The University of Jordan

Authorization Form

I, Ms. Eman S. Alwadiyeh, authorize the University of Jordan to supply copies of my Thesis/Dissertation to libraries or establishments or individuals on request, according to the University of Jordan regulations.

Signature:

Date: December 26, 2010

الجامعة الأردنيـــــة
كلية الدراسات العليا

التاريـــخ: / /

نموذج رقم (18)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

أنا الطالب: ايمان صبحي الوادية الرقم الجامعي: (8071637)

تخصص: علم الحاسوب الكليـــــــة: كلية الملك عبدالله الثاني لتكنولوجيا المعلومات

عنوان الرسالة:

Multipath Quality of Service Routing Protocol for Mobile Ad hoc Networks

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

توقيع الطالب: .... التاريخ: 23 / 12/ 2010

MULIPATH, QUALITY OF SERVICE ROUTING PROTOCOLS FOR MOBILE AD HOC NETWORKS (MANet)

By
Eman S. Alwadiyeh

Supervisor
Dr. Iman Almomani

This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Computer Science

Faculty of Graduate Studies
The University of Jordan

Dec, 2010

COMMITTEE DECISION

This Thesis/Dissertation (The Relationship Between Socioeconomic Status and Disruptive Behaviors in Early Elementary School Children in Greater Amman Municipality) was Successfully Defended and Approved on – 8/December/2010 -----

Examination Committee	**Signature**
Dr. Iman Almomani, (Supervisor) Assist. Prof. of Wireless networks and security.	------------------------------
Dr. Saleh Hosni Al-Sharaeh (Member) Prof. of Wireless networks and distributed computing. (Dean of the Faculty of Information Technology Systems in Aqaba)	------------------------------
Dr. Mohammad Alshraideh (Member) Assist. Prof. of Software Testing Using Evolutionary Algorithms	------------------------------ SSh. 22/12/2010
Dr. Mohammed Al-Abbadi (Member) Assist. Prof. of Image processing	------------------------------

DEDICATION

To the Soul of My Father..

To My Dear Mom..

To My Brothers, Sisters, Friends and

Those who always give me the greatest support and inspiration..

I dedicate this research

ACKNOWLEDGEMENT

First, thanks to Allah Almighty for giving me the courage and power to accomplish this research. I would like to express gratitude to my supervisor Dr. Iman Almomani for her encouragement, valuable advice, and follow up that enriched this thesis, which I greatly appreciate.

I am deeply indebted to the German Academic Exchange Service (DAAD) for granting me a scholarship and providing me with the financial support during my master study. I would like to single out Mr. Cyrus Salimi-Asl and Prof. Ferhard Sedar delegates of DAAD in Jordan, as well as Prof. Helga Baumgarten, DAAD coordinator in Jerusalem; for their endless efforts to support scholarship holders.

Extend my thanks and appreciation to my friends who helped me to accomplish this work, to Mrs. Wala' Qteeshat, Miss. Inas Abu Qadoom, Mr. Ala' Abu Rumman.

Finally, I convey my sincere thanks and greetings to my family in Palestine, who provided me with the moral support during period of study and research, and to my friends, Leena, Heba, Maram and Amany.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF APPREVIATION

Abbreviation	Name
AODV	Ad hoc On-demand Distance Vector routing
AOMDV	Ad hoc On-Demand Multipath Distance Vector routing protocol
AP	Access Point
CSMA/CA	Carrier Scene Multiple Access with Collision Avoidance
DCF	Distributed Coordination Function
DSDV	Destination Sequence Distance Vector
DSL	Digital Subscriber Line
EDMR	Efficient, Disjoint Multipath Routing Protocol
ESDMR	Efficient, Stable, Disjoint, Multipath Routing Protocol
LAN	Local Area Networks
LFMPR	Loop Free Multipath Routing protocol
MAC	Medium Access Control

MANet	Mobile Ad hoc Network
QoS	Quality of Service
RERR	Route Error message
RMPSR	Robust Multipath Source Routing protocol
RREP	Route Reply message
RREQ	Route Request message
RRSMP	Route Request Selection Based On Mobile prediction
RSS	Received Signal Strength
SMR	Split Multipath Routing protocol
SQMR	Stability based QoS Multipath routing

MULIPATH, QUALITY OF SERVICE ROUTING PROTOCOLS FOR MOBILE AD HOC NETWORKS (MANet)

By
Eman s. Alwadiyeh

Supervisor
Dr.Iman Almomani

ABSTRACT

The increasing spread of mobile nodes along with the technical advances in Mobile Ad hoc Networks (MANets) makes this kind of networks an important type of access network of next generation. The demand of multimedia services from these networks is expected to significantly grow in the next years. Multimedia services, though, require the provision of Quality of Service (QoS). Nevertheless, the resource constrains in MANets makes the QoS provision over MANets a matter that challenges attention. Developing routing protocols that react to the dynamic nature of MANets while efficiently using its resources is a challenging task.

This thesis proposed two multipath routing protocols. Efficient, Stable, Disjoint Multipath Routing protocol (ESDMR) and Efficient, Disjoint Multipath Routing protocol (EDMR), both provide a higher delivery ratio and throughput for multimedia stream compared with the Split Multipath Routing protocol (SMR). In addition, both of the proposed protocols use a developed mechanism that reduces the control packets overhead, while enabling a destination node to collect the required information.

In ESDMR, the Route Request phase is responsible for collecting the required information for the available paths with lower control overhead compared with SMR. The destination node is responsible for selecting the node disjoint route set and adding the interference information for each route. In addition, the destination node sends the Route Reply packets (RREP) through the selected routes set. Each RREP packet contains whole route information and the set of addresses for the interference nodes which interfere with that route. Finally, the source node distributes the traffic load on the most stable and the least interference two routes.

EDMR is a multipath routing protocol that combines between SMR and ESDMR. The Route Request phase of EDMR is the same as ESDMR. EDMR selects the shortest disjoint routes as the SMR protocol. In addition to select the least interference routes as the ESDMR. The source and the destination nodes responsibilities are the same as the ones in ESDMR, except that, the source node distributes the traffic load the least interference two routes.

The results show that the proposed routing protocols perform better in improving the delivery ratio and throughput compared with SMR protocol. They also reduce the control overhead compared to SMR. EDMR perform better that ESDMR in improving the delivery ratio and the throughput. The packet delivery ratio is improved in EDMR by percent of 35.72 %, throughput is increased by 30% and the number of control packets is reduced by the percent of 86.97% compared with SMR. On the other hand, ESDMR improves the delivery ratio with 24% and the control overhead is reduced by 86.7% and throughput is increased by 27% compared with SMR. End-to-End delay for the proposed routing protocols do not exceeds End-to-End delay in SMR.

1 Introduction

With the increased growth of the Internet communication applications, the world has become like a small village. The current needed communication application requirements exceeded the infrastructure wired networks to wireless networks. The infrastructure of wired line connection, which can be deployed using the base connection with cable modem or DSL, is not only cost effective and time consuming but also not preferred for unstable area. Hence, the emerging of wireless network was considered like a solution to overcome the wired networks' limitations, where wireless network has better services and facilities than those provided with wired network, such as the cost factor and interoperability.

Wireless networks consist of multiple stations communicating with radios. It is based on IEEE 802.11 standards. According to IEEE 802.11 MAC layer standard, wireless networks devices have different approaches to follow when they want to communicate with each other. (Sun, 2001) mentioned that there are two distinct approaches, infrastructure approach and infrastructure less approach (as presented in Figure1.1). With the first approach (infrastructure approach) the wireless network based on the cellular concept, and the mobile nodes communicate with each other through Access Point (AP) only. This access point will be connected to a fixed network infrastructure. The second approach (infrastructure less approach) allows the mobile nodes to establish the connection dynamically and communicate with each other without the use of any fixed network infrastructure. This form of network is termed an ad hoc network. This study focuses mainly on mobile ad hoc networks topic (MANet).

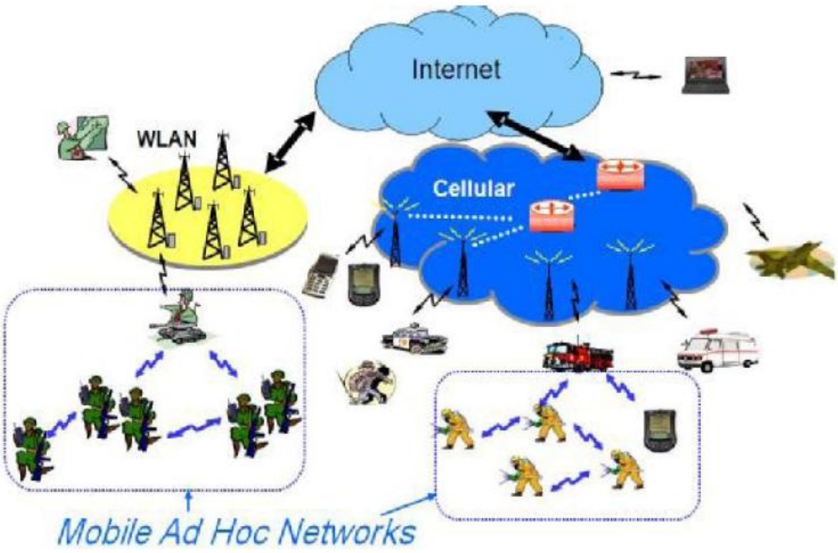


Figure 1.1 : Wireless networks approaches (Mahdy, 2010)

1.1 Research motivation

Rodreguez-covili et al., (2009) mentioned that a network for communication that is a peer to peer, which has been adapted to support the allocation of mobile node(s) is defined as Mobile ad hoc Network (MANet). This network was designed to be accommodated with the use of mobile device that might be heterogeneous. The fundamental feature of these devices is that they are equipped with transmitters and receptors to the signal of wireless networks, like Bluetooth, to enable them to achieve communication without the need to use any element of the fixed infrastructure.

The concept of ad-hoc network is not a recently-devised concept. It has been used since 1970 in the military field as a dynamic wireless network topology. According to Misra et al. (2009) the self configuration, self organization, and the dynamic changes in network topology can form a multi-hop class in MANets.

The versatility of mobile ad hoc networks and the unique features like the infrastructure absence and the speed in deployment, make those networks convenient and candidate for a wide range of applications and situations, especially for the emergency situations. With the development and improvement of the wireless network communications in recent years, ad-hoc networks have been attractive for commercial and business applications (Sun, 2001).

In case of natural disaster area, such as earth quake or hurricane, a radio link station, such as a WLAN station, may be damaged in a specific area in any time. In order to provide a coverage extension for this area(s) that would otherwise be impossible to cover. In this situation the node(s) further away from the other intact situations will rely on intermediate nodes for communications. This provides an important communication network used in such situations as illustrated in Figure 1.2. It presents a MANet which is formed by WLAN routes and Mobile nodes. The WLAN router forms the boundary between the MANets and the wireless LAN. The router is capable of supporting translation between the ad hoc protocols and the appropriate protocols used on the WLAN and the communication backbone.

Routing protocols in MANets have become an important area in research recently; this is due to the essential role of routing protocols in improving the MANets performance.

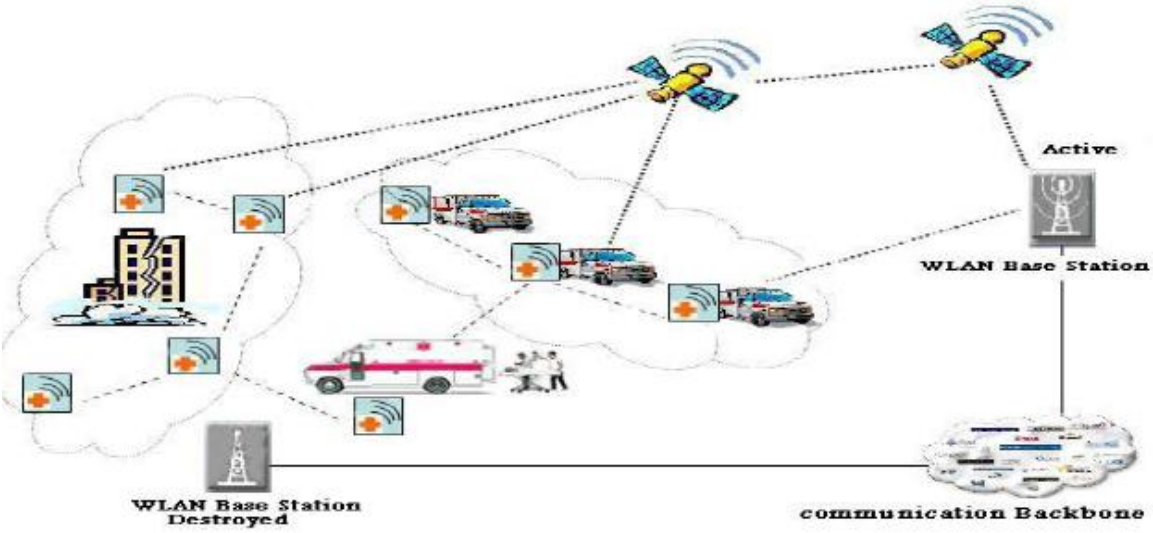


Figure 1.2 : MANet deployment over WLAN (Mahdy ,2010)

Routing can be defined as the process of packet delivery over the network from a source to a destination. Due to the dynamic change in the network topology in MANets and the nodes mobility, the routing protocol becomes a critical issue and its performance affects the overall MANet performance. The routing protocol plays an important role in selecting the best route from the different alternatives routes that satisfy the pre-specified quality of service parameters. Because of this, many research papers propose different routing protocols with different approaches to serve different goals, such as finding the shortest path protocols or finding the path with some Quality of Service aspects that are suitable for some situations and applications.

Another approach that finds a set of routes between a certain source node and a destination node is called multi-path routing protocols. Multi-path concept is used to achieve different goals, these goals can be classified as network oriented goals, QoS oriented goals or combination of the previous goals. Network oriented goals are concerned with preserving the nodes of the MANet, either by distributing the load on different paths, or choosing the less congested routes which usually lay away from the center of the networks, or reducing the required control packet to save network resources and so on. The last type is the combination of the previous two types; it finds the routes that satisfy the required QoS parameter taking into consideration the nodes status. This study mainly focuses on the third approach, in which the routing protocols use the concept of multipath routing for distributing the load on more than one path that satisfy the required QoS parameters. More details will be explained in section 2.1.

1.2 Problem statement

A fundamental problem in ad hoc networking is how to deliver data packets among nodes efficiently without a predetermined topology or centralized control; this is the main objective of ad hoc routing protocols. Because of the dynamic nature of the network, ad hoc routing faces many problems not present in wired networks.

Multipath routing approach plays an important role in improving the routing performance in MANets and overcome the limitations of single path routing protocols such as Ad hoc On-Demand Distance Vector Routing protocol

(AODV), Dynamic Source Routing protocol (DSR), Adaptive Dispersity QoS Routing (ADQR) (Su et. al, 2001), and so on. Many research papers use the concept of multipath routing to distribute the load on multiple disjoint routes to achieve different goals such as delay aware multipath routing protocols which use the concept of multipath routing to reduce the average end-to end delay. Cha and lee (2005) reduce the average end-to-end delay by distributing the load in multiplexing way on multiple paths. Lee and Gerla (2000) developed Split multipath routing protocol (SMR) to reduce the control overhead in the network by reducing the frequent route discovery process. It also benefits from the multipath concept to distribute the load on the maximally disjoint shortest paths. Qin Lu, et al. (2008) distribute the video stream on a multiple stable paths of the Ad hoc On Demand Multipath Distance Vector routing protocol (AOMDV) to improve the delivery ratio and reduce the average end-to-end delay of the AOMDV. The results show that there is a significant improvement in reducing the average end-to-end delay, while the delivery ratio seems to be same as the one of the AOMDV. This is due to the using of IEEE 802.11 standards in MAC layer, which has Carrier Scene Multiple Access Collision Avoidance (CSMA/CA) mechanism and Distributed Coordination Function (DCF) to avoid collision, thus, time is shared due to the single sharing channel between the multiple chosen routes as explained in the Figure 1.3.

As seen in Figure 1.3, *node No.29* on the first path is located in the range of *node No.13* on the second selected path, thus, according to the IEEE 802.11 standards, when *node No.29* gains the channel, *node No. 13* will wait until the channel become idle. So the total throughput of the multipath scheme in this situation seems to be likely as the one of the single path scheme in AOMDV (Mirna and Das, 2001). That's why the throughput of the proposed routing scheme in (Qin Lu, et al. 2008) seems to be likely as the one of AOMDV.

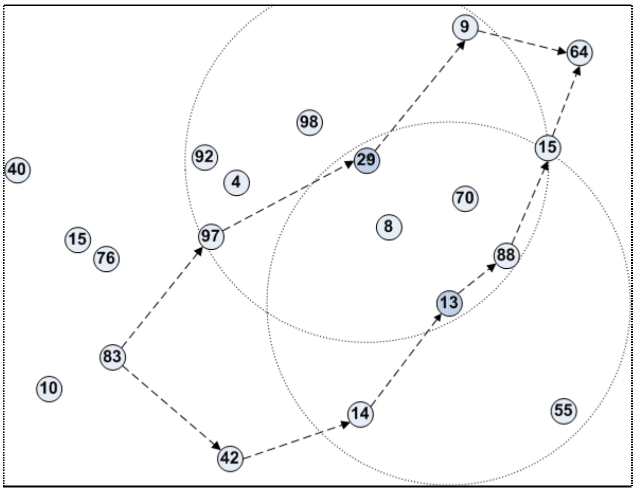


Figure 1.3 Collision between two paths when transmitting data simultaneously

As seen in Figure 1.3, node No. 29 on the first path is located in the range of node No.13 on the second selected path, thus, according to the IEEE 802.11 standards, when node No.29 gains the channel, node No.13 will wait until the channel become idle. So the overall delivery ratio of the multipath scheme in this situation seems to be likely as the one of the single path scheme in AOMDV (Mirna and Das, 2001). From this example, we said that node No.13 from the second route interfere with node No.29 from the first route.

Hidden terminal problem is another problem that rises in multipath routing protocols which use the concept of multipath routing to distribute a traffic load on the disjoint routes. Using CSMA/CA in MAC layer reduces hidden terminal problem, but does not prevent it. For that, the delivery ratio of this type of multipath routing protocols resembles the delivery ratio of multipath routing protocols that use one path to transmit the traffic load and the other paths are used for the maintenance issues.

1.3 Contribution

This thesis proposes least interference, node disjoint multipath routing protocols that improve packet delivery ratio and throughput by distributing the traffic load on the least interference, node disjoint routes. Selecting the least interference routes aims to reduce the shared channels between the selected disjoint routes. As a result, the throughput and the delivery ratio will be increased.

Hidden terminal problem rises in the multipath routing protocols that distribute the load on more than one path. It happens when two nodes that are out of transmission range of each other sends data packet to node that is located in the transmission range of both of them. So, the received packets were collided. Thus, the packets will be received with noise for the intended node, the MAC layer protocols dropped the noised packets and do not pass them to the network layer, thus, the delivery ratio is decreased as the number of collisions increased. Hidden terminal problem causes the degradation in the packet delivery ratio and the total throughput. The proposed routing protocols reduce the effect of hidden terminal problem by selecting the routes that have the least interference between them as will explained in more details in Chapter 3.

The proposed routing protocols depend mainly on the information collected about the other routes, thus, the routing overhead should be increased (route request packets). If the intermediate node passed all the duplicated route requests, the routing overhead could be increased exponentially and thus the network would be down when the number of nodes exceeds 24 nodes in 1000*1000 m^2 as we found in the experiments. The proposed routing protocols proposed a technique that enables the destination node to collect the required information with a very low control overhead. This will be explained in detail in Chapter 3.

1.4 Research objectives

The objectives of this research are two-fold. The first objective is to gain insight into and experience with MANets with an emphasis on MANets routing. Research in ad hoc networking has been ongoing for decades, but there are still many open problems to be solved. A lot of research papers have focused on ad hoc routing, a fundamental problem that distinguishes ad hoc networking from wired networking.

The second goal is to develop an efficient multipath routing algorithm for ad hoc networks. The emphasis in this research is on improving the efficiency of data transmission and the throughput of an ad hoc routing protocol.

1.5 Methodology and model development

This section presents the methodology followed to implement this study. It outlines and briefly discusses the general steps of the research methodology.

In the light of knowledge gained through the literature survey conducted so far, node disjoint multi-path routing scheme is selected to be developed based on the Split multipath routing protocol (SMR) concepts. The principle of link stability is chosen as a route selection criterion in the Efficient, Stable, Disjoint, multipath routing protocol (ESDMR). The methodology followed to implement this study is presented in Figure 1.4. The second proposed routing protocol (Efficient, Disjoint, Multipath routing protocol) uses the number of hops as a route selection criteria.

The first stage is to develop Split Multipath routing protocol (SMR) (Lee and Gerla, 1999) based on Dynamic source Routing Protocol (DSR). Efficient, Stable, Disjoint Multipath routing protocol (ESDMR) is developed based on the concepts of SMR routing protocol. ESDMR increases the multi-path routing throughput and delivery ratio by selecting the least interference, most stable, node-disjoint routes. The calculated link stability model depends mainly on the distance between the mobile nodes. It is calculated in the radio layer and processed in the network layer.

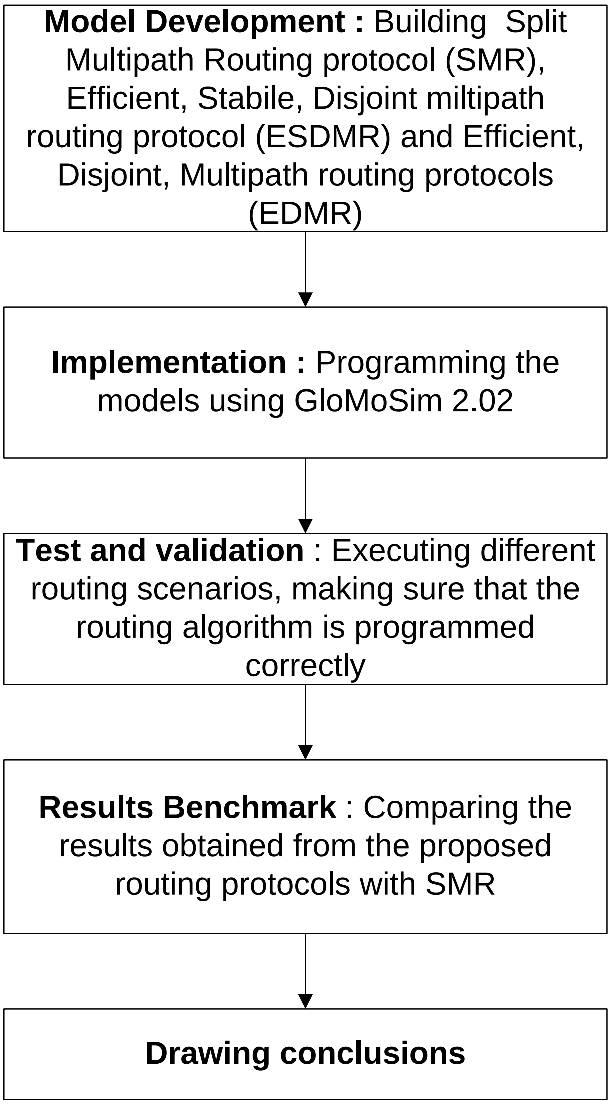


Figure 1.4: Research methodology general steps

The interference less feature is added to ESDMR to increase the practically throughput and the delivery ratio, because sending data on more than one route theoretically increase the throughput, but due to the interference between these routes, the totally throughput and delivery ratio is decreased to be likely as sending data on one route. The detailed description of the developed model is presented in Chapter 3.

Efficient Disjoint Multipath routing (EDMR) protocol is another version of the proposed routing protocol. It is based on the concepts of ESDMR. The concept of paths ordering is the main difference between EDMR and ESDMR, where EDMR arranges the path in ascending order according to their hop count, but, the ESDMR arranges them according to their stability value. EDMR is presented in more details in chapter 3.

The second stage is to implement the proposed routing protocols on a network simulation environment, the Global Mobile Information System Simulator (GloMoSim). It is a scalable simulation environment for large wireless and wired line communication networks. GloMoSim uses a parallel discrete-event simulation capability provided by Parsec.

The third stage is to test and validate the proposed routing protocol. For this purpose, different scenarios are applied on the simulated models to make sure that the simulated model is programmed correctly. These scenarios differ with number of nodes, nodes speed, seed numbers, pause time and the terrain areas. In the fourth stage the obtained results are compared with SMR routing protocol.

1.6 Thesis organization

Chapter 2 presents an overview on Mobile Ad hoc Network, routing in MANets, in addition to literature and the previous research works that are related to the field of research. Chapter 3 presents the proposed routing protocols, section 3.1 presents an overview of the proposed routing protocols, section 3.2 presents in details the components of ESDMR protocol, section 3.3 presents the structure of the control packets, section 3.2 presents an overview of the stability models and the used stability model, and the last section shows an overview of EDMR protocol. Chapter 4 presents an overview of the simulation environment and shows the results of the implemented routing protocols. It also contains a comparison between the three implemented routing protocols in results. Finally, conclusion and future works presented in chapter five.

2 Background and Literature Review

This chapter sheds the light on aspects of Mobile ad hoc networks. It consists of four main sections; a theoretical background on Mobile Ad hoc networks (MANet) is presented in Section 2.1. A review of the applications and challenges in MANets in sub sections 2.1.1 and 2.1.2. Routing concepts and the challenges of routing in MANet are given in section 2.2. Section 2.2.1 and 2.2.2 are mainly concern with routing protocols classification and the goals of each class. Section 2.3 presents an overview of some basic routing protocols that are considered as a base for the reviewed related research works, in addition to some MAC protocols. Section 2.4 reviews a literature of multi-path routing protocols and the goals of using multi-path concepts in each of them.

2.1 Background on Mobile Ad hoc networks

Mobile ad hoc networks (MANets) have become a very attractive research topic in recent years; this is due to its unique characteristics that enable it to be a candidate network kind in special scenarios and purposes.

It is a multi-hop wireless networks, in which a mobile node (*Devise*) establishes a connection with another node that is out of its transmission range through other intermediate mobile nodes, thus, each mobile node acts as both a host and a router. It acts as a host when it is an end point that sends or receives the data packets, while it acts as a router when it is an intermediate node that forwards data packets to other nodes. Figure 2.1

depicts a sample mobile ad hoc network, in which the mobile nodes communicate through a wireless radio links.

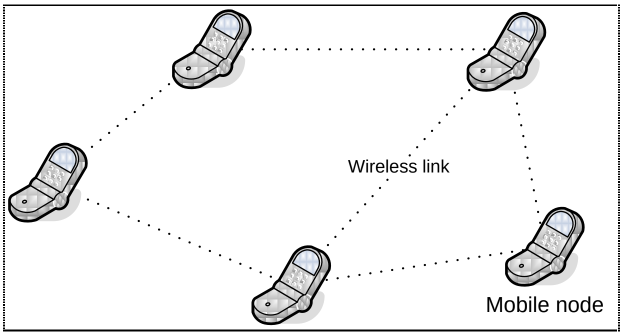


Figure 2.1: Sample mobile ad hoc network consists of mobile nodes

MANets are self-organized, self configured mobile wireless networks with decentralized control of operations, so they do not rely on a pre-existing infrastructure (*ex. Access* point) to communicate. In brief, MANETs can be defined as multi-hop temporary autonomous system of mobile nodes with wireless transmitters and receivers without the aid of pre-established network infrastructure (Marina and Das, 2001).

From the previous mentioned definitions of MANets, it is concluded that Mobile nodes are free to move randomly and organize themselves arbitrarily; thus, the wireless network's topology may change rapidly and unpredictably. The network has to be able to react on these topology changes and fix broken connections or find other routes that maintain the required level of Quality of Service. For that, developing efficient routing protocols for MANets that serve the multi-media and real time applications requirements are challenging task (Perkins and Royer, 2000).

2.1.1 Applications of Mobile Ad hoc networks

Due to the (infrastructure less) characteristic for MANets, it became a candidate type of networks in some fields where the fixed (infrastructure-based) solutions seem inflexible and costly.

- One of the hardest and largest applications is utilized in military environments. The way wars are being fought today has changed drastically. There is no fixed infrastructure when operating in a foreign country. Even when defending own country these infrastructures are most likely to be damaged or destroyed by enemy forces, so it is more critical than in civilian applications.

- Another huge public application in the area of emergency services. (Firefighters, police, etc...), sometimes they have to operate in areas where no information infrastructure is presented and operations still need to be coordinated. It is also a candidate communication media in the natural disaster areas (ex. earthquakes, flooding). Moreover, commercial field has a large sector of applications for MANets recently, such as collaborative computing (Bluetooth) (Lian et al., 2007).

2.1.2 Challenges of Mobile ad hoc networks

Although MANets have many characteristics, they have some challenges; they are not like a wired network.

- Mobile device has limited resources such as network bandwidth; CPU capacity, storage media and battery power are also limited resources, so developing routing protocols with little calculations will increase the battery lifetime and keep the CUP capacity. Moreover, due to the limited transmission range of wireless mobile devices, multiple hops are usually needed for a node to exchange information with any other nodes in the network (Kant and Chandha, 2008); therefore, designing an efficient routing protocol is one of the greatest challenges in MANETs.

- The dynamically changed network topology, due to the high nodes' mobility at an unpredictable time, this means that there is no fixed routing mechanism for the mobile Ad hoc networks, thus, designing an efficient routing protocol that are capable of maintaining extremely dynamic topology of MANets has become a challenging issue.

- Limited physical security is another challenge in MANET design. Mobility implies higher security risks such as peer-to-peer network architecture or a shared wireless medium accessible to both legitimate network users and malicious attackers. Eavesdropping, spoofing and denial-of-service attacks should be considered (Studi, 2003).

Several routing approaches have been proposed to mitigate the limitations of MANets and achieve better performance. Due to the rapid spread of using such networks in the commercial sector of applications beside natural disaster areas applications, there has been a great interest in developing routing protocols that support different quality of service requirements, while operate effectively to meet the demands of these networks.

2.2 Routing in MANets

Developing efficient routing protocols for MANets has gained a great amount of interest; this is due to the role of routing protocols in determining the overall performance of MANets. The special characteristics and design constraints of MANets requires efficient routing protocols. Designing an efficient routing protocol for MANets is a very challenging task and it has been an active area of research. This is due to the role of routing protocols in providing the required quality of service (QoS) metrics for different applications requirements; in addition, it to take into account the special characteristics of MANETs.

Routing in MANETs can be defined briefly as the process of sending data from the source mobile node to the destination node through the intermediate nodes with the required QoS metrics. There are different classifications approaches that explained in different research works according to different criteria in the routing protocols. In general, routing protocols in ad hoc networks can be divided into two main categories: proactive and reactive routing protocols (Tarique et al., 2009).

2.2.1 Proactive routing protocols

Proactive (table driven) routing protocols either based on the link state or distance vector routing schemes (Tarique et al., 2009). In proactive routing protocol, each mobile device maintains a routing table containing the routing information for every node in the MANET, regardless of whether or not these routes are needed, including nodes to which no packets are sent. Hence a route between any source and destination is always available. Nodes update their routing tables by periodically exchanging routing information among them. Although these protocols have low average end-to-end delay since they refresh their routing table information periodically, they generate large number of control messages in the network; therefore, it may waste bandwidth since control messages are sent out unnecessarily when there is no data traffic, and thus, it affects the network performance. Destination sequence distance vector (DSDV) (Perkins and Bahagwat, 1994) and Fish eye routing protocol (Pei et al., 2000) are examples of the proactive routing protocols. The reactive routing protocols were developed to overcome the limitations of the proactive routing protocols in reducing the control packet overhead, thus, keeping the MANETs performance from degradation.

2.2.2 Reactive routing protocols

Reactive (on-demand) routing protocols are designed to be adaptive to the dynamic environment of ad hoc networks, due to their low routing overhead and quick response to route disconnections (Sarma and Nandi, 2008)

In the reactive routing protocols, the source node establishes a route to the destination node when there is a need to communicate with that destination. They do not need to maintain routes to all the nodes in the network. Reactive routing protocols are proposed to overcome the limitations of the proactive routing protocols. Mainly it consists of two phases: (a) Route Discovery phase, (b) Route maintenance phase. In the route discovery phase, all the possible routes to the destination are established, while in the route maintenance phase the source node detects any topological change in the network to keep a route to the destination. A global search procedure is used by the route discovery mechanism in which a source node uses flooding mechanism to discover all the available paths to a destination. Once all paths have been discovered, a source node chooses a path, which is the shortest in most of the routing protocols (Tarique et al., 2009). Ad hoc On-Demand Distance Vector routing (AODV) (Perkins and Royars, 2001) and the Dynamic Source Routing Protocol (DSR) (Johnson and Maltz, 1999) are two examples of this type.

The reactive routing protocols are divided according to the number of paths that are established in the route discovery phase into two categories: Single path routing protocols, and multi-path routing protocols.

- **Single path routing protocols**

In the Single-path routing protocols, the source node chooses the shortest path to send the data through, when the shortest path is broken, due to the nodes movement, the source node start a new route discovery process.

Many research works show that the shortest path may not be a good choice for MANET, when the shortest path is used, the nodes that allocate around the center carry more traffic than other nodes in the same network that are around the perimeter, thus the communication links may be get congested, hence, it affects the performance of the network in term of delay and throughput. Due to the nodes movement, the route may be broken frequently; this increases the number of frequency of route discovery phase, so it increases the control overhead on MANets. To overcome the limitations of the single path routing protocols, the multi-path routing protocols are developed. DSR (Johnson and Maltz, 1999) and AODV (Perkins and Royars, 2001) are examples of single path routing protocols (Tarique et al., 2009).

- **Multi-path routing protocols**

In Multi-path routing protocols, the source node establishes more than one path to the destination node for many purposes. Different multipath routing protocols have their own unique advantages; it is hard to find a protocol or a class of protocols that fulfils all the requirements of an efficient routing protocol. According to the goals for which the routing protocols were developed, the routing protocols can be classified as:

(a) Delay aware multi-path routing protocols are proposed to reduce delay per packet. The main objective of these multi-path routing protocols is to ensure a fair load distribution among the mobile nodes, so that no section of a network gets congested. It chooses multiple paths so that the overall delay and performance of a network are improved. Lim et al. (2003) use the concept of multi-path routing in maintenance, while sending the data in single path that has the shortest delay or shortest path. Cha and Lee, (2005) use the concept of multi-path routing to reduce delay by sending the data on more than one path

(b) Reliable multi-path routing protocols, which have been proposed to provide reliable data communication between a source and a destination, they are specially designed to cope with the link breakages, which arise from node mobility, node failure and battery exhaustion. These protocols also try to cope with the link error, which arises due to communication through an unreliable wireless medium. Wang et al. (2005) developed a routing scheme that based on disparity routing scheme, which use the multi-path concept to improve the reliability by sending identical data packet in multi-path in the redundant routing scheme. While in non redundant routing scheme it improves reliability by partitioning the message and sending it on multiple paths.

(c) Minimum overhead multi-path routing protocols. These protocols aim to reduce the frequency of route discovery processes and thereby reduce the control overhead in the network. Split multi-path routing protocol (SMR) which is introduced by Lee and Gerla (2000) falls in this category. It is based on the DSR routing protocol, but the intermediate nodes does not allowed replying from their own cache. SMR uses the multi-path concepts to distribute the traffic load on multiple maximally disjoint two paths that are chosen by the destination node. The first path is the shortest path and the second path is the maximally disjoint path with that path.

(d) Energy efficient multi-path routing protocols. The need for energy aware routing protocols appears due to the limited resource in the mobile nodes.

(e) Hybrid multi-path routing protocols. These multi-path routing protocols use the shortest path algorithm at low traffic load conditions. But they switch to multi-path routing when a network starts carrying higher traffic loads (Tarique et. al, 2005).

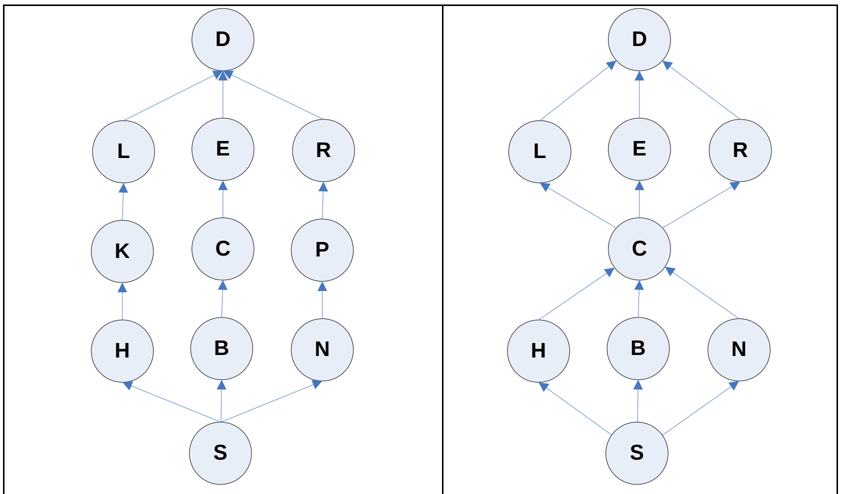
2.2.3 Multi-path routing scheme

There are different multi-paths routing schemes to construct between the source node and the destination.

- **Node-disjoint scheme** do not have any nodes in common except the source and the destination, so the paths are failure independent, node-disjoint multiple paths are used for traffic load-balancing, and provide fault-tolerance towards route breaks as shown in Figure 2.2 a, paths are maximally disjoint, since no nodes or links are shared between the paths except the source and the destination node (Reddeppa and Raghavan, 2005).

- **Link disjoint scheme** do not have common links, but may have nodes in common between the multiple paths, although link disjoint schemes are more available than node disjoint schemes, but link disjoint scheme are failure dependent, movement of the nodes in the conjunction causes failure for the entire paths that pass through it, as shown in the Figure 2.2 b, the movement of the mobile node C to be out of the transmission range of the neighbor nodes causes the link break for all the paths the pass through it (Reddeppa and Raghavan, 2005).

- **Hybrid routing scheme** that combine between the previous two routing schemes (Tarique et. al, 2009).



(a) : Node disjoint
(b): Link disjoint

Figure 2.2: Different type of multiple path schemes

2.3 Routing protocols in MANET

This section presents an overview description of some routing protocols which are considered as a background. This section is considered as a background to understand the proposed routing protocols and some routing protocols that are represented in the literature review.

2.3.1 Dynamic Source Routing Protocol (DSR)

Broch et al., (1998) proposed a Dynamic Source Routing Protocol (DSR). It can be classified as single path, on-demand routing protocol designed for MANets. Basically it has two phases: route discovery and route maintenance.

The route discovery phase is fired by the source node when there is no route in its route cache to the desired destination node. It uses the flooding mechanism of the Route Request packet (RREQ) to find the route to the destination node. Each intermediate node that receives the RREQ packet checks the accumulated path field and it appends its address in the path field if it has not seen it before, then it re-broadcasts it to its neighbor nodes. The idea behind this is to prevent the routing loops. The route reply (RREP) packet is generated by intermediate node that knows the route to the destination node. The destination node generates a route reply (RREP) packet for each received RREQ packet.

When a neighbor of a source receives a request packet, it first checks whether the request packet is intended for it or not. If a neighbor discovers that it is the destination, it sends a reply back to the source after copying the accumulated routing information contained in the route request packet into a route reply packet. If it is not the destination, it checks if there is any route available in the route cache for that destination. If this neighboring node is neither a destination nor does it have a route in the route cache to that destination, it appends its address in the route request packet, and then it re-broadcasts a route request packet to its neighbors.

Route maintenance is the mechanism by which a node is able to detect any change in the network topology. When a node detects a broken link, for example, by using missing MAC layer acknowledgments, it removes the path from its route cache that contains the broken link and generates a route error (RERR) packet with the address of unreachable node toward the source of the route. Each node that receives the RERR packet removes the route entry that contains the unreachable downstream node address.

2.3.2 Split Multipath Routing Protocol (SMR)

Lee and Gerla (1999) introduced Split multipath routing (SMR). The main objective of SMR is to reduce the frequency of route discovery processes and thereby reduce the control overhead in the network.

The protocol uses a per packet allocation scheme to distribute a load into multiple paths. When a destination node receives route request packets (RREQ) from different paths, it chooses multiple disjoint routes and sends replies back to the source. The basic route discovery mechanism of the DSR protocol is used in the SMR protocol, but an intermediate node is not allowed to reply from its route cache if it has some routes available to that destination. To avoid overlapped multiple paths, the authors introduce a different route request forwarding scheme. In that scheme, instead of dropping a duplicate request message, an intermediate node forwards this request packet in a different incoming link other than the link from which the first request was received and whose hop count is not larger than that of the first request message.

When a destination node receives a route request message, it selects two paths that are maximally disjointed. Between these two routes, the first one is the shortest path. The shortest path is chosen to minimize the route discovery time because it is the earliest discovered route. After processing the first request, for the second path selection, a destination waits for a certain duration of time to receive more requests and learns all possible routes. After this, it selects a route from one of the alternative paths, which is maximally disjointed with the shortest path. A maximally disjointed path is the path that has the least number of common nodes compared to the shortest path. If there is more than one maximally disjointed path is available, the shortest hop path is selected among them.

The intermediate nodes in this protocol do not need to maintain a route cache, for this reason, a node has a smaller cache. One of the drawbacks of the SMR is redundant control packets overhead, where the intermediate nodes accepts more than one route request packet.

2.3.3 Ad hoc On-Demand Distance Vector routing protocol (AODV)

Perkins and Royar (2001) proposed Ad hoc On-demand Distance Vector routing protocol (AODV). It is reactive, hop-by-hop, single path routing protocol designed for MANets, basically it has two phases: route discovery and route maintenance. It uses the basic on-demand mechanism of route discovery and route maintenance of DSR (Broch et al., 1998), plus the use of hop by- hop routing, sequence numbers, and periodic beacons from Destination-Sequenced Distance-Vector Routing (DSDV). (Perkins and Bhagwat, 1994).

The source node broadcasts a Route Request (RREQ) packet to its neighbors that includes the address and the last known sequence number for the destination node, the idea behind the use of the sequence number is to prevent loop routing. The RREQ packet is flooded in a controlled manner through the network until it reaches a node that has a route to the destination or the destination node, all the nodes that foreword the RREQ packets record a reverse path to the source node. The Route Reply (RREP) packet is generated when the RREQ packet is received by the destination node or another node that have a path to the destination. The RREP packet contains the hop count to the destination node and the last known destination sequence number. Each node that participates in relaying the RREP packet back to the source node, records the required routing information to that destination in its own routing table. Figure 2.3 depicts the routing table structure for the AODV. The main objective of the route maintenance phase is to keep the connection continuity and detect any network topological change that may cause path disconnect.

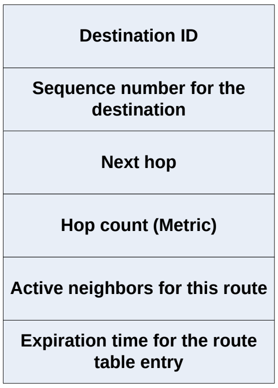


Figure 2.3 AODV Routing table structure

Since AODV is hop-by-hop routing protocol, each node along the path records the next hop information only not the entire route. In order to maintain the routes, AODV normally requires that each node periodically transmits a HELLO message, with a default rate of once per second. Failure to receive three consecutive HELLO messages from a neighbor is taken as an indication that the link to the neighbor is broken. Instead of using the HELLO messages, the node can detects any link break by using the methods in the physical or the link layer.

2.3.4 Ad hoc On-demand Multi-path Routing protocol (AOMDV)

Marina and Das (2001) introduced Ad hoc On-demand Multi-path Routing protocol AOMDV. It is a Multi-path Routing protocol based on the AODV; it is designed to accommodate the frequent link failures in a highly dynamic network environments.

The main idea in AOMDV is to compute multiple paths during route discovery phase, so it reduces the route discovery frequently overhead, by computing redundant multi-path in the route discovery phase instead of computing a single path as in AODV, the new route discovery phase is initiated only after all the redundant paths between the source and the destination are failed.

To keep track of multiple routes, the routing entries for each destination contain a list of the next hops along with the corresponding hop counts; the routing table entry for the AOMDV is illustrated in Figure 2.4.

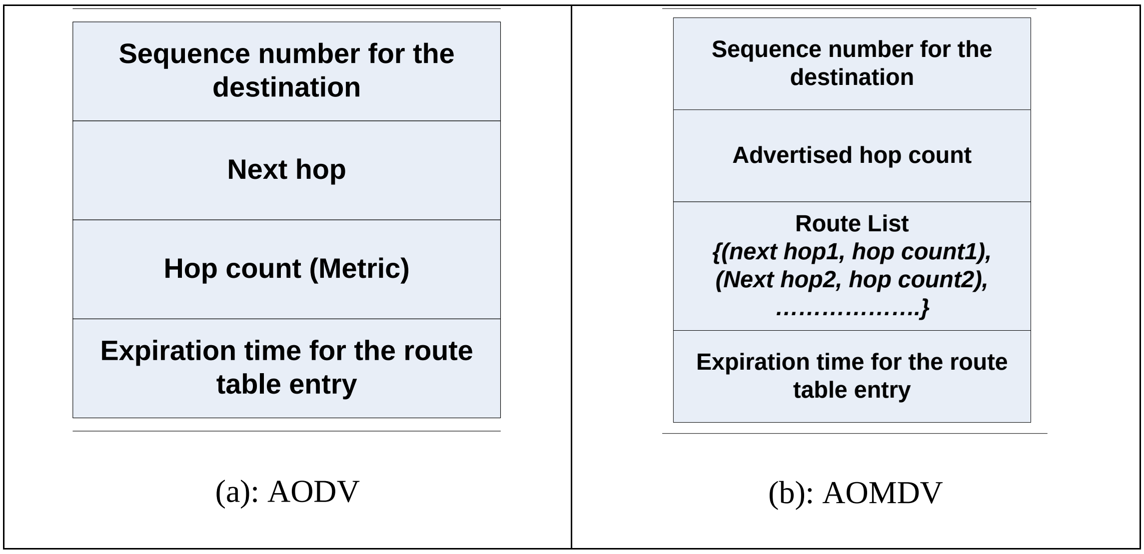


Figure 2.4 The structure of the routing entry for AODV and AOMDV

For each destination, a node maintains the advertised hop count, which is defined as the maximum hop count for all the paths. This is the hop count used for sending route advertisements of the destination; the node updates the advertised hop count whenever it sends a route advertisement. Each duplicate route advertisement received by a node defines an alternate path to the destination. To ensure loop freedom, a node only accepts an alternate path to the destination if it has a lower hop count than the advertised hop count for that destination.

These routing protocols presented in details due to its importance. It presents the base concepts for the most routing protocols presented in the next section. The proposed routing protocols based mainly on the concepts of the Split Multipath Routing Protocol (SMR). The idea behind choosing the SMR concepts is the need for the whole route information.

2.4 Related works

This section sheds the light on the researches papers that developed multipath routing protocols for MANets.

Multipath associatively based routing (MPABR-LL) (Carthy and Grigoras, 2005) introduces a new broadcast query forwarding technique for multipath routing protocol. In contrast to the flooding technique used in DSR, it uses link layer (LL) information in the flooding process. The key idea is that one node associates with another node over time.

In the MPABR-LL protocol, nodes periodically broadcast Hello messages. The associatively between two nodes is measured by the number of Hello messages exchanged between two neighboring nodes. Each node maintains a list of its current neighbors and a counter. The counter keeps track of how many Hello messages it receives from a neighbor. When a certain number of Hello messages are exchanged between two neighbors, these neighbors are called to be associated with each other. These nodes are more likely to form a stable and long lived route than the other nodes that are not associated.

When a source node wants to communicate with a destination, it creates a broadcast query (BQ) packet, which is similar to a route request packet. Each BQ has a unique source key and a sequence key. When an intermediate node receives a BQ packet, it adds its own ID, along with each of its neighbor's IDs and their associated ticks. Tick is the counter for Hello messages. Any subsequently received BQ packet with the same source and sequence number is dropped by an intermediate node. When a destination receives a BQ packet, it stores all the routes into a buffer and waits for a specified time period so that all other routes are discovered. After this time period, a destination node selects the most stable route using the tick recorded in the BQ packet. A destination node then attempts to find the second most stable route that is node- disjointed with the previous route. When a source node receives the route reply, it begins transmitting data packets along the first route. If this route is broken, it attempts to use an alternative route. If both routes are broken, it sends a new BQ packet to discover new routes again

Yang et al., (2006) developed a Loop-Free Multi-Path Routing protocol (LFMPR) with QoS (Quality of Service). It is based on the Ad hoc On-demand Distance Vector Routing Protocol (AODV) and the Dynamic Source Routing Protocol (DSR).

LFMPR is similar to DSR in the Route Discovery Phase and the Route Reply Phase; where in the former phase each node receives the route request packet (RREQ) appends its ID in it before re-broadcasting. Route Reply (RREP) packet contains the complete path from the source to the destination, which is similar to DSR.

Data packets in the DSR routing scheme are routed to the destination by the intermediate nodes using the complete path contained in the packet header. While (LFMPR) is similar to AODV in the data forwarding phase, in which the data packet is sent according to the next hop in the routing table that combined with the same flow id of data packet.

(LFMPR) use the flow-id for each RREP packet to avoid loops. If the transmission path is broken; the intermediate node can choose another backup path to send the data packets according to the flow-id in the routing table. (LFMPR) supports the required QoS by appending the required QoS metrics in the means of the required bandwidth and the maximum delay in the RREQ message, if the intermediate node satisfies the QoS requirements it appends its ID in the RREQ message and re-broadcast it. The LFMPR use the concept of multi-path routing in maintenance phase, but the data packets is sent on a single route only.

The idea by Sarma and Nandi, (2008) is based on the AODV; Stability Based Multi-path QoS Routing Protocol (SMQR) is developed to support throughput and delay sensitive real time applications in MANets. The QoS Route Request Packet (QREQ), which contains the minimum required throughput and the maximum delay is broadcasted in the route discovery phase.

The destination node executes the path selection algorithm to select the maximum of three node-disjoint paths with the higher stability after receiving the QoS Route Request message (QREQ) .The source node chose the path with the highest stability as the primary path and the others two path as a secondary path after receiving the RREP message.

(SMQR) periodically maintains and validates the alternate routes and switch primary route to an alternate route if the stability value of the alternate route is higher than the primary route, if all the paths are failed; a new route discovery process is initialized. SMQR performs well in increasing throughput and reduces the control overhead as well as the End-to-End delay compared with the (AOMDV).

A QoS Adaptive Multi-path Reinforcement Learning Routing Algorithm for MANets is proposed by Ziane and Mellouk, (2008). It aims to find a route that satisfies the required bandwidth constraints. It is basically based on the forward and backward exploration agents; the earlier one is responsible for exploring and reinforcing the paths of the network proactively, thus, they create a probability distribution at each node for its neighbors, while the Backward agents are used to propagate the information collected by forward agents through the network, and to adjust the routing table entries.

The creation of the first forward agent at a node for a source destination pair causes the routing table entries to be initialized with probabilities 1/K for each neighbor, where K is the number of elements of the set neighbor (i) of the node when the table is being established. In a second step, these probabilities are adjusted by backward agents. Each intermediate node that participates in the routing process chooses the most appropriate next hop based on the probability value for each neighbor node. The idea of the multi-path routing appears per hop in this routing protocol, in which each intermediate node between a pair of source and destination records more than one neighbor node as the next node for the same destination, but the data packet finally is sent on one path.

Yang and Huang, (2008) present a new QoS routing protocol based on the dynamic delay prediction that aims to find the path with the great stability factor that satisfy the required delay. A lot of research works has been done on development of routing protocols to achieve a degree of quality of service for MANets based on a single path routing, while using the multi-path concept in maintaining the route between the source and the destination node. The previous part of the presented research papers use the concept of multipath routing for the maintenance issues, while next part of the presented related research works use the concept of multipath routing for sending the data packets in more than one path.

In order to meet a stringent QoS requirement of a video application, Robust Multipath Source Routing (RMPSR) protocol is introduced in Wei and

Zakhor (2004). The basic idea behind RMPSR protocol is to discover multiple nearly disjoint routes between a source and a destination. The primary route connects a source and a destination node. Other alternative routes connect an intermediate node to a destination. The two route sets are nearly disjointed. The route discovery process of DSR is modified to increase the probability of discovering multiple paths.

The route sets are constructed at the destination. A destination node collects multiple copies of a request within a given time window. It then builds nearly disjointed multiple paths. A destination node returns the primary route to a source and the secondary route to an intermediate node.

Video transportation over multipath routing has been addressed in Mao et. al. (2005). Real time video transmission has stringent delay, bandwidth and packet loss requirements. Real time video transport over ad hoc networks is more challenging because of dynamic topology. That is why, the authors suggested using multiple paths in parallel for video transmission. In general, the quality of a path is changed over time; the system adjusts the transport and the coder accordingly to achieve the QoS requirements, the authors suggested that multipath transport of video streams can cause load distribution all over the network and hence can reduce congestion and improve delay. But this kind of distribution of traffic among different paths increases complexity and control overhead packets in the network.

The authors tried to find an optimum number of K paths. They show that when K is increased from 1 to 2, there is a significant improvement in network performance in terms of delay. But if K is greater than 2, there is not a significant performance improvement.

The multipath version of the AODV protocol (AODVM) has been modified to implement the split-n-save protocol (Cha and Lee, 2005) to achieve two major objectives:(1) to ensure the multipath routing is performing well over a time period in terms of the number of active nodes in a network and (2) to balance routing and forwarding through out a network. The authors quantify these two goals as two metrics namely network survivability and node satisfiability. The network survivability is defined as the number of active network nodes over a given period of time. This metric indicates a pattern of how a network changes, evolves, or vanishes overtime. The node satisfiability is defined as the ratio between how many packets are generated by a node and how many packets it forwards for other nodes. The authors proposed a simple multiplexing policy for switching traffic into different paths.

According to that policy, a source node will switch paths after transmitting k number of packets along a path. When k = p, this protocol switches path after transmitting p number of packets. When k=1, the protocol switches paths after sending one packet. When k = 0, the protocol uses a single path until this path is broken. The simulation results based on different values of k are presented in Cha and Lee (2005). The results show that the delay per packet is higher when k = 0 or 1 compared to when k = p. There is also a wide variation of delay when k = 0 or 1. But for other values of k, the delay variation was small.

Redundant source routing (RSR) is introduced by Wang et al. (2005). The RSR protocol is based on a disparity routing scheme. In a disparity routing scheme, a message is partitioned and sent over different paths. The key idea is that if a path fails, there is still a chance for other paths to send a packet successfully to a destination.

Disparity routing can be broadly classified in to two major types: non-redundant and redundant. In non-redundant disparity routing, a message is divided into sub-messages and these sub-messages are routed through different paths. In redundant disparity routing, a message is also divided in to sub- messages. But the number of sub-messages is less than the number of discovered paths that the routing protocol uses. In RSR, two paths are selected: one is the primary path and the other is the secondary path. Two identical packets are sent using these two paths. The original packet is sent along the primary path and the other copy of the packet is sent along the redundant path.

The traffic dispersion on different paths is done in around-robin fashion where each path has a constant weight of one packet. If no other alternate path is available, RSR performs similarly as DSR. In the source node RSR adds an agent named packet duplication agent (PDA) at the network layer to duplicate packets before sending them out. The PDA agent only duplicates TCP or UDP packets. Routing layer protocol packets, like route discovery and route maintenance packets, are sent with out any duplication. In the destination node, RSR has an agent named duplicate packet filter (DPF) at the network layer. The function of DPF is to filter out the duplicate packets. Moreover, when there is no intermediate node between a source and a destination, PDA does not duplicate a message. PDA also does not duplicate a packet if there is only one route available between a source and a destination. It is shown in Wang et al. (2005) that RSR has a lower packet drop rate and more delay robustness compared to DSR.

Qin Lu el at,(2008) present a multi-path routing scheme that extends AODV and AOMDV to provide the required QoS for video streams based on the route stability factor, the video stream is distributed over multiple paths that have the highest stability factor between the source and the destination node. The decision of route selection is taken by the destination node by selecting the routes that satisfy the required path stability threshold. For route maintenance mechanism, they proposed a path warning mechanism, which fire the RERR packet by any intermediate node that detects link stability value less than the threshold.

Ding and Liu, (2010) proposed a node disjoint multipath routing based on AODV. The main goal is to discover multiple node-disjoint paths with a low routing overhead during a route discovery. It improves the packet delivery ratio compared with AODV. The route request phase is similar to DSR where, each intermediate node receives the RREQ adds it's ID and re broadcast the RREQ. The destination node is responsible for selecting the node disjoint route set. Each intermediate node receives the route reply only it records the next hop for that destination. The source node then sends the data on multiple disjoint routes.

Galvez et al., (2010) proposed multipath routing protocol with spatial separation in wireless multi-hop networks without location information (SDMR). It is a reactive multipath protocol capable of finding multiple spatially distant paths between two nodes.

For a source node S to calculate disjoint paths to a destination D, it first needs a graph of the connectivity of the network, in a similar way to link-state routing protocols. S produces this topology graph using connectivity information received from other network nodes. The source node then searches the graph for candidate paths between itself and the destination and chooses the set of most disjoint paths according to a distance metric.

The route discovery method is thus similar to other link-state routing protocols like Optimized Link State Routing Protocol (OLSR), but the main difference stems from the fact that in OLSR all nodes periodically broadcast their connectivity information (link-state) to all nodes in the network, whereas in SDMR this information is only sent to a source node on demand. To achieve this reactively, S requests connectivity information to the set of Multipoint Relays (MPR) in the network and to the destination by flooding a

Topology Request (TREQ) message and these nodes send their 1-hop neighbor set back to the source in Topology Reply (TREP) messages, along the reverse paths formed during TREQ propagation. Data packets are routed along the paths using source routing.

All the previous reviewed research works use the idea of multi path routing protocol to distribute the traffic load on disjoint routes set. They were based on different criteria in the routes selection method, but none of them considers the interference between the selected disjoint routes.

3 Multipath, Quality of Service Routing Protocols for Mobile Ad hoc Network (MANet)

In this Chapter, the basic components of the proposed routing protocols are explained along side with an illustrative example, which simplify the explanation of the model. Section 3.1 presents the proposed Efficient, Stable, Disjoint Multipath routing protocol for MANets (ESDMR), which describes the processes flow in the proposed model. Subsections 3.1.1 through 3.1.5 describe in details the components of the proposed models. Section 3.3 presents the control packet structure. Finally, Section 3.4 presents an overview of the proposed Efficient, Disjoint Multipath routing protocol (EDMR).

As we explained in Chapter 2, Split Multipath routing protocol (SMR) routing protocol have three main phases similar to other routing protocols: Route Request, Route Reply and the Route maintenance phases. The proposed routing protocols are built based on these concepts, but with modifications in each phase.

The main idea behind choosing the Split Multipath routing protocol (SMR) as basic routing protocol for the developed models is the need for all nodes information that had participated in the process of forwarding Request packets. The destination node benefits from the collected information in selecting the maximally disjoint paths and concluding the interfering nodes set for each selected path. The latter two processes will be explained in details in Section 3.1.2 and 3.1.3.

Moreover, they are on-demand routing protocols, thus, nodes do not need to maintain routes to all destinations in the network in advance. Instead, in the Route Request phase the routing protocol finds routes to the destination when there is a need to communicate with that destination.

The main objective of the proposed routing protocols is to increase the delivery ratio and throughput for multimedia streams and reduce the routing overhead by reducing the frequency of the route discovery processes. The proposed routing protocols developed a mechanism, which avoid the late request packets from continuous travel in the network, and thus, the proposed routing protocols reduce the routing overhead significantly compared with SMR. The proposed routing protocols use a per packet allocation scheme to distribute the data traffic on multiple paths. Distributing the data traffic on multiple paths reduces the nodes congestion and helps to use mobile nodes resources efficiently.

3.1 An Efficient, Stable, Disjoint, Multi-path Routing Protocol for MANets (ESDMR)

This section presents an overview of the ESDMR in section 3.1.1. The detailed explanation of the basic components of ESDMR is presented through section 3.1.2 to 3.1.5.

3.1.1 An Overview of ESDMR

This section sheds the light on the main processes of ESDMR protocol. It presents an overview on ESDMR. Figure 3.1 explains the processes flow and the main steps of the ESDMR.

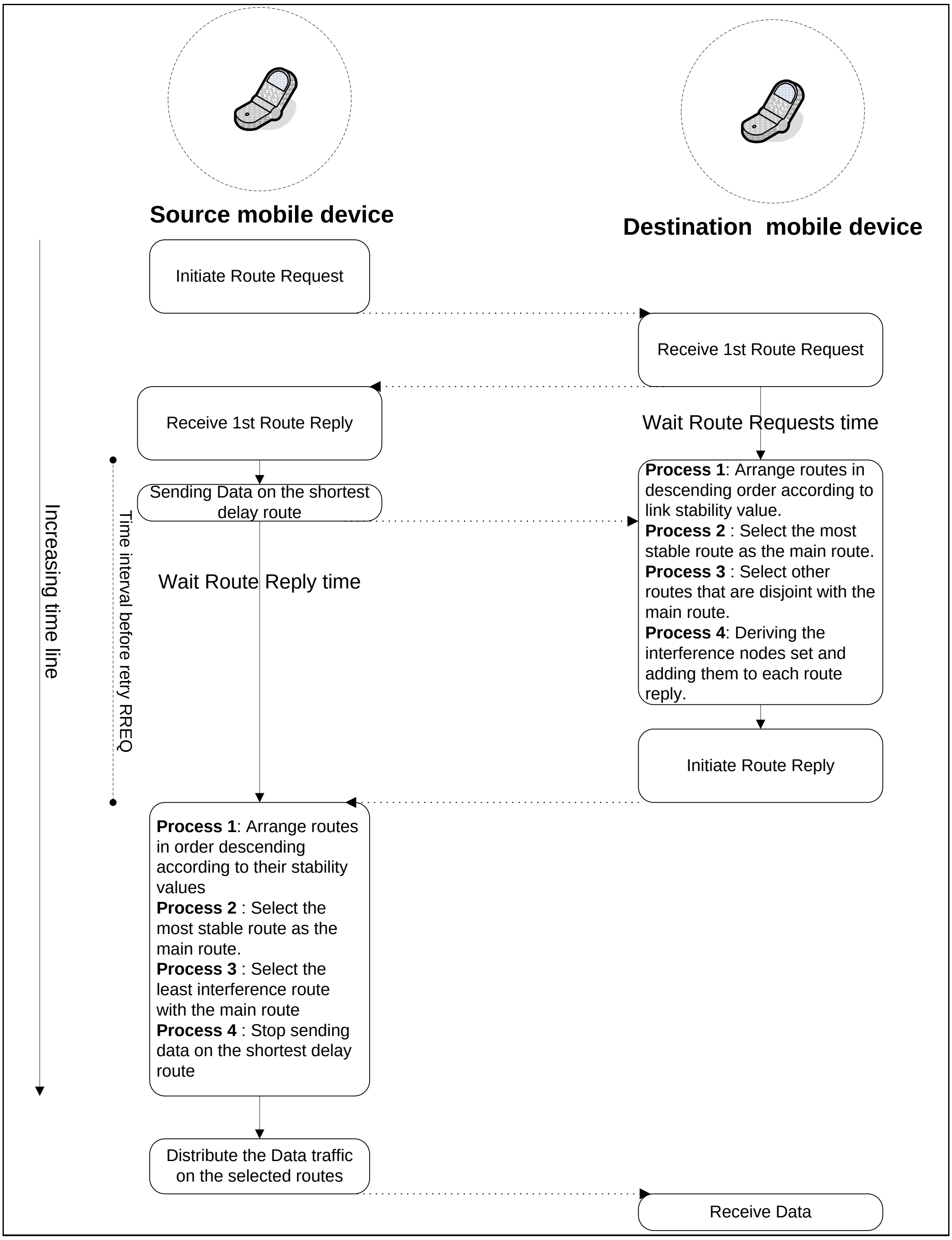


Figure 3.1: Processes flow of the proposed model

In the route request phase, each intermediate node receives a request packet from a different incoming link and it stops receiving the request packets after certain duration of time. The destination node sends reply for the shortest delay route and it waits a period to collect other request packets, and then it arranges the routes according to their stability values. It selects the highest stability route as a main route and a set of routes that are disjoint with the main route. With the disjoint route selection, it adds the interference node set for each selected route. Finally, it sends back the reply packets to the source node. The source node stops using the shortest delay route and selects the least interference two routes to send the data through them instead of using the shortest delay route.

The basic route discovery mechanism of SMR protocol is used, in which the intermediate node is not allowed to reply from its route cache if it has some available routes for that destination. To avoid overlapped multiple paths, ESDMR introduce a route request forwarding scheme that is similar to the one in the SMR, but with some modifications that allow the intermediate nodes to pass more requests packets.

To reduce routing overhead, the proposed routing scheme developed a mechanism which prevents the late request packets from the continuity of transition through the network, thus, it reduces the control overhead. In this scheme, instead of dropping a duplicate request packet, an intermediate node forwards the request packet in a different incoming link other than the link from which the previous requests was received. This process is designed to give the destination node the required information about the adjacent nodes to the intermediate node that pass the request packets. This information enables the destination node in deriving a group of interference nodes for each selected route. Each intermediate node has a specific time interval to pass RREQ packet. The idea behind that is to decrease the routing overhead and prevent the late request from being travel through the network.

When the destination node receives the request packets, it replies for the first request packet. The shortest delay path is chosen to minimize the route discovery time because it is the earliest discovered route. After processing the shortest delay route, a destination node waits for certain duration of time (*wait route request time*) to receive more requests and learns all possible routes to the source node as seen in Figure 3.1. After that it orders the routes according to their stability values, where the route with a higher stability value has the priority to be selected compared with the route that has a lower stability value. A destination node selects the most stable route to be the main route and finds the other routes that are maximally disjoint with the main route. It also finds the group of interference nodes for each route. For each selected route, the destination node sends back a route reply to the source node, which includes the route information and the related group of interference nodes addresses. After the source node receives the first reply packet for the shortest route, it waits a certain amount of time (*wait route reply time*) as seen in Figure 3.1 to receive the other route reply packets which can be described as the group of stable routes.

A source node moves from sending data on the shortest path after receiving the group of stable routes information to send data on the most stable maximally disjoint two routes which have the least interference between them. The source node maintains more than one route, these routes are disjoint with the main route for the maintenance and route recovery issues.

3.1.2 Route discovery phase

ESDMR is an on-demand multipath routing protocol that builds multiple routes in a request/reply cycle. When a source needs route to a destination but no route information is known, it floods the ROUTE REQUEST (RREQ) packet to the entire network. Because this packet is flooded, several duplicates that traverse through different routes reach the destination. The destination node selects multiple stable disjoint routes and sends ROUTE REPLY (RREP) packet back to the source via chosen routes. The RREP packet also includes the addresses of the group of the interference nodes for each route.

- **Route Request propagation**

The main goal of ESDMR is to find the least interference, maximally disjoint multiple paths. We construct the maximally disjoint routes to prevent a certain nodes from being congested, and to utilize the available resources efficiently. To achieve this goal in on-demand routing schemes, the destination must know the entire path of all available routes so that it can select the routes and derive the nodes addresses that can interfere with it.

Therefore, we use the source routing approach where the information of the nodes that consist the route is included in the RREQ packet.

When the source node has data packets to send but does not have the route information to the destination, it broadcasts a RREQ packet. The packet contains the source ID, a sequence number that uniquely identify the packet and the link stability value. Each intermediate node receives the RREQ packet adds its address and calculates the link stability value. If the calculated link stability value is less than the link stability value that is recorded in the RREQ packet, the intermediate node replaces the recorded link stability value in the RREQ packet with the calculated link stability value, thus, the RREQ packet carries the lowest link stability value for the route. The RREQ packet is re-broadcasted and the previous Route Request procedure is repeated for each intermediate node that receives the RREQ packet until it reaches the destination node. Figure 3.2 shows the pseudo code which explains the procedure of processing the RREQ message by the intermediate node.

If the intermediate node is restricted to accept only the first RREQ packet, the destination node will not be able to derive the group of the interference nodes addresses. However, if the intermediate node accepts all the duplicated RREQ packets, during the simulation we found that the networks become congested with control overhead and the delivery ratio was too low. In addition, accepting the duplicates RREQ wastes the network resources.

Processing RREQ message by intermediate node:
Input data: RREQ (RREQ message)
node (mobile device receiving the RREQ message)
hop_count (number of hops that RREQ message travelled)

Define: RSS = link stability value
- Set RSS to the current calculated link stability value

IF RREQ is not seen before
- Add *node.id* to *RREQ.path[hop_count]*
IF RSS is less than *RREQ.RSS*
- Set RSS to *RREQ.RSS*
End IF
- Increase hop_count by 1
- Broadcast RREQ
End IF

Figure 3.2: Pseudo code for processing the RREQ message by intermediate node

In order to benefit from the information that the RREQ packet gains without affecting the network performance, we introduce a different packet forwarding approach that enable the destination node to gain the required information about the route and maintain the network performance from degradation. Instead of dropping every duplicate RREQ packet, intermediate nodes forward the duplicate packets that traversed through a different incoming link than the link from which the previous RREQs are received. This ensures that the destination node has knowledge about the nodes addresses that locate within the range of nodes that participate on forwarding the RREQs. The main goal of the gained information is to enable the destination node to derive the group of node addresses that can interfere with the corresponding path.

However, as the network become dense as the number of RREQs packets that intermediate node forwards is increased, and thus, the network performance decreases dramatically. To maintain the network performance, each intermediate node receives RREQ packets for a specified period of time. This period of time *(t)* is determined as a function of the number of hops that the RREQ is travelled until it reaches the destination node as seen in the following equation.

$$t = \frac{\alpha * RREQhopcount}{MaxRREQDest}$$

Where α is a constant period of time, it is assigned to 10 milliseconds in the GloMoSim simulation environment, RREQhopcount denotes to the number of hops that the RREQ packet travelled, and the MAXRREQDest denotes to the maximum distance that the RREQ message can travel in the network.

As known, the number of RREQ packets increase exponentially as the RREQ packets travel through the network from a source to destination node. Thus, according to the previous equation, the period which a node spends in forwarding the RREQ packets increases as a number of hops for the RREQ packet increase. This enables the destination node to get more information about the available routes. Moreover it prevents the late RREQs from travelling through the network to a destination after it sends the RREPs.

When the destination node receives the first RREQ, it replies for it, then it waits time interval equal to *wait Route Request time* (t_1) as seen in Figure 3.1. The previous mentioned period of time can be defined as the time interval that the destination node waits to receive more RREQ messages. This period of time in addition to the processing time ($t_{processing}$) should be less than the time interval (t_2) which a source node waits before retry the RREQ phase, so (t_1) must satisfy the following equation. If (t_1) in addition to $t_{processing}$ was more than (t_2), the source node will always wait for the routing information until the time is ended and then will retry the route request another time. So after the second route request, the routing information for the first route request will be received by the source node. So the second route request only increases the routing overhead. That's why; (t_1) should satisfy the following equation

$$t_1 < t_2 - t_{processing}$$

The idea behind *wait Route Request time* (t_1) is to enable a destination node to gain more knowledge about the network status and enable the destination node to collect the maximum number of possible valid paths.

The determination of the value of the *Route Request time* (t_1) is very critical, where the large value of it will increase the number of the possible routes that the destination node will receive, while increasing the end-to-end delay. So we have to choose a value for it that balance between the need to gain the maximum number of valid routes and reducing the end-to-end delay.

3.1.3 Route Reply phase

The route reply phase is fired when a destination node receives the first RREQ packet. Route Reply phase is responsible for sending the complete routing information to the source node. In the ESDMR, the intermediate node does not need to record the route to a destination, because they are not allowed to send ROUTE REPLY (RREP) packet back to the source even when they have route information to the destination. If nodes reply from their caches, it is difficult to find the maximally disjoint paths and the required interference information for each route, because not enough RREQ packets will reach the destination and the destination node will not know the information of the route that is formed from the cache of intermediate nodes. Figure 3.3 presents the pseudo code for processing the RREP packet by the intermediate node.

```
Processing RREP message by intermediate node:
Input data: RREP ( RREP message)
            node ( mobile device receiving the RREP message)
            hop_count (number of hops that RREP message travelled)
            routing_table (destination,path,hop_num,stability)

- Increase hop_count by 1
- Farward  RREP
```

Figure 3.3 : processing Route Reply packet by the intermediate mobile node

- **Route selection Method**

In the Route Reply phase, the destination node selects the most stable route as the main route and finds the maximally disjoint routes set with the main route according to their stability value, where a path with the highest stability value have the highest priority to be selected.

The problem of finding a path from the source node to the destination node and forwarding a packet along the path is known as the routing problem. Finding multiple, disjoint paths for routing from the source to the destination is called node disjoint-path routing. The solutions for these routing problems are fundamental and critical for the performance of the routing algorithm.

The proposed model depends on the path stability value in path selection algorithm. When the destination node receives the maximum number of the RREQ packets within the Route request time interval, it arranges them in descending order according to their paths stability value, and then it selects the first route as the main route and finds the other routes that are disjoint with the main route. Figure 3.4 shows the pseudo code for selecting the stable disjoint paths

The problem of selecting the maximum set of node disjoint routes that satisfy the required QoS metrics had been discussed in many previous research works, but as the solution of the problem become better as the complexity of the algorithm increase, thus the time needed to get the solution also increase, which in the proposed model is a critical parameter that should be minimized as much as possible. Moreover, Mobile node resources are limited. For that the proposed model uses the simple procedure to get the node disjoint routes that have the highest stability value.

```
Selection of stable node disjoint paths
Input:   S (unarranged path set )
         S_size (size of S)

Define:D (set of stable, node disjoint path set)
         D_size( size of disjoint_set)
         LS_path (path stability)

-  Arrange S according to LS_path in descending order
-  Initialize D by adding S0  (S0  is the most stable route in S)
                               ( It isassumed to be the main route)
For  i=1 to S_size
            For j=1 to D_size
                  - compare Si with S0
            End For

            IF Si is node disjoint with S0
                  - Add Si to D
                  - Increase D_size by 1
            End IF
End For
```

Figure 3.4: Pseudo code for the selection of stable node disjoint paths

The destination node derives the group of interfering nodes for each route from the received information for other paths. It generates a Route Reply (RREP) packet for each selected route, and then it appends the path information from a source to a destination with RREP message, in addition to the group of addresses for the interference nodes.

- **Deriving interference node set**

This Section sheds light on the process of finding the group of interference nodes addresses for each route. Before reviewing the procedure of deriving the interference node set for each route, it is of great importance to define the interference concept and its effect on the multi-path routing.

Interference concept can be defined as the number of neighbor nodes covered by the link (M. Burkhart, 2004), (T. Johansson, and L. Carr-Motyckova, 2005). In another study, (H. Hassanein and A. Zhou, 2003) define the node interference as the number of paths passing through all of the neighbor nodes. (Qin Lu, 2008) define it as the compound of the influences among transmitting nodes which need to transmit simultaneously and the effects a receiver suffers from some transmitting nodes together.

Theoretically speaking, using multiple path for transporting data should lead to great increase in data rate, however, the existence of node interference can affect the multi-path routing performance by decreasing the total throughput and delivery ratio; this is due to the collision between the neighbor nodes on different paths when transmitting data simultaneously. So many retransmission processes occur to send the data packet correctly which decrease the total delivery ratio to be in some cases seems like sending the data on single path. For more clarification, let us consider the example in Figure 3.5, in which the source node 83 uses path 83-97-29-64 and path 83-42-14-13-88-64 to transmit data simultaneously to the destination node 64. The collision occurs when node 29 and node 13 send data in the same time, while node 88 is in listening mode (receiving mode) , so node 88 receive noise signals due to the collision. Thus, node 13 retransmits data packets until it is received correctly. The reason behind the collision problem can be referred to the location of the receiving node that located in the range of the two sending nodes, which send the data in the same time. The Distributed Coordination Function (DCF) and CSMA/CA are used in the MAC layer in IEEE 802.11 standards to reduce the collision affects. It organizes a channel gain process for the nodes that share a single channel. The CSMA/CA aims to reduce the collision by preventing a node from starting to send data since the channel is gained by another node that locates in its range. The waiting period in which a node waits to gain the channel leads to increase the end-to-end delay, decrease the throughput and the delivery ratio to be likely as sending data on single path.

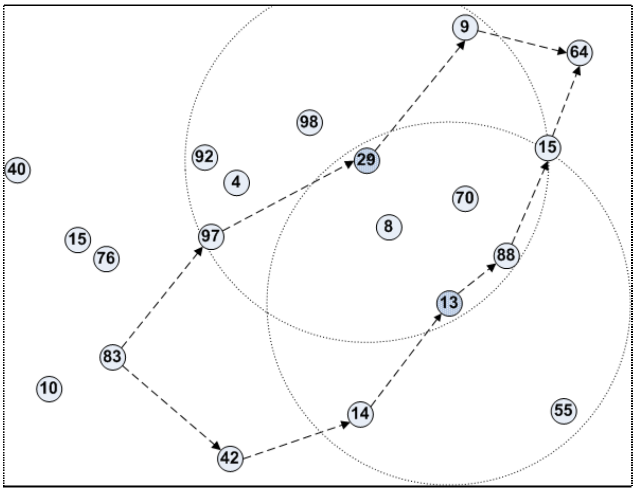


Figure 3.5: Collision between two paths when transmitting data simultaneously

Most of the node disjoint multi-path routing protocols select the route according to some criteria such as shortest path, stable path, battery life of the path and so on, but they do not take in to account the interference problem between the selected paths. Although the throughput is increased in some of these routing protocols in compare with the single routing protocols, but not as expected. This increasing in throughput and delivery ratio is due to reducing of route discovery frequency only. But the effect of sending data on multiple routes is still not appeared because of the interference problem between the routes.

The main idea behind this study is to increase the delivery ratio and throughput of the multi-path routing protocols that transport the data on multiple paths by decreasing the node interference between these selected paths.

In the proposed model as seen in Figure 3.1 in Section 3.1, the destination node is responsible for selecting the node disjoint route set in process (3) and adding the interference node set for each selected route in process (4). It is also responsible for deriving the group of interference nodes addresses for each route. The idea of finding the group of interference nodes addresses based mainly on the information that a destination node received via RREQ packet, which carry the information about path stability value and the nodes id that participate in forwarding the RREQ packet.

Back to Figure 3.5, suppose that the destination *node No. 64* received some of the following paths in different RREQ packets from the source *node No. 83* as shown in Figure 3.6.

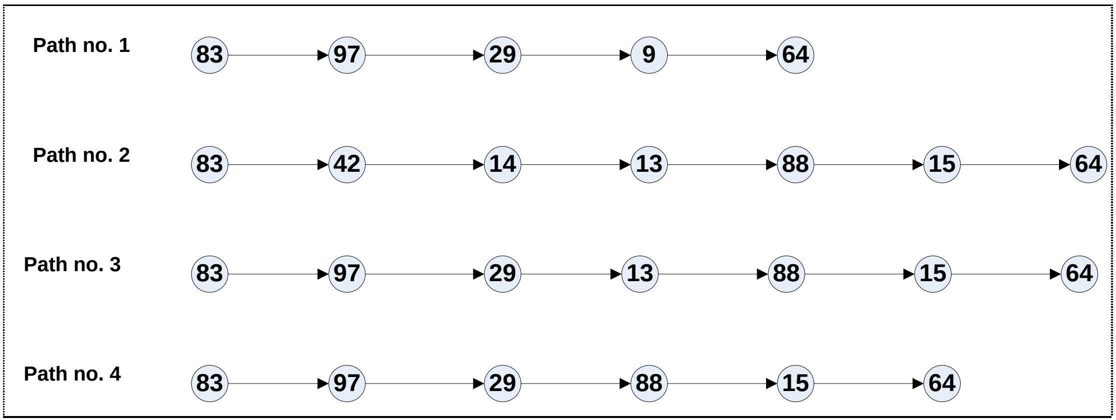


Figure 3.6: Sample of paths that the destination node received in the RREQ packet

From the Figure 3.6, the *path No.1* and the *path No.2* have no intersection nodes except the source and the destination node, so both of them represent a candidate routes for node disjoint multi-path routing protocol. While *path No.3* has intersection node with *path No.1*, so the destination node can derive the interference node set with *path No.1* by choosing the nodes in *path No.3* which are in the next or previous the intersection node between them, which is not an intersection node. Thus, the address of *node No. 13* will be added to the interference node set for *path No.1*. So any path that contains *node No.13* represents an interference path for *path No.1*. This scenario represents a hidden terminal problem, where *node No. 29* and *node No. 14* are in the sending mode while *node No.13* is in the receiving mode. *Node No.13* is located in the range of both sending nodes; this can be inferred from *path No.2* and *path No.3*. The two sending nodes are out of transmission range of each other. Thus, the sent packets will colloid before *node No. 13* receives them. Thus, *node No. 13* receives noise packets. According to MAC layer standards, *node No. 13* will consider these packets as corrupted packets and thus, it drops these corrupted packets and does not send them to the network layer, so the delivery ratio in the network layer will be decreased if we send the data on the *path No.1* and *path No.2* as in many routing protocols. This is due to the collision which happed between the sent packets to the node that locate within the transmission range of two nodes that are located in the two different disjoint routes. The sending nodes are out of transmission range of each other.

Single shared channel is another issue that rises in the multipath routing protocols that distribute the traffic load on more than one route. This issue mainly affects the total throughput for the disjoint routing scheme. Due to the single shared channel, the total throughput for the disjoint multipath routing was no as expected and the increasing of the throughput of these routing scheme is due to the reducing of the frequency of route discovery process but not due to sending the data on more than one routes that are disjoint.

Back to Figure 3.6, the *path No.1* and *path No.2* are node disjoint routes; therefore, they represent a candidate route for a disjoint routing scheme. Suppose that *node No. 29* from *path No.1* is gained the channel to send the data. Theoretically, sending data on *path No. 2* will not effect when the nodes on *path No.1* sends data.

However, from *path No. 3*, it is noticed that *node No. 13* is neighbor to *node No. 29*. Thus, according to MAC layer IEEE 802.11 standards, when *node No.29* gains the channel to send data, the channel become busy and thus, the *node No. 13* will wait a period of time until the channel become idle, then when *Node No.13* gain the channel, it will start to send the data. The waiting time that *Node No. 13* waits to gain the channel decrease the total throughput of the multipath disjoint routing scheme.

In the proposed routing protocols, we add node address 13 to the interference nodes set for *path No.1*, thus, any route that contain node address 13 will not be considered as a candidate route to send data through it with *path No. 1*

As said previously, the destination node is responsible for selecting node disjoint routes and adding the interference node set for each route only.

Figure 3.6 summarizes the in pseudo code the procedure for deriving the group of interference nodes addresses for each route.

```
Deriving interference nodes set for each route

Input: S (Set of path)
       S_size (number of paths)
       j_hopCount (numbet of hops of the path j)

Define:i_set (interference set)
For i=1 to S_size
    For j=1 to S_size
        If Si is not Sj
        - compare Si and Sj
        If Si and Sj have intersection nodes
            For x=1 to Si_hopCount
                For y=1 to Sj_hopCount
                    If Sj [x] equal Sj [y]
                        if (y==0)
                        -  Add Sj [y+1] to i_set  for path Si
                        End IF

                        else if (y== Sj_hopCount)
                        - Add Sj [Sj_hopCount-1] to i_set  for path Si
                        End IF

                        else
                        -  Add Sj [y+1] to i_set  for path Si
                        -  Add Sj [y-1] to i_set  for path Si
                        End IF
                    End If
                End For
            End For
        End If
        End If
    End For
End For
```

Figure 3.7: Pseudo code for deriving interference node set for each path

3.1.4 Data Relay Phase

As seen in Figure 3.1, when the source node receives the first RREP packet, it uses it to send the data until it receives other RREPs. It waits for (*wait route reply time*) interval to receive the other RREPs. The idea behind that time interval is to enable the source node to gain more routes, which the destination node sent. This time interval is much less, than the *wait route requests time*; this is due to the different goals for each time interval.

The source node arranges the received paths information in a descending order according to their stability value. It selects the first route as the main route and finds the least interfering route with the main route as a second route. Then it sends the data on the selected routes in a Round Robin fashion. The flow chart in Figure 3.8 explains the algorithm of selecting routes to send the data through them.

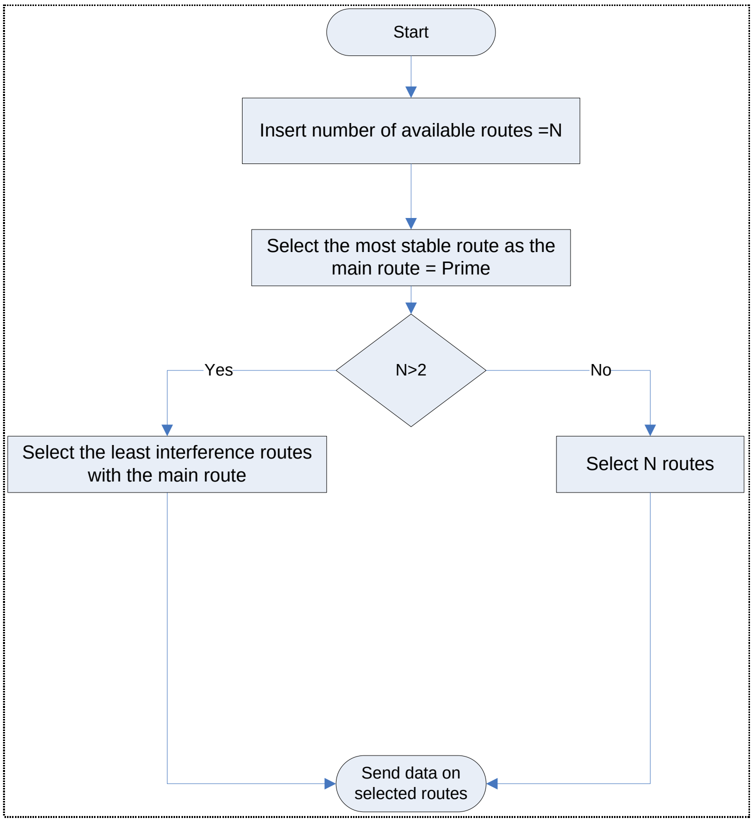


Figure 3.8: Flow chart of route selection algorithm

The algorithm of selecting the least interference routes will be explained in the next section.

- **Least Interference route selection algorithm**

The problem of finding the least interference routes set is one of the most important issues in the proposed model, where the overall system efficiency depends mainly on it. The efficiency of the routes selection algorithm depends mainly on the criteria that determine the sequence of selection of the routes.

In ESDMR, the source node selects the most stable route as the main route. Then it finds the least interfering route with it. This selection procedure is the simplest one. The main idea behind that is to reduce the end-to-end delay and to maintain the mobile nodes resources.

As known from the previous sections, that all the routes that the source node received are node disjoint and have the highest stability values, but the source node is responsible for selecting the least interference routes set to send the data through them. The pseudo code in Figure 3.9 illustrates the procedure for selecting the least interference routes. The idea behind selecting the value like 10000 for N_min in Figure 3.9 is only for comparison issues in programming. It means a big value only; it does not need to be 10000.

```
Selecting the least interference routes
Input : S (node disjoint path set)
        S_size (number of paths in S)
        Sj_iset(intereference set for path Sj)
        isetSize(i_set size)

Define : D (the least interference  path set)
         D_size (size of the least interference  path set)
         N (number of interference nodes)
         N_min (minimum number of interference
         node)=10000

- Arrange S  in descending  order according to  their
stability values
- Initialize D by adding S0

 For j=1 to  S_size
         - compare  S0_iset with Sj
         - count the number of interference node
         between Sj and S0  and assign it to N

         if (N_min >N)
                 - N_min =N
                 - Set Sj as the minimum interfering
                 route
         End IF
End For
```

Figure 3.9: Selecting the least interference routes

3.1.5 Route maintenance phase

As known, any routing protocol for MANets needs the maintenance phase, this is due to the frequently link breaks that occurs as a result of node movement.

In the proposed model, we developed a mechanism that enables the node to fire an Error (RERR) packet when it detects a link break. The RERR packet that carries the broken path is forwarded toward the source node. Each node receives the RERR packet stop using that route. When the source node receives the RERR packet, it applies the least interference route selection algorithm with the route that is in use to find another route that can replace the broken. Figure 3.10 presents the flow chart for selecting another route to replace the broken route.

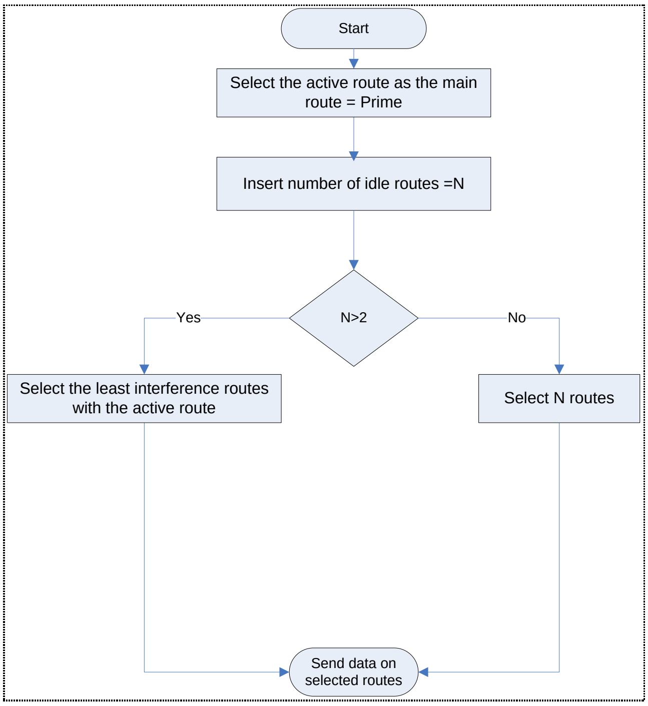


Figure 3.10 : Selecting another route in the route maintenance phase

3.2 Stability evaluation models and the applied stability model

Before starting to take about the available stability models ideas, it is of great important to define the stability metric and the role of stability models on the routing protocols for MANET.

Link stability metric can be defined as the prediction of the life time of the wireless link between the neighbor nodes. The essential role of stability metric is to establish a stable connection with less link break and higher delivery ratio, thus, stability metric is a required QoS metric in the application like video streams and real time applications.

Path selecting principle is very important for ensuring stable data communication. Most of routing protocols prefer the shortest path theoretically. However, a small movement of any node of this shortest path may leads to a break on the path as explained in Figure 3.11 (L. Geunhwi, et al, 2002), this is because the shortest path concept depends mainly on the hop count not on the real distance between the two nodes.

For that, the proposed model depends mainly on the path stability metric for path selecting principle, addition to the importance of the link stability metric to support a stable communication as mentioned previously.

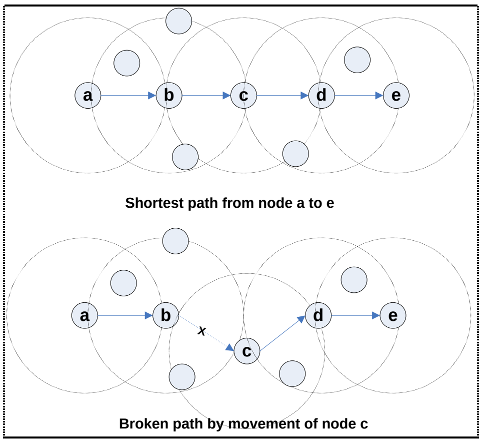


Figure 3.11: Easy broken of shortest path

Link stability metric can be estimated using many parameters, such as signal strength, pilot signals. Relative speed between two nodes or remaining battery power of a node can also be used. In this protocol, we use received signal strength (RSS) value to estimate link stability because link stability between mobile nodes is basically dependent on the distance between mobile nodes (Glomosim Tutorial).

Free space propagation model assumes two-dimensional area and predicts the RSS when the transmitter and receiver have a clear, unobstructed line of sight between them, once the distance between two neighbor nodes exceeds a certain extent, the transmitted signal will not be received correctly by the receiver, and thus it will result in link failure. This model predicts that transmission power is attenuated in proportion to the square of distance as illustrated in the following equation (Glomosim tutorial).

$$P_r = P_t \left(\frac{\lambda}{4\pi d}\right)^n G_t G_r$$

Where P_r is receiving power, P_t is the transmitting power, λ is the carrier wave length, d is the distance between the two nodes, G_t and G_r denotes to the antenna gain at the transmitter and receiver.

3.3 Control packets structure

This chapter presents the control packets structure that are used in the proposed routing protocol, which are responsible for controlling the overall processes flow in all the routing protocols for MANET. Each routing protocol has three main control packets, which are: Route Request (RREQ) packet, Route Reply (RREP) packet and Route Error (ERR) packet.

- **RREQ message**: The mobile node broadcasts the RREQ message when there is a need to communicate with a destination node that has no routing information for it. In addition to its primary role in finding the route to the destination node, it plays an important role finding the path stability.

Figure 3.12 present the RREQ message structure that is used in the proposed protocol.

Source node Address
Destination node Address
Link Stability value
Path (node_addr1,node_addr2,node_addr3,……..)

Figure 3.12: Structure of the RREQ message

As seen in Figure 3.12, the source node address and the destination node address fields contain the addresses of both the source mobile node of the route and the needed destination node. The link stability value always carries the minimum link stability value for the entire path. While the path field contains the addresses of all the nodes that had participate in forwarding the RREQ message. The path field plays an important role in selecting the node disjoint paths as explained in section 3.1.3, where it gives the destination node the required information about all the nodes in the route. Each intermediate node that receives the RREQ message checks the path field to make sure that it has not received it before, the goal of that is to prevent the routing loops that consume the network resources and increasing the control overhead.

- **RREP message:** the RREP message is generated by the destination node to inform the source node with the possible routes between them. Figure

3.13 illustrates the structure of the RREP message that used in the proposed routing protocol.

Source Address (Source of the Route Reply)
Target Address (Source of the route)
Path (node_addr1,node_addr2,node_addr3,….)
Interference node set (node_address1,node_address2,….)

Figure 3.13: Structure of the RREP message

As illustrated in Figure 3.13, the *Source Address* denotes to the generator of the route reply message, while *target address* denotes to the source of the route (source node in the RREQ message). The path field contains the nodes addresses that represent the entire path from the original source node to the destination node. The *interference node set* field contains all the nodes addresses that interfere with some nodes of the path. The procedure of deriving the interference node set is explained in details in section 3.1.2.

- **RERR message:** Is the last control message type that used in the proposed routing protocol. RERR message is fired when an intermediate node detects a link break in the path of data sending. It aims to inform all the node in the path with this link break, so all the nodes that receive the RERR message will delete all the paths that contain the unreachable node address from its routing table. In the proposed routing protocol the source node only maintain the route information. Thus, the source node only deletes the routing information that is related to the RERR message. Figure 3.14 illustrates the structure of the RERR message that is used in the proposed routing protocol.

Source Address (originator of the RERR message)
Destination Address (source of the broken route)
Unreachable Address
Path (node_addr1,node_addr2,node_addr3,…..)

Figure 3.14: Structure of the RERR message

As illustrated in Figure 3.14, the *source address* denotes to the address of the node that detects the link break and generates the RERR message, while the *destination address* denotes to the last node should receive the RERR message which is the source of the route. *Unreachable Address* denotes to the immediate downstream node address of the broken link. The *path* field contains the entire path from the original source of the route to the destination node. The main idea behind the path field is to define the next node address that will receive the RERR message.

3.4 Efficient, Disjoint multipath Routing Protocol for MANets (EDMR)

This section presents an overview on the proposed routing protocol (EDMR). It can be considered as a hybrid routing protocol that combine between ESDMR and SMR. It is developed to take the advantages of both of them. To clarify, EDMR can be defined as ESDMR, but with shortest path selection criteria instead of stability selection criteria.

The main objective of EDMR is to increase the packet delivery ratio and the throughput of the multimedia streams. It uses a per packet allocation scheme to distribute a traffic load into multiple routes. The basic route discovery mechanism that is used in the ESDMR is used in the EDMR, but an intermediate node does not need to calculate the Received Signal Strength in the radio layer as an indication for the link stability. When a destination node receives the route request packets, it selects the shortest delay routes as the main route. The shortest delay path is chosen to minimize the route discovery time because it is the earliest discovered route. After processing the first request, a destination waits for a certain duration of time to receive more requests and learns all possible routes. After this, it selects multiple routes that are disjoint with the main route. EDMR is similar to SMR in selecting the shortest disjoint routes. The destination node derives the interference nodes set for each routes and sends the route reply to the disjoint routes set after adding the addresses of the group of interference nodes to the route reply packets.

When the source node receives the route reply packets, it arranges the route in ascending order according to their number of hop count. It selects the least interference route with the main shortest delay route as the second route. Then it distributes the data traffic on both routes.

EDMR has a route maintenance mechanism to recovery the broken path. When an intermediate node detects a link break, it fires a RERR packet toward the source node. When the source node receives the RERR packet, it drops the broken route from it routing table and finds another route that is the least interference route with the active route.

4 Simulation Results

This chapter presents and analysis the results that show the behavior of the SMR, ESDMR and EDMR under different parameters. An overview of the used simulation environment is presented in section 4.1, the next section show the simulation metrics and the last section analysis and compare the results.

GloMoSim 2.2 was used to build the proposed idea and the SMR routing protocol. The performance of SMR, ESDMR and EDMR were evaluated and compared. SMR routing protocol is implemented to compare its performance with ESDMR and EDMR. The idea behind choosing the SMR to compare with is that it is the most similar routing protocol in its concepts with the proposed routing protocol.

4.1 Simulation environment

Simulation environment was the same for the three routing protocols to allow the comparison among them fairly. In this environment, the simulation area specified to be 1000*1000 m mainly with 50 mobile nodes moving inside the region. The mobility model that is used RANDOM-WAYPOINT, once the simulation begin, each node move toward randomly selected location with a random speed ranging to be between a pre specified minimum (0 m/sec) and maximum speeds (30 m/sec). The pause time is a period in which the node stop then it starts moving again. It can also be between minimum and maximum periods. Mainly in our simulation, the pause time set to be zero, so the nodes move continuously.

The simulation time is set to be 300 second in each simulation scenario. Each node sends the data at three packets per second, where the packet size is set to be 512 byte and the transmission range of 250 m. Channel bandwidth is 2Mbps and the MAC layer protocol is 802.11. The detailed simulation parameter is listed in the following Table 4.1.

Parameter type	**Parameter value**
Simulation time	300 sec
Simulation terrain	From 500*500 to 2000*2000 m
Number of nodes	50
Mobility model	RANDOM-WAYPOINT
Mobility speed	From 0 to 30 m/sec
Temperature	290.0 k
Transport protocol	UDP
Radio Model	Accumulative noise (ACCNOISE)
Radio frequency	2.4e9 Hz
Channel bandwidth	2Mbps
Mac protocol	IEEE 802.11
Transmission range	250 m
Traffic type	CBR
CBR data rate	3 packet per second
Packet size	512byte

Figure 4.1 Simulation parameter

Each simulation scenario is implemented under different seeds number that varies from 1 to 10. The seed number is used to determine the randomization degree of the simulation, the result is taken as an average for the produced result of the different seed numbers, and each result value is tested at least 10 times. The number of connections in the network varies from 5 to 10 connections that start at the same time in the network between different source and destination node. The node at any moment of the simulation time cannot be a source for one connection and a destination for another connection.

4.2 Simulation metrics

This section presents the performance metrics that are used to compare and evaluate the performance of the three routing protocols. Many metrics were used in the literature, but this section presents the metrics that are significant to the proposed routing protocols. Mainly the delivery ratio and the throughput are the most important metric in this study, it is considered as the goal which the proposed routing protocol improved it.

- **Packet delivery ratio**: the ratio between the number of the packets received by the application layer of the CBR destination and the number of the packets originated by the application layer of the source node.

- **Throughput:** is the average rate of successful message delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. The throughput is usually measured in bits per second (bit/s or bps).

- **Average end-to-end delay:** the average delay between the sending of the data packets by the CBR source and its receipt at the corresponding CBR receiver. This includes all the delay caused during the route accquesion, queuing, and processing at the intermediate node, and the transmission delay at the MAC layer caused by the packet collision.

- **Routing overhead:** the total number of the routing packet transmitted during the simulation time. For packets sent over multiple hops, each transmission of the packet counts as a one transmission. It contains (route request, route reply, and route error).

- **Number of dropped packets**: it measures the number of packet that does not t receive by the receiver and are not salvaged also.

4.3 Results and analysis

The packet delivery ratio, throughput, average end to end delay, routing overhead and number of dropped packets where used to evaluate the performance of the SMR, ESDMR, and EDMR, and compare among them.

4.3.1 Packet delivery ratio

Figure 4.2 shows the packets delivery ratio of the 10 number of connections, the packet delivery ratio was calculated by taking the average of the 10 runs with seed numbers from 1 to 10 at each speed value, it is noticed from the figure that the proposed routing protocols perform better than the SMR in the delivery ration. The EDMR improves the packet delivery ratio of ESDMR by

23%, this is due the stability model that is used in the ESDMR which depends on the concept that the nodes on the path be more stable as the distance between the nodes is decreased, thus, it will take longer time for any node to move out of the transmission range of the other nodes. However, as the nodes on the path become nearer as the interference between the nodes on the path is increased, thus the delivery ratio will decrease.

Although EDMR selects the shortest path, it has a higher delivery ratio compared with the ESDMR, which selects the most stable routes to send the data traffic through them; this is due to sending the data packets on the routes that have the least interference between them. Moreover, each of these selected routes has also the least interference between its nodes.

The idea behind the decreasing in the delivery ratio as the mobile nodes speed increase is the link breaks due to the nodes mobility. For ESDMR, according to Figure 4.2, the decreasing percent in the delivery ratio when the mobile nodes speed are less than 15 was 15%, whereas, the decreasing percent reduced to %5 when the mobile nodes speed become more than 15. The reason for that was as the nodes speed increase as the number of link breaks increase. Thus the source node chooses another route that is less interference with the main route. Certainly, the new selected route is less stable than the broken route. That is why the decreasing percent in the delivery ratio reduced as the mobile nodes speed increase.

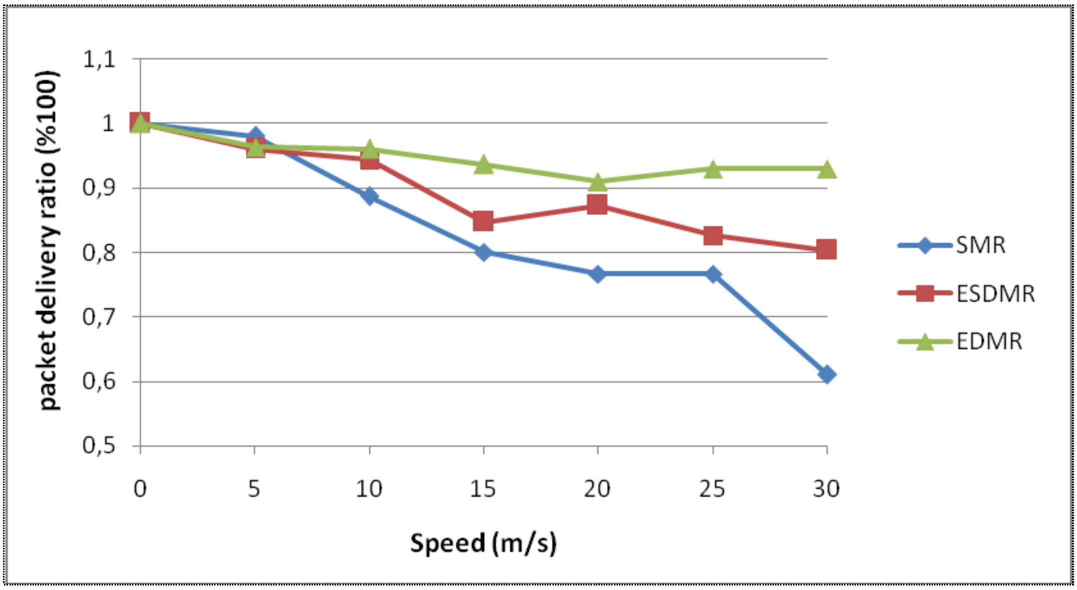


Figure 4.2: Mobile device speed VS. Packet delivery ratio

From Figure 4.2 it is noticed that EDMR improves the delivery ratio over SMR by 34 %. This improvement due to selecting the least interference routes in the EDMR, while selecting the maximally disjoint routes in SMR.

Figure 4.3 shows the packet delivery ratio when the speed of mobile nodes was 20 m/sec and the pause time varies from 0 to 30 sec. It is noticed from the figure that the EDMR maintains its delivery ratio with different pause time value. EDMR achieves a packet delivery ratio higher than the ESDMR and SMR. ESDMR and SMR have resembled packet delivery ratio. From this figure the effects of pause time on the delivery ratio is not significant, because the speed of the mobile nodes is not high enough.

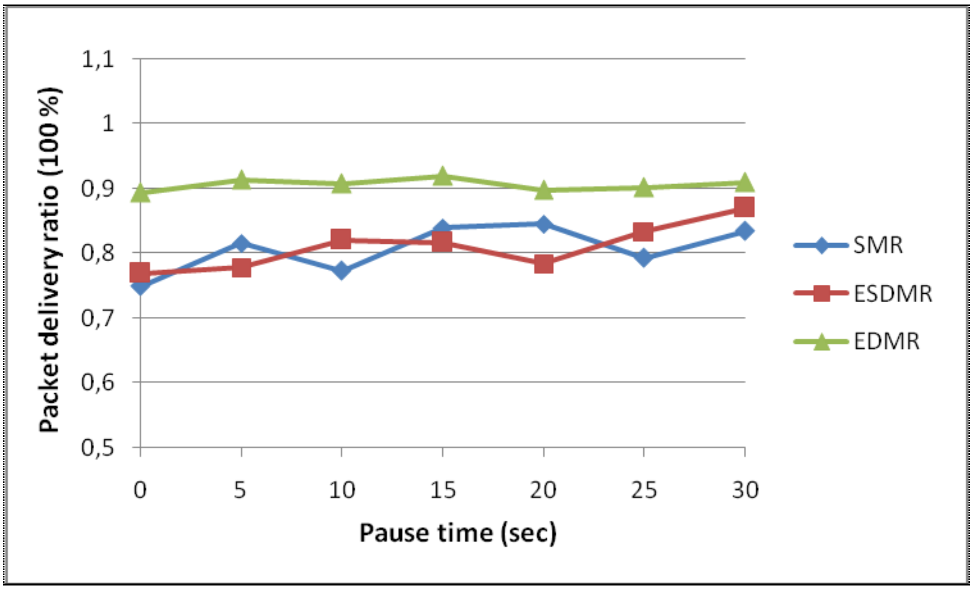


Figure 4.3 : Pause time VS. Packet delivery ratio (Speed 20 m/sec)

Figure 4.4 shows the packet delivery ratio when the speed of mobile nodes was 30 m/sec and the pause time varies from 0 to 30 second. The effect of the variation of pause time values is noticed in EDMR by improving the delivery ratio by %5. While the packet delivery ratio is improved by 1% in ESDMR as the pause time increased. In this situation we can say that the delivery ratio is increased due to the decreased number of link break.

As shown in (Figure 4.3 and Figure 4.4), EDMR maintian the packet delivey ratio from degradation when the pause time was 0 and the speed was 20m/sec or 30m/sec. Whereas, the packet delivery ratio of the SMR is improved as the pause time is increased. But as presented in chapter 3, the main difference between the SMR and EDMR is in the route selection algorithm. Were SMR selects the maximally disjoint shortest paths, while the EDMR selects the least interference maximally disjoint shortest paths. From that we can conclude that the improvement in the delivery ratio in the EDMR is due to the selection of the least interference routes, but not for the effeciency of the route maintenance mechanism. However in SMR, the improvement in packet delivery ratio is due to the reduction of the number of frequency of link breaks as the pause time increases.

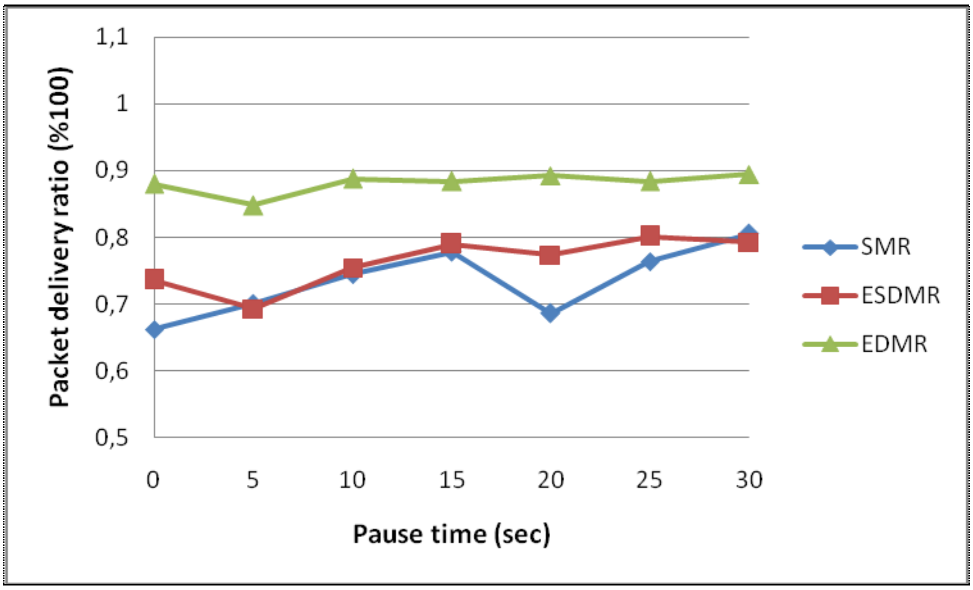


Figure 4.4 : Pause time VS. Packet delivery ratio (Speed 30 m/sec)

In order to change the density of nodes distribution gradually from a very dense mode to a sparse mode, the experimental scenarios assume a square terrain that has a side length ranging from 500, 1000, 1500, up to 2000 m. The aim of this set of experiments is to measure the merit of ESDMR and EDMR with maximally disjoint paths and SMR protocols as the node distribution changes from a dense mode where it is hard to find different paths because most of nodes fall in the range of each other. In the sparse mode of nodes distribution it is easier to find different paths since most of the nodes need other intermediate nodes in order to communicate, but if the distribution is sparse more than some limits the nodes will be out of range each other nodes and it is also hard to find more routes to distribute the load on them.

Figures 4.5 and 4.6 present the packet delivery ratio when the mobile nodes speed was 20m/sec or 30m/sec and the side length of square terrain varies from 500 to 2000 m. From these figures, it is noticed that as the distribution of the nodes become sparse as the delivery ratio decreased. This is because the number of available routes is decreased as the nodes distribution become sparser.

However, when the nodes distribution becomes the densest, the nodes become in the transmission range of each others. The value 500 for the side length of square terrain is an example for the densest nodes distribution in this scenario. The delivery ratio for the three routing protocols likely the same and has the highest value for it. This is because the sources and the destination nodes are in the transmission range for each other. Therefore, the sources and the destination nodes become one hop neighbors in most cases

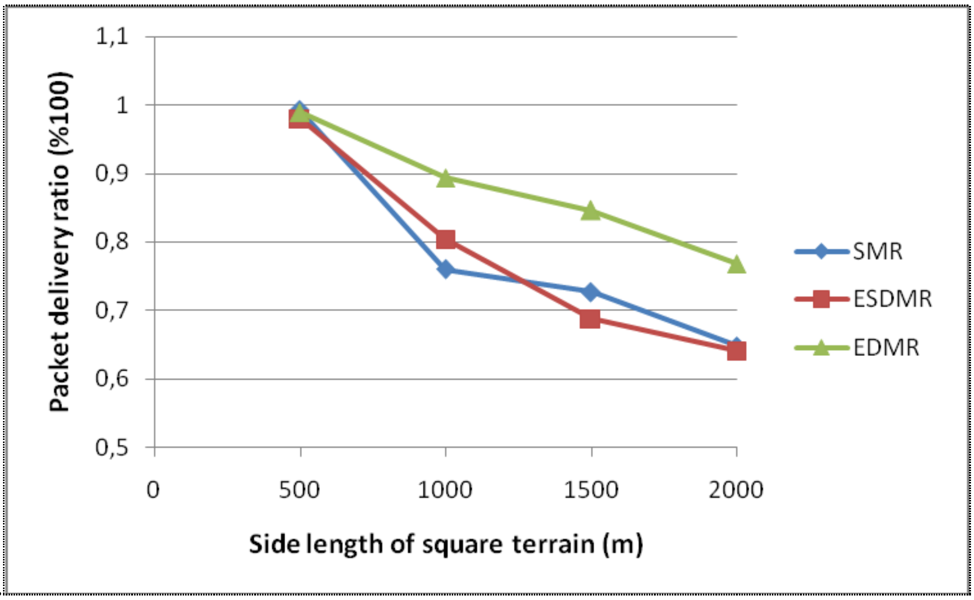


Figure 4.5: Side lenght square terrain VS. Delivery ratio (speed 20 m/sec)

As shown in Figure 4.6, ESDMR achieves better than SMR in packet delivery ratio by 1% when the mobile nodes speed is 30m/sec. This is because of selecting stable routes in ESDMR, in addition to the least interference selection criteria.

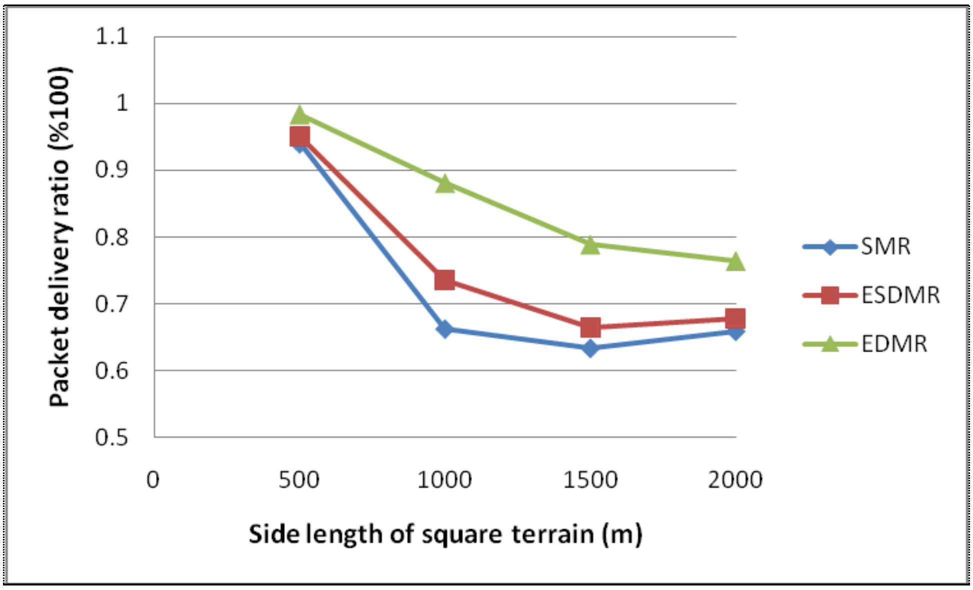


Figure 4.6 : Side length of square terrain VS. Packet delivery ratio (speed 30m/sec)

As shown in Figure 4.6, EDMR achieves better than ESDMR by 18%, this is because ESDMR uses a stability model that depends on the distance between the nodes on the path. So the path becomes more stable as the nodes on that path become nearer. Thus, not only this stability model selects the longest path in its hop count, but also the nodes on one path suffer from the interference between each others. That's why EDMR performs better delivery ratio than ESDMR. From Figures 4.5 and 4.6 it is noticed that EDMR achieves better than SMR by 33% at most. The delivery ratio in the three routing protocols is decreased as the side length of square terrain increased. This is due to the limited number of found paths.

4.3.2 End-to-End delay

Figures 4.7 to 4.10 show the average End-to-End delay for the three routing protocols varying the speed of the mobile nodes or the pause time of the node or the density of the nodes in the network. As illustrated in the figures, the average End-to-End delay for the proposed routing protocols do not exceeds the End-to-End delay of the SMR routing protocol, even though the proposed routing protocols have a little bit increased in the processing of routing phases.

As can be seen in Figure 4.7, the average End- to-End delay for the three routing protocols increased as the speed of the mobile nodes increased. This is due to the increased number of link breaks as the speed of mobile nodes increased.

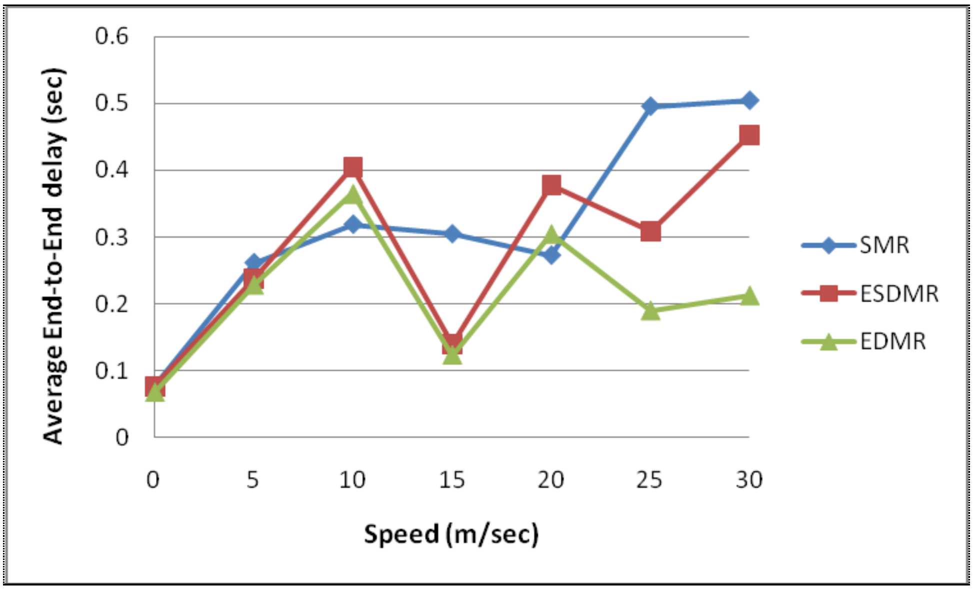


Figure 4.7 : Average end-to-end delay VS. Mobile node speed

Figures 4.8 and 4.9 illustrate the average end-to-end delay for the three routing protocols when the pause time of the nodes varies from 0 to 30 sec, and the speed of mobile nodes was 20m/sec and 30 m/sec respectively.

From Figure 4.8, it is noticed that the average End-to-End delay for the EDMR decreased as the pause time of the mobile nodes increased.

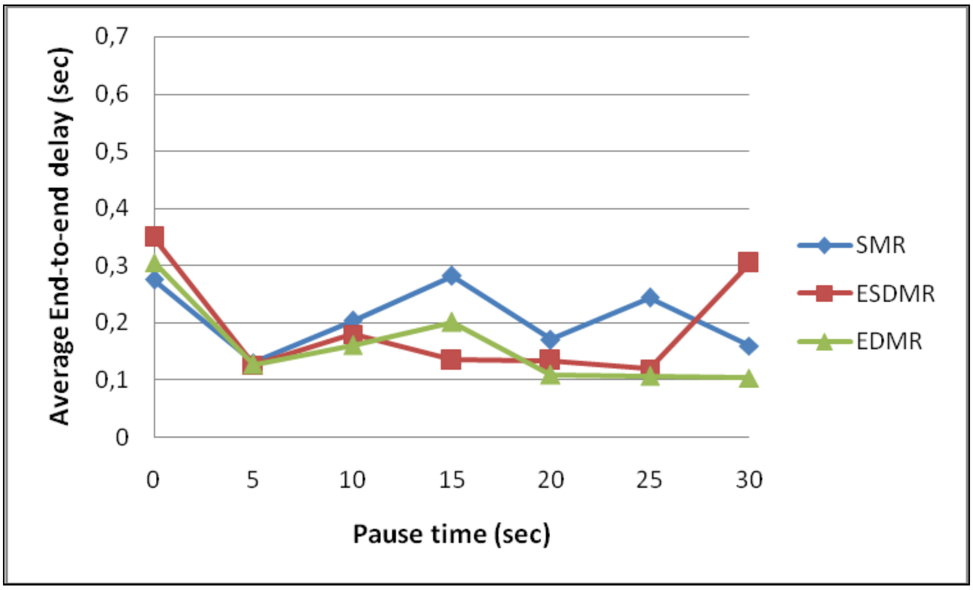


Figure 4.8 : Average end-to-end delay VS. Pause time (Speed 20m/sec)

As seen in Figure 4.9, the average End-to-End delay for the three routing protocols decreased as the pause time for the mobile nodes increased. This is mainly due to the decreased number of link breaks as the pause time for the mobile nodes increased.

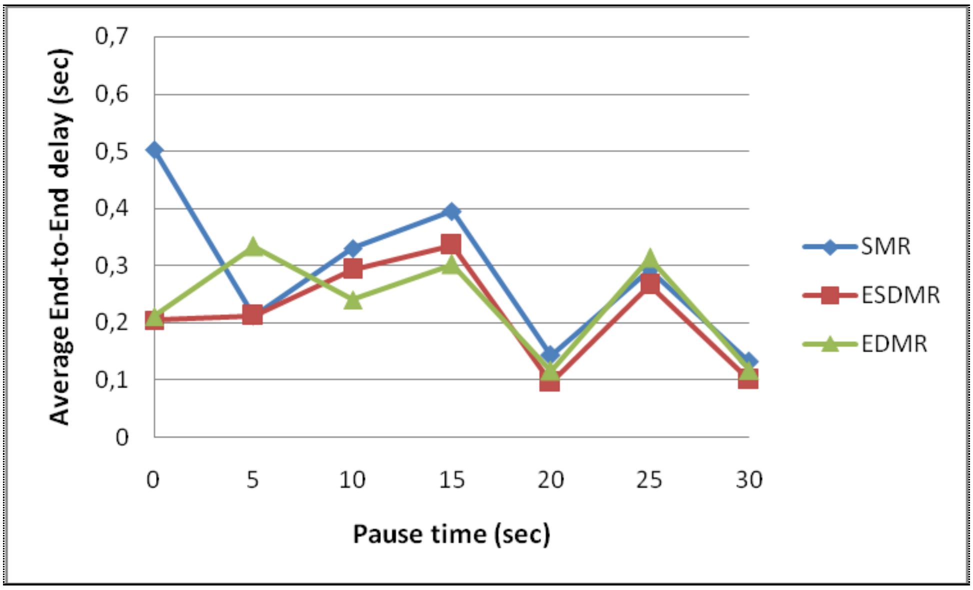


Figure 4.9 : End-to-End delay VS. Pause time (Speed 30m/sec)

Figure 4.10 studies the average end-to-end delay when the density of nodes in the terrain changed from the dense mode to sparse mode, the overall End-to-End delay for the proposed routing protocols roughly equals to the average End-to-End delay for the SMR.

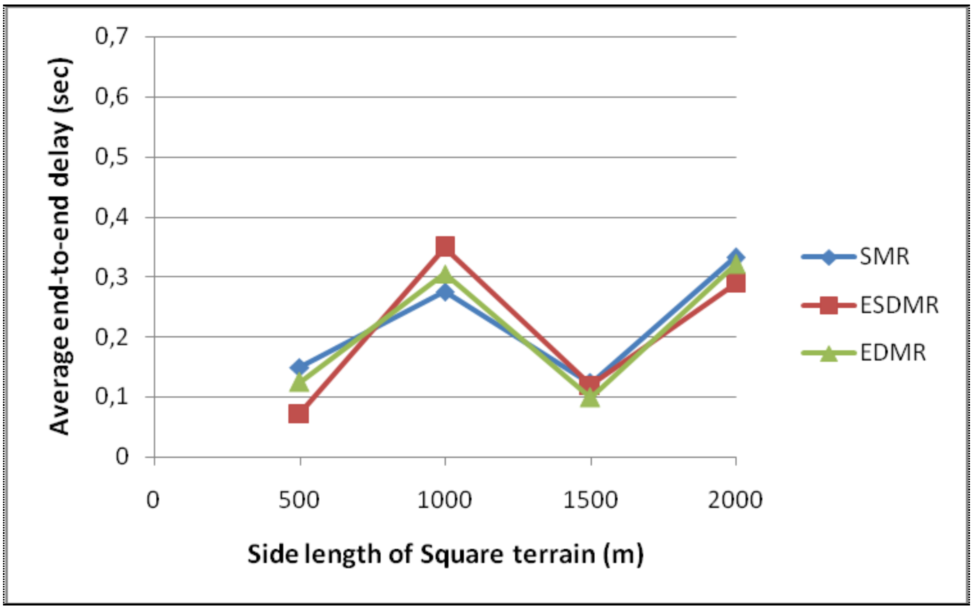


Figure 4.10 : Side length of square terrain VS. Average end-to end delay (speed 20m/sec)

4.3.3 Routing overhead

Figure 4.11 shows the average control packet sent varying the speed of the nodes or the pause time of the node or the density of the nodes. The control overhead was calculated by taking the average of 10 runs with seed number varying from 1 to 10 at each indicated speed value of terrain side length. There is a significant decrease in the routing overhead between the SMR and the proposed routing protocols, which is at most 86.6 %.

As shown in Figure 4.11, ESDMR and EDMR maintain the routing overhead level compared with the increasing level of routing overhead in the SMR as the speed of mobile nodes increased. The decrease ratio in the number of control packet in the new routing protocols compared with the SMR was 86%. The improvement in reducing the control overhead in the new routing protocols was due to the used technique which explained in the previous chapter. The main goal of that technique is to maintain the network resources and enable the other types of packets from the quick access to the required destination.

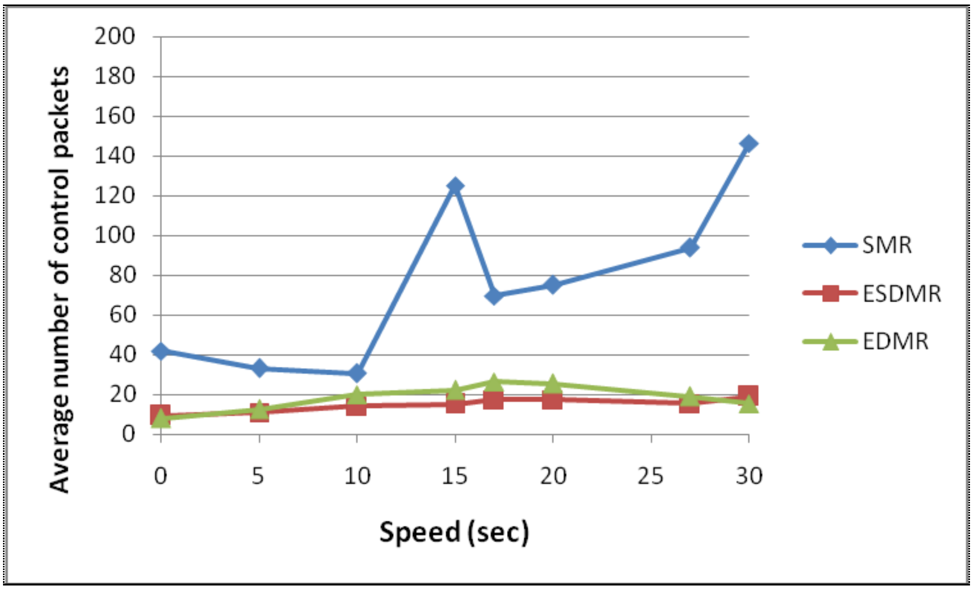


Figure 4.11 : Mobile node speed VS. Average routing overhrad

As can be seen in Figure 4.11, when the speed of the mobile node was 15 m/sec the average number of control packets was high compared with the next and the previous speed values. This is due to the number of link breaks in the selected routes when the speed was 15. Where the average number of link breaks was 2.05 when the speed was 15 m/sec, while in speed 20 m/sec it was 1.7 and in speed 10 m/sec it was 1.3. It is noticed from the Figure that the average number of control overhead increased as the speed of mobile nodes increased.

Figure 4.12 and 4.13 study the behavior of the three routing protocols when the pause time value is varied from 0 to 30 sec. It is noticed that EDMR and ESDMR maintain the number of control packets with different values for the pause time. While SMR affected with the different values of the pause time. Where, as increasing the value of the pause time, as decreasing the number of control packets. This due to the decreased number of link breaks, and thus decrease the number of route request frequency.

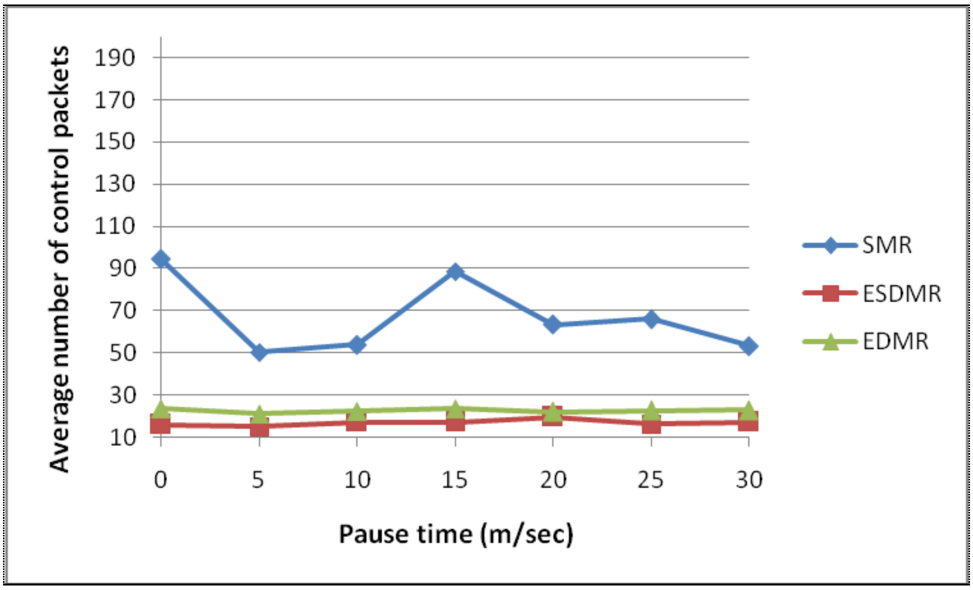


Figure 4.12 : Pause time VS. Average routing overhrad (Speed 20m/sec)

In Figure 4.13, it is noticed that the proposed routing protocols decrease the number of control packet by 83.6 % at most compared with the SMR.

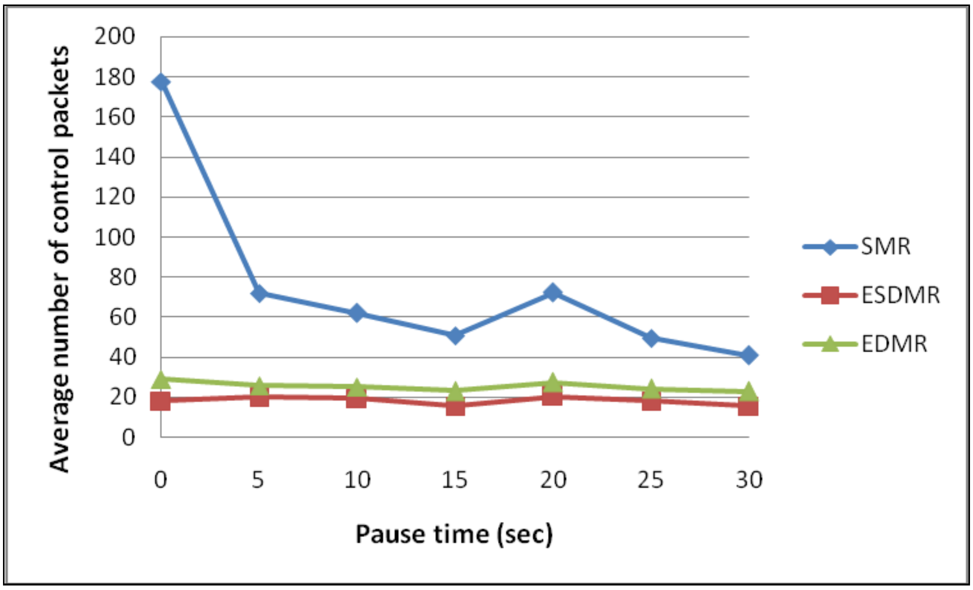


Figure 4.13 : Pause time VS. average routing overhrad (Speed 30m/sec)

Figures 4.15 and 4.16 study the control overhead when the density of nodes in the terrain changed from the dense mode to sparse mode; this is achieved by changing a side length of square terrain from 500 up to 2000 meter. There is a significant decrease in the number of control overhead in the proposed routing protocol compared with SMR. The proposed routing protocols decrease the average routing overhead by 88% at most.

As shown in Figures 4.14 and 4.15, the number of control packets in ESDMR and EDMR increase as the side length of square terrain increase. This is because the number of found paths decreased as the side length of square terrain exceeds a specific value. The reason for that is when the terrain area exceeds some limits; the nodes have more possibility to be out of transmission range of each other. Therefore, the number of paths that can be found is limited. Due to the nodes mobility, the number of link breaks increased, and thus the number of route request frequency is also increased. The average number of control packets increases as the route request frequency increase. For that the number of control packets in the three routing protocols increases as the side length of square terrain increases. Thus the three routing protocols have resembled the number of control packets when the side length of square terrain exceeds 1000 m.

As shown in Figures 4.14 and 4.15, SMR has the highest control overhead when the side length of square terrain was 1000 m. This due to the increased number of link breaks compared with the next and previous values for the side length of square terrain. From the experiments it is found that the average number of link breaks has its highest value which was 2.05 when the side length of square terrain was 1000 m. While the average number of link breaks was 1.73 when the side length of square terrain was 1500 m, and it was 1.36 when the side length of square terrain was 500 m.

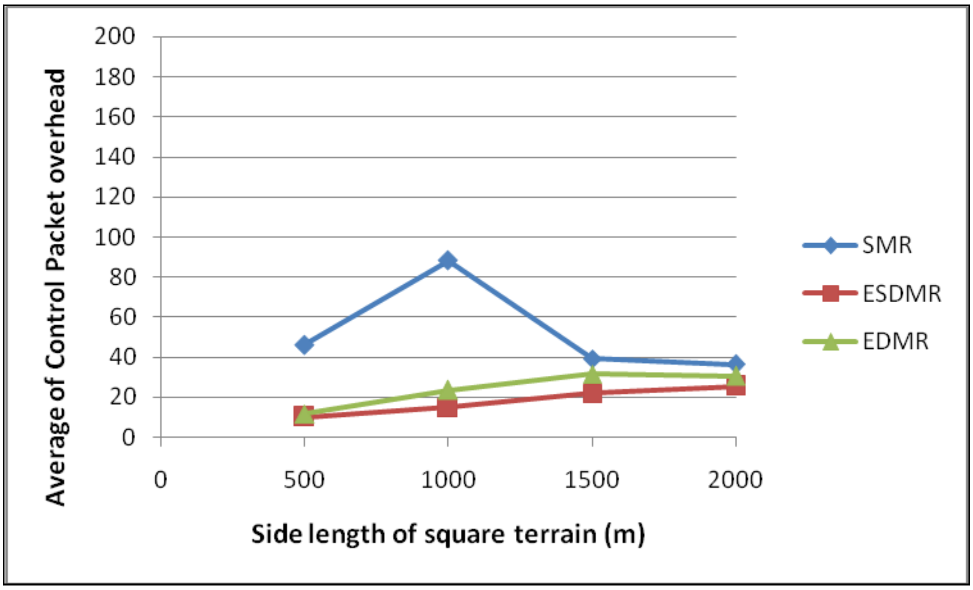


Figure 4.14 : Side length of square terrain VS. average routing overhrad (speed 20m/sec)

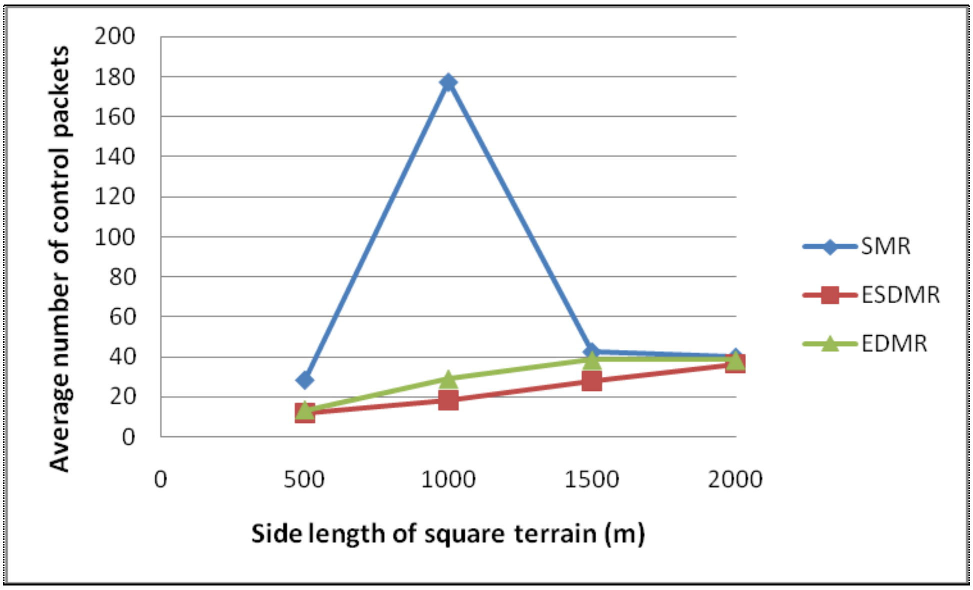


Figure 4.15 : Side length of square terrain VS. Average routing overhrad (speed 30m/sec)

As shown in Figure 4.15, when the side length of square terrain was 500 m, the average number of control packets for the three routing protocols seemed to be resembled. This is because the network become dense, and the sources and the destinations nodes become as neighbors, so no need for intermediate nodes to participate in forwarding the data packets in most cases.

4.3.4 Dropped packets

Figures from 4.16 to 4.23 illustrate the average number of dropped packets in the three routing protocols, when changing speed or pause time of the mobile nodes or intensity mobile nodes in the network.

Figure 4.16 illustrates the average number of dropped packets per connection. It is noticed that the average number of dropped packets in the three routing protocols increases with increasing speed of mobile node, this is due to the increased number of link breaks that increase when mobile node speed increase.

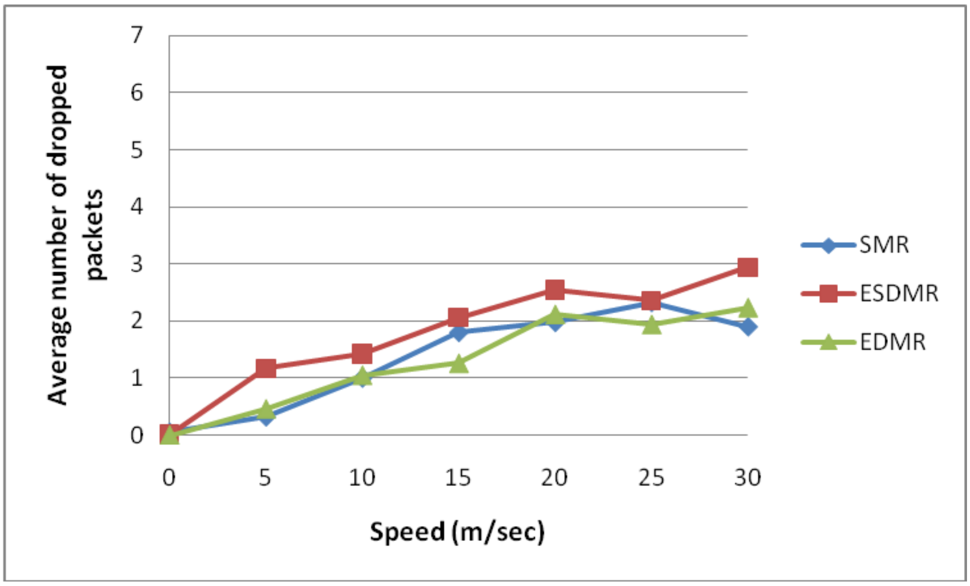


Figure 4.16 : Mobile device speed VS. Average number of droped packets

As shown in Figure 4.16, the average number of dropped packets in the three routing protocols in roughly equal. For clarity, the average number of dropped packets represents the number of packets that are dropped due to link breaks only. However, the packet delivery ratios of the three routing protocols do not seem equal with different speed of mobile nodes as shown in Figure 4.2. Consequently, there is another factor affecting packet delivery ratio other than link break factor. From experiments, it is shown that the packets collision is varied for the three routing protocols as shown in Figure 4.17. From the figure, it is noticed that the average number of collision increases as the mobile node speed increased. This is due to the increased number of link breaks and thus increases the frequency number of the route request.

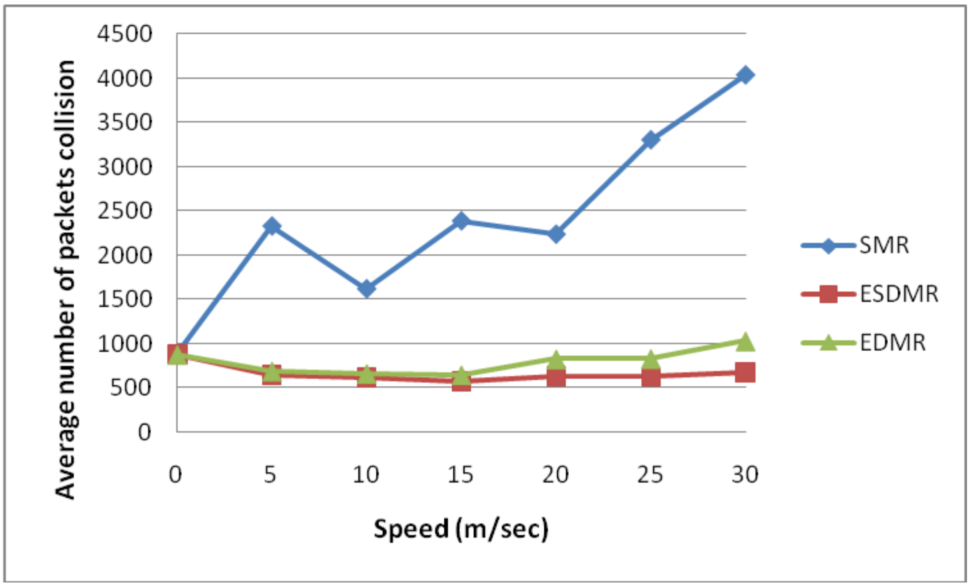


Figure 4.17 : Average number of packet collision VS. Mobile device speed

From Figure 4.17, it is noticed that EDMR and ESDMR perform better than SMR by 74 % in reducing the number of packets collision at most. Packets collision is one of the most important issues that affect the packet delivery ratio. This is because the more the packet collision, the more damaged packages. These corrupted packets are not received by the intended received node. This is the cause of the low packet delivery ratio, the more packets collisions. Figure 4.18 illustrates the average number of corrupted packets per connection when the mobile nodes speed varies from 0 to 30 m/sec.

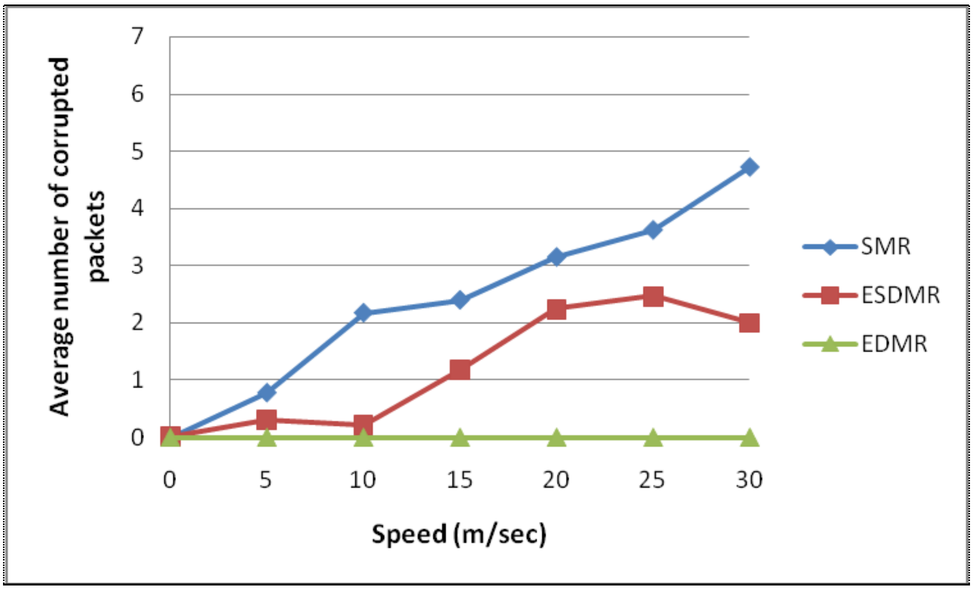


Figure 4.18 : Average number of corrupted packets VS. Mobile device speed

It is noticed from Figure 4.18 that the number of corrupted packets increases when the speed of mobile nodes increased. This is mainly because of the increasing number of packet collision when the speed of mobile node increased. As illustrated in the figure, ESDMR and EDMR perform better than SMR in reducing the number of corrupted packets. The main reason behind that is the selection of the least interference group of routes to send data packets through them. Were selecting the least interference routes reduces hidden terminal problem occurs and thus, reduces the number of packet collision.

ESDMR and EDMR perform better than SMR in reducing the number of corrupted packets by 57.7% and 100% respectively at most. The main reason behind the decreasing in the average number of corrupted packets in ESDMR and EDMR compared with SMR is the selection of the least interference routes.

EDMR performs better than ESDMR in reducing the number of corrupted packets. This is mainly because EDMR use the shortest path to send the data packets through them, while ESDMR uses the most stable routes to send the data through them. The used stability model depends on the distance between the nodes of the path. So the path becomes more stable as the nodes on that path become nearer. Thus, the main route which is the most stable route seemed to be the longest route in its hop count. Thus, it is rarely to find another route which is interference less with the main route, but, the second selected route will be the least interference route with the main route. This is not guarantee to be without interference with the main route, thus, there is packet collision. Packet collision leads to increase the average number of corrupted packets.

In conclusion, the delivery ratio is affected not only by the dropped packet due to link breaks, but also due to packets collision. Figure 4.19 illustrates the average number of dropped or corrupted packets when the speed of mobile node varies from 0 to 30 m/sec. This Figure represents the summation of the dropped packet due to the link break or due to the collision. The main idea in Figure 4.19 is to illustrate the total number of packets which are not received by the destination node. Thus, it explains the delivery ratio for the three routing protocols which illustrated in Figure 4.2.

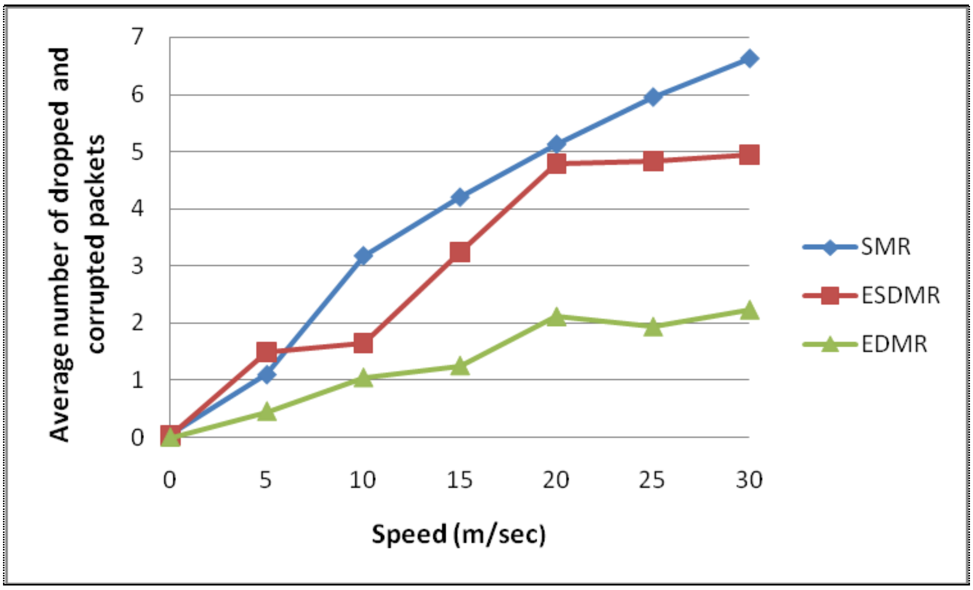


Figure 4.19 : Average number of dropped and corrupted packets VS. Mobile device speed

Figures 4.20 and 4.21 illustrate the average number of dropped packet when the speed of mobile nodes 20 m/sec or 30 m/sec respectively. The pause time of the mobile nodes varied from 0 to 30 sec. From the figures, it is noticed that the average number of dropped packet for the three routing protocols in roughly equal.

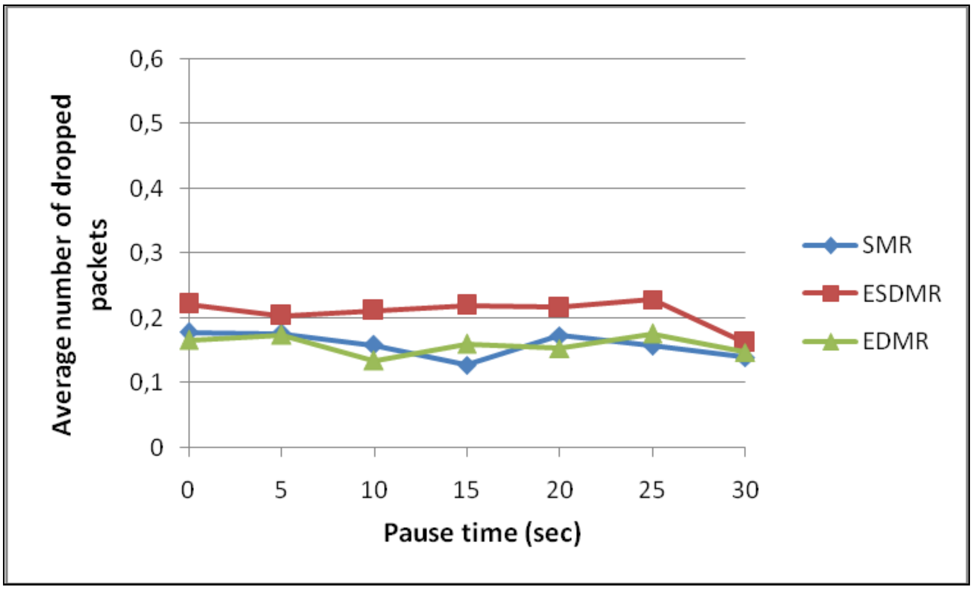


Figure 4.20 : Pause time VS. Average number of dropped packets (speed 20m/sec)

It is noticed in Figure 4.20 that the average number of dropped packet in the ESDMR is higher than SMR and EDMR. This is because the used stability model, were the most stable route is the route in which the distance between its node in the least. Thus, the route will be the longest route in its hop count. For that the ERROR (RERR) packet spends longer time to reach the source node. The source node continued to send the data packets on the broken path until the RERR packet reached it. That's why the number of dropped packet in ESDMR is the highest compared with EDMR and SMR.

In Figure 4.21, it is noticed that the average number of dropped packets for the three routing protocols increased when the speed of mobile node become 30m/sec compared with Figure 4.20. It is shown that the average number of dropped packets in the three routing protocols decreased as the pause time increase. This is due to the decreased number of link breaks as the pause time of the mobile nodes increased.

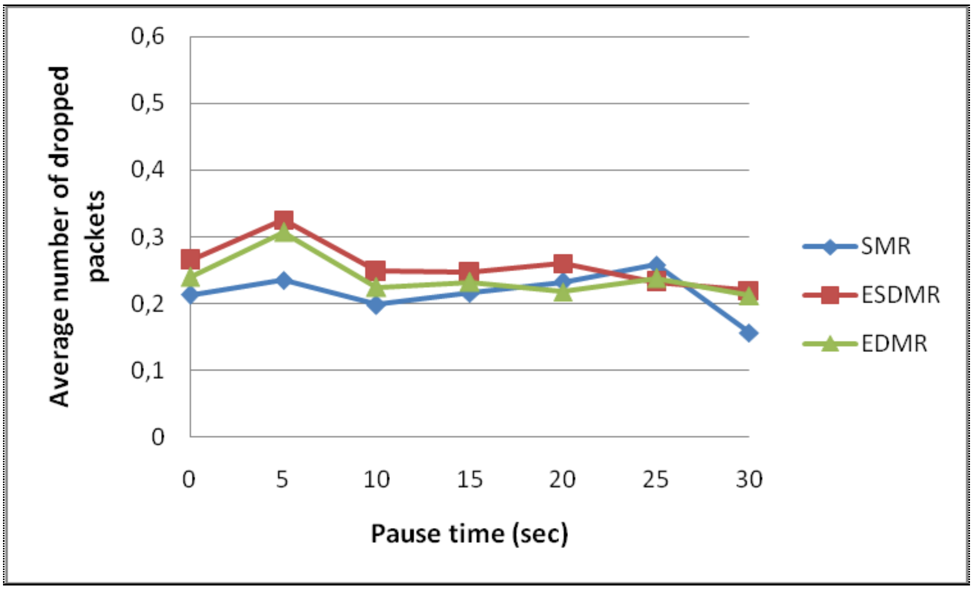


Figure 4.21 : Pause time VS. Average number of dropped packets (speed 30m/sec)

As shown in Figure 4.21, although the ESDMR uses a stability model, the average number of dropped packets in it is similar to those in EDMR and SMR. This is due to the used stability model, as explained in the previous figure. As illustrated in Figure 4.21, the number of dropped packets in EDMR and SMR increased when the speed of mobile node become 30 m/sec. This is mainly due to the increased number of link breaks when the speed of mobile nodes increased.

Figures 4.22 and 4.23 study the number of the dropped packets when the density of nodes in the terrain changed from the dense mode to sparse mode. The speed of the mobile nodes was 20 m/sec or 30 m/sec respectively, and the pause time was 0. The side length of square terrain changed from 500 up to 2000 meter.

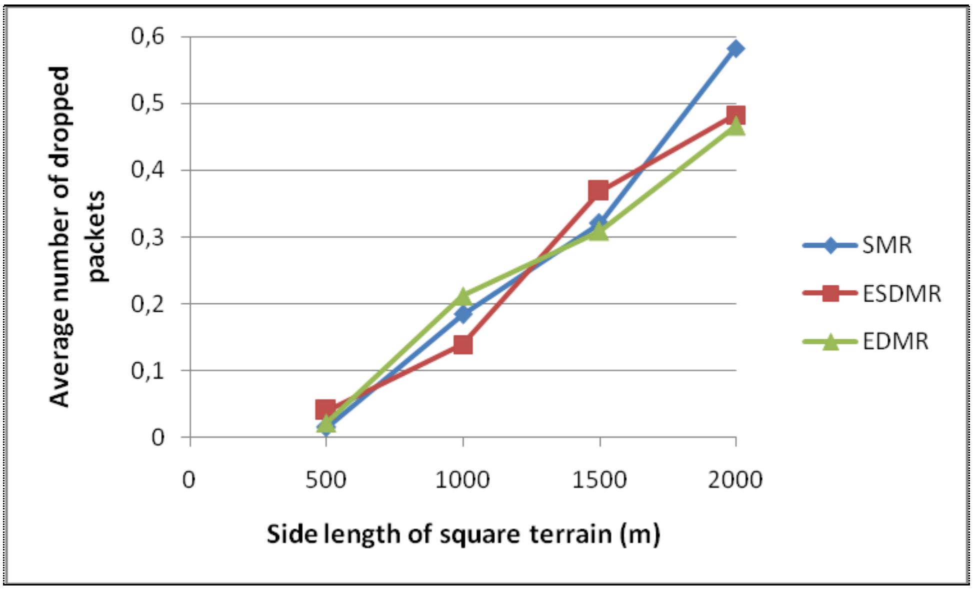


Figure 4.22 : Side length of Square terrain VS. average number of droped packets (speed 20m/sec)

There is an increasing in the number of the dropped packets for the three routing protocols with the increasing of the length of terrain side. This is due to the decreasing in the number of found routes when the side length of square terrain increased. The decreasing in the number of found routes as the side length of square terrain increasing is mainly because the nodes become out of transmission range of other nodes. Thus, a limited number of nodes received RREQ packets; this limits the number of found routes. In addition, as the side length of square terrain increases, the quality of the found route decreases. This is because the distances between the nodes on the route will increase, and thus, any simple movement of any intermediate node will lead to link break. The link break can be solved even by selecting another backup route or retry the route request.

The average number of dropped packets in the three routing protocols was the lowest when the side length of square terrain was 500 m. this is because the sources and the destinations nodes becomes one hop neighbor nodes in most cases. That's why; the average number of dropped packets has its lowest value for the three routing protocols.

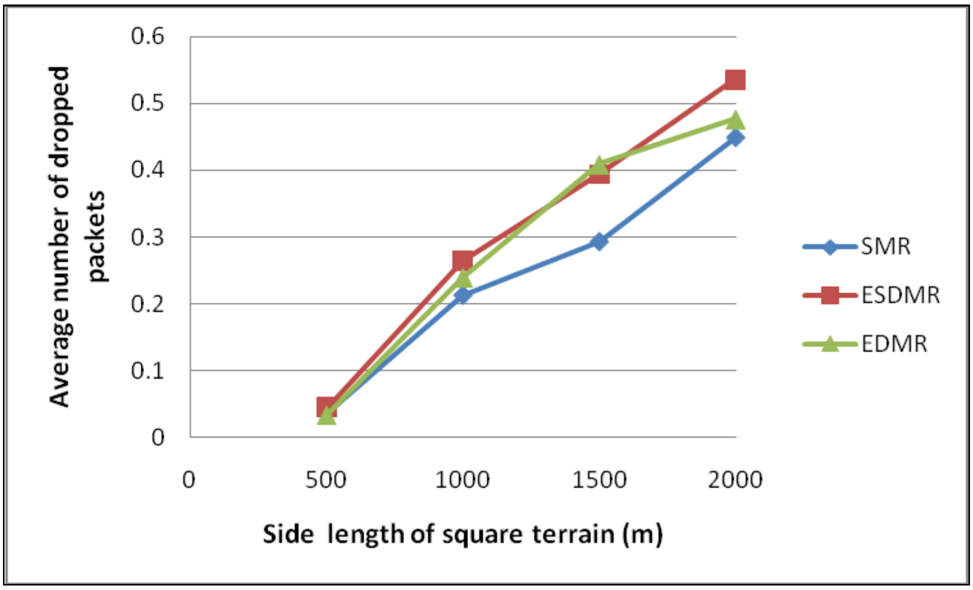


Figure 4.23 : Side length of square terrain VS. Average number of dropped packets (speed 30m /sec)

4.3.5 Throughput

The following Figures illustrate the average throughput of the three routing protocols when the speed of mobile nodes varied or the pause time or the density of the nodes in the network.

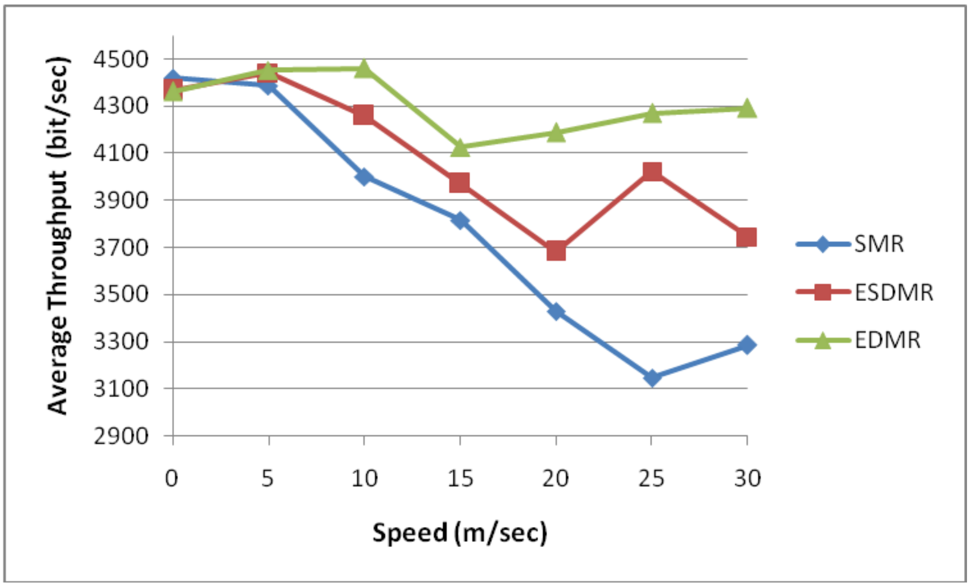


Figure 4.24 : Mobile device speed VS. Average throughput

From Figure 4.24 it is noticed that the average values for the throughput in the three routing protocols decreased as the mobile nodes speed increases. This is due to the increased number of average link breaks as the speed of a mobile node increases, thus, the average number of frequent route request increases. For that the average throughput decreased.

From Figure 4.24 it is noticed that EDMR perform better than ESDMR and SMR as the speed increased. EDMR performs better than ESDMR by 17.5% at most. The main reason for that is the quality of the selected route for both of them. Where, ESDMR selects the most stable routes to send the data packets through them. As mentioned previously, the stability model that is used in developing ESDMR depends mainly on the distance between the nodes of the path. Where, the greater the distance between two neighbor nodes, the less time it takes to be outside the transmission range of each other. Thus, as the distance between the nodes in the route is decreased, as the route become more stable. However, distance between the nodes in the route is decreased, as the interference between the nodes on the path is increased. For that the average throughput is decreased. Moreover, using this stability model leads to select the longest path. Choosing long path in the number of hop count also participate in increasing the sending delay. And thus, it decreases the average throughput.

From Figure 4.24 it is noticed that EDMR performs better than SMR by 30% at most. This is mainly depends on the quality of the group of selected routes to send data through them. Where, SMR selects mainly the shortest disjoints routes to send data through them. While, EDMR selects the shortest, disjoint least interference routes. In this case, selecting the least interference routes is main the reason for the improvement in the average throughput of EDMR.

Figures 4.25 and 4.26 study the average throughput when the pause time was varied from 0 to 30 sec; the speed of mobile nodes was 20m/sec and 30m/sec respectively. From the two figures it is noticed that EDMR performs better than ESDMR and EDMR in the average throughput. As can be seen in the Figures, EDMR maintains the average throughput from degradation. It performs better than SMR by 28.2% at most. The main reason for that is selecting the maximally disjoint, least interference routes.

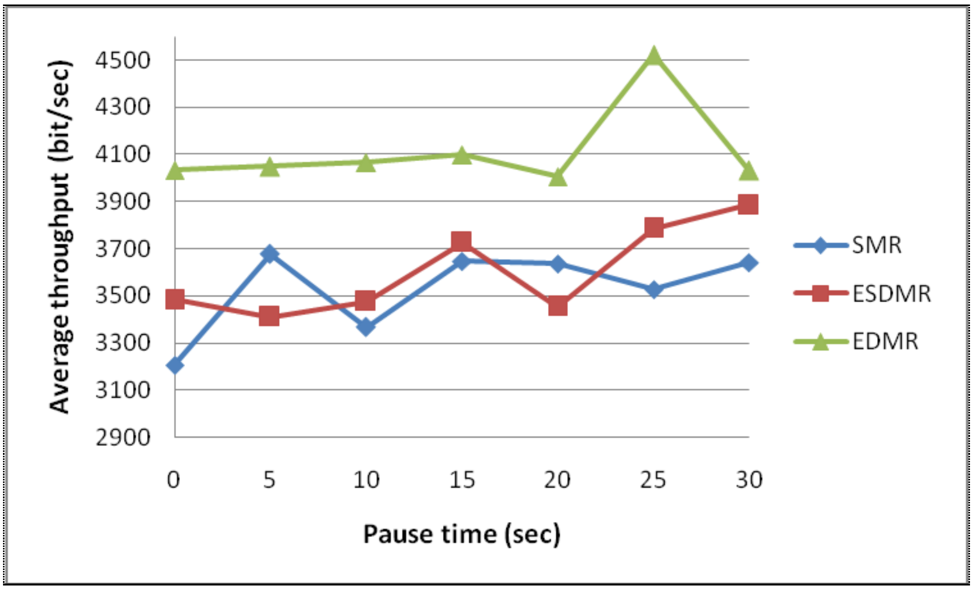


Figure 4.25 : Pause time VS. Average throughput (Speed 20m/sec)

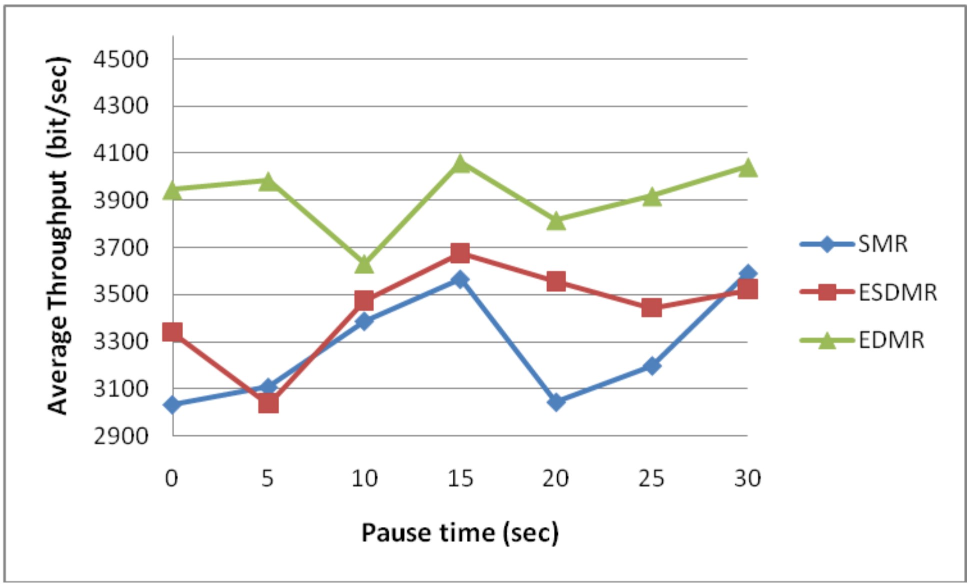


Figure 4.26 : Pause time VS. Average throughput (Speed 30m/sec)

From Figure 4.25 it is noticed that ESDMR and SMR have similar values for the average throughput. As shown in Figure 4.26, the three routing protocols have their highest value of the average throughput when the pause time was 15 sec; this is because the average number for link breaks was the lowest for the three routing protocols. It can be noticed that the three routing protocols have their highest value for average throughput when the pause time of the mobile nodes was 30 sec. This is due to the decreasing in the mobility of nodes. This leads to decreasing number of link breaks as the pause time increased, and thus, decreasing the frequency number of route request.

Figures 4.27 and 4.28 study the throughput when the density of nodes in the terrain changed from the dense mode to sparse mode; this is achieved by changing the side length of square terrain from 500 up to 2000 meter. From the Figures it is shown that when the side length of square terrain exceeds a certain limits, the average value of throughput for the three routing protocols decreased. It is noticed that EDMR performs better than SMR and ESDMR in improving the average throughput. EDMR improves the average throughput compared with SMR by 30% at most when the speed of mobile node is 30m/sec. This is mainly depends on the quality of the selected routes. Where, SMR selects the maximally disjoint two routes. Whereas EDMR selects the least interference two routes.

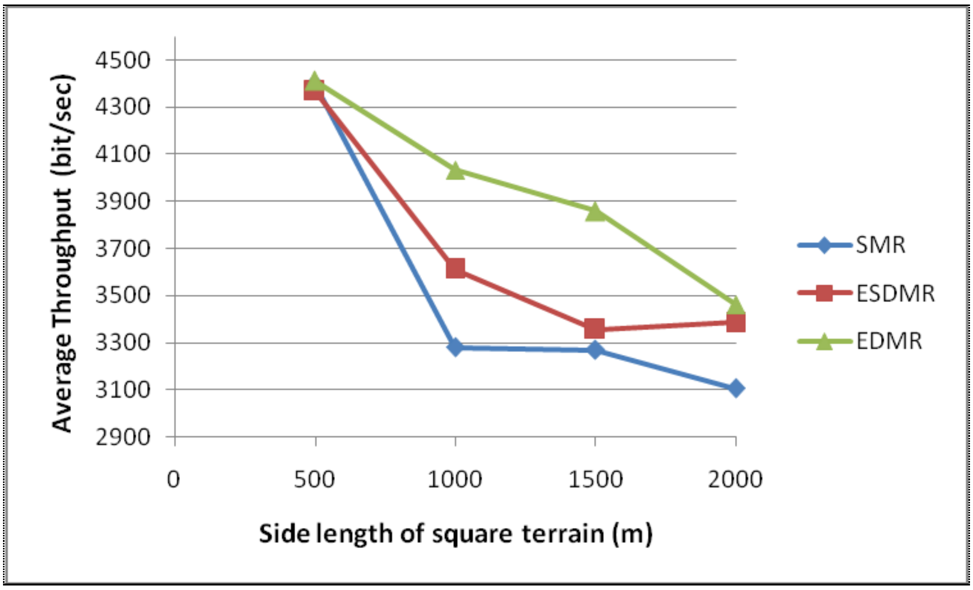


Figure 4.27 : Side length of square terrain VS. Average throughput (speed 20m/sec)

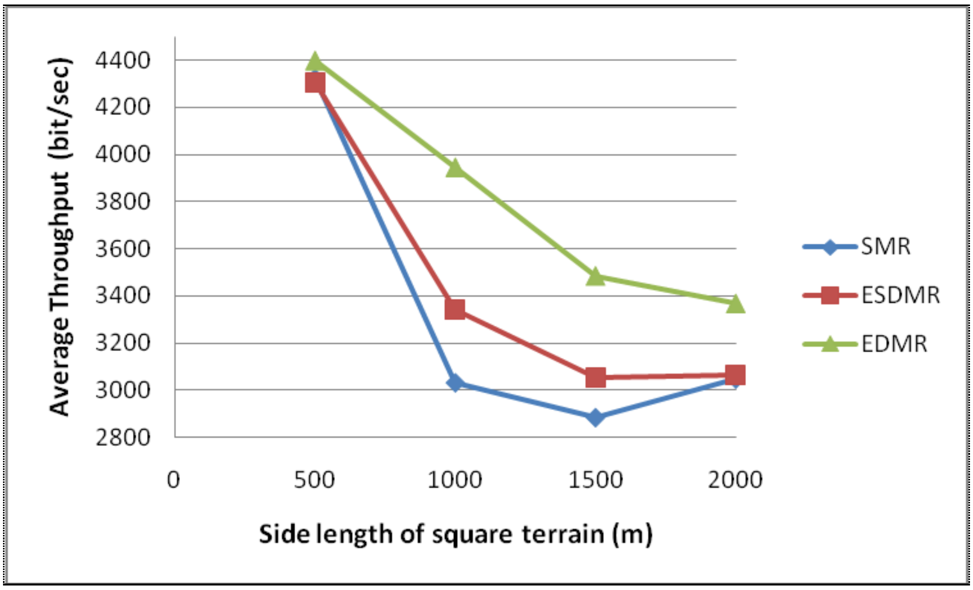


Figure 4.28 : Side length of square terrain VS. Average throughput (speed 30m/sec)

As shown in (Figure 4.27, Figure 4.28), ESDMR performs better than SMR by 10% in improving the average throughput. This improvement value is not as expected, the reason for that is the used stability model which made the interference between the adjacent nodes in each selected route. In addition, depending on the concept of the used stability model, the most stable route mostly is the longest route in its number of hops. That point also affects the improvement in the throughput. In conclusion, the main point that made the improvement in the average value of throughput in ESDMR compared with the SMR is the selection of the least interference two routes to send the data through them.

It is noticed from Figures 4.27 and 4.28 that EDMR performs better than ESDMR by 18.1 % at most in improving the average throughput. EDMR selects the routes which are the least interference; in addition, each route of these selected routes has less interference between its nodes compared with the selected routes in ESDMR. This is due to the used stability model in the ESDMR.

5 Conclusion And Future Works

The area of ad hoc network has been receiving attention among researches in recent years, as the available wireless networking is capable of supporting the promise of this technology. Over the past few years, a variety of new routing protocols targeting the ad hoc network has been proposed. The main objective of these protocols is to improve the performance of ad hoc network.

The proposed routing protocols are designed to overcome some problems that many multipath routing protocol that distribute the traffic load on more than one path have. Theoretically, sending data on more than one path should increase the delivery ratio, however, due to the interference between the nodes of the selected routes the delivery ratio seems to be the same as the single path routing protocols. As interference between the nodes of the selected routes increase as the collision between the data packet increase. The packets collision causes a noise in the received packets. The noised packets are dropped by MAC layer and do not be sent to the network layer. That's why the delivery ratio is decreased in SMR protocol. The proposed routing protocols solve this problem by selecting the routes with less interference to send the data through them. Thus, they reduce the effect of interference between the selected disjoint routes and as a result, they increase the data delivery ratio.

The proposed routing protocols developed a mechanism that enable the destination node to collect more routing information than the collected in SMR protocol with a lower overhead.

The performance of the ESDMR, EDMR and SMR was evaluated using the GloMoSim network simulator. It is clear from the simulation results in the previous chapter that the ESDMR and EDMR provide better performance than the SMR in most cases. Compared with SMR, the ESDMR and EDMR outperform the SMR protocol, since it overcomes the main drawbacks of it.

The results show that the proposed routing protocols perform better in improving the delivery ratio and throughput compared with SMR protocol. They also reduce the control overhead compared with SMR. The packet delivery ratio is improved in EDMR by percent of 35.72 %, throughput is increased by 30% and the number of control packets is reduced by the percent of 86.97% compared with SMR. On the other hand, ESDMR improves the delivery ratio with 24%, the control overhead is reduced by 86.7%, and throughput is increased by 27% compared with SMR. End-to-End delay for the proposed routing protocols does not exceed End-to-End delay for SMR protocol. Form the results we conclude that the proposed routing protocols reduced the effects of hidden terminal problem and reduced the shared channels between the selected disjoint routes. That is why; the delivery ratio increased in the proposed routing protocols compared with SMR.

There is a difference between the shortest path and the shortest delay path, not always; the shortest path should be the shortest delay path. In many previous works, they chose the hop count as a parameter for the shortest path. In these routing protocols, the shortest path could have congested nodes and thus the delay will increase, but selecting the shortest delay route does not mean the shortest route only. Beside the shortest route it takes in its account the loads on the nodes that build the route. In the future work for this research we will apply shortest delay route as the selected route, instead of choosing the shortest path or the most stable path.

The used stability model in ESDMR protocol depends mainly on the distance between the nodes on the route. Therefore, the route become more stable as the distance between the nodes on the route decreased. Thus, the number of hop count is increased as the path become more stable in most cases. Moreover, as the distance between the nodes on the path decreased, the shared channels between the nodes on the path increase. Thus the time is shared. For that, the throughput is not increased as expected. For this reason, we want to study and develop more stability models that can improve the performance of the ESDMR protocol.

6 References

Carthy M, Grigoras D, "Multipath associatively based routing," In: **Proceedings of the second annual conference on wireless on-demand network systems and services (WONS)**, 2005. p. 60–9.

Cha M, and Lee D, "Split-n-save multiplexing in wireless ad hoc routing" In: **Proceedings of the 24th annual joint conference of the IEEE computer and communications societies (INFOCOM)**, Miami, March 2005.

Ding S, Liu L, "A node-disjoint multipath routing protocol based on AODV," In: **Ninth International Symposium on Distributed Computing and Applications to Business**, Engineering and Science, 2010.

Johnson D.B, Maltz D.A., "Dynamic Source Routing in Ad Hoc Wireless Networking", **IEEE in Mobile Computing**, pp.153-181, 1996.

Kant L, & Chadha S, "MANET Management: Industry Challenges & Potential Solutions," **IEEE Mobile and Multimedia Networks, WOWMOM.08**, pp: 1 - 8, 23-26 June, 2008.

Lee S-J, Gerla M, "SMR: split multipath routing with maximally disjoint paths in ad hoc networks," **Technical report, Computer Science Department, University of California, Los Angeles**, August, 1999.

Lian J, Li L, ZHU X, "A Multi-Constraint QoS Routing Protocol with Route-Request Selection Based on Mobile Predicting in MANET," In: **IEEE International Conference on Computational Intelligence and Security Workshops**, CISW 2007, ppt: 342 - 345, 15-19 Dec. 2007.

Lim H, Xu K, Gerla M. "TCP performance over multipath routing in mobile ad hoc networks," In: **IEEE international conference on communication (ICC)**, vol. 2, 2003, p. 1064–8.

Lu Q, Du L, Zuo Z, Xiao X, "Improved Multi-path AODV Protocols for Real-time Video Transport over Mobile Ad Hoc Networks," In: **IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application**, Dec, 2008, pp: 621 – 625.

Mahdi A., "Implementing Mobile Ad hoc Networks in Unicast Routing protocol in NS-2", **University Utara Malaysia, thesis of Master**, October, 2010.

Mao S, Lin S, Wang Y, Panwar SS, Li Y. "Multipath video transport over ad hoc networks**. IEEE Wireless Communication**," August, 2005; 12(4):42–9.

Marina M.K, Das S.R, "On-demand multipath distance vector routing in ad hoc networks," In: **IEEE Proceedings of the International Conference for Network Protocols (ICNP)**, ppt: 14- 23, 11-14 Nov. 2001.

Misra S, Woungang I, Misra C. and S., "Routing in Mobile ad hoc Network," in Guide to wireless Ad hoc Network. USA: **Springer**, 2009, pp. 59-96.

N. Sarma, S. Nandi, "A Route Stability Based Multipath QoS Routing (SMQR) in MANETs," In: **First International Conference Engineering and Technology, 2008. ICETET '08**, ppt: 193 – 198, July 2008.

Nuevo J, "A Comprehensible GloMoSim Tutorial," **University of Quebec**, March, 2004.

Perkins C., Bhagwat P., "Highly Dynamic Destination Sequenced Distance Vector Routing (DSDV) for Mobile Computers," **ACM**, 1994.

Perkins C., Royer E. and Das S., "Ad hoc on-demand distance vector (AODV) routing," **IEIF RFC 3561**, 2000.

Reddyba L, Raghavan S, "SMORT: Scalable multipath on-demand routing for mobile ad hoc networks," **ScienceDirect Ad Hoc Networks**, ppt: 162-188 March, 2005.

Rodreguez-covili J, Ochoa S. F, Pino J. A, "HLMP: High Level MANET Protocol", Universidad de Chile, Santiago, Chile, Technical Report, Nov, 2009.

Studi P, "Quality of Service for Mobile Ad Hoc Networks," **Swiss Fediral institute of technology**, Diploma Thesis, March, 2003.

Su T, Lin C, Hsieh W, "A Novel QoS-Aware Routing for Ad Hoc Networks," **Technical report, Computer Science Department, National Sun Yat-Sen University**, Taiwan, 2001.

Sun J, " Mobile Ad Hoc Networking: An Essential Technology for Pervasive Computing," In: **International conferences of Info-tech and Info-net**, Ed. China: Citeseer, 2001, pp. 316- 321.

Tarique M, Tepe K, Adibi S, Erfani S, " Survey of multipath routing protocols for mobile ad hoc networks," In: **Journal of Network and Computer Applications**, July ,2009. pp: 1125–1143.

Wang L, Jang S, Lee T, "Redundant source routing for real-time services in ad hoc networks," In: **Proceedings of IEEE international conference on mobile ad hoc and sensor systems conference**, Washington, DC, November, 2005.

Wei W, Zakhor A. "Robust multipath source routing protocol (RMPSR) for video communication over wireless ad hoc networks," **In: Multimedia and Expo**, 2004. ICME '04. June 2004, ppt: 1379 – 1382.

Yang C., Ting Y., Yang C., "A Loop-Free Multi-Path Routing With QoS for Wireless Ad Hoc Network," In: **20th International Conference on Advanced Information Networking and Applications**. April, 2006.

Ziane S, Mellouk A, "A QoS Adaptive Multi-path Reinforcement Learning Routing Algorithm for MANET," In: **proceeding in Computer Systems and Applications**,

بروتوكولات التوجيه متعددة المسارات التي تدعم جودة الخدمة في شبكات المحمول المخصصة

إعداد
إيمان صبحي الوادية

المشرف
الدكتورة إيمان المومني

ملخص

تقترح هذه الرسالة بروتوكولان متعددة مسارات التوجيه والتي تهدف إلى زيادة نسبة وصولية البيانات والإنتاجية. تعتمد البروتوكولات المقترحة على مبدأ استخدام مسارات التوجيه المتعددة لتوزيع البيانات المراد إرسالها على أكثر من مسار.

يعتمد البروتوكول المقترح الأول (ESDMR) على اختيار مسارات التوجيه الأكثر استقرارا ويتم اختيار المسا ر الأكثر استقرارا كمسار رئيسي ثم يتم اختيار مسارات أخري بحيث تكون متباعدة مع المسار الرئيسي . وتختار النقطة المرسلة المسار الرئيسي لإرسال المعلومات عليه بالإضافة إلى مسار أخر حيث يعتبر الأقل تداخلا مع المسار الرئيسي, وفي حال حدوث انقطاع في احد المسارات فإن النقطة المرسلة تختار مسارا أخرا اقل تداخلا مع المسار الرئيسي.

يدمج البروتوكول الأخر (EDMR) بين البروتوكول السابق شرحه وبين بروتوكول التقسيم متعدد التوجيه (SMR) حيث يختار المسار الأقل تأخيرا كطريق رئيسي ويتم اختيار طرق أخرى متباعدة مع المسار الرئيسي. وتختار النقطة المرسلة المسار الأقل تأخيرا كمسار رئيسي لإرسال البيانات وتختار طريقا أخرا حيث يعتبر المسار الأقل تداخلا مع المسار الرئيسي لتوزيع البيانات المراد إرسالها على المسارين.