Geographic Information Based Protocol Analysis (EGMP)

K. Kavitha, K. Selvakumar, T. Nithya, S. Sathyabama

Abstract*—Mobile Ad-hoc Network (MANET) is a group of wireless nodes that are distributed without relying on any standing network infrastructure. Group communication plays an important role in MANETs. To implement this group communication, we propose an Efficient Geographic Multicast Routing protocol (EGMP) with the help of virtual zone based structure. This EGMP protocol deals with the position information which is used to construct zone structure, multicast tree and multicast packet forwarding. The performance metrics such as Packet Delivery Ratio (PDR), End to End delay and Control Overhead of EGMP are also evaluated through simulations and quantitative analysis by varying number of nodes, zone size and group size. Our simulation result shows that EGMP has high packet delivery ratio, low control overhead and multicast group joining delay under all test scenarios when compared with On-Demand Multicast Routing Protocol (ODMRP) and Scalable Position Based Multicast Routing Protocol (SPBM), and is scalable to group size.

Index Terms*—MANET, EGMP, SPBM, ODMRP, Zone Structure, Performance metrics.

I. INTRODUCTION

A mobile ad-hoc network (MANET) is a self-configuring network of mobile devices connected by wireless links. Applications include the exchange of messages among a group of soldiers in a battlefield, communications among the firemen in a disaster area, and the support of multimedia games and teleconferences. With a one-to-many or many-to-many transmission pattern, multicast is an efficient method to realize group communications.

Multicast Routing protocol can be categorized into two types; tree-based and mesh-based protocols. Due to topology changes and frequent joining and leaving from individual nodes, it is very difficult to maintain the tree structure using these conventional tree-based protocols (e.g., MAODV [3], AMRIS [4], MZRP [5], MZR [3]). The mesh-based protocols (e.g., FGMP [6], Core-Assisted Mesh protocol [7], ODMRP [8]) are proposed to enhance the robustness with the use of redundant paths between the source and the destination pairs.

In MANET unicast routing, geographic routing protocols [11] [14] have been proposed for more scalable and robust packet transmissions. The existing geographic routing protocols generally assume mobile nodes are aware of their own positions through certain positioning system (GPS), and a source can obtain the destination position through some type of location service [5]. In [13], an intermediate node makes its forwarding decisions based on the destination position inserted in the packet header by the source and the positions of its one-hop neighbors learned from the periodic beaconing of the neighbors.

By default, the packets are greedily forwarded to the neighbor that allows for the greatest geographic progress to the destination. To achieve efficient packet forwarding, a scalable geographic multicast protocol also needs to efficiently manage the membership of a possibly large group, obtain the positions of the members and build routing paths to reach the members distributed in a possibly large network terrain.

In this paper, we propose an efficient geographic multicast protocol, EGMP, which can scale to a large group size. The protocol is designed to be comprehensive and self-contained, yet simple and efficient for more reliable operation. Instead of addressing only a specific part of the problem, it includes a zone-based scheme to efficiently handle the group membership management, and takes advantage of the membership management structure to efficiently track the locations of all the group members without resorting to an external location server. The zone structure is formed virtually and the zone where a node is located can be calculated based on the position of the node and a reference origin. By making use of the location information, EGMP could quickly and efficiently build packet distribution paths, and reliably maintain the forwarding paths in the presence of network dynamics due to unstable wireless channels or frequent node movements.

II. RELATED WORK

An ad-hoc network is formed by a group of mobile hosts communicating over wireless channels without any fixed network interaction and centralized administration. Conventional topology-based multicast protocols include tree-based protocols and mesh-based protocols [8]. Tree-based protocols construct a tree structure for more efficient forwarding of packets to all the group members. Mesh-based protocols expand a multicast tree with additional paths which can be used to forward packets when some of the links break [4]. EGMP uses a location-aware approach for more reliable membership management and packet transmissions, and supports scalability for group size [2]. Besides the need of managing group membership as well as constructing and maintaining a multicast structure,

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a geographic multicast protocol also requires a location service [9][10] to obtain the positions of the members. The geographic multicast protocols presented in [11],[12] and [13] need to put the information of the entire tree or all the destinations into packet headers, which would create a big header overhead when the group size is large and constrain these protocols to be used only for small groups.

In this paper, zone-supported geographic forwarding is introduced to reduce the routing failure, and provide mechanism to handle zone partitioning. In addition, we introduce a path optimization process to handle multiple paths, and provide a detailed cost analysis to demonstrate the scalability of the proposed routing scheme.

III. EFFICIENT GEOGRAPHIC MULTICAST ROUTING PROTOCOL (EGMP)

EGMP supports scalable and reliable membership management and multicast forwarding through a two-tier virtual zone-based structure. At the lower layer, in reference to a pre-determined virtual origin, the nodes in the network self-organize themselves into a set of zones as shown in Fig(a), and a leader is elected in a zone to manage the local group membership. At the upper layer, the leader serves as a representative for its zone to join or leave a multicast group as required. As a result, a network-wide zone-based multicast tree is built. For efficient and reliable management and transmissions, location information will be integrated with the design and used to guide the zone construction, group membership management, multicast tree construction and maintenance, and packet forwarding. The zone-based tree is shared for all the multicast sources of a group. To further reduce the forwarding overhead and delay, EGMP supports bi-directional packet forwarding along the tree structure. That is, instead of sending the packets to the root of the tree first, a source forwards the multicast packets directly along the tree. At the upper layer, the multicast packets will flow along the multicast tree both upstream to the root zone and downstream to the leaf zones of the tree. At the lower layer, when an ontree zone leader receives the packets, it will send them to the group members in its local zone.

In EGMP, we assume every node is aware of its own position through some positioning system (GPS [10]) or other localization schemes.

Some of the notations to be used are:

zone: The network terrain is divided into square zones.

r: Zone size, the length of a side of the zone square. The zone size is set to $r \le r_t/\sqrt{2}$, where r_t is the transmission range of the mobile nodes.

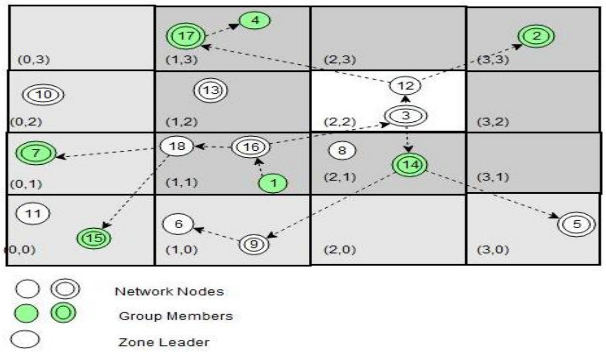


Fig (a) Zone Construction

zone ID: The identification of a zone. A node can calculate its zone ID (a, b) from its position coordinates (x, y) as:

$$a = \frac{[x-x0]}{r},\ b = \frac{[y-y0]}{r}$$

where (x_0, y_0) is the position of the virtual origin, A zone is virtual and formulated in reference to the virtual origin. For simplicity, we assume all the zone IDs are positive.

zone center: For a zone with ID (a,b), the position of its center (x_c, y_c) can be calculated as:

$$x_c = x_0 + (a+0.5) \times r,\ \ y_c = y_0 + (b+0.5) \times r.$$

A packet destined to a zone will be forwarded towards the center of the zone.

zLdr: Zone leader. A zLdr is elected in each zone for managing the local zone group membership and taking part in the upper tier multicast routing.

tree zone: The zones on the multicast tree. The tree zones are responsible for the multicast packet forwarding. A tree zone may have group members or just help forward the multicast packets for zones with members.

root zone: The zone where the root of the multicast tree is located.

zone depth: The depth of a zone is used to reflect its distance to the root zone. For a zone with ID (a,b), its depth is:

$$\text{depth} = \max(|a_0 - a|, |b_0 - b|);$$

where (a_0,b_0) is the root-zone ID. For example, in Fig (a), the root zone has depth zero, the eight zones immediately surrounding the root zone have depth one, and the outer seven zones have depth two.

In EGMP, the zone-structure is *virtual* and calculated based on a reference point. Therefore, the construction of zone structure does not depend on the shape of the network region, and it is very simple to locate and maintain a zone. The zone is used in EGMP to provide location reference and support lower level group membership management. A multicast group can cross multiple zones. With the introduction of virtual zone, EGMP does not need to track individual node movement but only needs to track the membership change of zones, which significantly reduces the management overhead and increases the robustness of the proposed multicast protocol. We choose to design the zone without considering node density so it can provide more reliable location reference and membership management in a network with constant topology changes.

IV. NEIGHBOUR TABLE CONSTRUCTION AND ZONE LEADER SELECTION

A leader is elected with minimum overhead for efficient management of states in a zone. As a node employs periodic BEACON broadcast to distribute its position in the underneath geographic unicast routing, to facilitate leader election and reduce overhead, EGMP simply inserts in the BEACON message a flag indicating whether the sender is a zone leader. With zone size $r \le r_t/\sqrt{2}$, a broadcast message will be received by all the nodes in the zone.

To reduce the beaconing overhead, instead of using fixed-interval beaconing, the beaconing interval for the underneath unicast protocol will be adaptive. A non-leader node will send a beacon every period of $Intval_{max}$ or when it moves to a new zone. A zone leader has to send out a beacon every period of $Intval_{min}$ to announce its leadership role. When receiving a beacon from a neighbor, a node records the node ID, position and flag contained in the message in its neighbor table. The zone ID of the sending node can be calculated from its position, as discussed earlier. To avoid routing failure due to outdated topology information, an entry will be removed if not refreshed within a period TimeoutNT or the corresponding neighbor is detected unreachable by the MAC layer protocol.

A zone leader is elected through the cooperation of nodes and maintained consistently in a zone. When a node appears in the network, it sends out a beacon announcing its existence. Then it waits for an $Intval_{max}$ period for the beacons from other nodes. Every $Intval_{min}$ a node will check its neighbor table and determine its zone leader under different cases:

1) The neighbor table contains no other nodes in the same zone, it will announce itself as the leader.
2) The flags of all the nodes in the same zone are unset, which means that no node in the zone has announced the leadership role. If the node is closer to the zone center than other nodes, it will announce its leadership role through a beacon message with the leader flag set.
3) More than one node in the same zone have their leader flags set, the one with the highest node ID is elected.
4) Only one of the nodes in the zone has its flag set, then the node with the flag set is the leader.

V. ZONE SUPPORTED GEOGRAPHIC FORWARDING

The zone structure’s communication process includes an intra-zone transmission and an inter-zone transmission. In our zone-structure, as nodes from the same zone are within each other’s transmission range and are aware of each other’s location, only one transmission is required for intra-zone communications. Transmissions between nodes in different zones may be needed for the network-tier forwarding of control messages and data packets. In EGMP, to avoid the overhead in tracking the exact locations of a potentially large number of group members, location service is integrated with zone-based membership management without the need of an external location server. At the network tier, only the ID of the destination zone is needed. A packet is forwarded towards the center of the destination zone first. After arriving at the destination zone, the packet will be forwarded to a specific receiving node or broadcast depending on the message type. Generally, the messages related to multicast group membership management and multicast data will be forwarded to the zone leader to process. In Figure 1, for scalability and reliability, the center of the destination zone is used as the landmark for sending a packet to the group members in the zone although there may be no node located at the center position. This, however, may result in the failure of geographic forwarding.

To avoid this problem, we introduce a zone forwarding mode in EGMP when the underlying geographic forwarding fails. Only when the zone mode also fails, the packet will be dropped. In zone mode, a sender node searches for the next hop to the destination based on its neighbor table, which can more accurately track the local network topology. The node selects as its next hop the neighboring node whose zone is the closest to the destination zone and closer to the destination zone than its own zone. If multiple candidates are available, the neighbor closest to the destination is selected as the next hop. To compare the distances of different zones to the destination zone, the node can calculate the distance value dis(a,b) of a zone (a,b) to the destination zone (a_{dst}, b_{dst}) as:

$$dis(a,b) = (a - a_{dst})^2 + (b - b_{dst})^2$$

A zone with a smaller dis value is closer to the destination zone. In the above example, if the underlying geographic unicast forwarding fails at node 18, it will try to continue the forwarding using zone mode. It checks its neighbor table. Since the dis value of zone (0, 1) has zero value to the destination zone (0, 1), node 18 selects its neighbor node 7 in zone (0, 1) as the next hop and forwards the packet to node 7. To avoid possible routing loop, an intermediate node only forwards a packet that is received for the first time.

VI. PERFORMANCE EVALUATION

We implemented the EGMP protocol using Network Simulator and is compared with ODMRP and SBPM. The simulations were run with 400 nodes randomly distributed in an area of 2400m × 2400m. The nodes followed the modified random waypoint mobility model. The moving speed of nodes are uniformly set between the minimum and maximum speed values which are set as as 1m/s (with pause time as 100 seconds) and 20 m/s respectively except when studying the effect of mobility. Each simulation lasted 500 simulation seconds. Each source sends CBR data packets at 8 Kbps with packet length 512 bytes. The CBR flows start at around 30 second so that the group membership management has time to initialize and stop at 480 second. By default, there is one source, and one multicast group with 100 members.

A. Performance Metrics

We focus on the studies of the scalability and efficiency of the protocol under the dynamic environment and the following metrics were used for the multicast performance evaluation.

1) Packet delivery ratio

It is defined as the ratio of total number of packets that have reached the destination node to the total number of packets originated at the source node.

2) Control overhead

It is defined as the ratio of the number of control packets transmitted to the number of the data packets delivered.

3) Data packet transmission overhead

The ratio of the total number of data packet transmissions and the number of received data packets.

4) Average joining delay

The average time interval between a member joining a group and its first receiving of the data packet from that group.

B. Simulation Results

We first compare the performance metrics such as packet delivery ratio, control overhead, data packet transmission overhead and average joining delay of ODMRP, SPBM and EGMP with the variation of moving speed and node density. We then study the scalability of the three protocols with the change of group size.

1. Performance Metrics Vs Moving Speed

It is critical and challenging for a multicast routing protocol to maintain a good performance in the presence of node mobility in an ad hoc network. We evaluate the protocol performance by varying maximum moving speed from 1m/s to 6m/s.

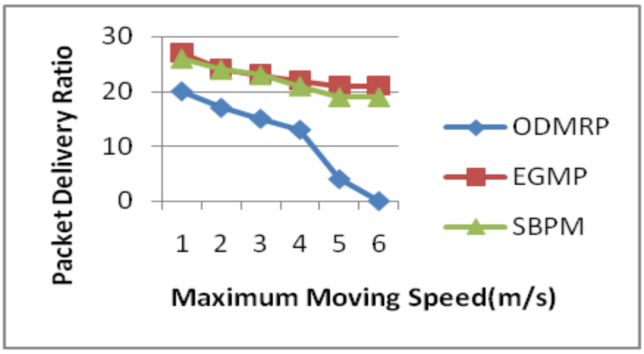
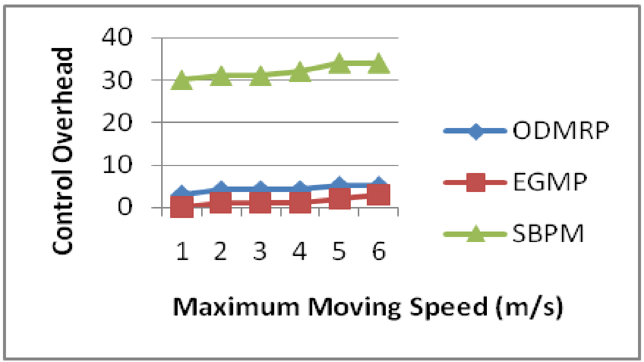


Fig (b) PDR Vs Moving speed

From Fig (b), the packet delivery ratios of EGMP, SBPM and ODMRP reduce as mobility increases, while the packet delivery ratio of ODMRP drops much faster.



Fig(c) Control Overhead Vs Moving Speed

The control overhead of EGMP seems to be lower than those of ODMRP and SPBM at different moving speeds (Fig(c)). The control overheads of all the protocols increase at higher mobility.

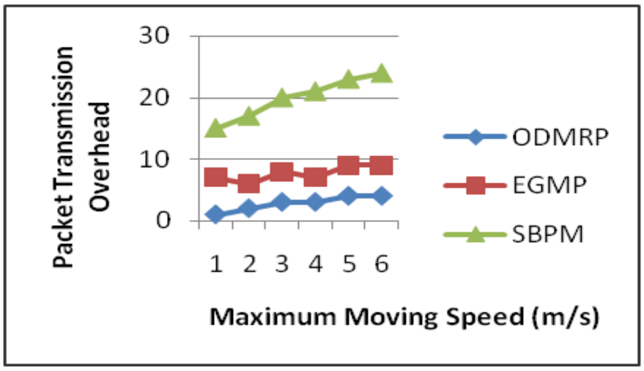


Fig (d) Packet Transmission Overhead Vs Moving Speed

In EGMP, when a node wants to join a group, it will start the joining process immediately, and with the efficient tree structure assumed, the nodes can join the multicast structure very fast as shown in Fig (d). SPBM seems to have the largest joining delay most of the time when compared with ODMRP and EGMP.

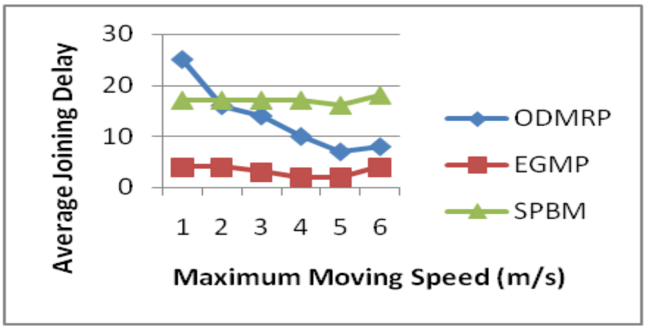


Fig (e) Avg. Joining Delay Vs Moving Speed.

2. Performance Metrics Vs Node Density

Geographic routing is sensitive to the node density and performs better in a dense network. Node density is also closely related to the performance of zone-based protocols. When the node density is low, there will be more empty zones, which will negatively affect the performance.

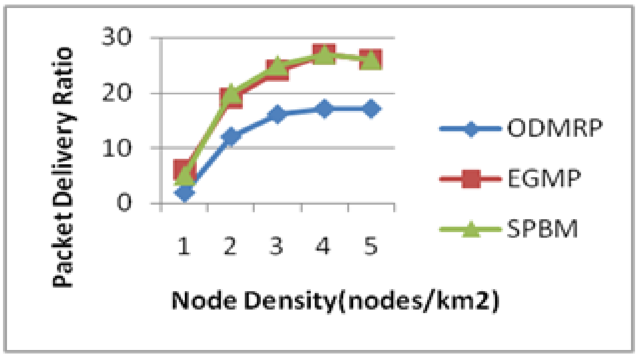


Fig (f) PDR Vs Node Density

Both EGMP and SPBM have higher delivery ratios at a higher node density (Fig (f)). The delivery ratios of all three protocols are lower when the network is sparsely populated. However, when the node density is higher than 50 nodes/km2, the increase of delivery ratio becomes slower, as there are more collisions among nodes and hence more packet loss.

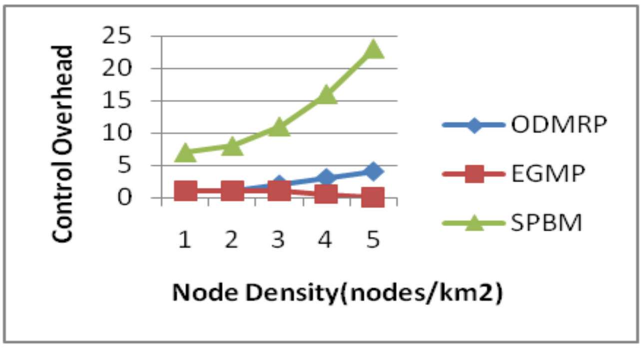


Fig (g) Control Overhead Vs Node Density

In Fig (g), the control overhead of SPBM rises quickly with the increase of node density as more nodes are involved in the periodic multi-level flooding for the membership management. When the network is very sparse, EGMP has a slightly higher control overhead than that of ODMRP.

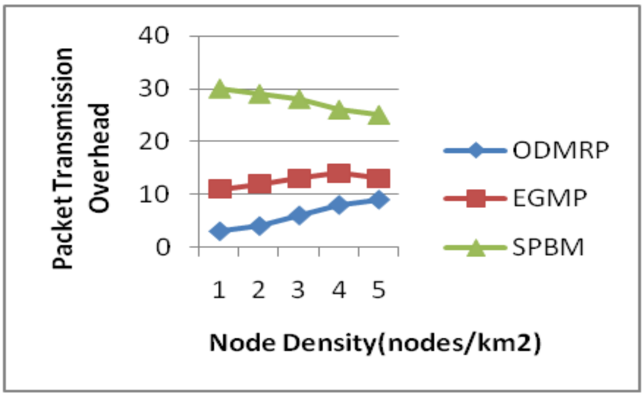
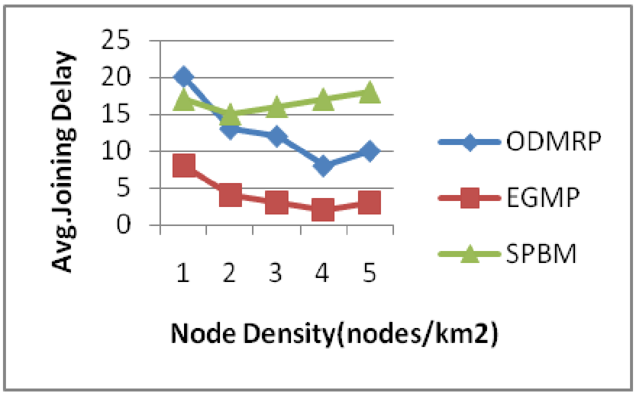


Fig (h) Packet Transmission Overhead Vs Node Density

SPBM has the highest Packet Transmission overhead when compared with other two protocols (Fig (h)). The Packet transmission overheads of both EGMP and ODMRP increase, when the mobility increases.



Fig(i) Avg. Joining Delay Vs Node Density

The average joining delay of SPBM is more at high mobility Fig(i) and the average joining delay of ODMRP is high at low mobility when compared with other two protocols.

3. Performance Metrics Vs Group Size

The protocol performances with the group size varied from 10 members to 200 members are evaluated.

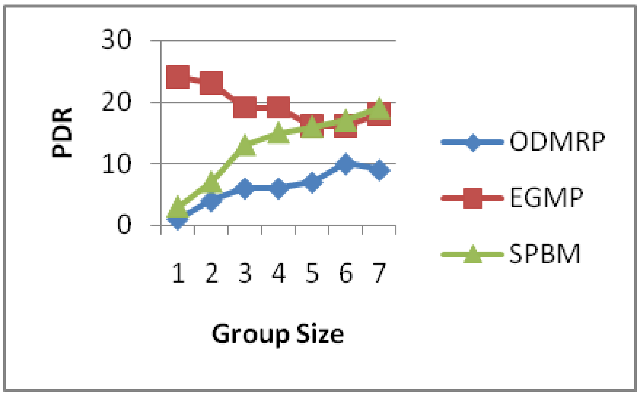


Fig (j) PDR Vs Group Size

Fig (j) demonstrates that EGMP can scale to a large group size and perform well with various group sizes. When the group size increases, the delivery ratios of ODMRP and SPBM rise. In EGMP, Packet delivery ratio is more when group size is small when compared with ODMRP and SPBM.

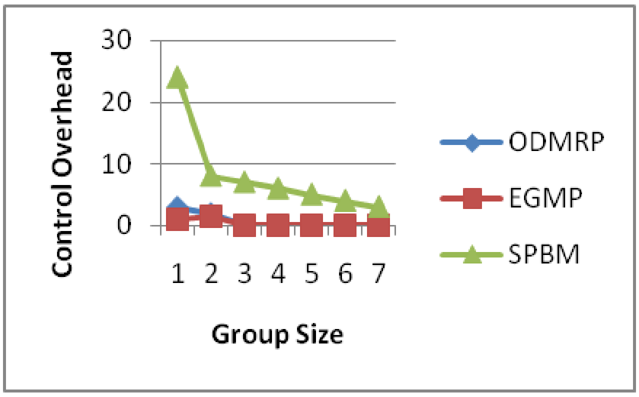


Fig (k) Control Overhead Vs Group Size

In Fig (k), ODMRP and SPBM are seen to have very high multicast control overheads when the group size is small. While in EGMP, the multicast overhead remains very low at different group sizes.

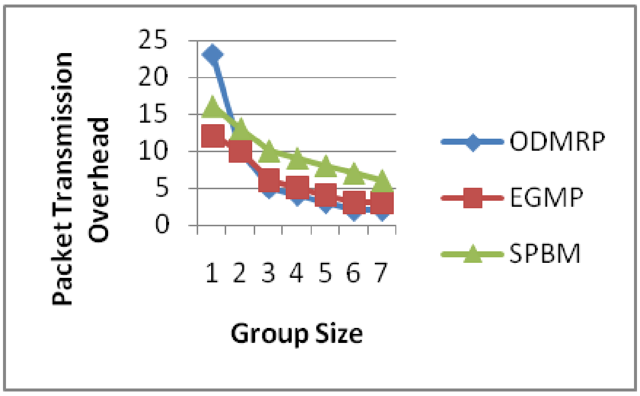


Fig (l) Packet overhead transmission Vs Group Size

In Fig (l), the data packet transmission overheads of all the protocols reduce when the group size increases as a result of the higher aggregations of packet transmissions. ODMRP has a high packet transmission overhead when the group size is small.

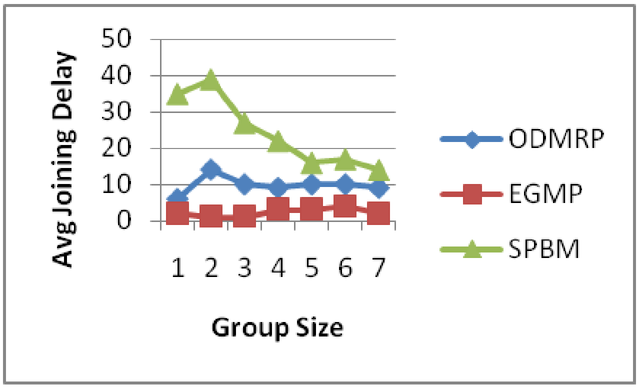


Fig (m) Avg. Joining Delay Vs Group Size

In Fig (m), the change of group size has different impacts on the joining delay of the three protocols. In ODMRP, the joining delay is lower when the group size is small. In EGMP, the joining delay is increased when the group size increases. The joining delay of SPBM drops as the group size goes up.

VII. CONCLUSION

In this paper, the performance metrics such as packet delivery ratio, control overhead, packet transmission overhead and average joining delay of the protocols such as EGMP, ODMRP and SPBM are compared with speed, node density, and group size. Compared to the classical protocol ODMRP, both geometric multicast protocols SPBM and EGMP could achieve much higher delivery ratio in all circumstances, with respect to the variation of mobility, node density, group size and network range. Our results indicate that geometric information can be used to more efficiently construct and maintain zone structure, and to achieve more scalable and reliable multicast transmissions in the presence of constant topology change of MANET. Our simulation results shows that EGMP has high packet delivery ratio and low control overhead and multicast group joining delay under all cases, and is scalable to group size when compared to both SPBM and ODMRP.

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