SGMRP: Scalable Geographic Multicast Routing Protocol for Mobile Ad Hoc Networks

Mohammad M. Qabajeh
Faculty of Engineering and Technology, Palestine Technical University Kadoorie, Hebron, Palestine
Email: mohammd.qabajeh@ptuk.edu.ps

***Abstract*—Recently, group communications over Mobile Ad hoc Networks (MANETs) have received considerable attention. Group communication needs support of multicast routing protocols for simultaneous delivery information of group of receivers. Thus, designing effective and efficient multicast routing protocol is necessary to support this kind of applications. Several efforts have been adopted to improve multicast routing. However, most of them did not consider the scalability issue. In this paper, we propose a novel Scalable Geographic Multicast Routing Protocol (SGMRP) to improve the scalability of multicast routing with reduced overhead. SGMRP uses virtual clustering strategy to implement scalable routing and efficient group management. This scheme based on partitioning the network into sectorial zones. The proposed solution performs efficient packet forwarding with reduced communication overhead. This scheme reduces the number of participating nodes and eliminates the duplicate packets. Compared with On Demand Multicast Routing Protocol (ODMRP) and Efficient Geographic Multicast Protocol (EGMP), simulation results show that SGMRP delivers more packets with significantly reduced overhead regardless of the network size, mobility speed and number of multicast members.**

***Index Terms*—Mobile ad hoc networks, multicast, routing, scalable, geographic, GPS.**

I. Introduction

Mobile Ad hoc Network (MANET) is a multi-hop autonomous network composed of a collection of self-organized mobile nodes connected through a wireless link without any network infrastructure. MANETs gain significant popularity due to the numerous fields of applications. Recently, there is interest in applications where users work in a cooperative way and interact in a close manner [1], [2]. Multicasting is essential and efficient method in such applications to realize group communication [3]-[6].

The multicast routing protocol forwards data to a group of nodes simultaneously, hence multicasting should be robust and efficient in critical application [7], [8]. Conventional multicast routing protocols depend on creating a mesh or a tree structure for the multicast member nodes in order to receive the data, in which each node has to maintain the state information of the created structure. The maintenance of the multicast state information leads to significant routing and memory overhead [9]-[11]. Recently, geographic routing protocols have evolved to provide scalable and efficient routing. In geographic routing protocols, participating mobile nodes are aware of their location information using Global Positioning System (GPS) or any location services [12].

With the fast revolution in wireless technology and reduced cost of their hardware devices, the location information of any mobile device can easily be obtained [13]. The availability of position information has been used to support network efficiency and scalability by restricting the transmission region of routing packets. As a result, routing based on location information has emerged as a promising routing mechanism.

Location-aware multicast routing protocols use position information to establish reliable routing and reduce the maintenance overhead. However, many challenges face implementing reliable and scalable multicasting over wireless communication [14]. For example, in position-based unicast routing, a data packet carries the position of the destination in the header of the packet to guide the packet forwarding. On the other hand, multicast routing considers a group of nodes as multicast receivers, which increases the packet size and the routing overhead, especially in large-scale MANETs. Despite these challenges, research efforts have recognized these challenges and worked on developing scalable and efficient multicast routing protocols [15].

The current paper proposes a tree-based multicast protocol called Scalable Geographic Multicast Routing Protocol (SGMRP) to solve the scalability issue. The proposed protocol virtually divides the network plane into 8 sectors. This type of structure constructs a minimum-length multicast tree with reduced communication overhead. The protocol performs restricted position-based route discovery, which potentially reduces the number of packet transmissions with reduced hop count to each multicast receiver. Thus, our protocol provides scalable routing over dynamic network topology. The primary contributions of this work include.

- Providing scalable multicast routing using clustering strategy that can adapt to MANET mobility to form a stable topology that supports various network functions such as multicast routing and resource utilization.
- The protocol constructs a virtual backbone to achieve more data packets forwarding and support scalable

Manuscript received October 24, 2021; revised January 19, 2022; accepted January 31, 2022.

Corresponding author: Mohammad M. Qabajeh (email: mohammd.qabajeh@ptuk.edu.ps).

doi: 10.18178/ijeetc.11.4.304-316

multicasting with a large number of receivers in large-scale networks.
- Unlike its predecessors, it does not broadcast packets throughout the network, but it uses restricted direction flooding in the route discovery journey, which decreases the number of routing packets.

We organize the rest of the paper as follows: In the consequent section, we discuss some previous works. Section III provides a detailed description of the proposed protocol. The simulation experiments performed are discussed in Section IV and the performance of the proposed protocol is compared with the well-known On Demand Multicast Routing Protocol (ODMRP) [16] and Efficient Geographic Multicast Protocol (EGMP) [17]. Section V provides a discussion of the paper and the conducted experiments. Finally, we conclude the paper in Section IV.

II. Related Works

In this section, the operation of the conventional multicast protocols and the location-aware multicast protocols in MANETs are described. Traditional topology-based multicast protocols (mesh and tree-based) consist of three main components that make their performance degrades in large-scale networks. First of all, membership management. When the network gets larger in terms of multicast members and network size, joining and leaving of multicast members become harder especially in highly dynamic network topology. Secondly, building multicast structures. The cooperation between the multicast sources and receivers establishes multicast communication. This structure is not stable in tree-based networks compared with mesh-based networks. To maintain a robust structure, extra control mechanisms need to be performed without exhausting the network resources. Finally, multicast packets forwarding. Propagation of multicast packets along the pre-built structure (tree and mesh) is susceptible to be frequently broken. This makes topology-based networks induce poor scalability [18], [19].

On demand Multicast Routing Protocol (ODMRP) [16] and Multicast Ad hoc On-demand Distance Vector Routing (MAODV) [20] are well-known examples of topology-based multicast routing protocols. This type of protocols involve large routing overhead, especially when the size of the network grows up. However, hierarchical design of the routing area provides scalability and prevents flooding, which effectively reduces the control overhead.

ODMRP [20] is a mesh on-demand multicast routing protocol that based on the concept of forwarding nodes. When a source node has multicast data to send, it broadcast a JOIN_QUERY packet in the entire network. Periodically, the multicast source floods JOIN_QUERY packet to refresh the membership in the multicast session and update the routes information (e.g. at an interval of 3 seconds). An intermediate node detects a duplicate packets by comparing the source ID and the sequence number. Node rebroadcast the packet if it is not duplicate and TTL does not reach (zero). When a multicast member receives this packet, it creates or updates the source entry in its MEMBER_TABLE and rebroadcasts a JOIN_REPLY packet to its neighbors. When receiving this reply packet, the node checks if the next node-ID of one of the entries in JOIN_REPLY_TABLE matches its own ID. If this is true, a node recognizes that it is on the routing path to the source and becomes portion of the forwarding mesh by setting the Flag of Forwarding Group (FG-FLAG). Then, it broadcasts the JOIN_REPLY_TABLE that built for matched entries. The multicast group members continue to forward the JOIN_REPLY packet through the shortest path until it reaches the sending node. The forwarding nodes build or update the multicast mesh between sources and receivers.

An Efficient Geographic Multicast Protocol (EGMP) is proposed in [17] to enhance the scalability of location-aware multicast protocols by exploiting a two-layer structure. EGMP partitions the geographic area into non-overlapping zones with square shape; in each zone, a leader is elected to represent its local zone on the upper tier. The leader node gathers the membership information for each zone to manage joining and leaving the multicast sessions. At the top layer, the leader nodes of member zones contact directly with sources to report the zone memberships through the learned tree-based construction or along the home zone.

EGMP makes use of the position information to build a membership management of the members using a hierarchical structure. EGMP constructs the multicast tree by presenting a notion known as the zone depth, it represents the depth of the member zone and root of the tree. The multicast source directly forwards the packet in the constructed tree, and then it moves through the constructed tree at the top layer. After receiving the packet by the zone leader, the packet is sent to the local zone to reach the group members. Nodes in the same zone are in the transmission range of each other and communication between different zones and performed using forwarding nodes.

In EGMP protocol, the hierarchical zone structure and the location service are combined. Here, the packet is sent to the destination zone center and after that, it is sent to the definite zone or rebroadcasted based on the packet type. When a multicast source needs to transmit packets, it floods a joining packet into the network and the nodes interested in the held multicast group can join the held session. The flooding can be easily performed but it introduces a huge amount of overhead. Moreover, the multicast packet size is large as it combines the next hop list for all intended destinations in addition to the list of destinations.

The location Aware Multicast Protocol (LAMP) [21] supports scalable multicast routing using greedy multicast forwarding. LAMP divides the network into hexagon zones to manage the membership of the group efficiently and to track the position of the multicast receivers. For each hexagon cell, the node closer to the center is elected as zone leader to sustain the membership table of the multicast receivers. The tree construction starts by initiating a broadcast packet to the whole network, containing all multicast members. Each node is aware if it is a multicast receiver, if yes, it replies by a join request packet to its local zone leader to construct the tree. When a source node needs to send data packets to a list of receivers, it splits the network region into 3 regions (120º) and a copy of the data packets is directed to each region using greedy multicast forwarding. LAMP shows scalable performance, however the multicast tree construction results in a large number of packets and increases the routing overhead. In addition to the overhead of network construction and node self-mapping.

Cheng *et al*. [22] have proposed a source-based hybrid geography-aided Multicast Zone Routing on-demand multicast routing protocol (GMZRP) that has the benefits of both geographic routing and topology routing. GMZRP is based on the unicast protocol ZRP [23]. GMZRP divides the network terrain into circle shape zones beginning from the center of the network and spreads to cover the network. Each individual circle maintains a hexagon cell with the same side length. GMZRP constructs a two-level multicast tree: node granularity and zone granularity. Since Zone granularity act similar to source routing, while the source node maintains a chain of zone ID which connect the source with each destination. Similarly, the intermediate nodes maintain the zone ID chain to connect their own zone to the downstream zone. Alternatively, on node granularity, both the intermediate and the source nodes keep information only about their child nodes. GMZRP can independently work on any location-based unicast protocol and it displays accepted delivery fraction and reduced the control overhead significantly. On the other hand, GMZRP acquires large unnecessary overhead to handle the multicast group management. This is a direct result of the large number of broadcast of request packets.

GMZRP works independently of any geographic unicast protocol and it shows competing packet delivery ratio and lower overhead compared with ODMRP protocol. However, GMZRP acquires large unnecessary overhead to handle multicast group management. This is a direct result of the large amount of broadcast of MRREQ packets.

A multicast routing protocol called WINDMILL has been presented in [24]. This protocol proposes a hierarchal routing algorithm to improve performance of the routing protocol by dividing the network area into square zones and a leader is elected to represent each zone based on different factors including power, memory and CPU processing power. In each zone, the nodes interested to join the multicast group send a JoinGroup packet to the zone leader. When a source node wants to send data to a multicast group, route setup is initiated by sending Source Route Request (SRREQ) packets. The source node sends External Route Request (ERREQ) packet to the adjacent zones and Internal Route Request (IRREQ) packet inside the zone. Restricted directional flooding is used to forward the packets for multi-hop forwarding.

Multicast Ad hoc on Demand Distance Vector (MAODV) [25] builds a multicast tree based on AODV unicast routing protocol where each multicast group is identified by a unique address and a group sequence number. The source nodes, multicast group members and tree members construct a shared tree for each multicast group. Route discovery is achieved on-demand in the form of a request/reply process. A node, wishing to join the tree, floods a route request (RREQ) packet, and any node on the tree responds with a route reply (RREP) packet indicating its distance to the group leader. This packet establishes the forwarding path that multicast data packets will follow. The group leader typically the first member of the group, it also periodically broadcasts group hello packet (GRPH) throughout the network to announce its status, to maintain sequence numbers and to become aware of reconnections. MAODV uses a hard state approach for the tree maintenance which means that the protocol must keep track itself of link failures in the tree and perform the maintenance operations when required.

The main advantage of MAODV is that it employs the same RREQ/RREP messages as AODV. Also, MAODV allows new group member to be quickly join the multicast tree, rather than waiting for the source to add it to the tree. However, in conditions of high mobility and traffic load, MAODV suffers from high end-to-end delay and high control overhead associated with fixing broken links because it relies on single path with the tree. Also, MAODV is not flexible since it suffers from a single point of failure, which is the multicast group leader.

It is obvious from the literature that using geographical routing can improve the performance of Ad hoc routing protocols. Utilizing node's geographical positions helps in reducing routing overhead, which improves robustness and scalability. This type of protocols utilizes the availability of small and inexpensive GPS receivers. Using GPS receivers, each node knows its precise geographic coordinates [26]. Table I gives a summary of the discussed protocols and highlighted their advantages and disadvantages.

This work presents a highly efficient multicast on-demand routing protocol using the position information to reduce packet flooding, reduce the forwarding overhead in a simple routing scheme. The protocol tries to overcome some of the problems of the previous schemes along with improving the protocol scalability and reducing the resulted control overhead. The protocol phases are described in detail in the following sections.

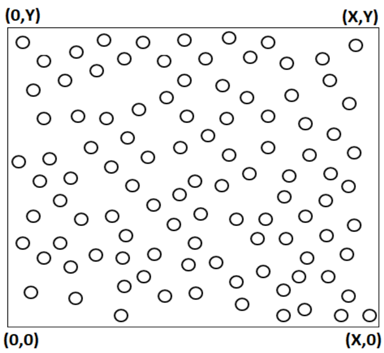
III. Protocol Overview

Our proposed protocol is a source-tree multicast routing protocol developed to improve scalability and reliability with reduced overhead. The protocol aims to be implemented in large-scale networks with large number of multicast members. This is achieved through constructing a virtual clustering strategy that partition the network coverage area into eight sectors. This protocol exhibits the efficiency of multicasting and forwards the packet to multiple destinations based on the location of the destinations, which assumed to be known previously. The protocol exploits the positioning information of the mobile nodes to reduce the number of nodes that participate in control packets forwarding.

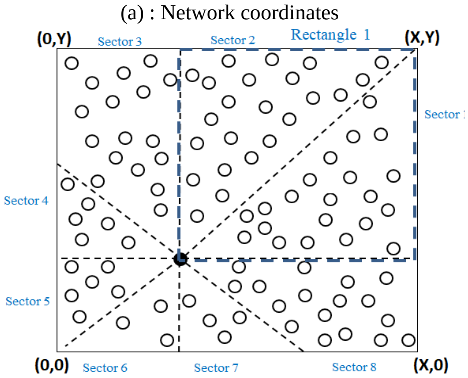
TABLE I: SUMMARY OF RELATED WORK PROTOCOLS

Protocol	Category	Strengths	Limitations
ODMRP [1]	Topology-based	1. Incurs high packet delivery ratio and throughput even under highly mobile network conditions. 2. Operates efficiently as unicast routing protocols.	1. The multicasting process is not efficient due to the use of multipath to the destination. 2. The control overhead increases with increasing the network size. 3. Produces large overhead due to keeping the current forwarding group and due to the global flooding of the *Join_Query* packets.
EGMP [2]	Location-based	1. EGMP is scalable. 2. Combine location service with membership management. 3. Robust against node mobility.	1. Flooding of the multicast session initiation incures large overhead. 2. The size of the multicast message is large because it contains the list of next hop for all destinations in addition to the destination list.
LAMP [3]	Location-based	1. Shows scalable performance 2. Robust against dynamic network topology	1. Incurs long delays and high control overheads.
GMZRP [4]	Combines both topological and geographic routing.	1. Does not rely on any geographic unicast protocol. 2. Packets propagation between geographic zones is efficient in eliminating duplicate packets. 3. Short route length of the discovered routes.	1. The dynamic membership management cause large overhead. 2. Performance is degraded in high mobile networks. 3. Large overhead when the network is large due to packet flooding.
WINDMILL [5]	Location-based	1. The simulation results shows scalable performance in large-scale networks. 2. Use different parameters to select the zone leader	1. Incurs high communication overhead in network construction and maintenance. 2. The routing length is so long due to the existence of zone leader.
MAODV [6]	Topology-based	3. Can be easily integrated with unicast routing protocols. 4. MAODV employs the same RREQ/RREP packets as AODV. 5. Loop-free protocol.	6. Has low packet delivery ratio in scenarios with high mobility, large numbers of members, or a high traffic load. 7. Suffers from a single point of failure, which is the multicast group leader. 8. Incurs long delays and high control overheads when fixing broken links.

In this protocol, we apply Restricted Directional Flooding (RDF) to achieve this promising results [26]. RDF uses the locations of mobile nodes and the position information of the destinations (which is obtained from the location service algorithm). Using RDF, the nodes only forward packets if they are in the way to the destination; this reduces the broadcast of packets and the network resources are utilized efficiently.



(a) : Network coordinates



(b): Network construction

Fig. 1. Network partitioning based on source position

A. Assumptions

In this section, we first present some definitions and assumptions. For simplicity, we assume the MANET is located in a two-dimensional area of $Am \times Am$ defined by the coordinates (0, 0) to ($X_{\max}$, $Y_{\max}$). The mobile nodes (N) are distributed randomly in this area and moving with different mobility speeds, as shown in Fig. 1 (a).

We also assume that each node previously knows the borders of the routing area and takes the origin of coordinates when it joins the network. In several applications of MANETs, network origin coordinates are set as consistent parameters. Examples of such applications includes zoos exhibitions, disaster areas, and metropolitan zones [27]. The location of each node is defined by (x, y) coordinates and the location is identified either by employing the GPS or any other localization method. Also, the locations of the destination nodes are assumed to be previously known through applying the location service algorithm. We also assume that the mobile nodes knows the setup time of the network and aware of the identity of the multicast groups [28], [29]. During the network startup, the assumed information distributed to the participating nodes.

B. Route Discovery

In our protocol, the sender can transmit packets without specifying the next-hop node, because the receiving node can decide to forward or drop the packet based only on its location and the location information of the destination node. This mechanism does not require routing tables, neighbor tables, in addition to eliminating the need to tree creation.

When a source node has data to send to a multicast group, it divides the network into four rectangles based on its network coordinates (Rect 1, Rect 2, Rect 3, Rect 4) and then splits each rectangle into two sectors (Rectangle 1 (sector 1, sector 2)) as shown in Fig. 1 (b). This results in a total of eight sectors. After that, it sends a separate RREQ packet to each sector that contains multicast receivers. The sectors are numbered from 1 to 8 based on the algorithm discussed in Fig. 1 (b).

In multicast session initiation, the source "S" sends a Route Request (RREQ) packet including all multicast members' identifiers and their position coordinates. This packet used to discover the specific routes to each destination. The source node determines the sector numbers that contain one or more multicast members and splits a copy of the RREQ packets only to those sectors. This is performed based on the position information of the source and destination nodes as explained in the algorithm in Fig. 2.

Each neighboring node that receives the RREQ packet subtracts the source coordinates from its coordinates; the result determines the rectangle that this node located in. Depending on the current position of the intermediate node relative to the sources current position. The intermediate node calculates Beta (β) which determines the sector that the intermediate node located in as shown in Fig. 2.

When a copy of the RREQ packet is received by the intended sectors, the packet is forwarded using RDF towards different destinations. Using RDF eliminates overflowing the network with extra packets and controls packet forwarding to only the nodes in the way to the intended destinations. By using RDF in forwarding RREQ packets, the nodes participate in forwarding RREQ packets is depending on calculating the Euclidean distance between the node sending the packet and the purposed receiver. To be precise, the node receiving the RREQ packets will be considered as a forwarding node only if the Euclidean distance is lower (towards any destination in the sector). This mechanism can reduce the resulted control overhead compared to broadcast mechanism (since all the network nodes take part in forwarding of the discovery packets).

When the intermediate node receives an RREQ packet, if the node is a member in the multicast session, it removes the fields that belong to that node (ID_D, (X_D, Y_D) and forwards the packet to next node using RDF. Otherwise, the distance is calculated between itself and the proposed multicast member and compares this distance with the "Res_Dist" field that is kept in the packet. If the intermediate node is further than the previous-node, the packet is dropped. Otherwise, it stores its previous hop node, which is used in the reverse path and packets forwarded using RDF.

```
Start
//Initialize ∝ which is used to determine if the intermediate node in the first or second sector of a rectangle ∝ = 45^0
//Calculate the coordinates between source node (ID_S) and intermediate node (ID_I)
    X_R = X_I − X_S, Y_R = Y_I − Y_S
//Determine the rectangle identifier of intermediate node
    IF (X_R > 0) and (Y_R > 0) then
        Rect_ID_I = 1                    // The Intermediate node is in rectangle 1
    ELSE IF (X_R < 0) and (Y_R > 0) then
        Rect_ID_I = 2                    // The Intermediate node is in rectangle 2
    ELSE IF (X_R < 0) and (Y_R < 0) then
        Rect_ID_I = 3                    // The Intermediate node is in rectangle 3
    ELSE IF (X_R > 0) and (Y_R < 0) then
        Rect_ID_I = 4                    // The Intermediate node is in rectangle 4
//Determine the sector identifier of intermediate node
    Calculate β = tan^-1 ( Y_R/X_R)
    IF β ≤ ∝ then
            Sect_ID_I = (2*Rect_ID_I) – 1
    ELSE
            Sect_ID_I = (2*Rect_ID_I)
    IF Sect_ID_I = Sect_ID_D in RREQ   //the intermediate node is in the same sector as the destination node
            For all destinations (D) in Sect_ID_I
                {Calculate Dist_ID = sqrt((X_D − X_I)^2 + (Y_D − Y_I)^2)
                 IF Dist_ID ≤ Res_Dist_D in RREQ   // the intermediate node is closer to destination node than its previous hop
                    {  Store previous node ID from Last_Node in RREQ
                       //Modify RREQ packet and continue RDF
                       Res_Dist_D in RREQ = Dist_ID
                       Last_Node in RREQ = ID_I
                       Send RREQ to 1-hop neighbor}
                }
    ELSE
        Drop packet
END
```

Fig. 2. Pseudo code for reaction of intermediate node on receiving a RREQ packet.

The receiving node uses the position information to compute the distance between itself and the destination. Then, the resulted value is compared with the field of the last distance to the destination node, if the value of the calculated distance is shorter than that stored in the field "Dist", the node forwards the RREQ packet after updating this value by replacing the previously computed value with the new value. For ease of reference, Table II summarizes the notation used in this model.

The fields of the RREQ packet are shown in Fig. 3. Pkt_ID (RREQ) is a sequence number increased monotonically for each RREQ packet and it is used with ID_S to uniquely distinguish the RREQ packets. Due to using RDF routing strategy, a node may receive more than one RREQ packet with the same RREQ_ID, then it will drop any received RREQ packet after receiving the first RREQ packet, which reduces packets routing load. The fields (ID_S, (X_S, Y_S)) represent the ID and location coordination of the source node. While the field "Dest_list" represents the list of the multicast members. The fields "Rect_ID" and "Sect_ID" represent the rectangle identity and identity of the sector for each destination respectively. The "Last_Node" field represents the last node that modifies and retransmits the RREQ packet. The field "Res_Dist$_D$" represents the distance computed between the last sending node and the destinations.

TABLE II: PROTOCOL NOTATIONS

Notation	Meaning
R	Transmission range
S	Source Node
D	Destination Node
I	Intermediate Node
X_S	X coordinate of node S
Y_S	Y coordinate of node S
X_I	X coordinate of node I
Y_I	Y coordinate of node I
X_R	Difference in X coordinate between nodes ID_S and ID_I
Y_R	Difference in Y coordinate between nodes ID_S and ID_I
ID_S	Identifier of Source node
ID_I	Identifier of Intermediate node
ID_D	Identifier of Destination node
Sect_ID_I	Identifier of the sector of node I
Rect_ID_I	Identifier of the rectangle of node I
Pkt_ID	Packet identifier
$Dist_{ID}$	Distance between I and D
Res_Dist	Last distance to the destination

Pkt_ID(RREQ)	RREQ_ID	ID_S	(X_S, Y_S)
Last_Node	Sect_ID_D	Dest_list	Res_$Dist_D$

Fig. 3. RREQ packet format.

C. Route Reply Process

Upon receiving RREQ packet by each destination node, it replies by the following RREP packet shown in Fig. 4. Pkt_ID (RREP) is the ID for the first RREQ packet and RREQ_ID is the request ID for the received RREQ packet and the fields "ID_S and ID_D" represent the address of the sending source and the address of the receiving destination respectively. When the RREP packet traverses back from each destination to the source node, each node along the selected path recognizes that it becomes a forwarding node and re_forwards the packet until it reaches the source node. When the source receives the selected routes to the multicast group members, it uses these routes to start the submission of data packets to the multicast members.

Pkt_ID (RREP)	RREQ_ID	ID_S	ID_D

Fig. 4. RREP packet format.

D. Route Maintenance

Since MANETs are dynamic networks, it is necessary to maintain the structure of the multicast tree. During sending of data packets, broken links may be resulted because of nodes movement or nodes failure. This broken link prevent data packets to reach some nodes. When a packet encounters a broken link, the upstream node of the broken link immediately will inform the upstream nodes about this failure by sending RERR packet backward until it received by the source node. While an immediate upstream node receives an RERR packet, it relays the packet to the upstream nodes, and the downstream nodes of the broken link deletes the related items in the routing table after a time interval is expired without reception of new data packets from the upstream nodes.

When the RERR packet received by the source node, it clears the related data from its own routing table, then it starts a new route searching process to reconstruct a new path to the affected destinations as discussed previously. The format of RERR packet is as shown in Fig. 5.

Pkt_ID(RRER)	RREQ_ID	ID_S	ID_D

Fig. 5. RERR packet format.

E. Detailed Example

Here, a detailed example of the proposed model is presented to explain how our protocol is employed. As shown in Fig. 6, the network has five destinations (D1, D2, D3, D4, D5) distributed randomly and one source node (S).

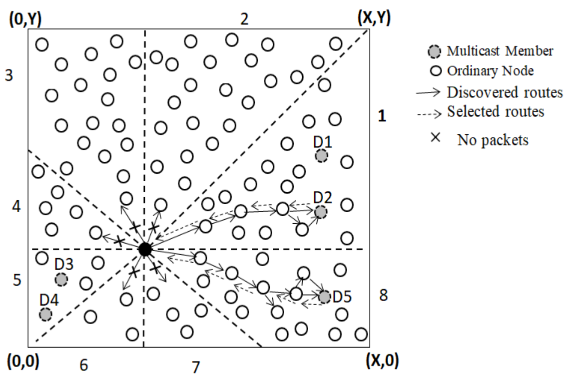


Fig. 6. Example of network with 1 source and 5 destinations.

It is shown that sectors (2, 3, 4, 6, and 7) have no multicast members and hence no packet is sent to those sectors. While sector (1) has two multicast members (D1 and D2), and thus a packet is sent restrictedly to these multicast destinations. Also, a copy of the packet is sent to sector (5) since it has 2 multicast members (D3 and D4). Sector 8 contains only one multicast member (D5), and also a copy of the packet is sent to this multicast destination. As shown in Fig. 6, it is clear that the number of control packets is reduced to only the sectors that contain multicast members. Also, the nodes closer to each destination participate in packet forwarding, which is clear in packet forwarding in sector (1). Fig. 7 shows the description of the fields related to the multicast members in the RREQ packet.

Sect_ID	Dest_ID, (X_D, Y_D), Res_Dist$_D$	Dest_ID, (X_D, Y_D), Res_Dist$_D$

(a) Structure of D_list in RREQ.

1	I, (X_I, Y_I), 50m	J, (X_J, Y_J), 70m

(b) D_list in RREQ sent to sector 1.

5	K, (X_K, Y_K), 150m	L, (X_L, Y_L), 40m

(c) D_list in RREQ sent to sector 5.

8	M, (X_M, Y_M), 30m

(d) D_list in RREQ sent to sector 8.

Fig. 7. Contents of D_list field in RREQ Packet.

IV. PERFORMANCE EVALUATION

In the following section, we study the effectiveness of SGMRP protocol through detailed simulation using GloMoSim [30]. GloMoSim is a scalable simulation environment for mobile wireless network using parallel discrete-event simulation capability provided by PARSEC. GloMoSim is considered as the second famous simulator after NS-2 simulator [31]. Comparisons are carried out between SGMRP and the well-known ODMRP Protocol and the position-based EGMP [17]. ODMRP has been selected for comparison because ODMRP has become a benchmark and a de facto baseline for performance comparisons in multicast routing protocols for MANETs and it is one of the elite multicast protocols [32]. The implementation of ODMRP following the specifications of the Internet Draft draft-ietf-manetodmrp-02.txt [16]. We chose ODMRP for our comparison because it has become a benchmark and a de facto baseline for performance comparisons in multicast routing protocols for MANETs. ODMRP simulations are based on the codes provided with the simulator and the parameters set as in [12].

A. Simulation Environment

The simulations were run with 240 nodes moving over a network area of 2km×2km, unless otherwise specified. Node mobility is simulated according to the *random waypoint* mobility model, since it is considered as one of the widely used mobility model in the literature [33]. Each simulation is executed for 600s. The behavior of SGMRP protocol has been studied neglecting the surrounding factors including fading effect, shadowing and noise effect. Mobile node transmission range of 250 meters is used as it is a typical value for wireless local area networks in a free area without any obstacles and is supposed to be fixed and cannot be dynamically control [34]. The used MAC layer was IEEE 802.11 and the channel capacity is 2Mbps. The nodes in the network are generated based on uniform distribution. The multicast source generates traffic of five 128-byte packets using a Constant Bit Rate (CBR) traffic generator. The data flow starts at 30 seconds, and group management is started at 10 seconds and stopped at 580 seconds. Nodes' mobility speeds are uniformly set between 1 m/s and 20 m/s (with pause time as 10 seconds), respectively, except when evaluating the effect of node mobility. The used multicast session was with a single multicast group with only 1 source and 48 multicast group members. The members of the multicast group are randomly chosen and joining the held multicast session when the simulation starts and remains as members in the group throughout the simulation. Each data point in the following figures represents an average of 5 simulation runs using the same configuration but with different seed values. The simulation parameters are listed in Table III.

TABLE III: SIMULATION PARAMETERS

Parameter	Value
Simulation area	2 km × 2 km
Total nodes	240
Movement model	Random-waypoint model
Simulation time	600s
Transmission range	250m
Channel capacity	2Mbps
Maximum speed	0, 2, 4, 6, 8, 10 m/sec
Pause time	10 seconds
MAC protocol	IEEE 802.11
Packet flows	Constant bit rate (CBR)

B. Performance Metrics

We are mainly focused on studying the efficiency and scalability of SGMRP under several circumstances. In literature, the performance metrics in Ad-Hoc routing protocols include the packet delivery ratio, the delay performance and the routing overhead. Meanwhile, typical network parameters of interest include the network size, mobility, the number of multicast members, network density, rate and data generation rate [35]-[38]. For this purpose, the effect of several parameters has been studied. These parameters are network size, mobility speed and the number of multicast members. For each parameter, the following commonly known metrics are used for evaluation of the performance of the multicast protocol:

- *Packet Delivery Ratio (PDR)*: The ratio of the total number of packets received by all receivers and the total number of packets expected to receive across all multicast receivers. This metric reflects the ratio of successful delivery, which shows the protocol's effectiveness.
- *Packet Routing Load (PRL)*: The total number of control packets transmissions divided by the total number of received data packets by all multicast receivers. This ratio reflects the effectiveness of consuming the control packets in supplying receivers with data packets. The considered routing packets are the packets sent during route discovery and route maintenance for the three simulated protocols.
- *Average Path Length (APL)*: The metric represents the average hop numbers traversed by the received data packet. This metric shows the performance of delivery latency.
- *Average Route Acquisition Latency (ARAL)*: The average delay time required for discovering a routing

path to a destination. ARAL is computed as the average time interval between sending the first RREQ packet and reception of the first RREP packet.

C. Simulation Results

In this section, performance of SGMRP and the simulated multicast protocols are compared with different network sizes, node densities, node speeds and group sizes.

1) Effect of network size

First, we study the performance of SGMRP with varied network sizes. The network configurations are traffic rate of 2 packets per second and mobility speed of 5m/s. One source node sending CBR flows to a multicast group of 48 receivers. The number of network nodes increases by increasing the network size and the density of nodes is preserved. To estimate the protocol scalability with varying the network dimensions, the network area varies from 1km×1km to 3km× 3km. The node density is set to 60 nodes/km^2. Therefore, the number of nodes for each network size varied from 60 nodes to 540 nodes.

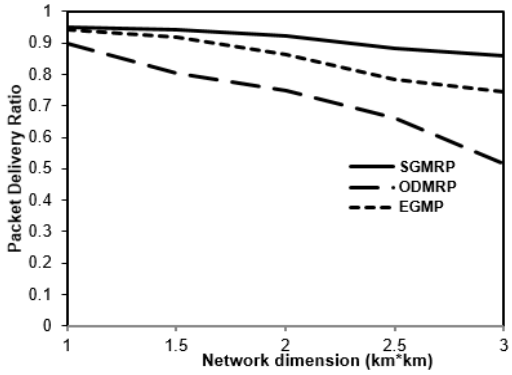
Fig. 8 (a) shows that SGMRP is more scalable with increasing the network range 1km to 3km. As expected, the delivery fraction for the three protocols decreases when the network size increases. However, the decrease of PDR for ODMRP and EGMP decreases faster as the network dimension increases while the PDR of SGMRP decreases gently. In large network sizes, there is increased probability of having far distance between the source and destination nodes. This causes a higher probability of link breakages, longer routes and more data packets drop. Compared to other protocols, the SGMRP protocol identifies the merged paths using the greedy multicasting technique which reduces transmissions.

Fig. 8 (b) reveals that PRL for the simulated protocols increases with increasing the network size. As the network area becomes larger, the probability of broken links in the discovered routes will be increased consequently; this results in generating higher route repair control packets. SGMRP utilizes the advantages of the sections structure effectively and establishes reliable routing with reduced overhead.

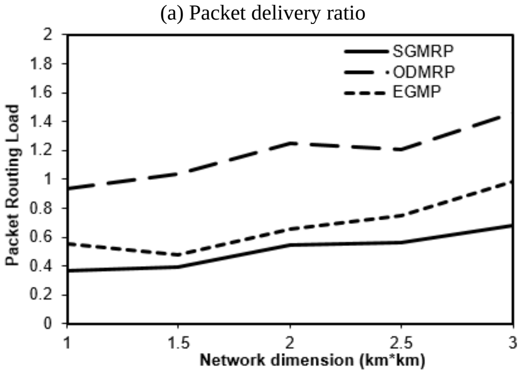
On the other hand, in EGMP protocol the periodic flooding of beacon messages causes high unnecessary overhead. In ODMRP, the PRL increases dramatically. The reason of this behavior is that increasing the range of the network area and using the same node density leads to more number of nodes that participate in performing the routing operation, this generates extensive amount of broadcast packets (JOIN_QUERY and JOIN_REPLY). ODMRP is robust, but it acquired considerable amount of control overhead in the network as shown Fig. 8 (b) [7].

Fig. 8 (c) shows the comparison results of average path length with different network sizes. ARL for the three protocols increases with increasing network size. In large networks, it is expected that the source may be located far away from the destination, which needs longer routes and extended time to setup them. Fig. 8 (c) indicate that SGMRP has shorter path length than ODMRP and EGMP. The reason is that the propagation of RREQ packets in SGMRP establishes multicast tree between the source and receivers with less hop counts.

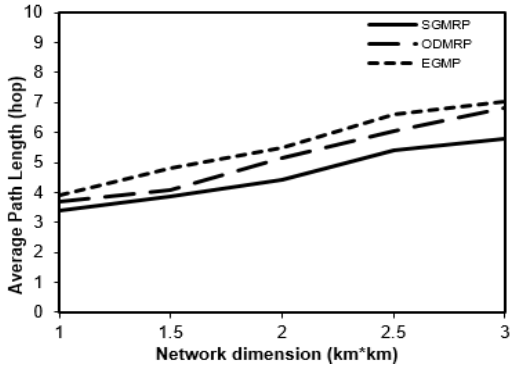
In Fig. 8 (d), the route acquisition latency of the three protocols takes longer time as the network size increases. The larger network range is, the longer routing path is resulted as well. This will intuitively increase the average packet delay. As shown in the figure, ODMRP has a less delay than SGMRP due to the time required in SGMRP to gather the position information and identity of the multicast members.



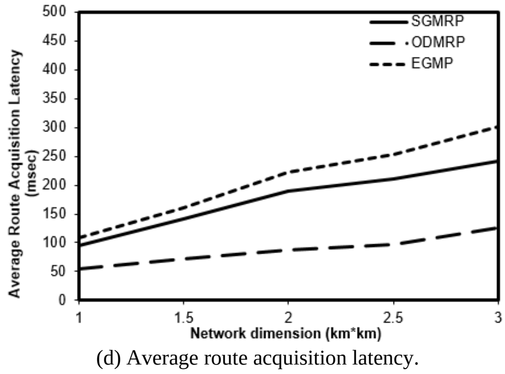
(a) Packet delivery ratio



(b) Packet routing load



(c) Average path length



(d) Average route acquisition latency.

Fig. 8. Performance of SGMRP with different network size.

Overall, position-based routing protocols perform better than topology-based protocols in large networks. SGMRP performs better than both ODMRP and EGMP in large networks. SGMRP has 11.3% higher delivery ratio in large network tests compared with position-based EGMP. While SGMRP achieves more than 30% higher delivery ratios than topology-based ODMRP at the larges network tests.

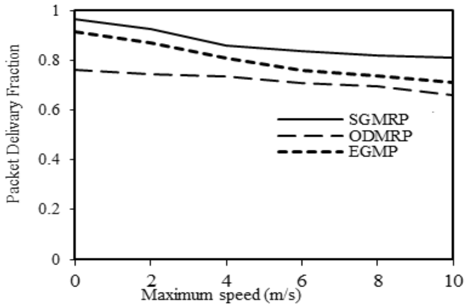
2) Effect of node mobility

We now study the effect of varying the moving speeds on the protocol performance. The simulation was implemented with 240 nodes moving over network area of 2km×2km and single source sends CBR flows to a multicast group of 48 members. The mobility speed varies from 0 to 10m/s.

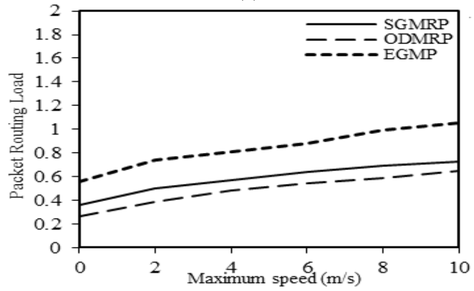
Fig. 9 (a) shows the comparison results for the three protocols with different moving speeds. As expected, increasing the node mobility is likely to lead to decrease in packet delivery ratio for the three protocols. This confirms that the delivery ratio is sensitive to mobility speed. Due to frequent node movement, the chance of frequent link broken and topology change rises, which increase the packet drop rate. In all protocols, the built multicast construction is expected to be more stable when the mobility speed is low; consequently, the delivery ratio is high. It is clear that SGMRP has greater PDR at moderate and low mobility due to the efficient multicast tree construction. The higher delivery ratio of SGMRP is due to the used geographic routing mechanism, which can adjust more quickly to the dynamic environment of MANET.

The use of RDF during route discovery results in stable routes and deliver more data packets. The delivery ratio of ODMRP seen to be stable and slightly drops with the increase of the moving speed. This is a direct result of the robust mesh construction of ODMRP, which delivers multiple paths. However, ODMRP has remarkable growth in routing overhead because the participating nodes in the multicast session need to periodically send control packets no matter what the established route is stable or not.

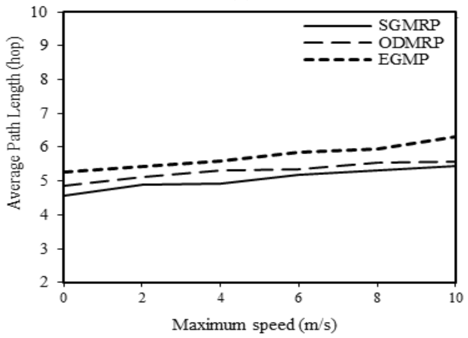
Fig. 9 (b) shows the packet routing load for the three protocols considering different mobility speeds. It's obvious that the packet routing load of SGMRP is less than that of EGMP in all the mobility cases. This issue because SGMRP reduces the number of nodes that participate in forwarding the routing packets. In SGMRP, forwarding of routing packets is restricted to only the nodes that are in the direction to the destination and avoid flooding the routing packets. However, in EGMP, when the mobility speed increases, more control packets will be generated to keep the construction of the multicast tree connected. The packet routing load of SGMRP seen to be higher than that of ODMRP. The reason is as follows. As expected, at higher mobility the control overheads of SGMRP increases due to frequently uses route discovery packets and due to the large number of triggered packets to maintain the network structure. However, SGMRP outperforms the other two protocols and deliver much higher data packets in all the mobility cases.



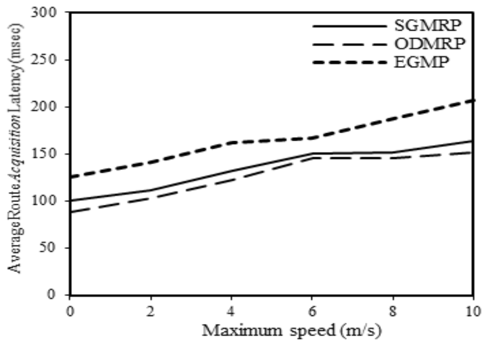
(a)



(b)



(c)



(d)

Fig. 9. Performance of SGMRP with different mobility speed: (a) Packet delivery ratio, (b) packet routing load, (c) average path length, and (d) average route acquisition latency.

On the other hand, ODMRP has less packet routing load compared to SGMRP and EGMP. The routing load of ODMRP is slightly increases when the mobility speed increases. The used mesh structure in ODMRP is more robust compared with the tree structure. However, ODMRP performs periodic Join_Query requests that broadcasts to the entire network at the same rate for different mobility speeds. When the movement speed of the nodes increases, the opportunity that the next hop will move away will increase, which makes the learned reverse routes through Join_Query are not stable and not reliable. Therefore, whenever the next hop is no longer available, the Join_Reply packet is dropped. This makes the Join_Reply packets to be flooded several times looking for next hop node. Therefore, the node floods another Join_Query request to find a new route towards the multicast source. When a neighbour node receives such Join_Query packet it needs to reply by sending Join_Reply packets, hence, the packet routing overhead increases as the mobility speed increases.

Fig. 9 (c) demonstrates the effect of average path length. ODMRP and EGMP have longer paths compared with SGMRP. This is due to the hierarchical feature structure of EGMP since the sent data packets sent to leader of each zone and then to the multicast receivers, which takes more number of hops to reach the destination. ODMRP has less number of hops due the mesh structure and the connectivity of the forwarding nodes. While in SGMRP, the packet goes along the shortest path from the source to the destinations, so the path consists of less number of hops.

Fig. 9 (d) shows the comparison results on ARAL under different mobility speeds. ARAL slightly increase with increasing mobility speed for both SGMRP and ODMRP based on the forwarding strategy they used. The figure shows that ARAL for SGMRP is slightly longer than that of ODMRP. This is because SGMRP need to execute the virtual clustering algorithm that requires extra time. Also, the nodes need more processing time before forwarding the RREQ packet. However, ODMRP performs broadcast over the whole network and selects the shortest path.

In SGMRP, the RREQ packets reach the destinations through the shortest paths using RDF packet forwarding and the destinations reply to the first received RREQ packet. This mechanism reduced the ARAL time. While ODMRP sends the Join_Query along the shortest paths and the multicast mesh is created with less ARAL. On the other hand, the zone-based structure of EGMP introduces longer routes and significantly increases the ARAL.

In summary, the performance of all routing protocols degrades with high mobility networks. SGMRP deliver 10% more packets than EGMP and 14.7% than ODMRP in highest mobility scenarios. Also, the control overhead at the highest mobility speed is reduced by 32% compared with EGMP and shows comparable results with ODMRP. In contrast, SGMRP achieved reduced route discovery time by 43.9 ms compared with EGMP and less than by 12% compared with ODMRP at the highest mobility simulations. This indicates that SGMRP can effectively handle the increase in mobility speed with reduced number of transmissions. Thus, the proposed SGMRP protocol significantly performs scalable and efficient multicast routing under a highly mobile ad-hoc network.

3) Effect of network density

The objective of this experiment is to study the effect of varying the node density on the performance of SGMRP protocol and to compare its performance with that of ODMRP and EGMP. Here, we consider a single multicasting with 48 members including the source node. The node mobility speed is 5m/s with pause time set to 30s. Fig. 10 shows the performance of the proposed SGMRP with the node density varied from 80, 160, 240 and 320 nodes and located in network area of 2km×2km. These situations show 20 nodes/km^2, 40 nodes/km^2, 60 nodes/km^2 and 80 nodes/km^2 node density values respectively.

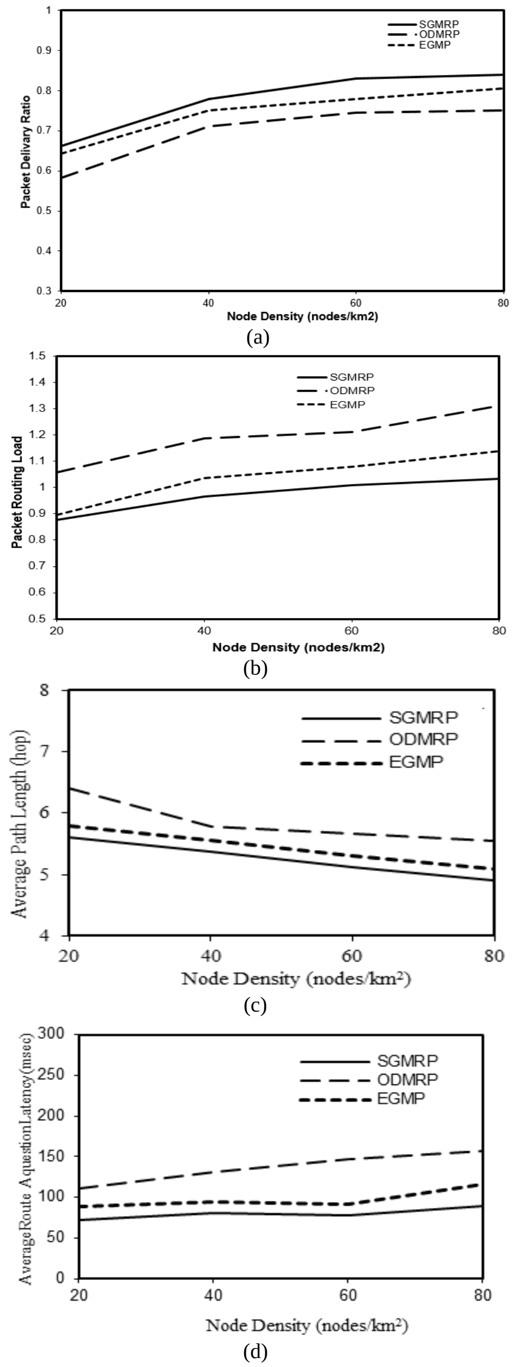


Fig. 10. Performance of SGMRP with different node density: (a) Packet delivery ratio, (b) packet routing load, (c) average path length, and (d) average route acquisition latency.

In Fig. 10 (a), the results of PDR for each node density scenario are presented. The figure indicates that both SGMRP and EGMP have consistently higher delivery ratios than ODMRP. The reason is that position-based routing directly affected by node density and shows better performance in dense networks. When the node density is low (20 node/km2 for example) PDR drops much faster since the mobile nodes are distributed from each other which leads to more empty zones and the probability reduced to finding a routing path, which accordingly affect the performance. When the node density is high, both SGMRP and EGMP have higher delivery ratios due effective forwarding of data packets. However, when the node density exceeds to more than 60 nodes/km^2, the delivery ratio slowly increase, as there are more collisions occurs among mobile nodes and hence more packet loss.

Fig. 10 (b) presents the PRL of SGMRP, EGMP and ODMRP. In the figure, it's clear that increasing the node density will increase collisions between neighbouring nodes and cause more packet loss. This rate of collision is proportioned to number of packets that need to be generated. SGMRP shows better performance than that of EGMP and ODMRP. This is due to the efficient network construction and reduced number of control packets produced. While EGMP has slightly higher PRL than SGMRP due to the stable zone structure used in EGMP. On the other hand, ODMRP has lower packet transmission due to mesh structure and the reduced control packets generated.

Fig. 10 (c) demonstrates the average path length for SGMRP, EGMP and ODMRP under different node density. As the network becomes denser, the average number of hops decreases; this is because increasing node density will increase the chance for an intermediate node in the way to the destination. For ODMRP, the flooding of Join_Query packets makes more nodes participate in route establishment, the routing length became longer. However, it's shown in Fig. 9 (c) that geographic routing protocols has fewer nodes in the created routes.

Regarding ARAL of the selected routes, Fig. 10 (d) shows that the ARAL of the three protocols increases as the network becomes denser, since more nodes are involved in performing route discovery process. When the node density is high, the number of participating nodes becomes larger which causes congestion and increase the delay in processing control packets.

In summary, at high node density SGMRP outperforms EGMP and ODMRP, and it has significantly higher delivery ratio and lower control overhead. This is because SGMRP can efficiently construct the multicast structure to build more and short stable routes even.

V. Discussion

From the simulation results presented in section IV, many points can be highlighted. First, in Ad hoc networks, clustering approach improve routing protocol scalability in terms of network dimension and number of nodes. However, network construction and network setup increase the routing overhead. The results also shows that selecting the cluster shape has direct impact on the control overhead of cluster-based routing protocols. Second, from the analysis, it is obvious that network maintenance operations add extra overhead if these operations does not performed locally. In general, if flat structure is used in a large network, routing tables and location updates would grow to a huge size. Therefore, partitioning the network into multiple clusters can limit the size of routing tables. Moreover, detailed topology information for a particular cluster is only exchanged among local cluster members whereas aggregated information is propagated between neighboring clusters in a higher hierarchical level. Distributing the load among multiple nodes improves performance and scalability of the routing protocol. It also helps in achieving robustness and solving the single point of failure problem.

VI. Conclusion

Group communications in MANETs are essential in supporting multimedia applications. Multicast routing is efficient strategy for group communication, where data is forwarded to a group of nodes simultaneously. Recently, proposing a multicast protocol that scales to large networks with large number of receivers face several challenges. This paper proposes a Scalable Geographic Multicast Routing Protocol (SGMRP) by using the location information in route discovery and maintenance. SGMRP petitions the network plane into sectorial regions to efficiently manage the multicasting process. This construction is used to propagate the route request packets only to the regions that contain multicast members. Simulations are conducted to evaluate the scalability and the efficiency of SGMRP protocol. As it turns out, SGMRP protocol achieves decent performance and lower routing overhead compared with the classical multicast protocol ODMRP and well-known geographic multicast protocol EGMP.

Future works can include comparing this protocol with other existing scalable multicast protocols. Additionally, work can be done on examining the effect of other. Furthermore, the researchers are looking for performing a simulation study to compare hexagonal gridding with square and triangle gridding using the same routing methodology.

Conflict of Interest

The author declares no conflict of interest.

Acknowledgment

The authors wish to thank Palestine Technical University Kadoorie, Palestine for their cooperation and support to publish this research.

References

[1] A. Banerjee and S. Ghosh, "Weight-based energy-efficient multicasting (WEEM) in mobile ad hoc networks," *Proc. Computer Science*, vol. 152, pp. 291-300, 2019.

[2] A. Goyal, V. K. Sharma, S. Kumar, and K. Kumar, "Modified local link failure recovery multicast routing protocol for MANET," *Journal of Information and Optimization Sciences*, vol. 41, no. 2, pp. 669-677, 2020.

[3] M. G. Vaighan and M. A. J. Jamali, "A multipath QoS multicast routing protocol based on link stability and route reliability in mobile ad-hoc networks," *Journal of Ambient Intelligence and Humanized Computing*, vol. 10, no. 1, pp. 107-123, 2017.

[4] A. K. Yadav and S. Tripathi, "QMRPRNS: Design of QoS multicast routing protocol using reliable node selection scheme for MANETs," *Peer-to-Peer Networking and Applications*, vol. 10, no. 4, pp. 897-909, 2017.

[5] T. N. Tran, T. V. Nguyen, K. Shim, and B. An, "A game theory based clustering protocol to support multicast routing in cognitive

radio mobile ad hoc networks," *IEEE Access*, vol. 8, pp. 141310-141330, 2020.

[6] B. Yang, Z. Wu, Y. Shen, X. Jiang, and S. Shen, "On delay performance study for cooperative multicast MANETs," *Ad Hoc Networks*, vol. 102, no. 4, pp. 1-14, 2020.

[7] S. Baskaran, J. A. V. Selvi, V. S. J. A. M. Dhulipala, and A. I. J. Information sciences, "Trust based cluster-energy efficient multicast routing in mobile ad hoc networks," *Applied Mathematics & Information Sciences, An International Journal*, vol. 12, no. 2, pp. 421-429, 2018.

[8] H. R. Hussen, S. C. Choi, J.-H. Park, and J. Kim, "Predictive geographic multicast routing protocol in flying ad hoc networks," *Int. Journal of Distributed Sensor Networks*, vol. 15, no. 7, pp. 1-20, 2019

[9] Y. H. Robinson, R. S. Krishnan, E. G. Julie, R. Kumar, L. H. Son, and P. H. Thong, "Neighbor knowledge-based rebroadcast algorithm for minimizing the routing overhead in mobile ad-hoc networks," *Ad Hoc Networks*, vol. 93, Oct. 2019.

[10] M. M. Qabajeh, A. H. Abdalla, O. O. Khalifa, and L. K. Qabajeh, "A survey on scalable multicasting in mobile ad hoc networks," *Wireless Personal Communications*, vol. 80, no. 1, pp. 369-393, 2015.

[11] H. R. Hussen, S. C. Choi, J. H. Park, and J. Kim, "Predictive geographic multicast routing protocol in flying ad hoc networks," *Int. Journal of Distributed Sensor Networks*, vol. 15, no. 7, July 2019.

[12] S. Tharani, G. Arutchelvan, and G. Arulanandam, "Location based clustering implemented for multicast backbone MANET," in *Proc. Int. Conf. on Communication and Signal Processing*, 2017, pp. 0728-0732.

[13] M. Alnabhan, S. Alsaraireh, B. K. Pattanayak, *et al.*, "Performance analysis and enhancement of position-based routing protocols in MANETS," *International Journal of Knowledge-based and Intelligent Engineering Systems*, vol. 23, no. 2, pp. 109-120, 2019.

[14] W. A. Jabbar, M. Ismail, R. Nordin, and S. Arif, "Power-efficient routing schemes for MANETs: A survey and open issues," *Wireless Networks*, vol. 23, no. 6, pp. 1917-1952, 2017.

[15] K. Rajkumar, S. Abinaya, P. J. I. J. O. S. Swaminathan, and Technology, "Efficient resource allocation in multicasting over mobile adhoc networks," *Indian Journal of Science and Technology*, vol. 7, no. S4, pp. 71-75, 2014.

[16] Y. Yi, S. J. Lee, W. Su, and M. J. D. Y. M. O. T. Gerla, "On-demand multicast routing protocol (ODMRP) for ad hoc networks," Internet-Draft, January 2000.

[17] X. Xiang, X. Wang, and X. Zhou, "An efficient geographic multicast protocol for mobile ad hoc networks," presented at 2006 Int. Symposium on a World of Wireless, Mobile and Multimedia Networks, 2006.

[18] K. A. Farhan, F. Abdel-Fattah, F. Altarawneh, and M. Lafi, "Survey paper on multicast routing in mobile ad-hoc networks," in *Proc. IEEE Jordan Int. Joint Conf. on Electrical Engineering and Information Technology*, 2019, pp. 449-452.

[19] A. Goyal and V. Sharma, "Design and implementation of modified local link repair multicast routing protocol for MANETs," *Int. Journal of Scientific & Technology Research*, vol. 9, no. 2, pp. 2316-2321, 2020.

[20] E. M. Royer and C. E. Perkins, "Multicast operation of the ad-hoc on-demand distance vector routing protocol," in *Proc. 5th Annual ACM/IEEE Int. Conf. on Mobile Computing and Networking*, 1999, pp. 207-218.

[21] R. Shankar and E. J. J. O. I. T. Ilavarasan, "Scalable multicasting through hexagonal zone based structure over mobile ad hoc networks," *Journal of Internet Technology*, vol. 19, no. 7, pp. 2111-2124, Dec 2018.

[22] H. Cheng, J. Cao, X. J. M. N. Fan, and Applications, "GMZRP: geography-aided multicast zone routing protocol in mobile ad hoc networks," *Mobile Networks and Applications*, vol. 14, no. 2, pp. 165-177, April 2009.

[23] N. Beijar, "Zone routing protocol (ZRP)," Networking Laboratory, Helsinki University of Technology, Finland, vol. 9, pp. 1-12, 2002.

[24] L. K. Qabajeh, "WINDMILL: A scalable multicast routing protocol for mobile ad-hoc networks," *Int. Journal of Electrical and Electronic Engineering & Telecommunications*, vol. 10, no. 5, pp. 341-354, Sept. 2021.

[25] J. Gupta and N. Gill, "Tuning and performance analysis of geographical routing protocol in MANET," *International Journal of Innovative Research in Computer and Communication Engineering*, vol. 2, no. 5, pp. 4452-4459, 4452-4459, May 2014.

[26] R. K. Banka and G. Xue, "Angle routing protocol: location aided routing for mobile ad-hoc networks using dynamic angle selection," in *Proc. MILCOM 2002*, 2002, pp. 501-506.

[27] H. W. Tsai, T. S. Chen, and C. P. Chu, "Service discovery in mobile ad hoc networks based on grid," *IEEE Trans. on Vehicular Technology*, vol. 58, no. 3, pp. 1528- 1545, March 2009.

[28] D. Y. Kim, J. W. Cho, J. Y. Lee, and S. K. Park, "Enhanced on-demand multicast routing protocol for multimedia," *Journal of Ubiquitous Convergence Technology*, vol. 3, no. 1, pp. 20-26, 2009.

[29] K. Viswanath, K. Obraczka, and G. Tsudik, "Exploring mesh and tree-based multicast routing protocols for MANETs," *IEEE Trans. on Mobile Computing*, vol. 5, no. 1, pp. 28-42, 2006.

[30] UCLA Parallel Computing Laboratory. Network Simulator (GloMoSim). [Online]. Available: http://pcl.cs.ucla.edu/projects/glomosim/

[31] M. Qabajeh and L. Qabajeh, "A survey and comparative study for performance evaluation technologies for wireless networks," *Int. Journal of Computer Science and Network Security*, vol. 19, no. 10, pp. 43-50, 2019.

[32] C. Zhang, Y. Liu, X. Ren, and Y. Guo, "LSODMRP: Improved-ODMRP multicast routing protocol based on local broadcast and stable links for MANET," in *Proc. International Conference in Communications, Signal Processing, and Systems*, Springer, Singapore, July 2017, pp. 574-581.

[33] Y. Jungkeun, M. Liu, and B. Noble, "Random waypoint considered harmful," presented at Twenty-Second Annual Joint Conf. of the IEEE Computer and Communications, San Francisco, 2003.

[34] K. Farkas, D. Budke, B. Plattner, O. Wellnitz, and L. Wolf, "QoS extensions to mobile ad hoc routing supporting real-time applications," in *Proc. of IEEE Int. Conf. on Computer Systems and Applications*, 2006., pp. 54-61.

[35] X. Hong, K. Xu, and M. J. I. N. Gerla, "Scalable routing protocols for mobile ad hoc networks," *IEEE Network*, vol. 16, no. 4, pp. 11-21, 2002.

[36] E. I. INN, "Mobility-adaptive clustering and network-layer multicasting in mobile ad hoc networks, Ph.D. Thesis. National University of Singapore, 2007.

[37] J. Schleich, "Robust dominating set based virtual backbones for wireless ad hoc networks," University of Luxembourg, Luxembourg, Luxembourg, 2010.

[38] K. A. Darabkh and O. A. Alsukour, "Novel protocols for improving the performance of ODMRP and EODMRP over mobile ad hoc networks," *Int. Journal of Distributed Sensor Networks*, vol. 11, no. 10, #348967, 2015.

Mohammad M. Qabajeh received his B.Sc. degree from Palestine Polytechnic University, Palestine in 2000 and M.Sc. degree from Jordan University of Science and Technology, Jordan in 2006 in computer Engineering. He worked as a network administrator in the periods (2000-2003) and (2006-2008). During these periods he worked as a part time lecturer in many Palestinian universities. He has secured his Ph.D. degree in Computer

Engineering in 2012 from International Islamic University Malaysia, Malaysia. Currently he is Assistant Professor at Palestine Technical University Kadoorei (PTUK). His current research interests include Distributed Systems and Ad-Hoc Networks.