (6.13) Surface Plot: PDR %: (a) original Simulation , (b) predicted

(C) Throughput modeling

Since throughput is the ratio of the total amount of data that a receiver receives from the sender to the time it takes for the receiver to get the last packet, a low delay in the network translates into higher throughput. The ***p-value*** (***P***) determines which of the effects in the model are statistically significant. ***P*** is compared to a-level of (**0.05**), and if the ***p-value*** is less than to **0.05**

(P<0.05) we can conclude that the effect is significant; else we conclude that the effect is not significant. In this case, it can be seen that from Table (5.10) both mobility and density are significant terms in the model.

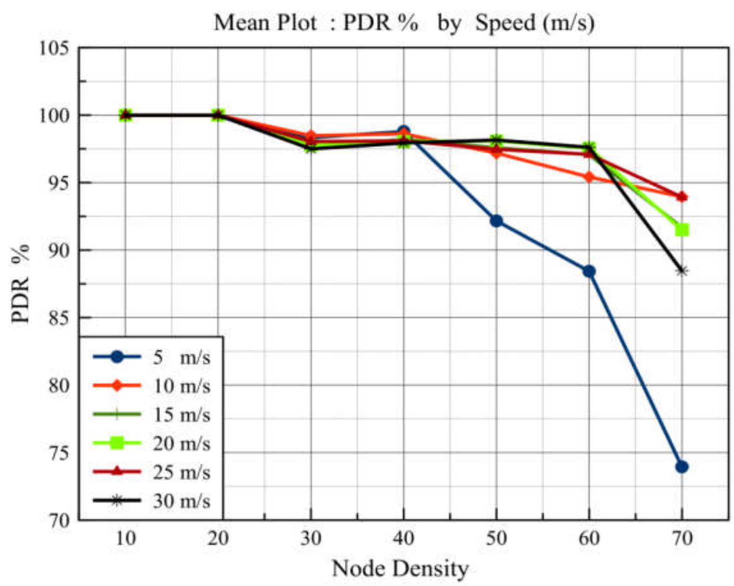


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Figure (6.14) mean plot PDR % by speed

R^2 and adjusted R^2 (adjusted for the number of terms in the model) are other measures to determine the amount of variation around the mean as explained by the given model; their values are always between 0 and 100%. The higher the value of R^2 the better the model fits the data. However, the predicted R^2 calculated for this model is ($R^2 = 0.9$) which is high and means that the model fits the data well.

Table (6.7): Multiple Regression and ANOVA Report for Throughput

Run Summary

Response (Y)	**Throughput**
Fixed Factor(s)	Speed, Nodes
Covariate(s)	Speed, Nodes
Model	Speed + Nodes

Parameter	**Value**	**Rows**	**Value**
R^2	0.9050	Rows Processed	42
Adj R^2	**0.9002**	Rows Filtered Out	0
Coefficient of Variation	0.2372	Rows with Y Missing	0
Mean Square Error	6.83404E+10	Rows with X's Missing	0
Square Root of MSE	261420	Rows Used in Estimation	42
Ave Abs Pct Error	44.710	Completion Status	Normal Completion
Error Degrees of Freedom		39	

Descriptive Statistics

Variable	Count	Mean	Standard Deviation	Minimum	Maximum
Speed	42	17.5	8.642634	5	30
Nodes	42	40	20.24243	10	70
Throughput	42	1102247	827382.1	84464.07	2642125

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F-Ratio	P-Value	Significant at 5%?
Model	2	2.540173E+13	1.270087E+13	**185.847**	0.0000	Yes
Speed	1	3.166879E+11	3.166879E+11	**4.634**	0.0376	Yes
Nodes	1	2.508504E+13	2.508504E+13	**367.060**	0.0000	Yes
Error	39	2.665275E+12	6.83404E+10			
Total(Adjusted)	41	2.806701E+13	6.845611E+11			

Model Coefficient T-Tests

Independent Variable	Model Coefficient b(i)	Standard Error Sb(i)	T-Statistic to Test H0: β(i)=0	P-Value	Reject H0 at 5%?
Intercept	**-621366.3**	122351.1	-5.079	0.0000	Yes
Speed	**10168.99**	4723.9	2.153	0.0376	Yes
Nodes	**38641.39**	2016.899	19.159	0.0000	Yes

Throughput metric is desired to be high in case of MANETs and more specifically for transmitting real time contents. The linear regression model for the throughput prediction is given by formula (6.3). From the formula, speed and node density factors are positives, which mean that when the node density increases and mobility speed increases the throughput will increased. However, the speed can affect the performance of QoS-OLSR in terms of throughput but not the nodes density.

$$\text{Throughput} = -621366.3 + 10168.99 * \text{Speed} + 38641.39 * \text{Node} \quad (6.3)$$

Fig.(6.15) shows the modeled throughput which is represented by the estimated formula (6.3). From the figure we can observed that the throughput decreases only when mobility speed is high and node density is low or when mobility is low and density is high (70 nodes with 5 m/s speed). The peak value of the throughput is at 70 nodes with mobility 20 m/s. Fig (6.16) – (a) and (b) shown the effect of mobility speed and scalability (density) on the throughput respectively. The surface plot of the original simulation data for throughput and predicted throughput are shown in Fig.(6.17) –(a) and (b). It is also obvious from the figure (a) that the throughput is steady when changing the mobility speed, but it is grows when increasing the node density as shown in figure (b).

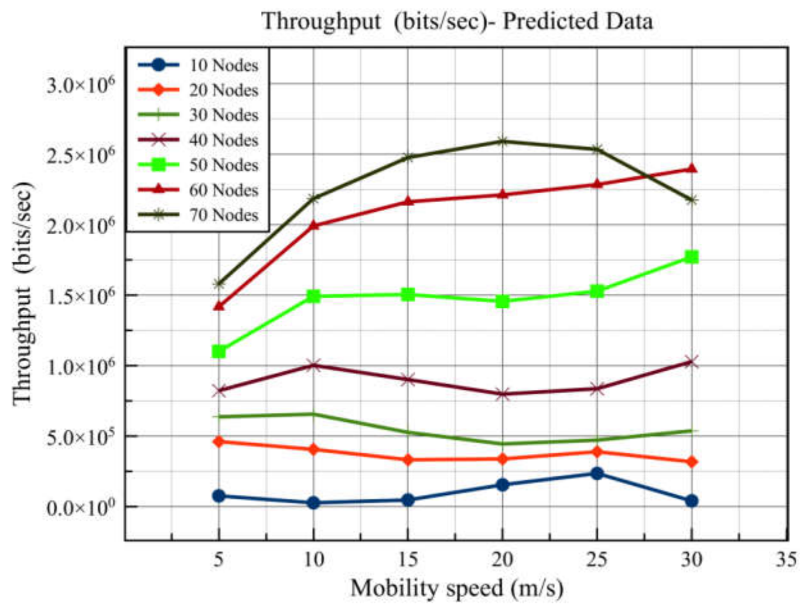


Figure (6.15) Throughput: Predicted Data

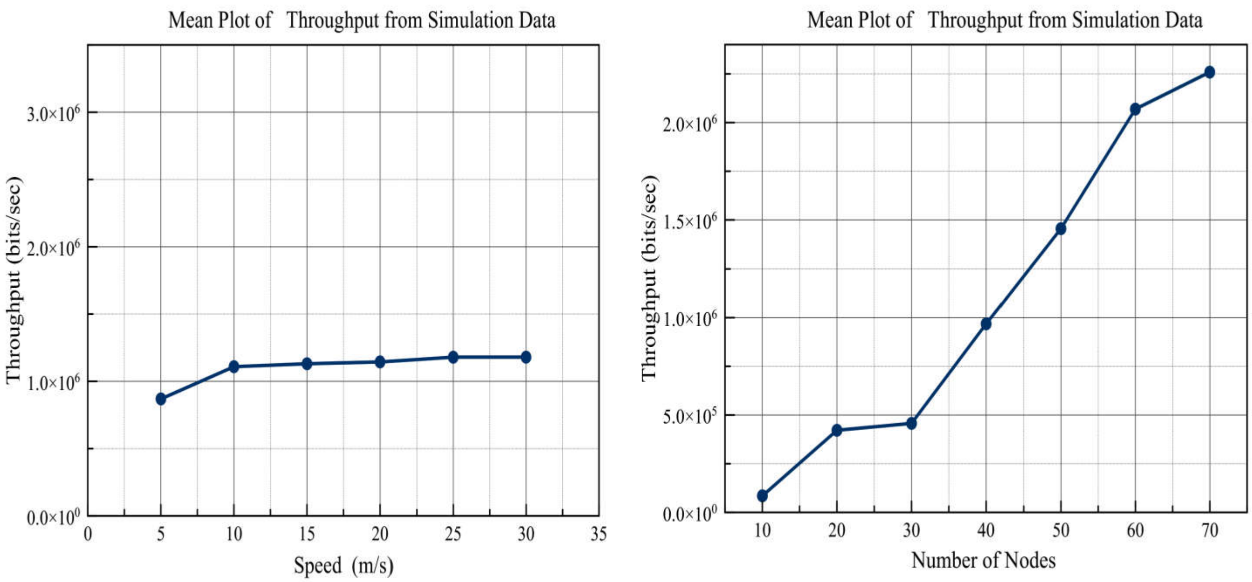
(D) Normalized Network Load (NNL) modeling

Normalized Network Load (NNL) is defined as the ratio of the number of control packets propagated by every node in the network, to the number of data packets received by the destination nodes. In the previous section had been showed that NNL is one of the drawbacks of tuning QoS-OLSR, therefore we need to investigate to which extent the NNL will remain stable.

In this section, we present the impact of mobility speed and node density on network load. In addition, have been aim to detect the relationship between the NNL to both scalability and mobility via MLRM, and which predictor influences the NNL such that it is minimized for efficient performance. Fig. (6.8) – (a) shows the computed NNL among the variable mobility speeds between (5 -30 m/s). It is clear that the NNL slightly increases when the mobility increases as shown in Fig. (5.23) – (b). So the mobility does not potentially increased NNL.

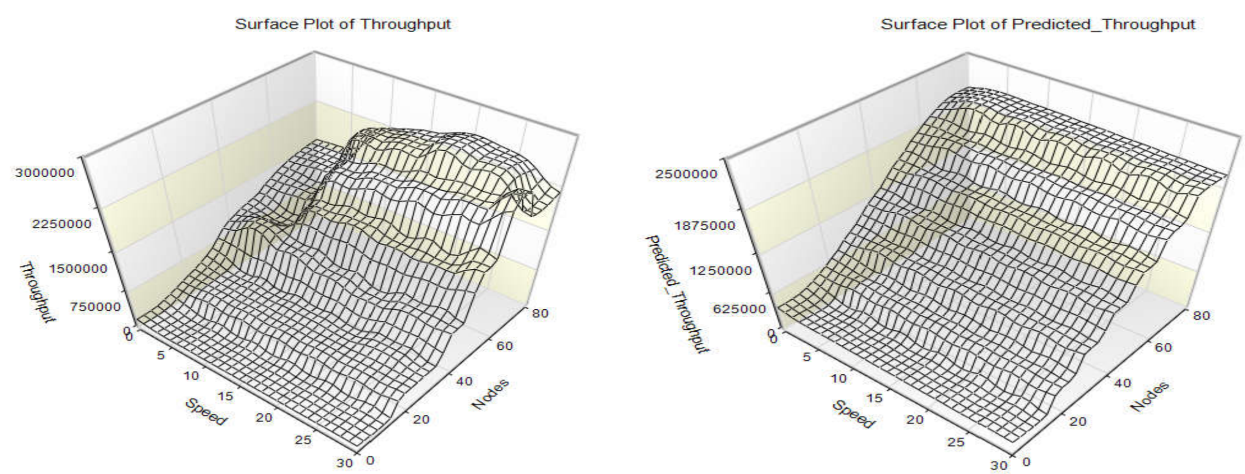
The second factor, scalability represented by node density, as shown in Fig. (6.19) – (a) describes the impact of the proposed QoS-OLSR configuration on the NNL under different node densities. The network load is low when the node density is less, and gradually increases when the network is extended. Fig.(6.20) – (b) shows the mean plot of network load by node density which is generated from ANOVA analysis. Evidently, that the scalability influenced the NNL more than the mobility. Table (6.8) describes the ANOVA analysis of the observed NNL from the simulation works, where R^2 achieved highest value (**R^2=0.9469).**

The NNL estimated model computed from the model coefficients listed in the last part of Table (6.8) are given by the formula (6.4). The original observed NNL and the predicted one are shown in Fig.(6.20) – (a) and (b) respectively.



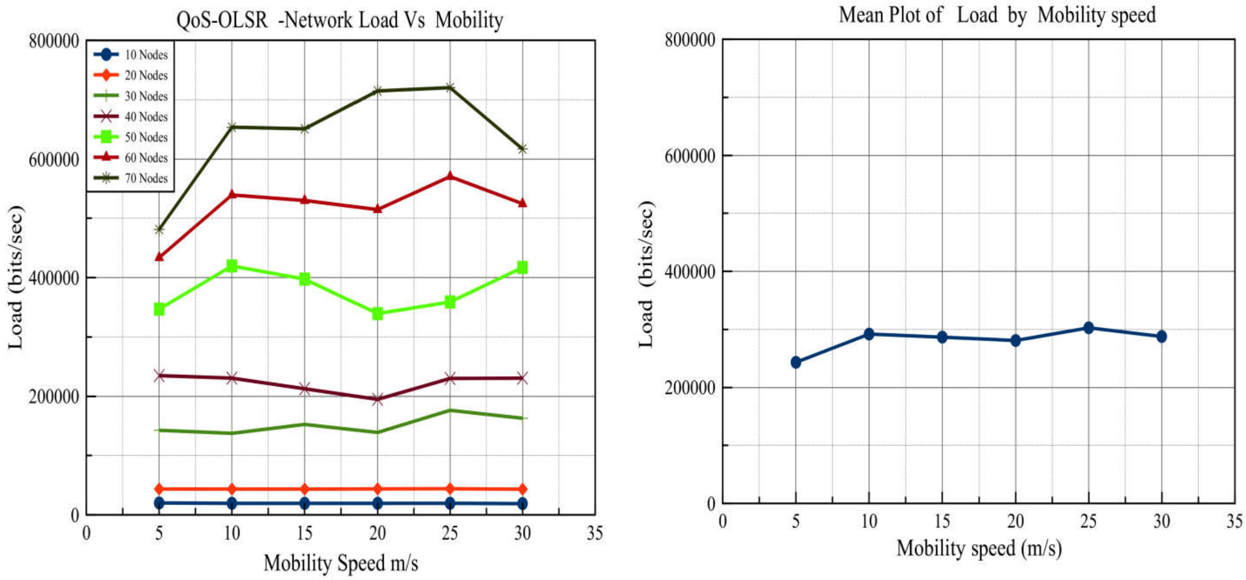
(a) Throughput Vs Speed (b) Throughput Vs Node Density

Figure (6.16) Throughput : ANOVA Mean Plotted simulation Data



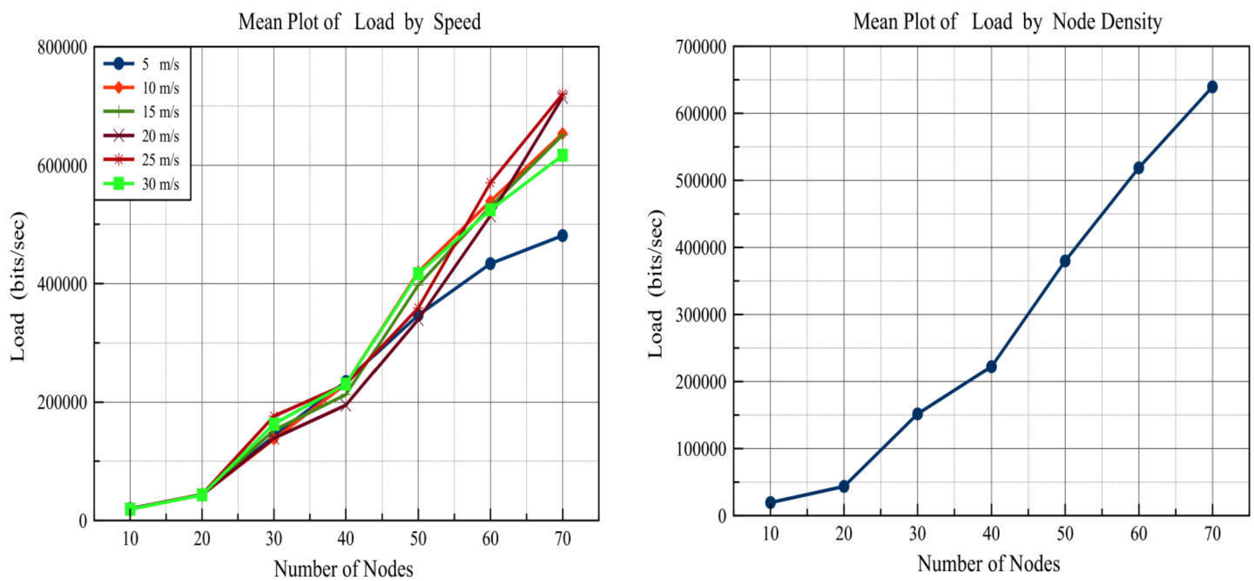
(a) (b)

Figure (6.17) Surface Plot :Throughput: (a) Original Simulation , (b) Predicted



(a) Load Vs Mobility Speed (b) Mean Plot : Load Vs Speed

Figure (6.18) Network Load Vs Mobility Speed



(a) Load Vs Mobility Number of Nodes (b) Mean Plot Load Vs Scalability

Figure (6.19) Network Load Vs Scalability

Table (6.8): Multiple Regression and ANOVA Report for Network Load

Run Summary

Response (Y)	Load
Fixed Factor(s)	Speed, Nodes
Covariate(s)	Speed, Nodes
Model	Speed + Nodes

Parameter	**Value**	**Rows**	**Value**
R^2	**0.9469**	Rows Processed	42
Adj R^2	0.9442	Rows Filtered Out	0
Coefficient of Variation	0.1893	Rows with Y Missing	0
Mean Square Error	2.85459E+09	Rows with X's Missing	0
Square Root of MSE	53428.36	Rows Used in Estimation	42
Ave Abs Pct Error	62.995	Completion Status	Normal Completion
Error Degrees of Freedom		39	

Descriptive Statistics

Variable	**Count**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Speed	42	17.5	8.642634	5	30
Nodes	42	40	20.24243	10	70
Load	42	282199	226155.7	18926.26	720380

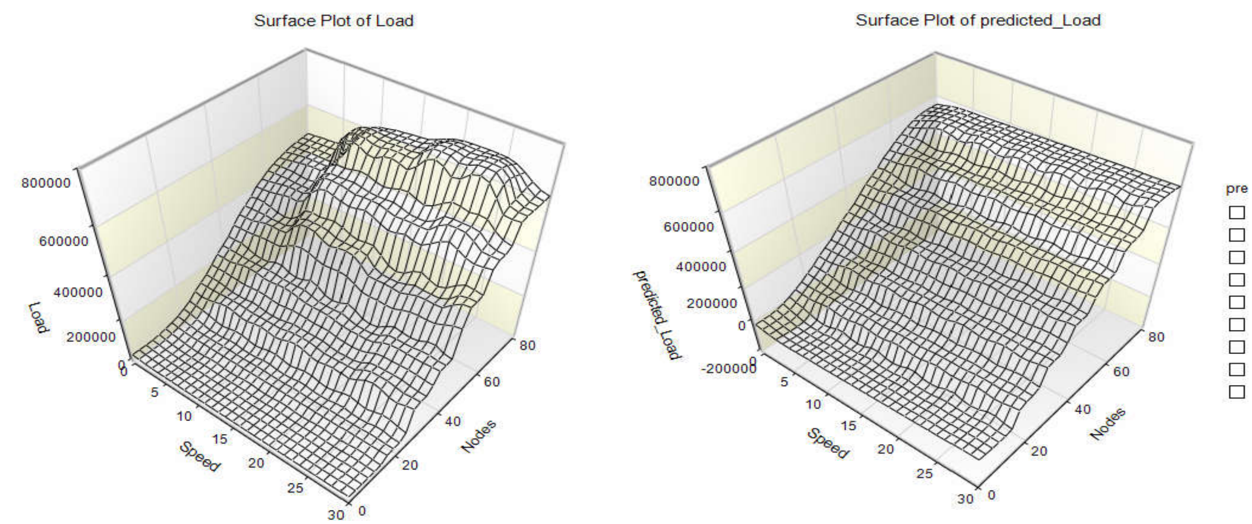
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Ratio**	**P-Value**	**Significant at 5%?**
Model	2	1.985674E+12	9.92837E+11	347.804	0.0000	Yes
Speed	1	6.202255E+09	6.202255E+09	2.173	0.1485	No
Nodes	1	1.979472E+12	1.979472E+12	693.435	0.0000	Yes
Error	39	1.11329E+11	2.85459E+09			
Total(Adjusted)	41	2.097003E+12	5.114642E+10			

Model Coefficient T-Tests

Independent Variable	**Model Coefficient b(i)**	**Standard Error Sb(i)**	**T-Statistic to Test H0: β(i)=0**	**P-Value**	**Reject H0 at 5%?**
Intercept	-176895.5	25005.82	-7.074	0.0000	Yes
Speed	1423.104	965.4589	1.474	0.1485	No
Nodes	10854.75	412.2087	26.333	0.0000	Yes

$$\text{NNL} = -176895.5 + 1423.104 * \text{ Speed} + 10854.75 * \text{ Node} \qquad (6.4)$$



(a) NNL Original simulation Data (b) NNL Predicted

Figure (6.20) Surface Plot : network load

6.7 OLSR Security Enhancement

Traditional MANET routing protocols assume that all nodes work in a benevolent manner, which may lead to MANETs being vulnerable against malicious attacks when selfish and malicious nodes are present. Routing protocols, data, battery power, and bandwidth are the common targets of the attacks [157]. The dynamic nature and structure of

MANETs have led to a variety of highly vulnerable attacks. S. Maharaja and et al. (2019) [158] stated that the fundamental need for secured networking is secure protocols that confirm the secrecy, accessibility, authenticity, and reliability of the network. Zang and et al. (2018) in [159] have proven that forward selfish behavior will affect the network performance seriously; for example, a small portion of selfish nodes (10%-40%) will lead to a significant decrease (16%-32%) in the network performance. MANETs are being utilized in many applications such as military, rescue search and disaster response primarily due to their flexibility, mobility, and lack of fixed infrastructure. For these same reasons, security in MANETs is a challenge and much different than security in wired networks. To properly protect these systems with limited resources, the security practitioners need to understand the possible security threats and their effects on MANET and have a framework to ensure that the protections implemented to mitigate the vulnerabilities in the systems are the most efficient ones possible. The framework developed in our thesis adds new efforts to do that.

This part of the thesis aims to examine the effects of the new configuration of OLSR routing protocol on the overall performance when the MANET network is under two attacks which are a black hole and jamming attacks on the network layer and MAC/PHY layer respectively. Had been focuses on how the new configuration of OLSR can defend or mitigate MANETs from these attacks. The new configured OLSR is named Security Aware OLSR (SA-OLSR) for this purpose in this context.

6.7.1 SA-OLSR defense from Black Hole Attack

In this section and the following subsections, has been investigate the impact of the modified configuration of SA-OLSR on protecting the MANETs from black hole attack when the network is carrying heavy and delay-sensitive traffic such as video conference. Since Black Hole attack occurs in the network layer, this layer should be protected. One way that can help to achieve this is by using the IPSec protocol that works on the network layer and furthermore, not one of the studies conducted have applied the IPSec protocol specifically with tuning OLSR protocol. The prime objective of our model is to prevent (or reduce the impact of) black hole attacks in OLSR based MANETs. We aim to show the effect of applying the IPSec on the SA-OLSR and OLSR and to what extent it can defend the network from the black hole attack.

6.7.1.1 Simulation Setup and Parameters Configuration

For the IPSec configuration, the IP Security demand is used between all the nodes in a full mesh manner in order to get more accurate results. The transport mode is preferred, as communication is only within peer-to-peer. The destination and source port of the IP Security demand is set to ‘video conferencing’ and the value ‘8’ denotes Best Effort that is set for the Type of Service. The malicious node is IPSec-enabled, thus it can send and receive the IPSec packets from the normal nodes.

In Black hole attack, an attacker node sends false routing information to the neighbor node that it is having the shortest path to reach the destination. So, the other nodes send information through the malicious nodes. Therefore, all the data will be captured by the attacker. An attacker destroys the data packets coming from the source node or modifies them and send them to the destination. The destination node does not realize is the data modified by the attacker. In the simulation setup have been used 2% of the mobile nodes as malicious nodes as a worst case in each scenario. The mobile nodes selected as malicious are configured as mentioned in Table (6.9).

In order for the malicious node to advertise itself and deceive other nodes that it has the shortest path, it needs to be able to show its availability of fresh routes. To accomplish that, the malicious node must have a low buffer size. The buffer size relates to the maximum size of the higher layer data buffer in bits. Once the buffer limit is reached, the data packets arriving from higher layers are discarded until some packets are removed from the buffer so that the buffer has some free space to store these new packets. Hence, the malicious node must have a low buffer size to show that it is always available to process other nodes' requests and later on drops the request packets it has received, to ensure the validity of the attack. In OLSR black hole attack, a malicious node forcefully selects itself as MPR which is discussed in Chapter (2). A malicious node keeps its willingness field to WILL ALWAYS constantly in its HELLO message. So in this case, neighbors of a malicious node will always select it as MPR. Hence the malicious node earns a privileged position in the network which it exploits to carry out the denial of service attack. The effect of this attack is much vulnerable when more than one malicious node is present near the sender and destination nodes.

Table (6.9): OLSR and SA-OLSR configuration for Black Hole attack nodes

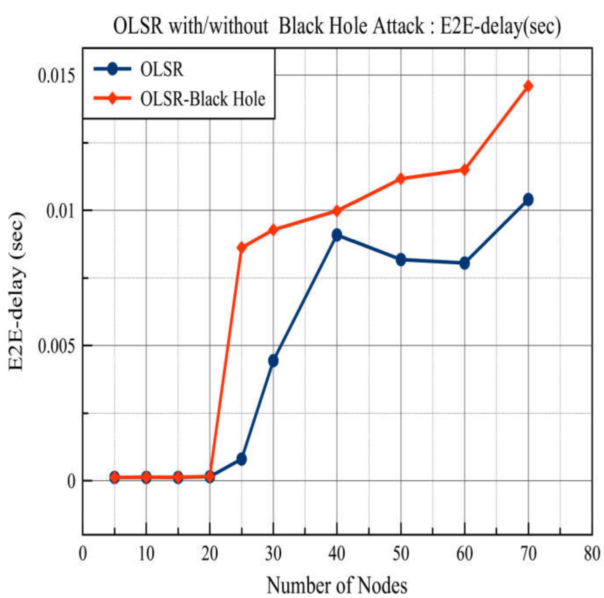
Parameters	Without Attack	With attack
Willingness	Default=3	High=7
Buffer size (bits)	32000	4000
IPSec Configuration	Disabled	Destination and Source Port=Video
		Type of Service =Best effort(8)

6.7.1.2 Findings and Results Analysis

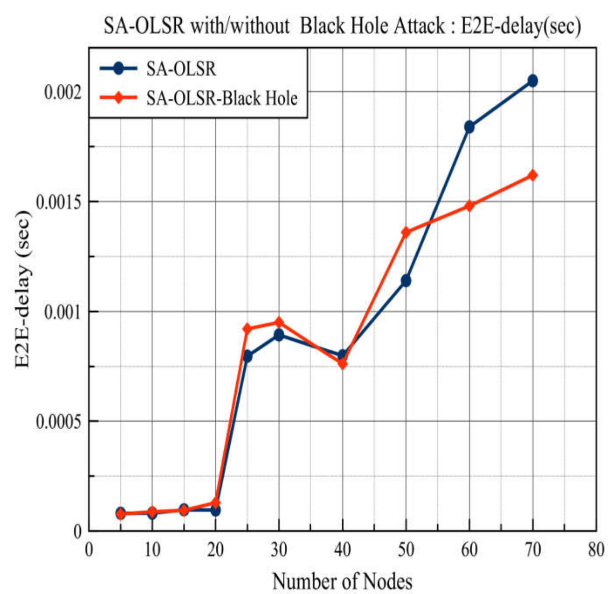
(1) E2E- delay Analysis

Considers OLSR without attack have a minimum E2E-delay. After a malicious node is added there will be increases in E2E-delay. Fig. (6.21) – (a) shows that a reliable E2E-delay achieved when there is no malicious node in the network. In a low-density network (5 to 20 nodes) under the black hole attack configured by using OLSR protocol, the E2E-delay is not significantly changed. But in the Middle and Large network densities, when the number of malicious nodes increases the E2E-delay increased. Fig. (6.21) – (b) shows the E2E-delay in case of SA-OLSR with/without black hole attack. It is obvious from the figure that SA-OLSR performs better in terms of E2E-delay under the black hole attack. The E2E-delay under the attack is slightly increased compared to without attack in the Middle network size, while the E2E-delay is less than the normal when the network is not under the attack and the network becomes dense and enlarged. This is because in black hole attack, the malicious nodes sit in between the actual sender and receiver and creates the illusion to each other. So during the path creating process, the malicious node sends replays quicker than the real destination and pretends to be the real destination. So, the sender begins to send the data which is received by the malicious node. So in the presence of a malicious node (attack scenario) the delay is reduced. In Fig. (6.21) – (b), delay in case of 60 and 70 nodes for SA- OLSR is high in the case when there is no attack on the network. This is because during the black hole attack, there is no need of RREQs and RREPs because the malicious node already sends its RREQs to the sender node before the destination node replies.

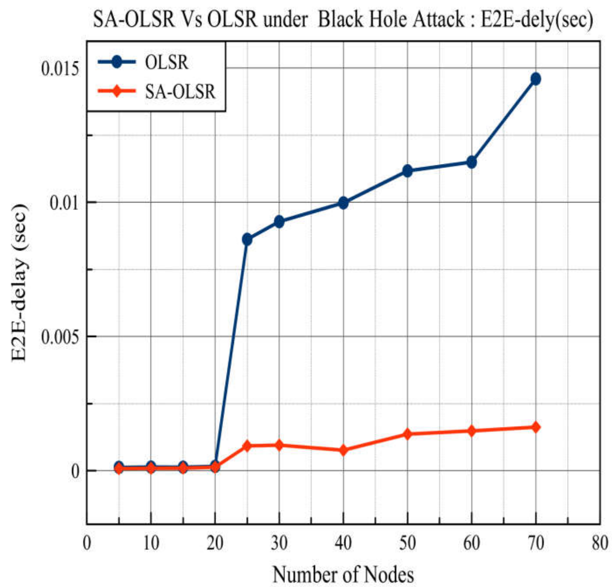
As a comparison in terms of average E2E-delay between OLSR and SA-OLSR when the two routing protocols are under the black hole attack, we found that SA-OLSR has a 65% less E2E-dealy with compared to the OLSR as shown in Fig.(6.21) – (c) .



(a) OLSR : E2E-delay



(b) SA-OLSR : E2E-delay



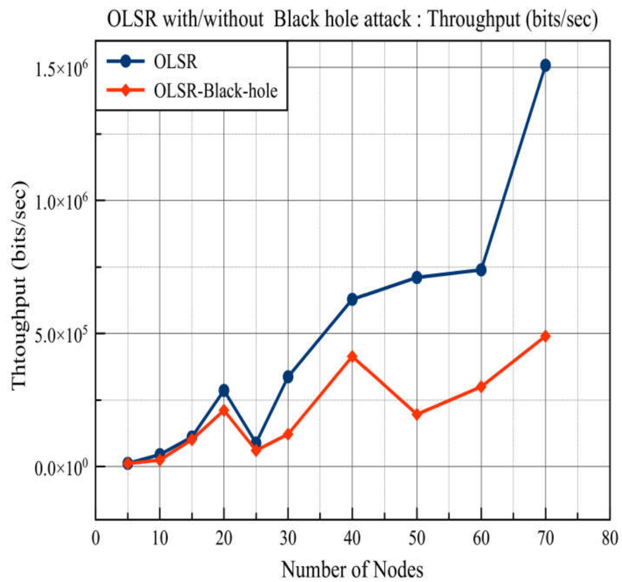
(c) OLSR Vs SA-OLSR

Figure (6.21) E2E-delay comparison under Black Hole attack

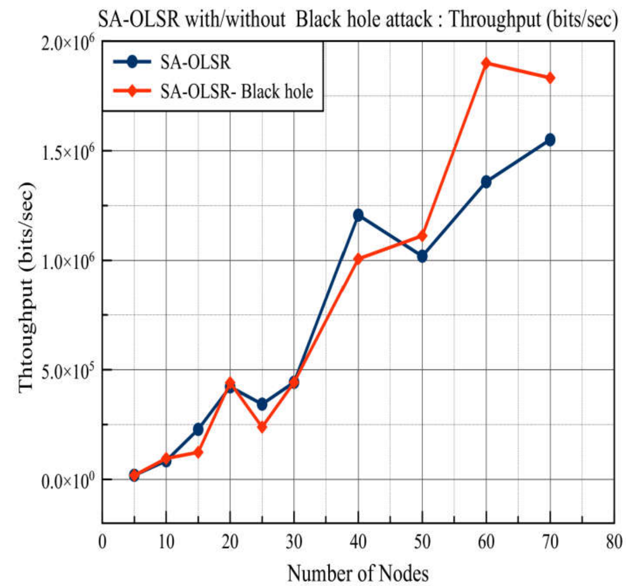
(2) Throughput Analysis

Throughput for OLSR in case of no attack (no malicious node present) is higher than the throughput of OLSR under attack (in the presence of malicious node) in all network sizes. This is because of the fewer routing forwarding and routing traffic. Here the malicious node discards the data rather than forward it to the destination, thus effecting throughput. Fig. (6.22) – (a) shows that OLSR without black hole attack obtained the highest throughput value and OLSR has the lowest throughput value with regard to the existence of black hole malicious nodes which affecting the throughput by decreasing it as a result to dropping packets . As the malicious node in Black Hole attack usually deals with RREQ and RREP messages with its surrounding nodes, the network using OLSR protocol is least affected by the attack because OLSR focuses on using Hello messages between the nodes for route discovery. Furthermore, being a table-driven protocol, OLSR stores and updates the routing information in its routing table permanently.

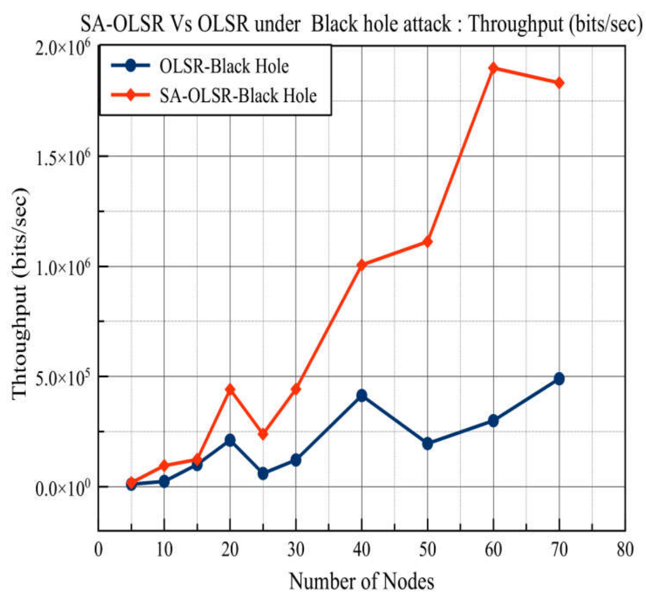
Similarly, in Fig. (6.22) – (b) in case of SA-OLSR the throughput is slightly higher without attack in Small and Middle network sizes for node densities between 5 to 45 node. At the high mobile density the throughput without attack is less than with the attack because of the higher number of nodes and higher control traffic due to using small interval of time for HELLO and TC messages. The IPSec protocol is expected to improve the performance as the attack occurs at the network layer, where it is proven true in terms of the throughput of this attack.



(a) OLSR with/without Black hole attack: Throughput (bits/sec)



(b) SA-OLSR with/without Black hole attack : Throughput (bits/sec)



(c) OLSR Vs SA-OLSR : Throughput under black-hole attack

Figure (6.22) Throughput comparison under Black Hole attack

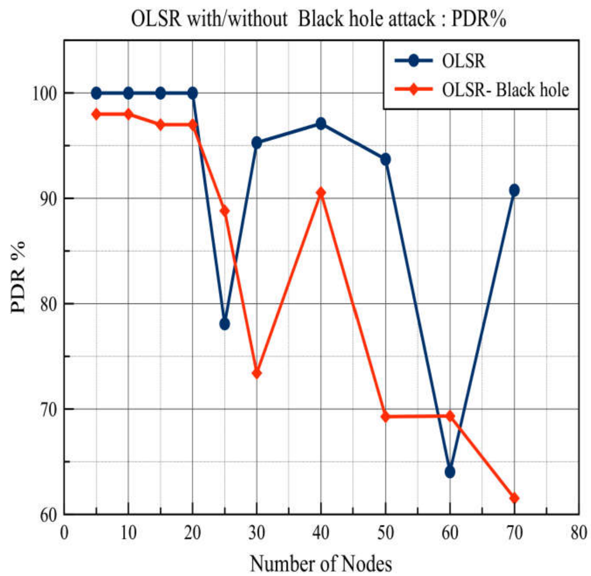
Although the results are not really significant, it provides enough evidence that the lower buffer size can help improve the simulations with IPSec. More generally SA-OLSR is not affected by the black hole attack in terms of throughput specifically when the network is enlarged; in addition, the IPSec configuration has no negative impact on the throughput in case of SA-OLSR.

However, IPSec has produced slight increase of the throughput for SA-OLSR in Small/Middle network sizes, while the increase is up to 63% on Large/dense network compared to that of OLSR when the two protocols become under the black hole attack as shown in Fig. (5.31) – (c). This is because of the fewer routing forwarding and routing traffic due to high packet discarding in case of OLSR.

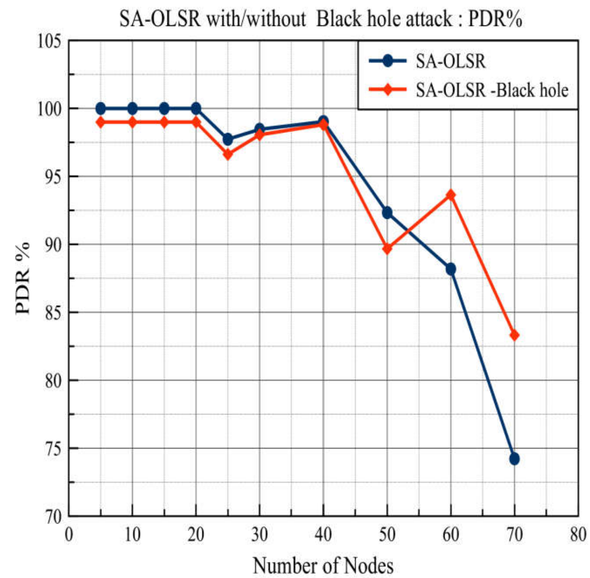
(3) PDR % Analysis

PDR % is decreased with the increases of number of black-hole nodes. The reason is that, when the destination node moves rapidly, it has more chance to select a node other than the black hole node as MPR which forcefully selects itself as MPR hence it keeps the willingness field to be always constantly in its hello message. So their neighbors will always select it as MPR. As shown in Fig. (6.23) – (a) in case of pure OLSR, the results show that when the number of black hole nodes increases the Packet Delivery Ratio (PDR %) decreases. When using the modified SA-OLSR with the IPSec configuration, there is a slight difference between SA-OLSR with/without attack in terms of PDR%. Both SA-OLSR with/without attack have similar values of PDR % with small variation as shown in Fig. (6.23) – (b), this implies that SA-OLSR performs efficiently under black hole attack. Similarly when both protocols are compared with each other, it was analyzed that in case of PDR% as in Fig. (6.23) – (c), shows that SA-OLSR has a high PDR% compared to OLSR in all network sizes and under varies node densities. Using IPSec to protect the network layer is not entirely effective to act as a defense as efficient routing protocols also play an important part to defer this type of attack.

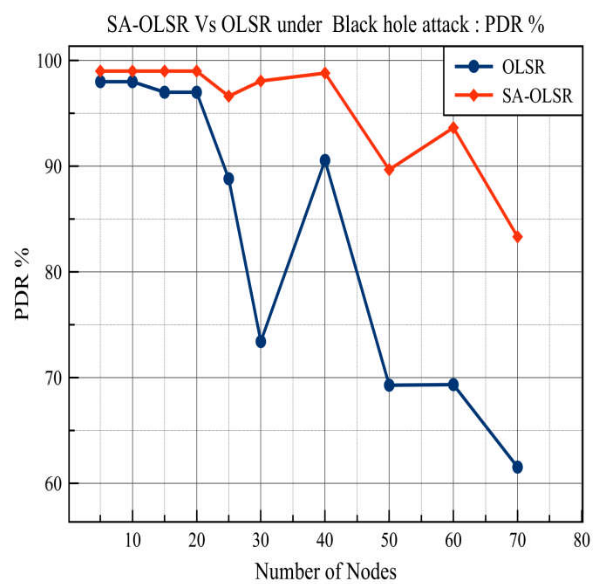
Although IPSec works on the network layer, it does little and has minimum control over the routing of the network. The actual routing protocol, in this case, SA-OLSR, determines the routes towards the destination. After the route towards the destination is established, only then the IPSec works to ensure data authentication, integrity and confidentiality of the data, depending on the AH and ESP protocols used in IPSec. This results in high PDR% in case of SA-OLSR as shown clearly in Fig. (6.23) – (c).



(a) OLSR with/without Black hole attack: PDR %



(b) SA-OLSR with/without Black hole attack : PDR%

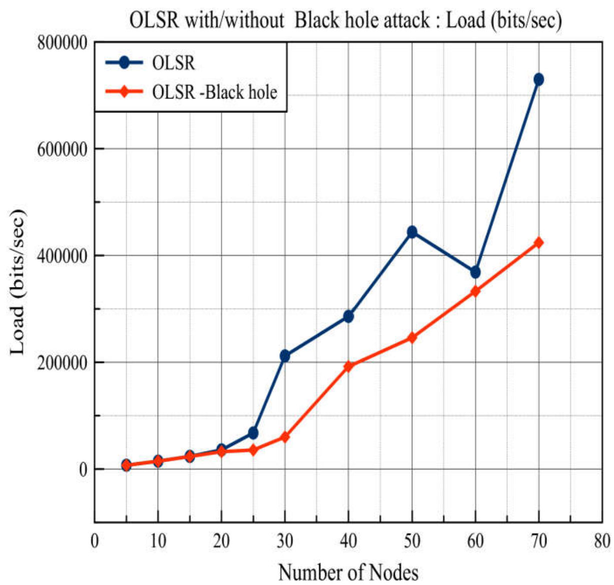


(c) OLSR Vs SA-OLSR : PDR % under black-hole attack

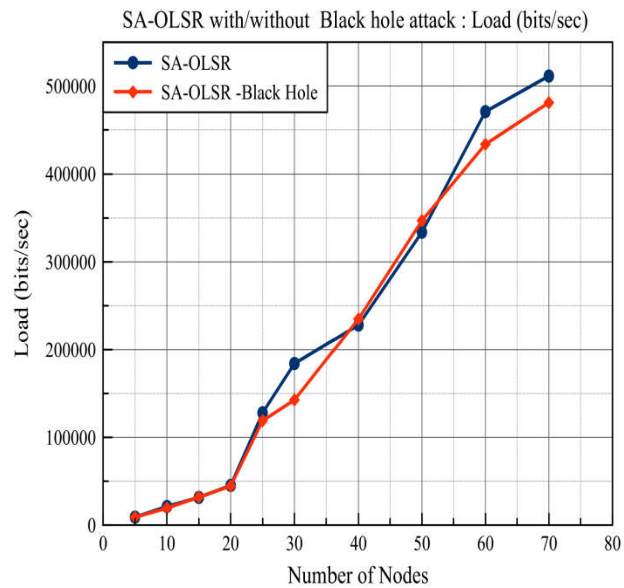
Figure (6.23) PDR % comparison under Black Hole attack

(4) Network Load Analysis

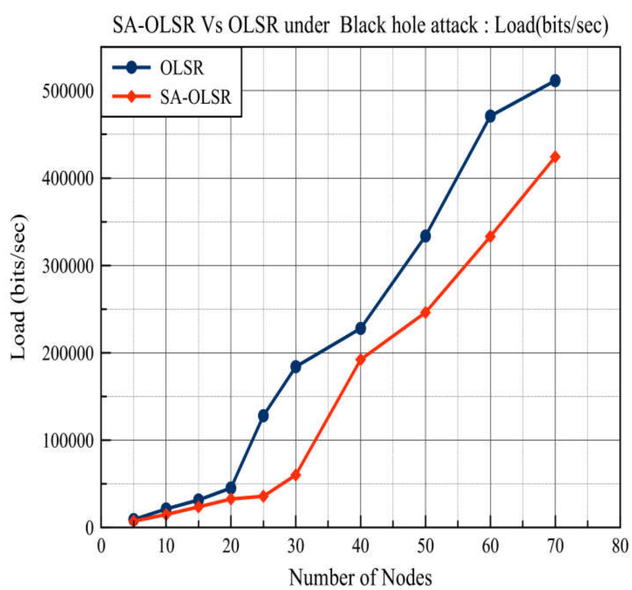
In case of an attack, OLSR has less network load as compare to without attack. From Fig. (6.24) – (a) it was analyzed that the network load of OLSR is nearly 26% times higher in case of without attack which implies that it is actually routing its packet to the entire destination properly. In case of (5 to 20) nodes the network load of OLSR is 0.8% times higher in case of without attack which implies that there is slight variation in between OLSR with/without attack in small network size and low mobile density; actually routed their packets to their destinations properly. But under attack it cannot send its packet i.e. packet discarding leads to a reduction of network load, and this appears clearly when the network becomes dense and enlarged, in this case the network load with attack is less than without attack.



(a) OLSR with/without Black hole attack: Load



(b) SA-OLSR with/without Black hole attack : Load



(c) OLSR Vs SA-OLSR : Load(bits/sec) under black-hole attack

Figure (6.24) Load(bits/sec): comparison under Black Hole attack

The same pattern is followed by SA-OLSR in Fig. (6.24) – (b). However SA-OLSR shows no changes in both cases because the traffic increases as a result of small HELLO interval and at the same time decreases due to the packets discarded by malicious nodes, which makes the load nearly the same with and without attack.

Fig. (6.24) – (c) shows a comparison in terms of network load between OLSR and SA-OLSR under black hole attack. SA-OLSR has less network load compared to OLSR in spite of tuned OLSR has higher load than the standard OLSR as mentioned in Chapter (3) .

The usage of IPSec protocols in this study are limited, it is clear that they do not add extra E2E-delay and load, and at the same time increase the throughput and PDR% which is desired in case of video-conferencing applications. However, we cannot clarify whether security goals of authentication, integrity and confidentiality are achieved. Therefore, in the future, further studies on IPSec in the network can be explored specifically to highlight whether the security goals can be achieved by using different combinations of the AH and ESP protocols, under different mobility speeds and densities.

5.7.2 SA-OLSR defense from Jamming Attack

In this section, we will explain the jamming attack model, which in general produces a Denial of Service (DoS) effect in the target nodes. Jamming attack deliberately transmits of radio signals to disrupt communications by decreasing the signal-to-noise ratio. A jammer is defined in [160] as "an entity who is purposefully trying to interfere with the physical transmission and reception of wireless communications". Jamming models can be ***stationary*** or ***mobile*** whether or not the attacker stays in the same position during the attack. The detection of jammer that moves through the network is more difficult, because the detector needs to consider the dynamic behavior of the channels in each node. Jamming models can also be classified into four different classes based on their behavior; ***constant***, ***deceptive, random*** and r***eactive***. A ***constant*** jammer continuously sends a radio signal or random bits to the channel without either checking the state of the channel (idle or not) nor following any MAC-layer protocol; a ***deceptive*** jammer constantly injects regular stream of packets to the channel without keeping any gap between subsequent packet transmissions; ***random*** jamming fluctuates between jamming and sleeping mode to conserve energy; ***reactive*** jamming jams only when it senses activity on the channel otherwise it stays idle.

While all jamming attacks can harm the network performance equally, the main difference is the detection difficulty.

In [161] Sonam Mahajan et al. (2019) stated that the jammer's transmitted signal is always strong enough to be sensed by a sender, it will always sense the medium as busy. The reactive attack is dangerous attack and is considered to be the most effective type of jamming because it usually drops the throughput to zero for a long period of time until it runs out of energy.

In the random jamming model, the jammer switches between active and sleeping modes; when the attacker is in the active mode, it behaves as either a constant or deceptive jammer. In contrast, in the reactive jamming model, the attacker remains quiet while the channel is idle; when it detects a packet, it sends an interference signal in order to corrupt the ongoing transmission. Jamming attacks reduce the performance of the network.

5.7.2.1 Simulation Setup

In this context we describe the simulation setup parameters. Pulse jammer attack is implemented on MANET network with integration of IPSec protocol. Jammer band base frequency is set to 2402 Hz; jammer bandwidth is set to 100,000 MHz, and to transmit at power 0.001W. Consequently the normal mobile nodes are set to transmit at 0.005W. The jammer transmission power is set to 0.001W which is less than the transmission power of the normal node in the network to prove that the jammer with low transmission power can have impact on the operation of the network by degrading the overall performance on the network. The number of pulse jamming nodes in the network is approximately equal to 10% of the total number of node density (we take the approximate nearest integer) and placed at different locations in each network size. As the jammer attack generates noise on the wireless radio frequency medium to stop the communication, it causes packet lost or corruption of packets. The results of a number of QoS metrics such as E2E-delay, throughput, PDR%, and network load are compared under the influence of the attack.

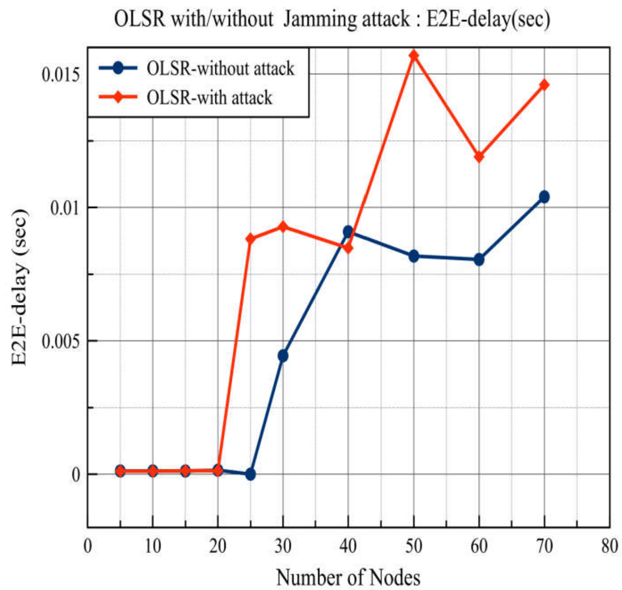
5.7.2.2 Experimental Results and Discussion

(1) E2E-delay in (sec)

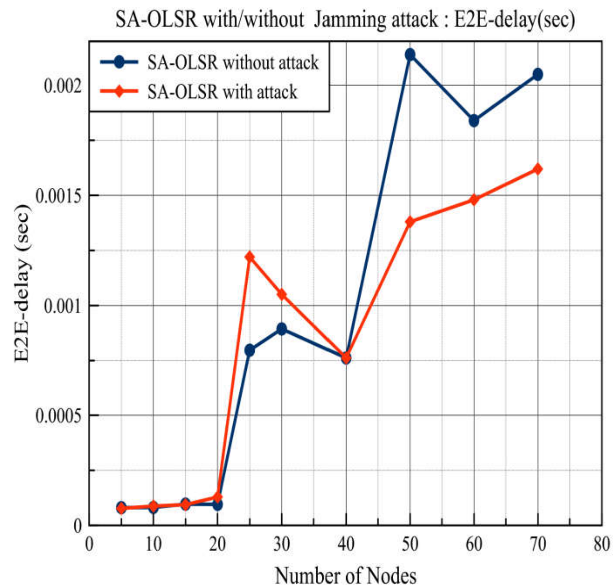
As shown in Fig. (6.25) – (a), in case of OLSR routing protocol, the E2E-delay is increased when the network becomes under jamming attack, which means that the jamming attack has a great impact on the ordinary OLSR. Fig. (6.25) – (b) shows the impact of the attack on the E2E-delay in case of SA-OLSR. It is obvious from the figure that SA-OLSR with the new configuration including the tuning of parameters, IPSec settings, and PCF functionality, defends the network from the jamming attack specifically when the network becomes dense and sparse. The E2E-delay in case of the jammed network became less compared to when the network is not under the attack.

Values depicted in Fig. (6.25) – (c), showed that increasing HELLO interval in Small network size, gives a small improvement for SA-OLSR specifically at nodes density from 5 to 20 mobile nodes. The figure also shows that when decreasing the HELLO interval at the Middle and Large scale network size, SA-OLSR achieved less E2E-delay values compared to OLSR at varying mobile densities between (30-70) nodes. This is due to the high control overhead, which leads to a faster update of routing information. Therefore it gives packets the ability to reach their destination effectively. However, the jamming attack has no significant impact on the SA-OLSR configuration in terms of E2E-delay which is an important metric desired to be low for transmitting video traffic efficiently. But E2E-delay increases when node density is increased in case of ordinary OLSR routing protocol. The E2E-delay increases systematically to a higher level by placing the jamming nodes in the network. We can say that jamming nodes generate noise on the wireless radio frequency medium to stop the communication, making the network more vulnerable and prevent the MANET nodes to continue the transmission on the network.

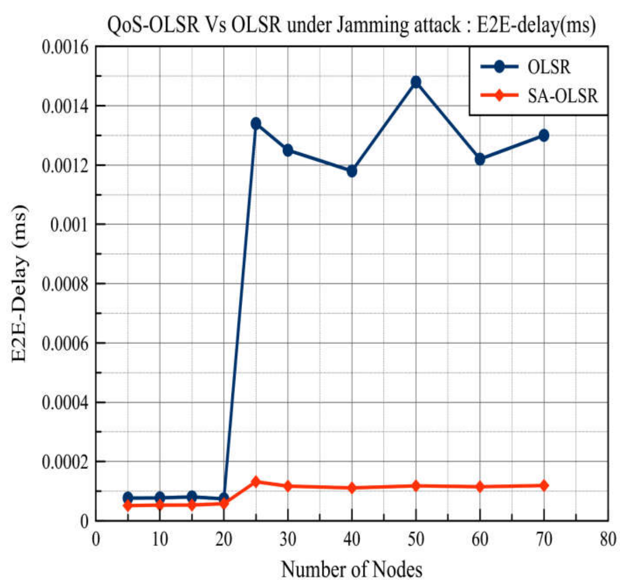
The higher values of E2E-delay under the jamming attack shown when the network becomes dense are due to the extra dummy packets injected into the shared medium. They cause interference with existing communications which leads to additional E2E-delay of all the packets received by the wireless LAN MACs of all WLAN nodes in the network and forwarded to the higher layer. Jamming causes additional routing table recalculations in all nodes in the network and this consequently adds additional processing time. SA-OLSR outperforms OLSR in the dense network and the E2E-delay reduced on average by 61%. A lower delay results in higher throughput.



(a) OLSR : E2E-delay



(b) SA-OLSR : E2E-delay



(c) OLSR Vs SA-OLSR

Figure (6.25) E2E-delay comparison under Jamming attack

The delay in the network with IPSec is higher than the delay without IPSec because IPSec protocol consumes more time for processing and transmitting packets from source to destination. This time has an influence on the overall delay in the network. The time taken to establish a route between two mobile nodes in case of the network with IPSec integration is greater compared to the vulnerable network.

(2) Packet Delivery Raito (PDR%)

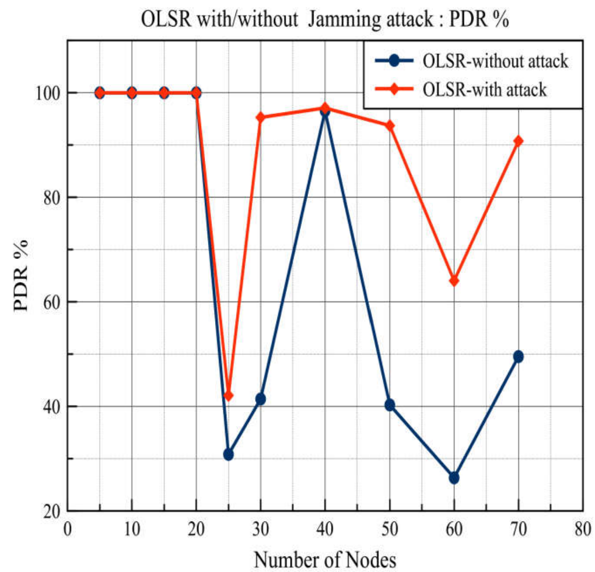
As we mentioned before PDR% represents a serious QoS metric for measuring the performance of transmitting video traffics effectively. The PDR% is degraded drastically when the network is under jamming as shown in Fig. (6.26) – (a) in case of ordinary OLSR. Oppositely SA-OLSR is not affected by the jamming attack on the Small and Middle network size, and this is due to the tuning and using IPSec as shown in Fig. (6.26) – (b). As a comparison between OLSR and SA-OLSR in terms of PDR % Fig. (6.26) – (c) shows the result of PDR %. There is no difference between OLSR and SA-OLSR at the low mobile density, both of them achieved 100% PDR. This is due to the fact that when the density of the nodes is low, the control messages such as HELLO and TC are very few since we are using a long interval time in case of SA-OLSR. For this reason, the network is not congested and all packets sent by the sender reached their destination.

When the number of nodes increased the PDR % slightly dropped for both protocols. That it is because the bandwidth is reserved by the attacker by the flood of a huge amount of unauthorized packets in the network. These packets are sent by the attacker to consume the available bandwidth of links and by that the links have become congested. However, pulse jammers could affect the network by increasing dropped data as shown in the figure.

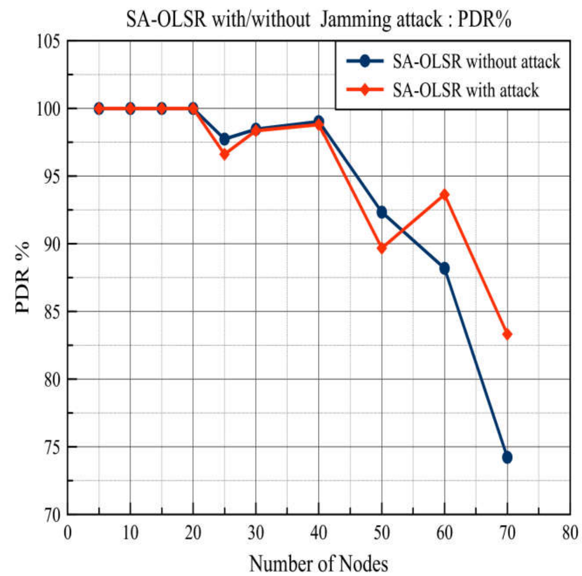
One of the findings related to this context, is that the frequency of control messages, with minimum intervals imposed for HELLO and TC, may limit the impact of the jamming attack. SA-OLSR outperforms OLSR in Middle and Large network size with the increase in PDR% by 15%.

(3) Throughput (bits/sec)

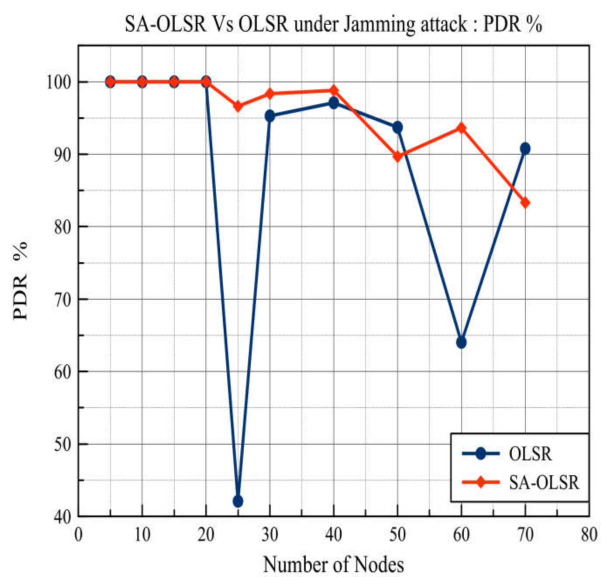
When the jammer sends useless packets to flood the network, the throughput of the node dropped. The jammer attack reduces the traffic on the network when it is compared to the normal network traffic. There is significant destruction of packets transmission in the network when applying a pulse jammer attack. Fig. (6.27) – (a) shows that the normal network throughput average value is 54.5 KB/sec in case of OLSR without jamming. Later in case of OLSR with jamming nodes in the network, it shows that the network throughput average value is 30.25 KB/sec. The average dropped in throughput in case of the ordinary OLSR routing protocol by 44%. Fig. (6.27) – (b) demonstrates the impact of the jamming attack on the throughput in case of SA-OLSR. For the Small and Middle network size, as shown in the figure there is a very slight difference in the throughput. At the dense network, we used a long HELLO and TC interval of time in order to detect the topology changes which led to extra control messages and from then increased throughput and load.



(a) OLSR : PDR%



(b) SA-OLSR : PDR %



(c) OLSR Vs SA-OLSR

Figure (6.26) PDR % comparison under Jamming attack

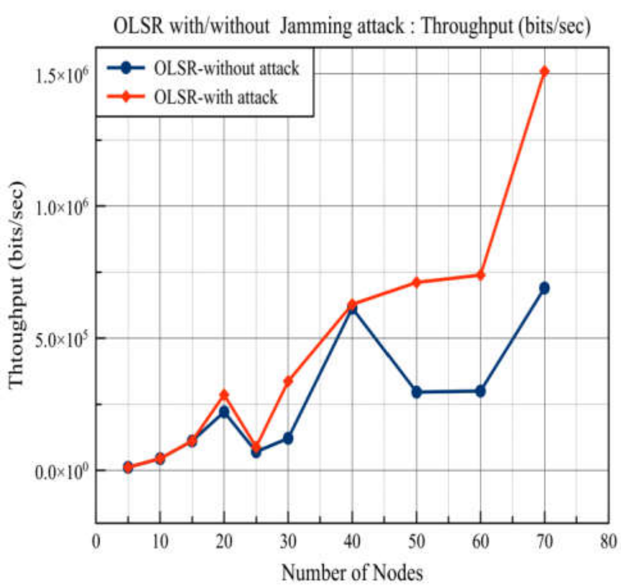
Therefore we can say that pulse jammer attacks use the wireless medium and decrease the network traffic throughput. The experiment of the pulse jammer attack shows that the jammer attack is harmful to the network as jammer can easily break down the communication in the network nodes.

Fig. (6.27) – (c) shows a comparison in terms of throughput between OLSR and the new version SA-OLSR when they are under jamming attack. SA-OLSR has a high throughput in all network sizes.

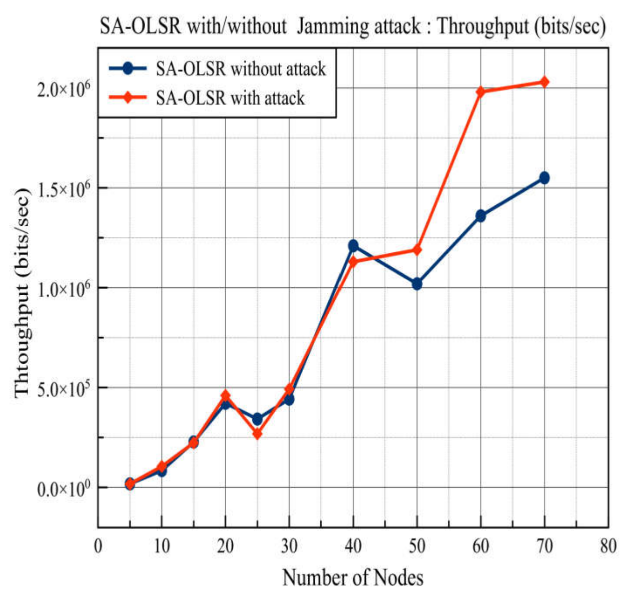
However, the throughput for the network without IPSec is less than the throughput with IPSec. The degradation of throughput in case of security solution is due to the increased overhead on the network added by IPSec protocol. Fig.(6.27) – (a), (b), and (c) show that the implementation of IPSec protocol has slightly improved the throughput.

(4) Network Load (bits/sec)

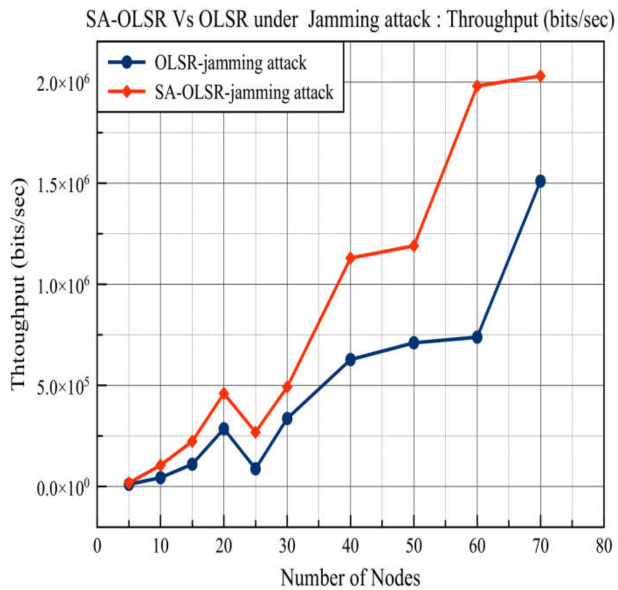
The function of the jammer is to deny the network transmission services to authorized users by generating noise on the wireless medium in order to block the access for authorized nodes. In Fig. (6.28) – (a), we analyze the network load of the entire network with and without pulse jammer in case of OLSR. The normal traffic network load is recorded as an average of 13.05 KB/sec and later with jamming nodes in the network; the network load is noted as 26.73 KB/sec.



(a) OLSR : throughput



(b) SA-OLSR : throughput

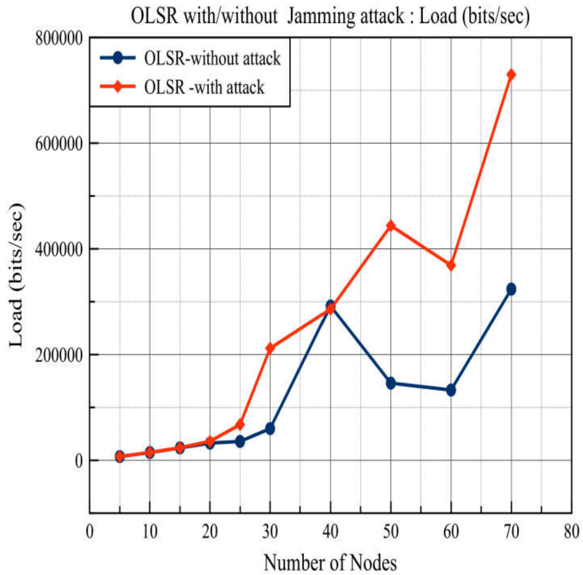


(c) OLSR Vs SA-OLSR : Throughput

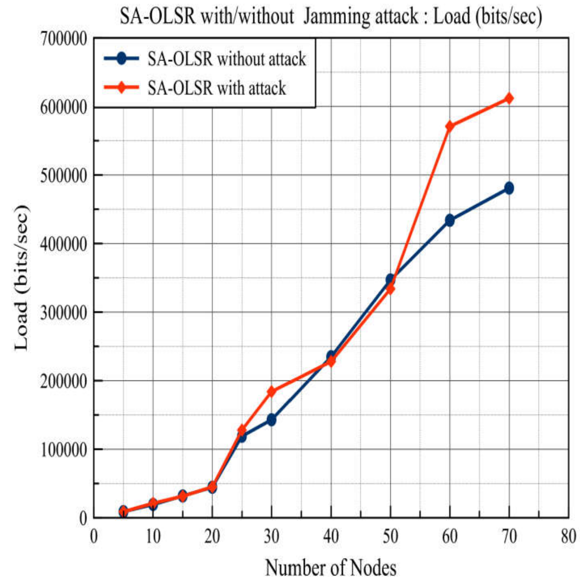
Figure (6.27) Throughput comparison under Jamming attack

There is a difference between the normal network load and with the jamming nodes in the network. Jamming nodes clearly reflect the availability and reliability of MANET nodes in terms of security. In case of without attack, OLSR has fewer network loads as compared to with attack. However, under attack, it cannot send its packet i.e. packet discarding leads to a reduction of network load.

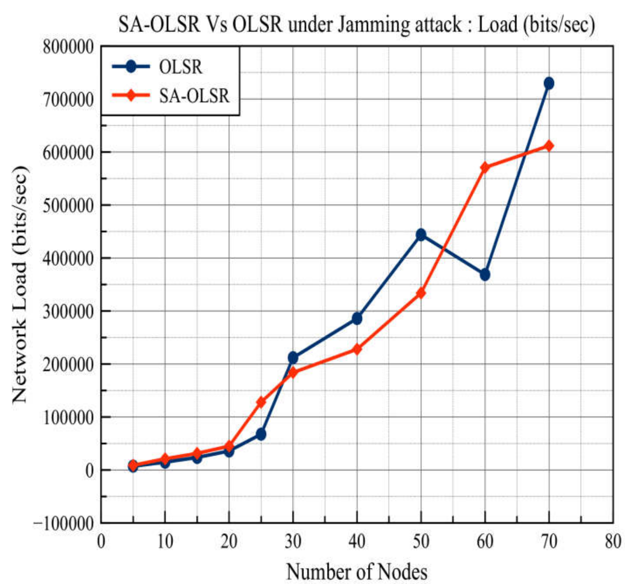
These results are compatible with the assumptions mentioned before aims to defense from jamming attacks. Thus, conclude from these results that the enhanced scheme based on the parameters tuning of standard OLSR can improves the performance when MANET network becomes under jamming attack.



(a) OLSR : Network Load



(b) SA-OLSR : Network Load



(c) OLSR Vs SA-OLSR : Network Load

Figure (6.28) Network Load comparison under Jamming attack

6.8 Energy –Aware OLSR (EA-OLSR) based on MANETs

In a MANET network, nodes are often powered by batteries. Every message sent and every computation performed drains the battery. The routing protocol must be designed in such a way to reduce the amount of information exchanged among the nodes since communication incurs the loss of power. Increase in the number of communication tasks also increases the traffic in the network, which results in loss of data, retransmissions, and hence more energy consumption. Power failure in the mobile node does not only affect the node itself but also affect the ability to forward data packets [139, 162].

Optimization of power:

In MANETs the optimization of power consumption can be divided according to functionality into:

- The maximum power utilized for the transmission of a message.
- The maximum power utilized for the reception of a message.
- The minimum power utilized while the system is idle.

Reducing the power consumption on mobile nodes becomes a critical issue when we decide to enhancement the overall performance of any routing protocol. Controlling and optimizing the power consumption will protect the network from link breakage, packets dropped, retransmission, and at the same time prolong MANET lifetime. For powerful routing protocol, reducing the number of retransmission across the network can be controlled effectively. For utilizing effective routing algorithms, network life time and energy will be conserved and redundant transmission will be reduced [13].

6.8.1 Energy conservation techniques

To maximize network lifetime various power conservation techniques have been proposed to improve energy efficiency. Some significant work has been done to achieve energy efficiency in MANET. Different techniques are proposed in literature to improve energy efficiency. Energy conservation techniques can be broadly classified into two types:

- **Topology Control Approach**

Topology of MANET is affected by many uncontrollable factors like node mobility (mobility speed), node density, weather conditions, environmental interference and obstacles and some controllable factors like transmission power, antenna direction and duty-cycle scheduling. The topology control is an effective technique for power saving. In dense networks too many links leads to high energy consumption, network throughput, and quality of services. The primary target of topology control is to replace long distance communication with small energy efficient hops [163].

– **Transmission Power Management Approach**

Power management approach basically aims to switch off the radio transceiver of the mobile terminal to save energy. This power management state can also be called as sleep/power down mode. Turning the transceiver off, result on the node not listening to the channel and not take an active participation in packet transferring. So turning off the station should be done with a condition not to incorporate delays in packet transmission. Synchronization should be maintained in routing so that switching off one node does not affect the performances of overall network connectivity.

In order to study the impact of the tuning and optimized configuration of OLSR in the power consumption we follow the topology control approach. In OLSR, since HELLO and TC intervals have a great impact on the performance, we suggest that when minimizing the amount or the number of control messages that will decrease the energy consumption on mobile nodes. This objective can't be achieved unless we configure OLSR in such a way that generates a control messages adapted with the topology changes. Here we investigate the EA-OLSR (Energy Aware OLSR) based MANET. The performance of EA-OLSR protocol have been discussed and evaluated on the basis of power or energy consumption, "HELLO" message sent, routing traffic sent and received, total TC message sent and forwarded, total HELLO message and TC traffic sent are analyzed. In addition, the study of the impact of mobility on the energy consumption in EA-OLSR, and the ANOVA model for energy consumptions under varies number of nodes and mobility speeds. The best solution and the predicted energy consumptions within specific MANETs conditions specially transmitting video contents is generated using PSO.

6.8.2 Power consumption Model in MANETs

The energy required for each device to perform the communications depends on its mode:

– **Idle mode**: is the default mode of wireless interfaces in ad hoc networks, where nodes keep listening and the interface can change the mode and start transmitting or receiving packets.

– **Active (Transmit and receive) modes:** are the modes for sending and receiving data through the medium.

– **Sleep mode**: is the mode when the node radio is turned off, and thus the node is not capable of detecting any signal.

– **Overhearing mode:** a node listens to the packet that is not destined for it. The energy consumed in this mode is the same as reception mode.

During the period of communication, each node in MANET exists in four modes as given in Equation (6.5) [161],[164]. Each mode has a different consumption of energy. For example Equation (6. 6) shows that the node in active mode consumes most power as compared to sleep mode.

$$E_{totaal} = E_{sleep} + E_{active} + E_{idle} + E_{overhear} \quad (6.5)$$

$$E_{active} = E_{recv} + E_{trans} \quad (6.6)$$

$$E_{sleep} \cong 0 \quad (6.7)$$

In this work, the behavior of OLSR has been modified in order to reduce the power consumption due to data exchange (control or information messages). We deal with energy-awareness in MANETs by optimizing the power consumption of the two operational states that act during the packet exchange: ***transmit*** and ***receive*** states. Therefore, we consider the *per-packet power consumption* modeled by Cano et al. (2000) [165], in which only transmit and receive modes are taken into account to compute the power consumption to be optimized.

(A)- Power Consumption of Nodes in two states (Transmission and Reception):

The energy is computed according to the power requirements in transmitting (P_{send}) and receiving (P_{recv}) states, and the time needed to transmit the packets (***time***). These values are obtained by using the network interface card (NIC) characteristics of electric current (I_{send}, I_{recv}) and power supply (V_{send},V_{recv}) in each state, the size of the packets, and the bandwidth used. Equations (6.8) and (6.9) represent the energy required for packet transmission (E_{send}) and for packet reception (E_{recv}) [165-167].

$$E_{send} = P_{send} \times time = (I_{send} \times V_{send}) \times \frac{Packets\ Size}{Bandwidth} \quad (6.8)$$

$$E_{recv} = P_{recv} \times time = (I_{recv} \times V_{recv}) \times \frac{Packets\ Size}{Bandwidth} \quad (6.9)$$

In MANET high speed of mobility or continuously changing network topology causes link breakage and invalidation of end-to-end route. The link failure is indicated by the absence of HELLO messages. To reduce the link failure the messages are retransmitted. By retransmitting the messages the routes consume more energy and the system life time will be less. Therefore radio power consumption must be minimized to extend system lifetime. Under radio power cost the IEEE802.11 network card has the radio power cost of T_x=1400, R_x=1000, idle=830, sleeping=120. Transmission consumes more power than receiving and sleep consumes much less power than idle [168].

In MANET each node sends data to another node in the network on the transmission mode consuming energy named transmission energy (T_x), it is related with packet size (in bits) of data, Equation (6.10) give the formula of transmission energy.

$$T_x = E_{send} = (1400) \times \frac{Packets\ Size}{11 \times 10^6} \times total\ packets\ sent \qquad (6.10)$$

In reception mode each node in network which receives the data requires energy named reception energy (R_x), similar to transmission mode, in reception mode the reception energy is depends on packet length of data, and the formula of the reception energy is given as in Equation (6.11). The total energy consumed (E_{total}) due to send/receive is given by Equation (6.12).

$$R_x = E_{recv} = (1000) \times \frac{Packets\ Size}{11 \times 10^6} \times total\ packets\ send \qquad (6.11)$$

$$E_{total} = \frac{\sum_{i=1}^{n} E_{sent} + \sum_{i=1}^{n} E_{recv}}{\text{Total Simulation Time}} \qquad (6.12)$$

Where: n is the number of packets sent/received

(B) Energy consumed by tuned OLSR

Table (6.10), and Fig. (6.29) show the total energy consumed due to send/receive modes of communication in the MANET network based on the EA-OLSR and OLSR routing protocols. It is obvious that EA-OLSR consumes similar energy as OLSR in mobile density (10-20 nodes). In the low mobile density, there are no significant differences between them, that is because the topology is stable and the HELLO and TC messages intervals in case of EA-OLSR are close to the intervals in case of ordinary OLSR. As we mentioned in our assumption we do not need frequent and long interval HELLO and TC messages in case of low mobile densities because the topology change is more precise due to less number of nodes and low speed. At the middle and higher mobile densities (30-70 nodes) EA-OLSR outperformed OLSR .We also observed that, when the number of mobile nodes increases, the energy consumed also increased.

Table (6.10): Energy consumed in EA-OLSR and OLSR Vs number of Nodes

# Nodes	10	20	30	40	50	60	70
OLSR	8.301333	16.55283	32.29967	33.52517	31.25533	35.09033	39.981
EA-OLSR	8.217	17.672	18.97533	12.61733	20.51233	24.13	26.30017
Reduction%	1	-7	41	62	34	31	34

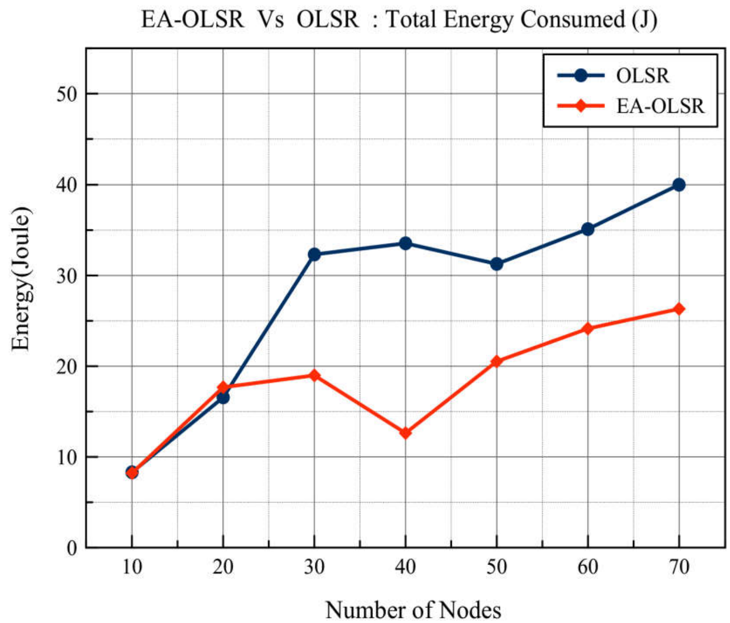
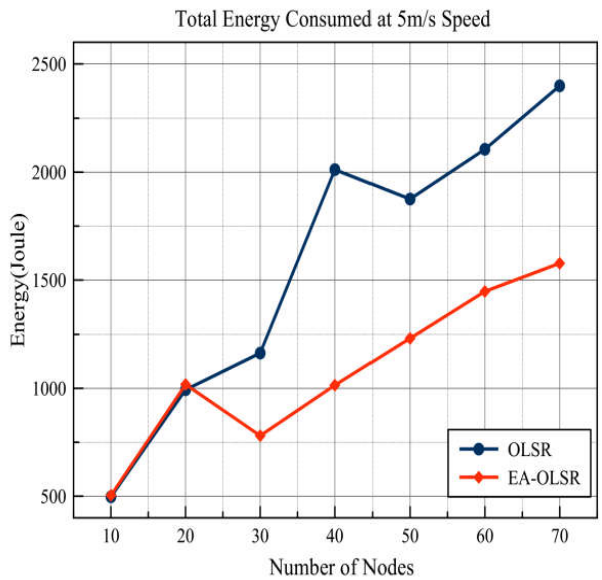


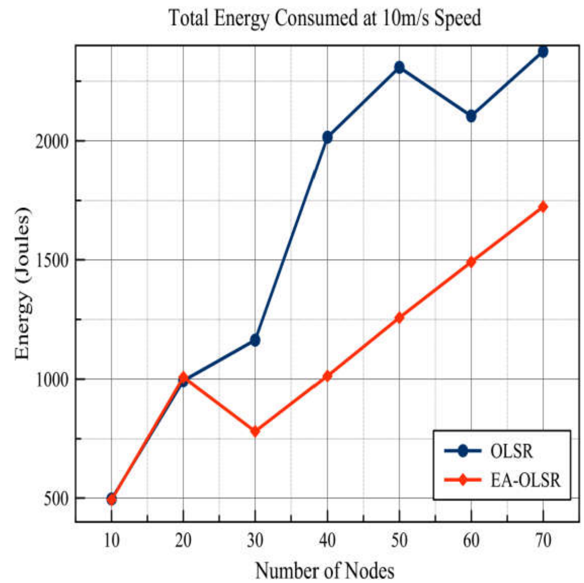
Figure (6.29) EA-OLSR vs OLSR : total energy consumption (Joule)

(C) Impact of varying mobility speeds on the power consumption in EA-OLSR

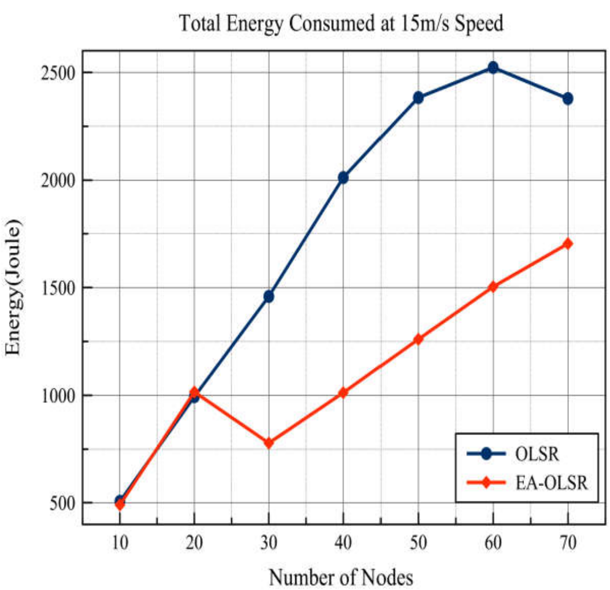
In this section, we investigate the impact of the tuned configuration (EA-OLSR) on the energy consumption under different mobility speeds and various mobile densities. In this scenario, we chose different mobility speeds that vary between 5m/s to 30m/s and mobile densities vary between 10 nodes to 70 nodes. Fig. (6, 30) shows a comparison between EA-OLSR and OLSR.



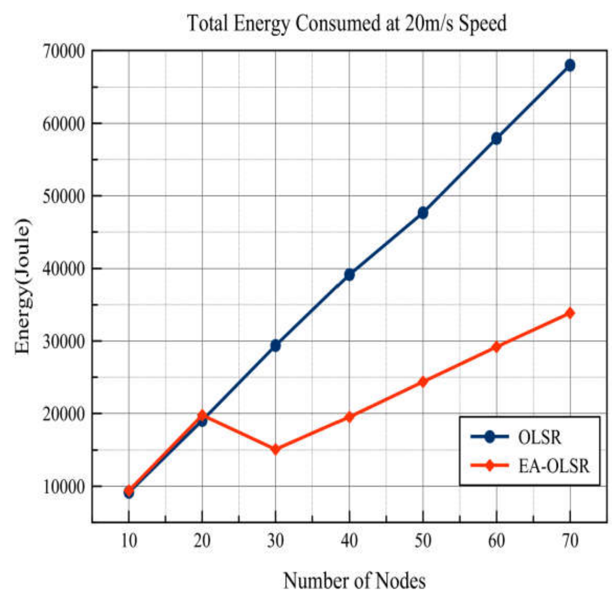
(a) Energy consumptions at 5m/s



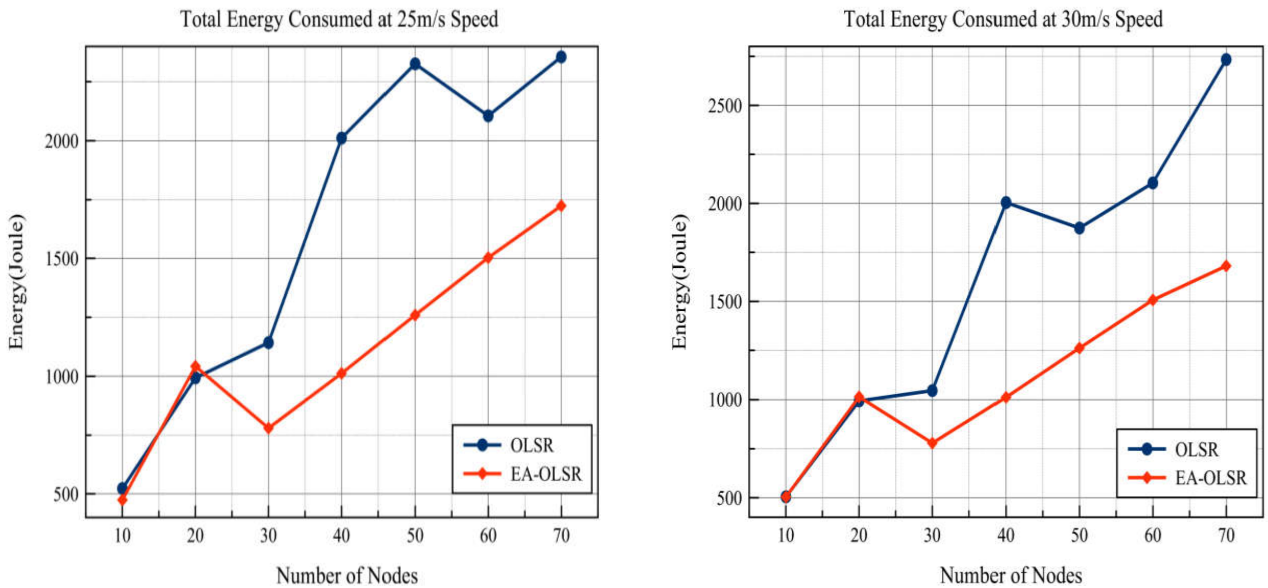
(b) Energy consumptions at 10m/s



(c) Energy consumptions at 15m/s



(d) Energy consumptions at 20m/s



(e) Energy consumptions at 25m/s (f) Energy consumptions at 30m/s

Figure (6.30) EA-OLSR vs OLSR energy consumption: various speeds , densities

Table (6.11): Average Energy Consumption OLSR vs EA-OLSR

Protocol	Speed m/s	Mobile Node Densities						
		10	20	30	40	50	60	70
OLSR	5	498.08	993.17	1162.79	2011.51	1875.32	2105.42	2398.86
	10	496.56	993.17	1163.38	2015.61	2308.80	2104.73	2376.22
	15	507.16	993.17	1459.03	2011.16	2382.86	2522.51	2378.24
	20	9152.31	19051.5	29372.92	39140.32	47664.38	57906.29	67997.71
	25	522.76	993.17	1142.54	2011.47	2326.83	2105.77	2356.2
	30	504.19	993.17	1045.77	2004.57	1874.71	2104.67	2733.87
EA-OLSR	5	505	1017.42	780.48	1014.17	1230.74	1447.8	1578.01
	10	493.02	1007.81	780.31	1012.9	1257.67	1491.63	1723.37
	15	490.95	1015.36	777.79	1011.83	1259.92	1504.01	1704.35
	20	9396.06	19783.82	15066.52	19532.16	24376.09	29188.28	33854.3
	25	474.39	1042.13	779.29	1011.93	1259.54	1503.49	1723.64
	30	503.37	1013.84	778.06	1011.4	1262.67	1507.67	1681.43

From Fig. (6.30), it is clear that in all subfigures (a) through (f), there are no significant differences between EA-OLSR and OLSR in the low mobile densities and low mobility speeds. The energy consumed by EA-OLSR is very steady and grows with the increasing of nodes and increasing of the mobility speed, but in the case of OLSR the energy consumed fluctuated, and the overall performance of EA-OLSR is better than OLSR. This is because EA-OLSR transmits fewer control packets compared to OLSR where the TC messages are transmitted periodically. So EA-OLSR generates less traffic on the bases of HELLO and TC messages and adapts to the network topology change. For these reasons as shown in Table (6.11), EA-OLSR maximizes the network lifetime and has power conservation on average between 41% - 62% for middle densities (30-40 nodes) with mobility (30-40 m/s), while conserved power reached 34% for high density and high-speed scenarios. The EA-OLSR protocol is an efficient proactive routing protocol which is very suitable for such dense and large-scale MANETs. EA-OLSR is less influenced by the mobile density and irrespective of the mobility of the nodes. Also, the average energy consumptions of nodes increases from low density to high density, and its increase follows a similar pattern.

(D) Multivariate Regression Modeling and optimization of EA-OLSR

From the previous section **(B)** we conclude that the tuned configuration of OLSR results in an energy aware behavior of OLSR. But it is important to show the limitations of the EA-OLSR regarding the three factors ***mobility***, ***density***, and ***network size***. The ANOVA technique had been used to model the real observed values from the simulation in order to find an approximate relationship between the ***response factor*** (*Energy consumed*) and the ***predictors*** (*speed, density, network size*).

Fig. (6.31) shows the energy consumption data collected from the simulation work after 20 runs of simulation for EA-OLSR, while Fig. (6.32), shows the predicted data after the implementation of a multivariate regression model. The ANOVA summery results in Table (6.12) show an achieved high $\mathbf{R^2}$ =0.99, which means that we can obtain a best fit model in this case.

In Fig. (6.33), the simulation results showed that the mobility speed had little influence in the energy consumptions, but the mobile density had a great impact on the energy consumption which is typical as addressed in the case of QoS-OLSR, where the tuned parameters has great impact on the overall performance except the network load, and in the same time the tuned parameters not affected by the mobility speed, but the mobile density degraded the performance of the protocol.

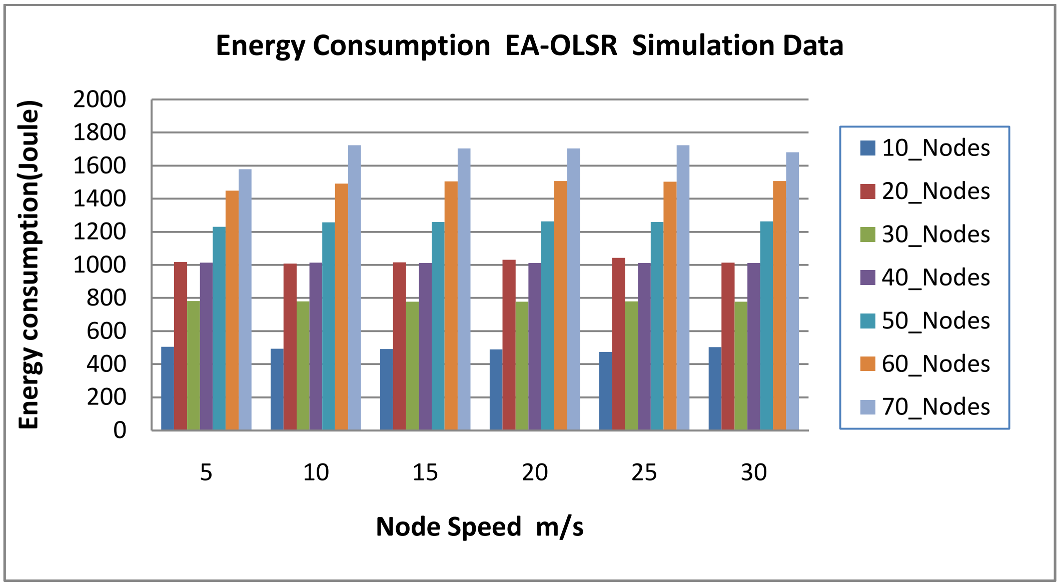


Figure (6.31) Energy consumed: Observed data from 20 simulations runs

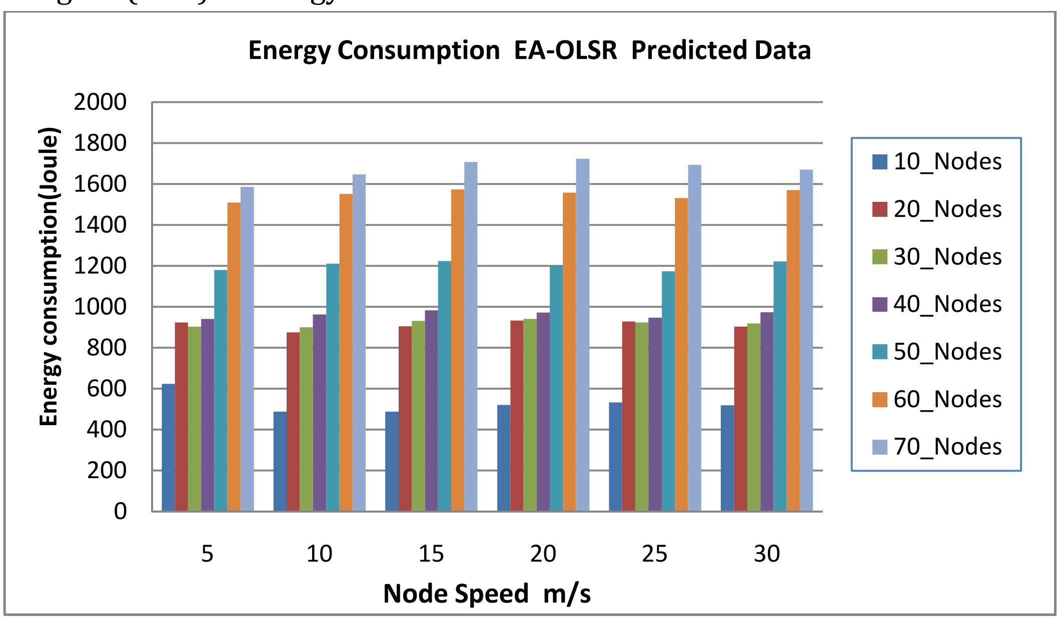


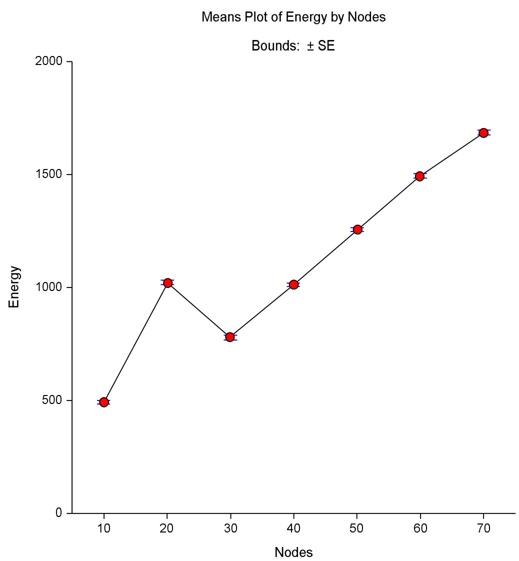
Figure (6.32) Energy consumed: Predicted data after AOVA analysis

Table (5.12): Energy consumed summary output

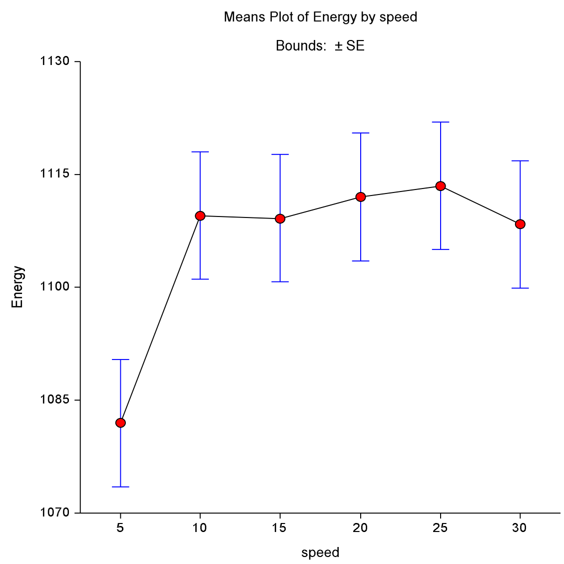
Regression Statistics	
Multiple R	0.997606
R^2	**0.995217**
Adjusted R^2	**0.953997**
Standard Error	102.771
Observations	42

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	16	57144728	3571546	338.1541	3.7E-25
Residual	26	274609	10561.89		
Total	42	57419337			

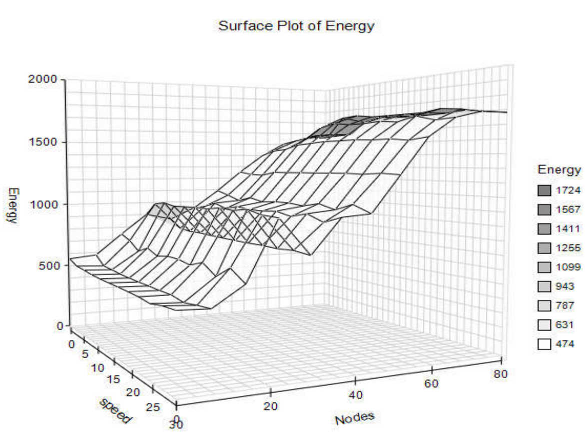


(a) Energy vs Node density

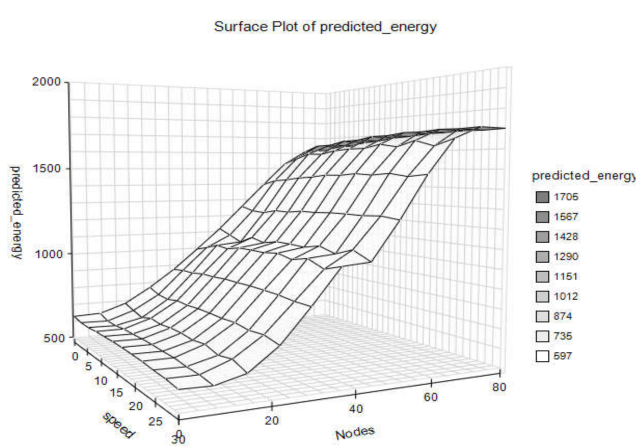


(b) Energy vs Speed m/s

Figure (6.33) Predicted energy consumed



(a)



(b)

Figure (6.34) Surface plot of Energy : (a) simulation data , (b) predicted data

The obtained estimated equation for the energy consumption among different speeds is in the range (5m/s ~ 30m/s) and node density is in the range (10 ~ 70 nodes) and is given by Equation (6.13).

$$\text{Energy} = 267.3859 + 1.0063 * \text{speed} + 19.6402 * \text{Nodes} \qquad (6.13)$$

However, in this section we presents a new version of standard OLSR, called (EA-OLSR), through modification of routing parameters, in such a way that minimize energy consumption of nodes and realization of balanced traffic load of nodes, in addition to adaptation of transmission power of exchanged data packets among communicating nodes, resulting in prolong life time of nodes, hence increase life time of the routes and relative stability of network. In proposed scheme, the routing parameters selection depending on two combined variables: nodes density and their mobility speed.

6.9 Optimal configuration of QoS-OLSR

In the previous sections we discussed the impact of the new tuned configuration of OLSR on the QoS of effectively transmitting video conferencing over MANETs. In addition, the proposed scheme was evaluated for defending MANETs from a two popular attacks which are black hole and jamming attacks. Moreover we study the impact of the new configuration on the energy consumption by the enhanced version of OLSR.

In order to show the impact of mobility and scalability on the modified versions QoS-OLSR and EA-OLSR, we used the MLRM and ANOVA analysis. The obtained models are statistically analyzed; the models show that the studied performances accurately follow a linear evolution. These models provide invaluable information and can be useful in analyzing, optimizing, and predicting performances for MANETs routing protocols.

Now we are going to answer tow critical questions: 1) to which scalability limitations can MANETs be extended to effectively and efficiently transmit videoconferencing without degradations the performance? , and 2) to which mobility speed the performance of transmitting video conferencing be optimum?.

To answer these questions we used the PSO technique as described in section 4.9.3. This objective was achieved through creating a fitness functions from the QoS modeling formulas

(4.16) to (4.19). The following table (6.13) summarizes our findings after implementing PSO to find the best fit solutions taking in considerations the network contexts (mobility and scalability). Similarly the optimal performance related to MANETs context after implementing the PSO algorithm mentioned into Tables (4.6) and (4.7) achieved the results illustrated into table (6.14).

Table (6.13): Optimal OLSR routing parameters

Attribute	Value (Number of Nodes)									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Willingness	3	4	3	4	4	4	4	4	4	4
Hello Interval (seconds)	5	3	2.8	3.5	3.5	4	2	1.6	1.4	1.3
TC Interval (seconds)	9	6	4.8	7.5	3	3	3	2.8	2.8	2.8
Neighbor Hold Time (seconds)	7	10	6	7	6	6	6	4	3.8	3.3
Topology Hold Time (seconds)	20	20	20	15	12	12	12	10	8	6
Duplicate Message Hold Time (seconds)	40	40	40	20	20	20	20	16	14	12
Addressing Mode	IPv4	IPv4	IPv4	IPv4	IPv4	IPv4	IPv4	IPv4	IPv4	IPv4

Table (6.14): Optimal MANET configuration

Nodes Range	**Speed Range**	**HELLO interval Setup**					
		WILL_	HELLO	TC	NEI_HT	TOP_HT	DUP_MESS
10 — 17	5m/s	3	3.316	5.961	8.334	20	40
18 — 30	18m/s	3	2.558	5.114	6.010	20	40
31 — 51	7—28 m/s	4	3.220	5.233	6.335	15	20
52 — 70	30m/s	4	3.303	3.000	6.000	12	20

5.10 Chapter Summary

The evaluation of the proposed scheme based on changing the behavior of OLSR protocol to cope with most challenging tasks facing the transmission of video conferencing via MANET had been performed. The new configured OLSR achieved high performance in terms of QoS, defense from security attacks (black hole, jamming), and power consumptions due to send/receive packets.

Transmission power of packets among nodes through the selected route is adaptive. Simulation results proved that, the performance of the proposed protocol are better than original OLSR with respect to: successful packet delivery percentage, total delay time, normalized overhead, and nodes energy consumption.

The obtained models are statistically analyzed; the models show that the studied performances accurately follow a linear evolution. These models provide invaluable information and can be useful in analyzing, optimizing, and predicting performances for mobile Ad-hoc routing protocols.

Chapter Seven

Conclusions and Future Works

7 Conclusions and Future Works

Real-time video transmission over MANETs is necessary for the deployment of useful and crucial services over MANET networks. However, there are many challenges to overcome in order to fulfill all video streaming requirements.

7.1 Conclusions

The research in this thesis considers the QoS, security, and energy efficiency as critical issues facing the deployment of MANET routing protocols in a variety of applications, specifically in transmitting real-time video contents they represent our research scope in this thesis. We found that in overall the literature reviewed different proposed solutions for each individual challenge and therefore not exist an integrated solution. In addition, video transmission over MANET became the driving force of our daily life due to the great diffusion of mobile devices, and at the same time, nearly 80% of transmitted contents are video traffic. All these motivated us to develop an integrated scheme to overcome these challenges at once.

Therefore, the point of view of this thesis is that, although there have been many proposed MANET routing protocols; each protocol is designed based on a particular context condition. To date, no MANET routing protocol is able to produce optimal performance under all possible conditions. This is problematic because network conditions are not constant and, in a MANET dynamic environment, that particular context condition will not last long. This problem could be solved in two ways. The first solution is proposing a routing protocol that considers all the context-aware parameters. The second solution is developing a scheme that, given a change in the network context, selects the optimum routing protocol parameters configuration from a predefined list which contains all important and well-implemented parameters. The research in this thesis started by surveying the area of mobile networks in general, and MANET in particular, to understand the field. Another survey was then performed to understand the role of optimization in a MANET routing protocol.

We implemented a comprehensive simulation study on proactive protocols (OLSR, DSR), reactive (AODV, TORA), and hybrid (GRP) MANETs routing protocols to investigate which routing protocols have the capability to efficiently transmit real-time contents over MANETs. Our simulation results showed that Optimized Link State Routing protocol (OLSR) performs better under variable network sizes and mobile densities for transmitting video conferencing.

But there were remaining questions: **firstly**: to what extend OLSR is capable to transmit video contents efficiently considering the network size, mobile nodes density, and mobility speed?. **Secondly**: OLSR is not supported with any security services, then how to configure it in such a way that can provide a defense or a mitigation from security attacks such as black hole and jamming attack and without degrading the performance?. **Thirdly:** energy consumption due to packets send/receive can affect the network lifetime, then how to configure OLSR in order to save energy consumption and prolong network lifetime?.

All these questions motivated us to develop an enhanced scheme for transmitting video conferencing by modifying the behavior of OLSR through tuning the protocol parameters to provide a high QoS for transmitting video conferencing in terms of jitters, E2E- delay, PDR %, throughput, and network load. Moreover, supporting security services, and saving power during data communication.

It is observed that the HELLO interval in OLSR routing protocol plays a crucial role in improving the QoS parameters and at the same time is dependent on the mobility of the nodes and nodes density. To improve the performance of OLSR we need to reconfigure it by tuning their routing parameters to cope with QoS, security, and energy consumptions.

For the tuning process we proposed an algorithm for selecting the OLSR routing parameters. The algorithm based on the assumption that, when the network is in low mobile density and low mobility speed we need not a redundant HELLO and TC messages because there is no noticeable change of topology. However when the network becomes dense and sparse there is a great need to update the topology change via redundant control messages without influencing the performance metrics such as jitter, E2E-delay, PDR%, throughput and etc..

Our proposed algorithm provided a new configuration for OLSR routing protocol parameters. The new modified version which we called (QoS-OLSR) achieves high performance compared to conventional OLSR in terms of QoS metrics required for transmitting video conferencing effectively and the obtained results were as follows:

1- QoS-OLSR outperforms OLSR in terms of average E2E-delay and jitter which dropped by 27% and 47% respectively. Also, the throughput, and PDR was increased by 38% and 29% respectively compared to OLSR.
2- We found that reducing the HELLO message interval time improved QoS-OLSR's performance mainly in the middle network size.
3- The impact of tuning the HELLO interval increases with increased node speed. When the network is relatively stable with less mobility, tuning HELLO interval has smaller impact than with high mobility.
4- The impact of tuning the HELLO interval has no obvious relationship with network density, specifically low density (10-30) nodes.
5- The number of TC packets increases with mobility and decreases as the HELLO interval increases.
6- Performance improvement achieved by reducing the HELLO interval is at the expense of increased overhead and consequently network load. This is one of the drawbacks of tuned OLSR.
7- The overhead grows with node density; that is, the overhead in a high-density network is much larger than that in a low-density network.
8- QoS-OLSR HELLO traffic is less than OLSR that is because we use a long HELLO interval which consequently reduces HELLO traffic. In middle and high density the QoS-OLSR has relatively higher traffic than OLSR due to shorter HELLO interval.
9- In the Small / Middle network size with Slow /Medium mobility speed, QoS-OLSR has fewer MPRs compared to OLSR. But the MPRs count increases instantly after 40 nodes.
10- Less retransmissions were achieved by QoS-OLSR restrictedly when the number of nodes was between (35-70) nodes. This proves that QoS-OLSR performes better on high density, and the tuned parameters have a great impact on the protocol performance in terms of retransmission attempts.

We studied the impact of the mobility speed and the scalability on the performance of the new configured QoS-OLSR, we used the MLRM and ANOVA techniques. The findings summarized as follows:

1- The impact of mobility speeds on most QoS metrics is not noticeable, while the scalability has a greater impact. So we can say the QoS-OLSR has improved the performance regardless of the mobility speed variations, and this represent a new evidence that the QoS-OLSR can be implemented on transmitting video conferencing on Drone and Vehicular networks which include high speed nodes.

2- The modified configuration of QoS-OLSR decreased jitter when the number of nodes increased.
3- Mobility speed has less impact on the E2E-delay (F-Ratio=0.028), when the mobility increased there is no significant change on the E2E-dely, while the node density has a great impact on the E2E-delay (F-Ratio =97.404), as the number of nodes increases the E2E-delay starts to increase.
4- The slow mobility speed has a noticeable effect on PDR% specifically in the high density. That is because link breakage and packet loss occurs while QoS-OLSR maintains consistent paths resulting in low PDR% when the network become sparse and dense.
5- However, QoS-OLSR had a consistent PDR% and suffered from less PDR % as the network grew larger but speed did not have profound effects on the performance.
6- Evidently, the scalability influenced the NNL more than the mobility.

Our research aimed to find a suitable configuration for OLSR that can defend the network from security attacks such as black hole on network layer and jamming attack on MAC/PHY layer. The proposed scheme is based on configuring IPSec in the network layer with the tuned OLSR version. The combination is called Security-Aware OLSR (SA-OLSR). As per simulation results and quantitative metrics calculations using OPNET modular 14.5, the jitter(sec), throughput (bits/sec), packet delivery ratio PDR%, E2E-delay (sec), packet loss and normalized routing load of the revised SA-OLSR model have shown notable performance improvements in these metrics as compared to the standard OLSR with and without attacks. These results are based on the general network parameters that we set for our analysis and revised parameter attributes of the standard OLSR routing protocol. Attributes of various parameters of the standard OLSR routing protocol have been altered only for testing and study purposes.

Have been founded that SA-OLSR mitigate and defense the MANET network from black hole and jamming attack without degraded the overall performance, and this clearly shown in the following foundlings obtained from our simulation:

1- As a comparison between OLSR and SA-OLSR in terms of average E2E-delay when the two routing protocols are under the black hole attack, we found that SA-OLSR has 65% less E2E-dealy compared to the OLSR.
2- The throughput for SA-OLSR is high compared to that of OLSR when the two protocols become under the black hole attack having the same network conditions, and the average rate of improvement is 63% over all the network sizes.
3- Using IPSec to protect the network layer is not entirely effective as efficient routing protocols also play an important part to defer this type of attack.
4- The simulation results showed that the proposed configuration significantly improves routing performance under different conditions of traffic density.

The energy consumed due to packets send/received is considered a critical issue when aiming to prolong the network lifetime. We investigated the new configuration of OLSR (EA-OLSR) for power savings and we found the following results:

1- EA-OLSR maximize the network lifetime and power conservation was on average between 41% - 62% for middle density (30-40 node) with mobility (30-40m/s), while in high density and high-speed scenarios the achieved power conservation was 34% .
2- The EA-OLSR protocol is an efficient proactive routing protocol which is suitable for dense and large-scale MANETs.
3- EA-OLSR is less influenced by the mobile density and the mobility of the nodes. Also, the average energy consumptions of nodes increase from low density to high density, and their increase follows a similar pattern.
4- Generally the simulation results showed that the mobility speed had a little influence in the energy consumptions, but the mobile density had a great impact on the energy consumption which is typical as addressed in most reviewed literature.

Moreover, the thesis aimed to find the best modeling and optimizing techniques compatible with MANET. The research was based on the modeling technique (MLRM), and optimization technique (PSO) to study the best fit configuration to fulfill the network context (scalability, density, and mobility). Regarding this issue, we found that the optimal performance of MANET networks for transmitting video conferencing effectively was when the density was between 10-40 mobile nodes with an average velocity of 18m/s.

7.2 Future Works

To improve the current work presented in this thesis, we recommended the following:

1- Further research can be taken onward for large set of nodes, higher values of node velocities and node transmission power, diverse simulation scenarios including different parameters of the transmission region, transmission range, large numbers of source/sink pairs, different mobility models, different Wi-Fi rates, different traffic generators and QoS considerations and etc.

2- However, the usage of IPSec protocol in our study are limited, it is clear that it did not add extra E2E-delay and load, which is desired in case of videoconferencing contents, and at the same time increasing the throughput and PDR%, thus we cannot clarify whether security goals of authentication, integrity and confidentiality are achieved. Therefore, in the future, further studies on IPSec in a network can be explored specifically to highlight whether the security goals can be achieved by using different combinations of the AH and ESP protocols, under different mobility speeds and densities.

3- In the future we want to incorporate the analysis of video transmission in the Drone Networks on the basis of the new modified OLSR and GRP routing protocols.

4- On the basis of the evaluation metrics, a comparative analysis is presented that can help in the selection of appropriate routing protocols for specific requirements or for specific network context, this will motivate us in the future run to investigate the video transmission over the geographical routing protocols, when the network enlarges due to rapid topology change and mobility speed.

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Appendices

Appendix (A) - Basic PSO –Algorithm

```
% Copyright (c) 2019
% Project Code: Diaa Eldein Mustafa
% Project Title: Implementation of Particle Swarm Optimization in MATLAB
% Contact Info:diamahmed@gmail.com
clc;
clear;
close all;
%% Problem Definition
CostFunction=@(x) Sphere(x);        % Cost Function
nVar=10;            % Number of Decision Variables
VarSize=[1 nVar];   % Size of Decision Variables Matrix
VarMin=-10;         % Lower Bound of Variables
VarMax= 10;         % Upper Bound of Variables
%% PSO Parameters
MaxIt=1000;         % Maximum Number of Iterations
nPop=10;            % Population Size (Swarm Size)
% PSO Parameters
w=1;                % Inertia Weight
wdamp=0.99;         % Inertia Weight Damping Ratio
c1=1.5;             % Personal Learning Coefficient
c2=2.0;             % Global Learning Coefficient
% If you would like to use Constriction Coefficients for PSO,
% uncomment the following block and comment the above set of parameters.
% % Constriction Coefficients
% phi1=2.05;
% phi2=2.05;
% phi=phi1+phi2;
% chi=2/(phi-2+sqrt(phi^2-4*phi));
% w=chi;          % Inertia Weight
% wdamp=1;        % Inertia Weight Damping Ratio
% c1=chi*phi1;    % Personal Learning Coefficient
% c2=chi*phi2;    % Global Learning Coefficient
% Velocity Limits
VelMax=0.1*(VarMax-VarMin);
VelMin=-VelMax;
%% Initialization
empty_particle.Position=[];
empty_particle.Cost=[];
empty_particle.Velocity=[];
empty_particle.Best.Position=[];
empty_particle.Best.Cost=[];
particle=repmat(empty_particle,nPop,1);

GlobalBest.Cost=inf;
```

```
for i=1:nPop
   % Initialize Position
   particle(i).Position=unifrnd(VarMin,VarMax,VarSize);
    % Initialize Velocity
   particle(i).Velocity=zeros(VarSize);
    % Evaluation
   particle(i).Cost=CostFunction(particle(i).Position);
    % Update Personal Best
   particle(i).Best.Position=particle(i).Position;
   particle(i).Best.Cost=particle(i).Cost;
    % Update Global Best
   if particle(i).Best.Cost<GlobalBest.Cost
            GlobalBest=particle(i).Best;
         end
   end
BestCost=zeros(MaxIt,1);
%% PSO Main Loop
for it=1:MaxIt
      for i=1:nPop
            % Update Velocity
      particle(i).Velocity=w*particle(i).Velocity+c1*rand(VarSize).*(particle(i).Best.Position-
particle(i).Position)  +c2*rand(VarSize).*(GlobalBest.Position-particle(i).Position);
            % Apply Velocity Limits
      particle(i).Velocity = max(particle(i).Velocity,VelMin);
      particle(i).Velocity = min(particle(i).Velocity,VelMax);
            % Update Position
      particle(i).Position = particle(i).Position + particle(i).Velocity;
            % Velocity Mirror Effect
      IsOutside=(particle(i).Position<VarMin | particle(i).Position>VarMax);
      particle(i).Velocity(IsOutside)=-particle(i).Velocity(IsOutside);
            % Apply Position Limits
      particle(i).Position = max(particle(i).Position,VarMin);
      particle(i).Position = min(particle(i).Position,VarMax);
            % Evaluation
      particle(i).Cost = CostFunction(particle(i).Position);
            % Update Personal Best
      if particle(i).Cost< particle(i).Best.Costparticle(i).Best.Position=particle(i).Position;
         particle(i).Best.Cost=particle(i).Cost;
               % Update Global Best
         if particle(i).Best.Cost< GlobalBest.Cost
                        GlobalBest=particle(i).Best;
             A =particle(i).Position ;
        B =particle(i).Cost ;
         end

      end
         end
```

```
        BestCost(it)=GlobalBest.Cost;
        disp(['Iteration ' num2str(it) ': Best Cost = ' num2str(BestCost(it))]);
        w=w*wdamp;
    end
BestSol = GlobalBest;
%% Results
figure;
for i=1:nPop
plot(particle(i).Position ,'X');
axis([-2 50 -2 50])
pause(2)
end
figure;
%plot(BestCost,'LineWidth',2);
semilogy(BestCost,'LineWidth',2);
xlabel('Iteration');
ylabel('Best Cost');
grid on;
```

Appendix (A) - Fitness Function

```
clear all
close all
rng default
LB=[10  5]; %lower bounds of variables   No of Nodes (N) , Mobility speed (M)
UB=[30  30]; %upper bounds of variables
% pso parameters values
m=2; % number of variables
n=100; % population size
wmax=0.9; % inertia weight
wmin=0.4; % inertia weight
c1=2; % acceleration factor
c2=2; % acceleration factor
% pso main program----------------------------------------------------start
maxite=1000; % set maximum number of iteration
maxrun=40; % set maximum number of runs need to be
for run=1:maxrun
run
% pso initialization----------------------------------------------start
for i=1:n
for j=1:m
x0(i,j)=round(LB(j)+rand()*(UB(j)-LB(j)));
end
end
x=x0; % initial population
v=0.1*x0; % initial velocity
for i=1:n
f0(i,1)=ofun(x0(i,:));
end
[fmin0,index0]=min(f0);
pbest=x0; % initial pbest
gbest=x0(index0,:); % initial gbest
% pso initialization------------------------------------------------end
% pso algorithm---------------------------------------------------start
ite=1;
tolerance=1;
while ite<=maxite && tolerance>10^-12
w=wmax-(wmax-wmin)*ite/maxite; % update inertial weight
% pso velocity updates
for i=1:n
for j=1:m
v(i,j)=w*v(i,j)+c1*rand()*(pbest(i,j)-x(i,j))...
+c2*rand()*(gbest(1,j)-x(i,j));
end
end
% pso position update
```

```
for i=1:n
for j=1:m
x(i,j)=x(i,j)+v(i,j);
end
end
% handling boundary violations
for i=1:n
for j=1:m
if x(i,j)<LB(j)
x(i,j)=LB(j);
elseif x(i,j)>UB(j)
x(i,j)=UB(j);
end
end
end
% evaluating fitness
for i=1:n
f(i,1)=ofun(x(i,:));
end
% updating pbest and fitness
for i=1:n
if f(i,1)<f0(i,1)
   pbest(i,:)=x(i,:);
f0(i,1)=f(i,1);
end
end
[fmin,index]=min(f0); % finding out the best particle
ffmin(ite,run)=fmin; % storing best fitness
ffite(run)=ite; % storing iteration count
% updating gbest and best fitness
if fmin<fmin0
gbest=pbest(index,:);
fmin0=fmin;
end
% calculating tolerance
if ite>100;
tolerance=abs(ffmin(ite-100,run)-fmin0);
end
% displaying iterative results
if ite==1
disp(sprintf('Iteration Best particle Objective fun'));
end
disp(sprintf('%8g %8g %8.4f',ite,index,fmin0));
ite=ite+1;
end
% pso algorithm-----------------------------------------------------end
gbest;
```

```
fvalue=(gbest(1)-1)^2+(gbest(2)-2)^2;
fff(run)=fvalue;
rgbest(run,:)=gbest;
disp(sprintf('--------------------------------------'));
end
% pso main program----------------------------------------------------end
disp(sprintf('\n'));
disp(sprintf('*************************************************************'));
disp(sprintf('Final Results-----------------------------'));
[bestfun,bestrun]=min(fff)
best_variables=rgbest(bestrun,:)
disp(sprintf('*************************************************************'));
toc
% PSO convergence characteristic
plot(ffmin(1:ffite(bestrun),bestrun),'-k');
xlabel('Iteration');
ylabel('Fitness function value');
title('PSO convergence characteristic')
```