Interference-Aware Multipath routing protocols for Mobile Ad hoc Networks

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***Abstract*— Routing is considered as one of the most critical research issues in the area of mobile ad hoc networks (MANETs), where it plays the main role in determining the overall throughput and the delivery ratio in the mobile networks. This paper proposes two on-demand multipath routing protocols. Efficient, Stable, Disjoint Multipath Routing protocol (ESDMR) and Efficient, Disjoint Multipath Routing protocol (EDMR), the main goal of the proposed routing protocols is to reduce the influence of interference between the selected node-disjoint multipath scheme, by selecting a node-disjoint routes with the minimal interference between them. In addition, both of the proposed protocols used a new proposed technique that aims to reduce the control packets overhead, while it enables the destination node of collecting the required information. Simulation results show that the proposed routing protocols have a higher delivery rate and higher throughput compared with the ones in Split multipath routing protocol (SMR).**

The significant improvement in packet delivery ratio resulted mainly from reducing the impact of hidden terminal problem. While, increasing the number of available channels between the selected disjoint routes is the main reason for the dramatic improvement in throughput. The efficiency of the proposed protocols and SMR protocol is evaluated by GloMoSim simulator.

***Index Terms*—MANETs, Interference, Multipath, Routing.**

I. Introduction

Mobile ad hoc networks (MANETs) are a multi-hop temporary autonomous system of mobile nodes with wireless transmitters and receivers without the aid of pre-established network infrastructure.

Due to the dynamic nature of the network structure as well as limited resources, the efficiency of the existing routing protocols has become a critical and challenging issue and their performance might have a great impact on the network's overall performance [1].

As found in literature, there were several attempts to handle different routing scenarios that focused on developing multipath routing protocols to distribute the traffic load on multiple node-disjoint routes. These researches aimed to enhance the existing routing protocols. Such protocols vary in their enhancements criteria such as load balancing, power saving or increasing the delivery ratio and throughput such as LS-AOMDV [2] and NDM _ AODV [3]. However, the existence of interference between the multiple node-disjoint paths remarkably affects overall performance of MANETs by all means such as data loss, conflict, retransmission, channel share etc. [4]. Hence, it has been discovered that interference is one of the most important factors that have to be taken into consideration in developing such a multiple path disjoint scheme.

II. Problem definition

Interference is the possibility of any node to be positioned in the range for any other node's carrier sensing range in the same network. Carrier sensing range for any node is the range in which a node can receive signals but cannot appropriately decode them. For instance, when a node gets an access to the channel and start to transmit data, all other nodes that are located within its carrier sensing range will be interfered as shown in fig.1.

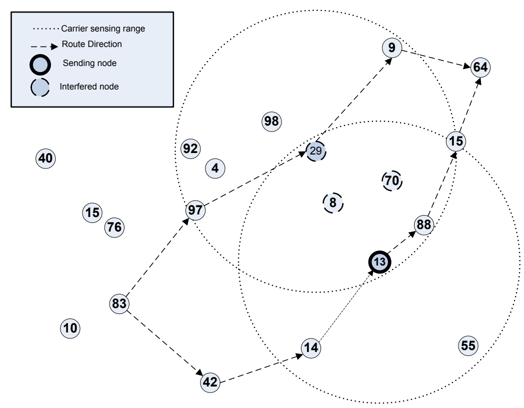

Fig. 1 Interference between nodes in MANET

Theoretically speaking, the use of multiple disjoint paths to transfer data in parallel should lead to a significant increase in data rate and throughput. However, the presence of interference between the nodes on the selected node-disjoint paths affects the efficiency of multi-path routing by decreasing the total packet delivery ratio and throughput to be nearly equal to the possibility of sending the traffic load on single route; this is mainly resulted by the existence of hidden terminal problem [5] between the selected routes in addition to single shared channel problem. The existence of hidden terminal problem mainly affects the packet delivery ratio. While, the existence of single shared channel mainly affects the overall throughput for the selected disjoint routing scheme.

Channel sharing appeared as a solution in MAC protocols to reduce the impacts of collision (CSMA/CA) by organizing the channel gain between the interfered nodes. Consequently, in multiple node-disjoint routing scheme, it could prevents a node that belongs to a route from starting to send data where the channel is gained by another node that locates in its transmission range and belongs to another disjoint route in the same multipath disjoint route scheme . That waiting period experienced by the node to gain channel cancels the idea transmitting data in parallel. Moreover, it almost turned the multipath routing scheme to a single path routing scheme.

To alleviate the previously mentioned problems, this paper presents two on-demand multipath routing protocols ESDMR and EDMR, both of them has Route Request phase, Route Reply phase, Data Relay and Route maintenance Phase.

In ESDMR, the destination node selects the most stable route to be the main route and other set of stable routes, which are also considered the set of least interference routes with the main route. The data is sent on the main route and the least interference route with the main route of that chosen set. EDMR is based on the same idea for ESDMR; whereas, EDMR used the criteria of least delay route instead of using the stability criteria. Both of the proposed protocols use a new developed technique in the Route Request phase to reduce the routing overhead, it prevents the continuous relay of late control packets after the destination node selects the disjoint route set. This process reduces the routing overhead significantly compared with Split Multipath Routing Protocol (SMR) [6].

The rest of the paper is organized as follows. In Section 3 we explained in details the main steps of ESDMR. Section 4 explains the main steps of EDMR in brief. Section 5 studied performance factors in the developed protocols and analyzed the results. Finally, we conclude the paper in section 6.

III. Efficient, Stable Disjoint, Multipath routing PROTOCOL FOR MANETs

This section presents an overview of the basic steps in ESDMR protocol in first sub-section. Then, it explains in details the procedures in the route request phase, route reply phase, data relay phase and route maintenance phase in ESDMR.

A. Overview of ESDMR

As in all routing protocols in MANETs, ESDMR has four main phases, Route Request, Route Reply, Data relay, and Route maintenance phase. The route request phase is fired by the source node when there is a need to communicate with any destination node. Thus, it broadcasts a route request packet. Each intermediate node is allowed to receive the request packet only from a different incoming link. The intermediate node stops receiving the request packets after certain duration of time. When the destination node receives the request packets, it replies for the shortest delay route (the first received route request), then, it waits a period of time to collect other request packets. The destination node is responsible for selecting the disjoint routes set and deriving the interference node set for each selected route. For that, it arranges the routes according to their stability values. It selects the most stable route as the main route and a set of other routes that are disjoint with the main route. With the disjoint route selection process, it adds the interference node set for each selected route. Finally, it sends back the reply packets to the source node. When the source node receives the route replies packet, it uses the interference node set to select the most stable route as the main route and least interference route with that route to send the data through them instead of using the shortest delay route.

B. Route Request phase

The basic route discovery mechanism of SMR protocol is used, in which the intermediate node is not allowed to reply from its route cache and RREQ packet carries the total routing information from the source to destination node. ESDMR introduced 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 request packets with a lower routing overhead as will be discussed later.

In ESDMR, each intermediate node receives the RREQ packet appends its address and calculates the link stability value; the calculated link stability value is compared with the recorded one on the RREQ packet; the RREQ packet always carries the lower link stability value for the route, the intermediate node rebroadcasts the RREQ packet.

In this scheme, instead of dropping a duplicate request packet, an intermediate node forwards only the request packets in a different incoming link other than the links from which the previous requests were received. This process is designed to give the destination node the required information about the neighbor nodes of that intermediate node which passed the request packets. This information enables the destination node to derive the group of interference nodes for each selected route. To reduce routing overhead, each intermediate node has a specific period of time to pass RREQ packets. The idea behind that is to decrease the routing overhead by preventing the late request packets from being travel through the network. 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 Equation 1

$$t = \frac{\alpha * RREQhopcount}{MaxRREQDest} \tag{1}$$

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.

This equation enables the nodes that are near the destination node to gain more routes information, thus it increase the number of available routes in the destination node.

The destination node replies for the first RREQ packet and waits a period of time to get more requests. The first RREP packet is denoted only for the shortest delay route. This route is a temporary route until the source node receives the selected stable disjoints multiple routes set.

C. 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 required complete routing information to the source node. In ESDMR, the intermediate nodes don't need to record a route to a destination, because they are not allowed to send ROUTE REPLY (RREP) packet back to the source. The destination node is responsible for replying for the first received RREQ packet, selecting the main route, selecting the node disjoint routes with the main route, deriving the group of interfering nodes for each selected route and finally sending the RREP packets to the source node.

- **Disjoint Route selection method**

In the Route Reply phase, the destination node replies for the first RREQ packets, and waits Route request time interval to receive the maximum number of the RREQ packets. It arranges the received routing information in its routing table 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 that main route. The previously mentioned time interval denotes to a pre specified period of time, this time interval is restricted to be less than re-try route request period.

- **Deriving interfering nodes set**

This process aims to guide the route discovery to select a route with the highest number of available channels with the main route.

The main idea in deriving the interfering nodes for each selected route is by comparing each of the selected routes with the rest routing information. The goal of that comparison process is to gather the addresses of all the neighbor nodes for that route. Interfering nodes set for a route can be defined as a set of nodes addresses that are considered as neighbor nodes for that route.

In this phase, the destination node compares each of the candidate routes with all other received routes to get the interference nodes set. The intersection nodes considered as the critical nodes to gain the interference information.

Figure2 presents a candidate route and other routes to compare with. Path No.1 is considered as a disjoint routes with the candidate route, thus, any disjoint routing protocol can select them if they satisfy the other pre specified criteria (shortest route, battery life time, etc...). However, path No.3 has an intersection node with the candidate route in node No.29. This intersection node guides ESDMR to the interference node No.13. Where node No.13 locates within the transmission range of node No.29, so, if both of these nodes are in sending mode, selecting path no.1 as a disjoint route will not increase the throughput due to the single channel share.

Another scenario can happened if node No.13 is in receiving mode, while node No.14 and 29 are in sending mode and both of them are out of transmission range of each other and node No.13 are in transmission range of both node No.13 and node No.29 (hidden terminal problem), so selecting both of these routes will decrease the delivery ratio due to the packet collisions in node No.13.

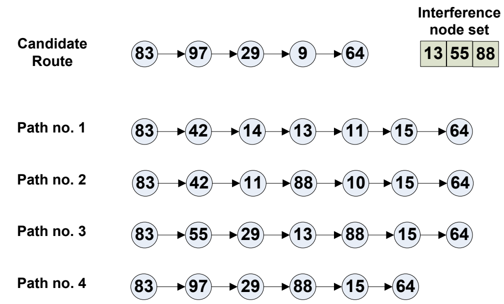

Fig. 2 An example of routes set in the destination node

After collecting the interference node set for each selected route, the route reply packets are generated and sent back to the destination node. Route reply packet contains the whole route and the interference nodes set for that route.

D. Data Relay phase

This section focus on the process of selecting the least interference routes set to send the data through them.

The source node start to send data on the shortest delay routes until it receives the other stable routing information. The source node arranges the received routing information in a descending order according to their stability value. It selects the first route as the main route and finds the other least interference route with the main route as a second route. Finally, it sends the data on the selected routes in Round Robin fashion.

- **Least interference route selection algorithm**

In ESDMR, the source node is responsible for finding the least interference route with the main route. Figure.3 presents an example of a set of routes that the source node received.

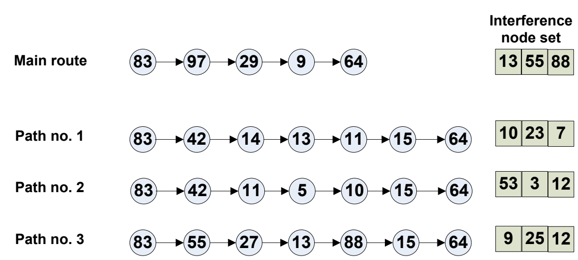

Fig. 3 Adding interference set of addresses to disjoint routes and main route

From the figure, it is noticed that, three routes are disjoint with the main route. The source node selects the least interference route by comparing the interference node set of the main route with the other disjoint routes and vice versa comparing the interference nodes set of the disjoint routes with the main route.

Node address 13 belongs to path No.1 and interference set of nodes for the main route, therefore, path No.1 creates interference with the main route. However, path No.2 considered a candidate route with the main route, where there is no interference between them.

Given the path No.3, the interference nodes set for the path No.3 contains node address 9, and node No.9 is a member in the main route, therefore, path No.3 leads to interference with the main route if it is selected.

In ESDMR, the source node selects the least interference route to participate with the main route in the data relay.

E. Route maintenance phase

ESDMR fires an error message (RERR) when it detects a link break. The RERR packet that carries the broken path is forwarded from the intermediate node that detects the link break toward the source node. The source node applies the least interference route selection algorithm to find another least interference route with the active route.

IV. EFFICIENT, DISJOINT MULTIPATH ROUTING PROTOCOL FOR MANETS (EDMR)

EDMR is another routing protocol that is proposed in this paper. It can be defined as ESDMR protocol, but with the least delay path selection criteria instead of stability factor selection criteria.

EDMR is developed to overcome the shortcomings in ESDMR. Although ESDMR proofs its efficiency in increasing throughput and data rate, the used stability model increased the interference between the nodes on each of the selected route. This is because the used stability model depends on the distance between the nodes. The stability factor increased as the distance between the nodes on the path decreased. The short distance between the nodes on the route increases the interference between the nodes on that path. This impacts the results of ESDMR.

In EDMR, the Route Request phase is fired when the source node needs to communicate with a destination node which has not known routing information. This phase is responsible for collecting the required routing information for all possible routes with a lower control overhead compared with SMR. In the route reply phase, the destination node is responsible for replying for the first received RREQ packet, selecting the node-disjoint routes set with the main selected route, deriving the interference nodes set for each selected route, and sends back RREP packets. Each RREP packet contains the whole route information and the set of addresses of the interfering nodes with that route. In the data relay phase, the source node distributes the traffic load on the shortest delay route and the least interfering route with that route. The route maintenance phase is fired when an intermediate node detects a link break, the RERR packet is sent back to the source node, the source node try to find another route which is considered as the least interfering routes with the main route.

V. PERFORMANCE EVALUATION

The performance of the three routing protocols (SMR, ESDMR, and EDMR) is studied with implemented simulations.

A. Simulation environment

The three routing protocols have been implemented with Global Mobile Simulation (GloMoSim) [7]. The implementations are completely modular and designed in compliance with other MANET protocols specified for radio/wireless models.

Parameter type	Parameter value
Simulation time	300 sec
Simulation terrain (m * m)	Varying between 500*500 and 2000*2000 m^2
Seed values	From 0 to 10
Number of nodes	50 to 100
Mobility model	RANDOM-WAYPOINT
Mobility speed	Varying between 0 and 30 m/sec
Pause time	From 0 to 30 sec
Transport protocol	UDP
Radio Model	Accumulative noise (ACCNOISE)
Radio frequency	2.4e9 Hz
Propagation model	Free Space
Temperature	290.0 k
Channel bandwidth	2Mbps
Mac protocol	IEEE 802.11, Distributed Coordination Function (DCF)
Transmission range	250 m
Traffic type	CBR (Constant bit rate)
CBR data rate	3 packet per second
Packet size	512byte
Number of data session	12 to 20

Table 1. Simulation Parameters

B. Results and analysis

The performance of the developed routing protocols has been measured in terms of following metrics:

- **Packet Delivery Ratio:** The ratio of the number of data packets successfully delivered to the destinations to the total number of data packets actually sent by the sources.
- **Throughput:** The total number of data packets received by the destination node per second.
- **Routing overhead:** The total number of routing packets which are transmitted during the simulation time. For packets sent over multiple hops, each transmission of the packet counts as one transmission. It contains (route request, route reply, and route error).

- **Average number of dropped packets**: This gives the total number of data packets dropped during the communication in the networks.

The performance metrics of the developed routing protocols has been evaluated in consideration of the following parameters:

- **Speeds of the mobile nodes:** Testing the behavior of the developed routing protocols under different and random speeds of nodes that varies between 0 and 30 meter in second. In the simulation environment the speed of mobile nodes varies between 0 to 30 m/sec.
- **Terrain area:** Changing the side length of square terrain leads to change the density of nodes distribution in the simulation area. Testing this factor studies the behavior of the developed routing protocols in very dense mode to a very sparse mode. In the simulation environment the side length of square terrain varies between 500 meters to 2000 meters.
- **Pause time:** changing pause time means to increase the randomness in the nodes behavior. In the simulation environment the pause time values varies between 0 to 30 second.

- **Packet Delivery Ratio**

In fig.4, a 50 nodes network has been considered with 1000*1000 terrains area and no pause time with different speeds. It is noticed from the figure that the proposed routing protocols perform better than the SMR in packet delivery ration. The EDMR improves the packet delivery ratio of ESDMR by 19.6%; this is due to the used stability model in the ESDMR, which increase the interference between the nodes on the path, therefore, the delivery ratio decreased. EDMR improves the delivery ratio of the SMR by 32.8 %. ESDMR improves the delivery ratio of the SMR by 11%. As the speed of the mobile nodes increase, the delivery ratio decreased due to the link breaks.

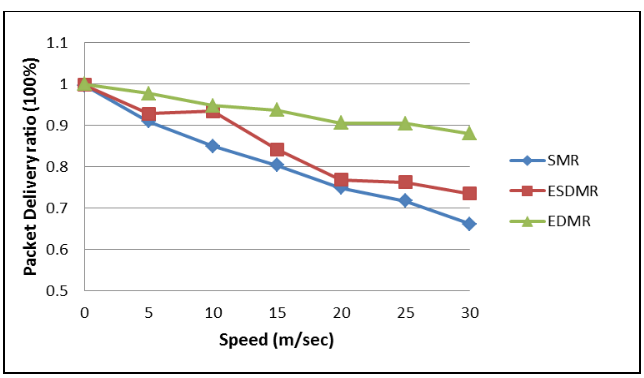

Fig. 4 Packets delivery ratio VS. Mobile node speed

Packet delivery factor was tested for the three routing protocols with pause time parameter. The overall result in fig.5 shows that the delivery ratio increased for the three routing protocols as the pause time increase. EDMR improves the delivery ratio of SMR by 22 % when the speed was 30m/sec and pause time 0. The delivery ratio of ESDMR seems to be similar to the one of SMR due to the used stability mobel.

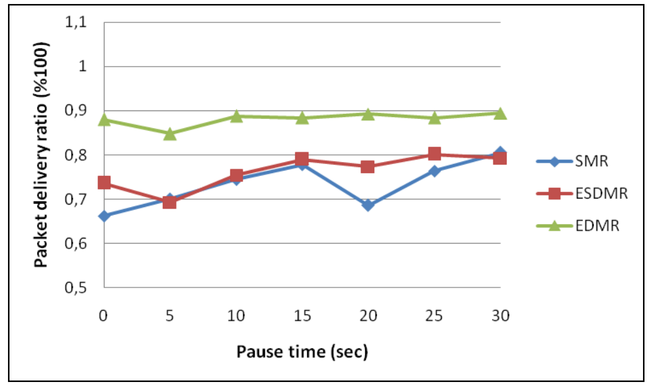

Fig. 5 Pause time VS. Packet delivery ratio

The packet delivery factor was tested over the density of the mobile nodes by changing the terrain area and the speed of mobile nodes was 30m/sec as showen in fig.6 . 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, because the nodes become out of transmission range of each others. EDMR performs better than SMR by 33% when the mobile node speeds was 30 m/sec.

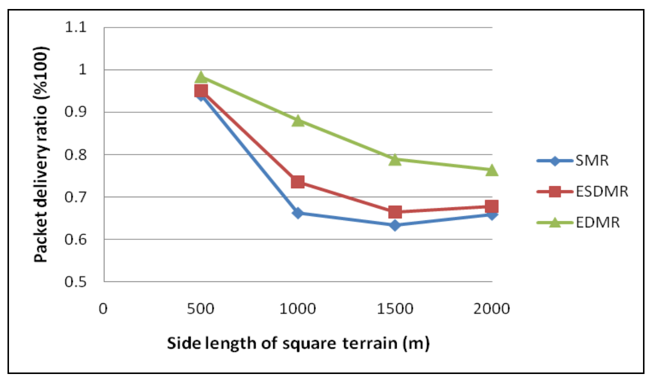

Fig. 6 Side length of square terrain VS. Packet delivery ratio

- **Throughput**

Throughput factor was tested for the three routing protocols with speed parameter. From fig.7, it is noticed that the average values for the throughput in the three routing protocols decreased as the speed of mobile nodes 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. EDMR improves the throughput of the SMR by 30% at most.

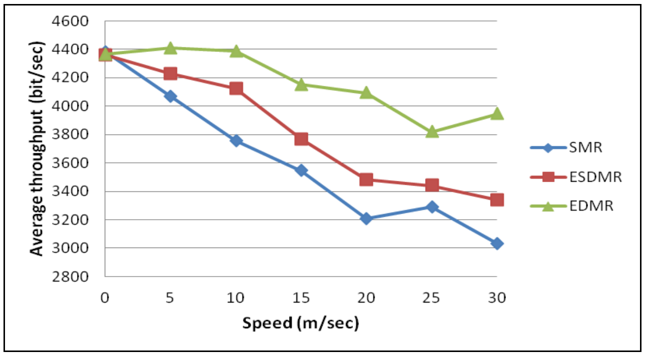

Fig. 7 Average throughput VS. Mobile node's speed

Throughput factor is tested over the pausetime parameter. The results show the following figure with 30m/s for the mobile node speed. It is noticed that EDMR improves SMR by 28% in the average throughput.

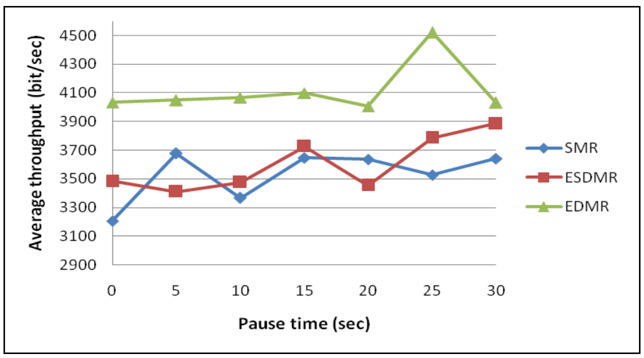

Fig. 8 Average throughput VS. Pause time

Throughput factor is also tested over the density of nodes in the terrain area. The density of the nodes can be changed by changing the terrain area. Fig.9 presents the average throughput for the three routing protocols with a speed of mobile node 30 m/s. The average throughput is decreased for the three routing protocol as the density of the nodes decrease. EDMR improves the throughput of SMR by 30% and ESDMR by18.1%. ESDMR improves the throughput of the SMR by 10%.

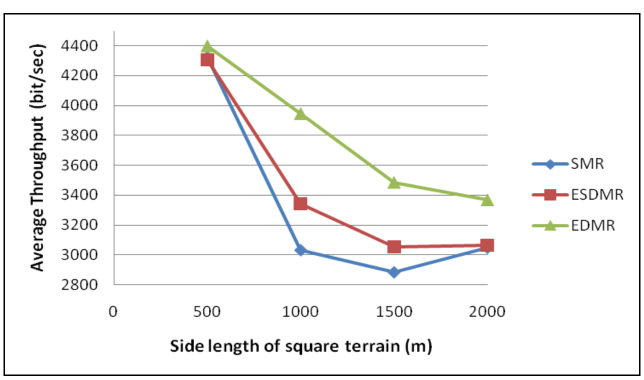

Fig. 9 Average throughput VS. Side length of Square terrain

- **Routing Overhead**

The routing overhead factor is one of the most important factors which determine the overall performance of the developed protocols. The developed routing protocols developed a technique that helps each node to get the required information while maintaining the low routing over head. Figure.10 represents the average number of control packets for the three routing protocols with different speed values. It is noticed that the proposed routing protocols reduced the average number of control packets by 83% compared with SMR.

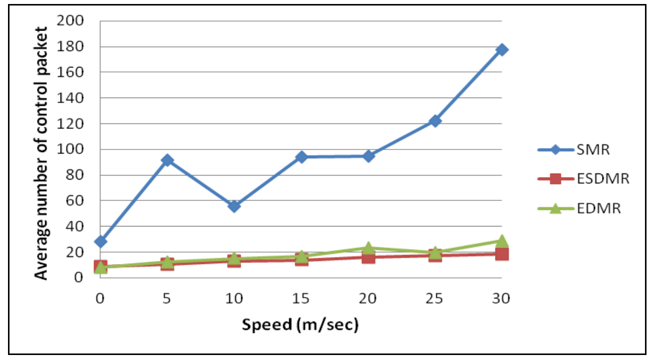

Fig. 10 Average number of control packets VS. Maximum speed

Routing overhead factor is also tested against pause time parameter. The following figure illustrates the behavior of the three routing protocols when the mobile node speeds were 30 m/sec. it is noticed that the new routing protocols performs better than SMR, this is due to the developed technique which prevents the late control packets from travelling through the network.

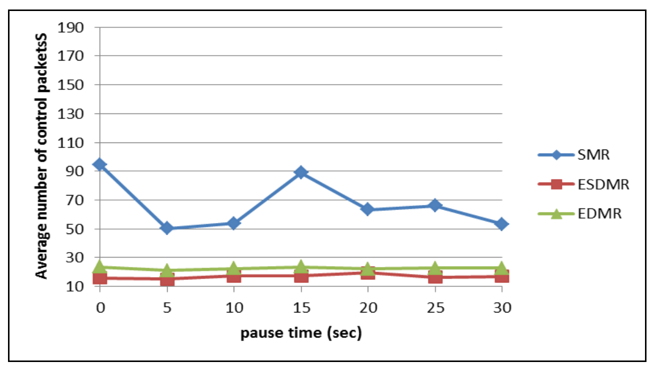

Fig. 11 Average number of control packets VS. Pause time

- **Average number of dropped packets**

The number of dropped packets is one of the most essential factors that determine the performance of the developed routing protocols. It is also impacts the delivery ratio, which is one of the most important goals that any developed routing protocols aims to raise. Dropping of packets not only occurs due to the link break, but also it occurs due to the packets collision which causes corrupted packets. Figure.12, illustrates the Average ratio of dropped and corrupted packets for the three routing protocols with different speed values.

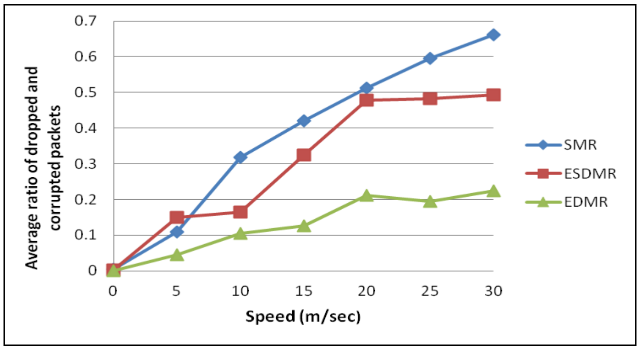

Fig. 12 Average ratio of dropped and corrupted packets VS. Maximum speed

Figure.13 illustrates the average number of packets collisions in the three routing protocols. It is noticed that ESDMR and EDMR routing protocols reduced the average frequency of packets collision by 74%. Fig.12 and fig.11 explain the delivery ratio for the three routing protocols which illustrated in fig.3

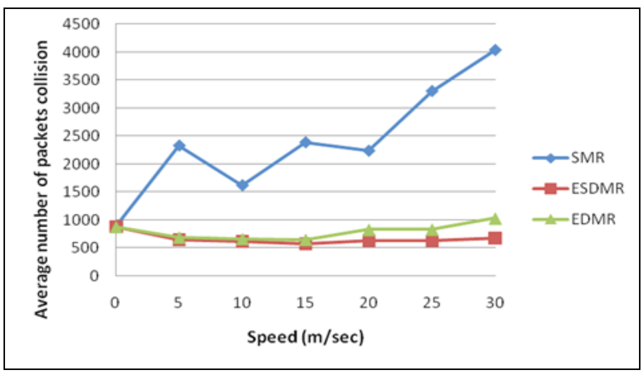

Fig. 13 Average number of packets collisions VS. Maximum speed

VI. CONCLUSION

This paper focused mainly on increasing the delivery ratio and throughput in multipath routing schemes which used the concept of multipath routing in distributing the traffic load on multiple node-disjoint routes. This paper achieved its goals by reducing the impact of interference between the selected node-disjoint routes. Single channel share and hidden terminal problem are the main consequences of interference that are discussed in this paper and are considered in the developed routing protocols. The developed routing protocols reduced the impacts of interference by detecting single channel sharing and hidden terminal problems between the selected disjoint routes, and thus avoiding the routes that cause them as much as can. In this paper, we proposed two on-demand, interference aware, node-disjoint multipath routing protocols for MANETs. The developed routing protocols aimed mainly to increase the delivery ratio and the real throughput of the multiple path routing scheme to be as theoretically expected from it. Both of the developed routing protocols achieved its goals by choosing the node-disjoint routes with the minimal interference between them.

Both of the developed routing protocols succeeded in collecting the required routing information in the route request phase, with the remarkably lower routing overhead compared with SMR, this is due to the developed technique that is used to prevent the late requests messages from continuous transmission through the network.

The results showed that ESDMR and EDMR performed better than SMR in increasing throughput and delivery ratio, and decreasing the routing overhead remarkably.

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