Scalable Multicasting through Hexagonal Zone Based Structure Over Mobile Adhoc Networks

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Abstract

Mobile Ad-hoc NETwork (MANET) is a multi-hop autonomous network formed exclusively with a collection of mobile nodes without any centralized infrastructure. A multicast routing protocol is essential to enable efficient group communication for critical applications. Recently, several stateless multicast routing protocols have evolved to achieve scalability. However, overhead in group membership management and zone construction under a highly dynamic network topology are the key issues in scalability. Hence, this paper proposes a Location Aware Multicasting Protocol (LAMP) to improve the scalability of multicast routing with limited overhead. The proposed LAMP encompasses three mechanisms such as minimum length multicast tree construction, zone based greedy multicast forwarding and mobility adaptive tree maintenance. The LAMP employs minimum length based multicast tree construction and creates the hexagonal zone-based structure. This type of structure significantly increases the coverage and the number of nodes associated with the leader of each zone. The large coverage reduces the communication overhead as well as the propagation delay considerably while performing multicast routing and tree maintenance. The hexagonal zone based greedy multicast forwarding scheme decides the multicast tree branches and strategically selects the greedy forwarder for a group of receivers to reduce the overall path length. The mobility adaptive tree maintenance optimizes the performance of multicast routing by adjusting the tree structure over concurrently changing topology. The zone members facilitate the ultimate forwarding decision by enabling the up-to-date positions. The experimental results demonstrate that the LAMP has a high throughput and significantly lower routing overhead regardless of network size, group size, and node speed. From the results, it is observed that the proposed LAMP protocol improves the throughput by 7.3% and reduces the delay by 23 % compared to the EGMP.

Keywords: Multicast, Stateless routing, Greedy multicast routing and mobility prediction

1 Introduction

The Mobile Ad-hoc Network (MANET) is composed of self-organizing mobile nodes connected through a wireless link without any network infrastructure [1]. The multicast routing is a robust method for group communication, where informationis forwarded to a group of nodes simultaneously [2]. The conventional multicast routing depends on the prior creation of a tree structure or mesh, in which each node has to maintain the state information. In dynamic network conditions, the maintenance of multicast state leads to a significant routing and memory overhead [3]. Recently, the multicast routing has been exploiting the knowledge of geographical information to enable the multicast sender to choose the best route to advance the multicast traffic.

The geographical multicast routing is considerably scalable and robust for a highly dynamic network topology [4-6]. However, significant issues remain in the implementation of scalable and efficient geographic multicast routing. For instance, the unicast geographic routing enables a node to carry the position of the receiver in thepacket header to guide the packet forwarding. However, the multicast routing considers a group of nodes as multicast receivers. Even though pushing all the information of the receivers into the packet header is an easy and straightforward method, it is suitable only for a small group. In addition to the efficient packet forwarding, the multicast routing also needs efficient membership management of a large group and packet transmission to the receivers spread over a vast network area. Moreover, multicast routing has to manage potentially conflicting properties: (1) The path length to the individual multicast receivers has to be as short as possible and (2) Maintain a minimum number of hops to advance the packet to all multicast receivers.

This work proposes a Location Aware Multicasting Protocol (LAMP) to solve the network scalability issue. The LAMP divides the network into hexagon zones to

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manage the group membership efficiently, and successfully track the position of all the multicast receivers without any location server externally. The hexagon is an effective structure for network partitioning, compared to circle and square because the circle creates gaps and the square shrinks the area. The greedy multicast routing potentially reduces the number of transmissions by engaging the hexagonal zone structure, while decreasing the hop count to reach the individual multicast receiver. Moreover, the LAMP utilizes the mobility prediction approach to estimate the lifetime of each terminal link in the hexagonal zone. Thus, the proposed work decisively balances the multicast delay and routing overhead over a dynamic network topology. The primary contributions of the work are:

- The proposed LAMP enables a scalable multicast routing for efficient group communicationusing the knowledge of geographical information.
- The LAMP facilitates the sender to forward a packet to the middle of the receiver zone without the assistance of any specific geographical information of receivers or any external server to identify the position of multicast receivers.
- The LAMP partitions the network terrain into hexagonal zones to support a scalable multicasting that maintains a large network with potentially a significant number of multicast receivers. Utilizing the advantage of the hexagonal zone structure apparently, takes up a circle area without overlaps and holes. Thus, it covers a large number of nodes in a single transmission and reduces the overhead of the zone membership management.
- The hexagonal zone supported greedy multicast forwarding reduces the numbers of transmissions that groups the geographically closer zones of multicast receivers and divide off packets depending on the direction of the group.
- The Mobility Adaptive Tree Maintenance predicts the position of neighbors and enables adaptive beaconing. Thus, reducing the routing overhead while maintaining the multicast tree.

2 Related Works

The network scalability is a major issue in several multicast routing protocols due to high processing overhead and the frequent update of topology. Several topology based multicast routing protocols have been proposed such as On-Demand Multicast Routing Protocol (ODMRP) [7]. The ODMRP exploits the mesh approach for delivering the packets and enables the sources to build the mesh structure, rather than receivers. The nodes involved in the mesh structure maintaining the cache to determine and control the duplicate data packets. The nodes can select either soft or hard state. Unlike the hard state, the soft state implies the receivers to avoid the use of explicit control messages to leave the mesh group. During group joining, it is necessary to use two kinds of control packets, such as join query and join response. The overhead in ODMRP is constant, as it does not trigger any explicit messages to update the node movement. Thus, the ODMRP support a high mobility scenario, but not scalable to a large number of nodes. An Adaptive-ODMRP (A-ODMRP) in [8] extends ODMRP with the adaptive control mechanism. This control mechanism avoids the interference issue of ODMRP in the dynamic network topology. The geographic multicast routing is the best way to support large scale networks due to the stateless nature. The following section discusses several geographic routing protocols and summarizes the techniques employed to improve the scalability.

2.1 Location Aware-Tree/Mesh-Based Multicasting Techniques

The Geographic Multicast (GEM) routing in [9] follows the Euclidean Steiner Tree for multicast tree construction to support scalable routing. This mechanism significantly reduces the total length of the multicast tree and considering only the hop count of the un-weighted graph and not the path length of the individual multicast receiver. Moreover, while performance analysis, it works based on the assumption that all nodes are distributeduniformly, and this makes it hard to provide the same efficiency under a practical network environment. In the design of an Adaptive Distributed Multicast Routing Protocol (ADMRP) [10], the characteristics such as topology change, battery energy [11-13], and network capacity are the factors to compute the forwarding list dynamically and preserve the network bandwidth and reduce the channel collision. The Scalable Energy Efficient Location Aware Multicast Protocol (SEELAMP) [14] effectively minimizes the root search and maintenance overhead by applying the local connectivity management. Moreover, it employs a preventive route configuration mechanism that completely restricts the communication delay in terms of link breakage and also protects the network from partitioning. However, these techniques are ineffective in a large scale network because pushing all destination ids into the packet header increases the overhead significantly. To accomplish better performance over a large-scale network, a stateless multicast routing protocol is enhanced with a fisheye view of the dynamic mesh in [15].

2.2 Location Aware-Zone Based Multicasting Techniques

To scale to large size network, an Efficient Geographic Multicast Protocol (EGMP) [16] exploits two-tier architecture. This structure implements a zone based multicasting to handle the group member management. By using the location information, the source node transmits the packets to the zone leader, and the leader applies flooding to deliver the multicast packets to the group members, which are located in the same zone. Additionally, the membership management is used to track the location of members, instead of using the external location server. EGMP results in relatively constant overhead, and so it can provide more reliable communications over high mobility scenario. The source zone is announced as a root zone, which plays a vital role in measuring the zone depth and facilitating a reliable group communication. The EGMP floods the data within the zone area, instead of following the network-wide flooding. This flooding makes the EGMP more scalable to both the large group and network. The Scalable Geographic Service Provisioning (SGMP) [17] exploits the advantage of management layers based on the density and capability of nodes. In each layer, it selects one node as a service coordinator, which assists mobility management. In Hierarchical Rendezvous Point Multicast (HRPM) [18], the service coordinator executes the service aggregation and management over different levels of hierarchies.

The EGMP [16, 19] and Position Based QoS Multicast Routing Protocol (PBQMRP) [20-22] support multiple group members using the zone-based scheme to provide scalability in terms of group and network size. It tracks the location information of the group members efficiently without adopting any external location service. Besides the empty zone problem, it is possible to handle even in a dynamic network topology by adjusting the virtually formed zone structure [19, 23]. The PBQMRP mainly addresses the scalability problem in multicast routing. Irrespective of the group and network size, the multicast routing protocols should provide better performance for real-time multimedia applications. The main aim of PBQMRP is to design a scalable multicast solution using a virtual clustering model. This model divides the network area into hexagonal clusters and searches the routes with some specified QoS constraints using location information. Moreover, it transmits the multicast packets from one cellto another cell with reduced routing overhead, by utilizing the properties of hexagonal clustering effectively. This process supports the PBQMRP with no duplicate packet transmission. Furthermore, a hierarchical construction of the multicast members has been proposed to improve forwarding efficiency and scalability. However, the PBQMRP does not explain the provision of cell identification. In the case of using additional control messages, it escalates the interference and packet loss with the increase in network size. To avoid the duplication, [24] extends the Protocol Independent Multicast (PIM) by removing the usage of explicit control messages. In [25], the mobility prediction is applied to schedule the links for efficient routing. It reduces the beacon overhead but does not consider the tree length in a multicast tree construction and data forwarding, which results in unnecessary data delay. Moreover, high routing overhead due to membership maintenance is a significant challenge in multicasting.

3 Location Aware Multicasting Protocol

This work presents a scalable and mobility adaptive position based multicast routing protocol by embracing the location information. The proposed work uses Minimum Length Multicast Tree Construction, Zone Supported Greedy Multicast Data Delivery and Mobility Adaptive Tree Maintenance. The LAMP protocol partitions the network topology into multiple hexagonal zones and efficiently handles the group membership. The greedy multicast routing extends the position-based greedy routing, and it has to solve two key problems in the multicast scenario. In the first scenario, at a particular node, a multicast packet has to be made into multiple copies to deliver to the multicast receivers; here the challenge is to make a decision when such a copy has to be created. In fact, instead of considering the position information of the individual receiver, the LAMP enables the sender to select a greedy zone for the receivers that are co-located in the same zone or neighboring zones. In the second scenario, the LAMP adapts to accept the zone of receivers as the destination and ignores the external location server. Finally, the LAMP optimizes the performance of multicast routing and the routing overhead through updating the location information based on the topology changes. Thus, the proposed LAMP significantly implements efficient and scalable multicast routing under a highly mobile ad-hoc network.

3.1 Minimum Length Multicast Tree Construction

The proposed work virtually forms the zone with the assistance of location information and reduces the overhead in multicast tree maintenance rather than connecting the multicast members directly to the tree. Even though the communication range of a node is a circle, the conventional multicasting works divide the network into square zones because the circle zone creates gaps. However, it is essential to identify the shape which apparently takes up a circle area.

The proposed work divides the network into hexagon zones. The hexagon is the most efficient structure for network partitioning since the circle creates gaps and the square makes the area smaller. There are two main reasons to consider hexagonal zones in the proposed work. Firstly, taking into account the circle, square, and hexagonal zone shapes, and it is assumed that the transmission range (R) is the maximum distance between the nodes in a zone. It compromises the overhead of network maintenance and the location service, especially when managing a large network. The radius of the circle shape is reduced to R/2, and the side length of the hexagon and square shapes are taken as the R, divided by 2 and 2√2 respectively as shown in Figure 1. Thus, ensures the maximum distance between zone members as R. The area covered by the circle with the radius of R/2 is 0.785 R^2. As the circle creates gaps in network partitioning, it is essential to identify the shape which apparently takes up a circular area of 0.785 R^2. The area covered by the hexagon shape (0.6495*R^2) is closer to the circle than the square (0.5*R^2).

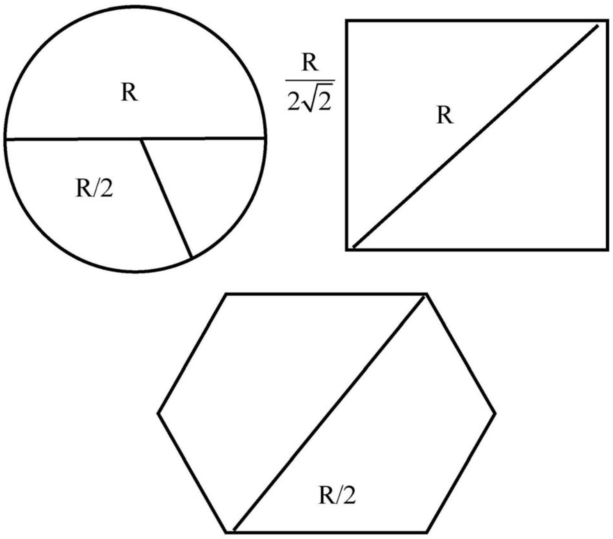


Figure 1. Deciding circle's radius and side length of square and hexagonal shapes

The large zone area indicates that the number of zone leaders is small, i.e., minimize the overhead due to zone member or leader movement, failure, and electing newleaders. Moreover, when there is a larger area, the hexagonal zone shape potentially covers a large area in a single communication, which increases the coverage of the number of nodes associated with the leader of each region.

This scenario reduces the communication overhead significantly and minimizes the transmission delay in performing the multicast routing and tree maintenance. Moreover, the zone offers hexagonal transmission in six directions, maintaining the same distance between the centers of the neighbor zones. On the other hand, the square shape has a larger number of neighbors (8), but the distance between the centers of the neighbor zones is different, resulting in differences in packet propagation to various neighbor zones.

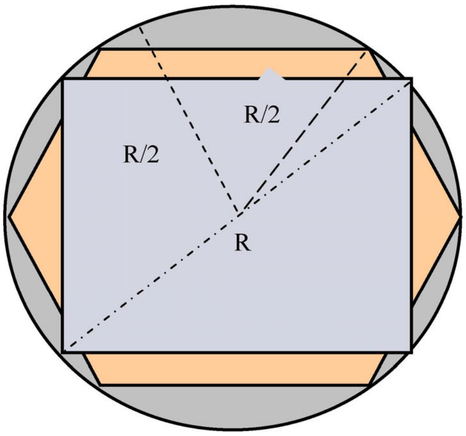


Figure 2. Area comparison of square, hexagon, and circle

3.1.1 Notations

The network environment is divided into hexagonal zones as shown in Figure 3. The notations used are:

ZN_{id}: Zone identification. A node which calculates its zone ID (i, j) from its location coordinates (x, y).

Z_{ldr}: Zone leader, the node which has the responsibility to maintain group membership.

H-zone: Indicates the zone in which the multicast tree originates.

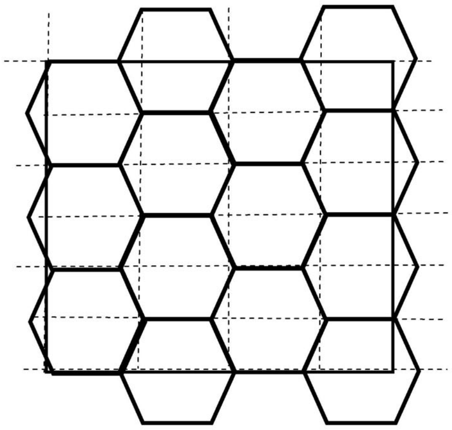


Figure 3. Hexagonal network partitioning

3.1.2 Zone Construction

Let the nodes spread over a square region (A) with the dimensions of H and W units. The network areais virtually dividedinto equal size hexagonal zones, and each node calculates its corresponding zone id. The location information of each node is defined by(x, y) coordinates and the location is identified either by employing the GPS or any other localization method. To reduce the control overhead, each node identifies its corresponding ZN_{id} using the equation (1) to maintain the multicast tree. In the proposed work, each node is allowed to measure zone's id using its location coordinates and reduces the control overhead explicitly. Where, m= 2x/3R, n=y/R, and R'=R/2.

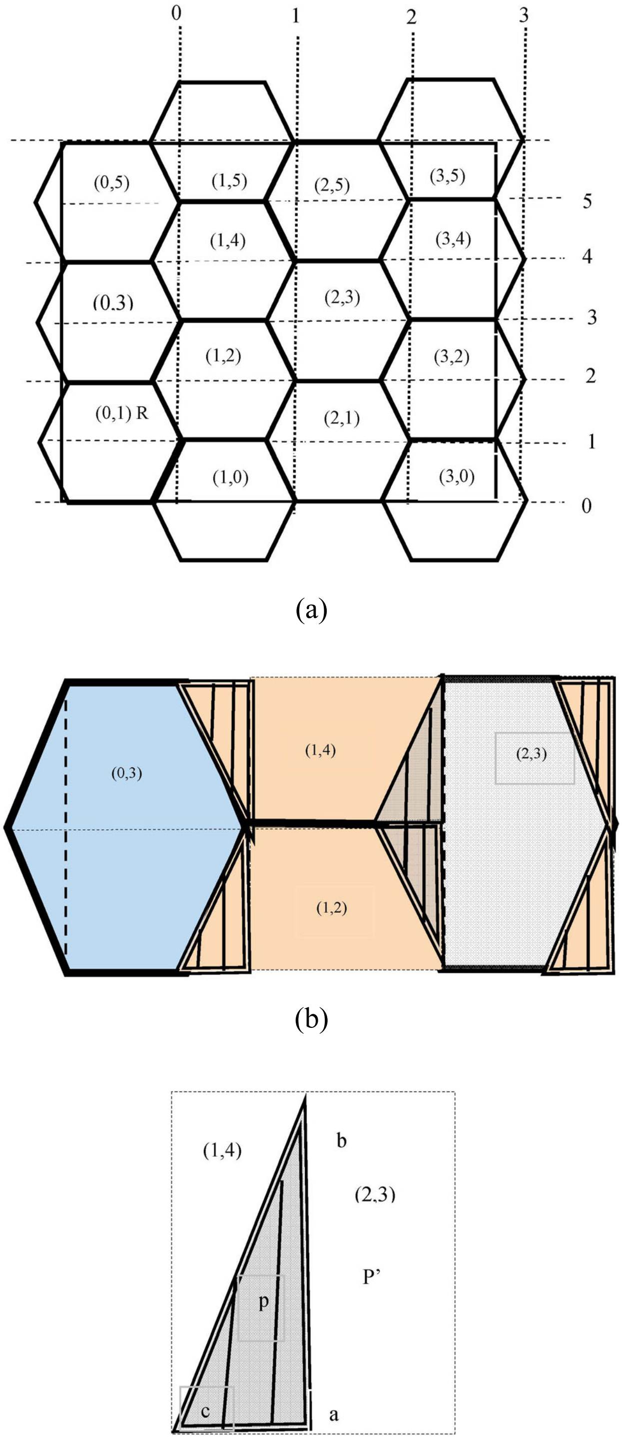
$$ZN_{id}(i,j)=\begin{cases} \left.\begin{array}{ll} \{(2m+1),\ n-2\} & \text{if } Fe(UT)(i,j) \text{ is true} \\ \{(2m),\ (2n-2)\} & \text{if } Fe(DT)(i,j) \text{ is true} \\ \{(2m-1),\ (2n-1)\} & \text{else} \end{array}\right\} & \text{if } (2m-1) == \text{zero (or) even} \\ \left.\begin{array}{ll} \{(2m),\ ((2n/3)+2)\} & \text{if } Fe(UT)(i,j) \text{ is true} \\ \{(2m),\ (2n/3)\} & \text{if } Fe(DT)(i,j) \text{ is true} \\ \{(2m-1),\ ((2n/3)+1))\} & \text{else} \end{array}\right\} & \text{if } (2m-1)==\text{odd } \& \ R'>y<(H-R') \\ \left.\begin{array}{ll} \{(m+1),2n\} & \text{if } Fe(UT)(i,j) \text{ is true} \\ \{(m+1),\ 2n-1)\} & \text{if } Fe(DT)(i,j) \text{ is true} \\ \{m,2n-1\} & \text{else} \end{array}\right\} & \text{if } (2m-1)== \text{ odd } \& \ R'<y>(H-R') \end{cases} \quad .... (1)$$

```
Every node estimates its corresponding zone id by executing the satisfied if condition.

If (2m-1) returns zero (or) even value, where m=2x/3R
{
        If even Function of UT returns true
        {  Zone Id = {(2m+1), n-2}  }
        ElseIf even function of DT returns true
        {  Zone Id = {(2m), (2n-2)}   }
        Else
        {  Zone Id = {(2m-1), (2n-1)}  }
}

ElseIf (2m-1) returns odd && R'>y<(H-R')
{
        If odd function of UT returns true
        {  Zone Id = {(2m), ((2n/3)+2)}  }
        elseIf odd function of DT returns true
        {  Zone Id = {(2m), (2n/3)}      }
        else
        {  {(2m-1), ((2n/3)+1))}        }
}

Else (2m-1) returns odd && R'<y>(H-R')
{
        If odd function of UT returns true
        {     Zone Id = {(m+1),2n}     }
        elseIf odd function of DT returns true
        {     Zone Id = {(m+1), 2n-1)}  }
        else
        {     {m,2n-1}            }
}
```

Figure 4. Pseudo code for distributed zone ID provision

To cluster the nodes into several hexagonal regions, the proposed LAMP protocol initially divides the network into rectangles to simplify the zone id provisioning, as shown by dotted lines in Figure 5(a).

The zoom in on a particular region of Figure 5(b) is illustrated in Figure 5(c).



(a)

(b)

(c)

Figure 5. Network partitioning in LAMP

The nodes in the shaded rectangles are presented in three different hexagonal zones. For example, the node which satisfies the condition of(2m-1)==odd & R'>y<(H-R') is either in the zone {(2m), ((2n/3)+2))}, {(2m), (2n/3)} or {((2m-1), ((2n/3)+1)} as in the equation (1). The nodes in the yellow rectangles in figure 5(b) lie either in (0,3), (1,2), or (1,4). Using the equation (1), the LAMP enables the nodes in a yellow rectangle to identify whether its coordinates lie inside the crossed yellow triangles or not. In the equation (1), the function (F_o) returns true, if the coordinates lie inside the crossed yellow triangle, otherwise returns false. Based on these functions, the nodes in the shaded yellow rectangles identify its ZN_{id}..

In Figure 5(b), the nodes in the gray triangle are either in Upper or Lower crossed gray triangles (UT and DT). Let the coordinates of three corners of Upper triangle be a, b, and c as shown in Figure 5(c) be clearly visible in a triangle using the location coordinates. Consider the coordinates of the given node P be (x_p, y_p) to find the results of F_e, since the zone of (2,3) satisfies the condition of(2n-1) == even. The triangular area of pcb, pac, and pab is equal to the area of abc, and the function F_e returns true. However, for p' it returns false. From the equation (1), each node uses its coordinates to associate itself with a hexagonal zone. Each node executes this equation locally and exerts a lightweight in communication overhead.

3.1.3 Location Table Generation and Zone Leader Election

A member node in the routing zone maintains a location table. The location table is a location database which holds its geographical position information and as well as neighbors within the communication range, R. Each entry in the location table includes node's ID, location, and a timestamp. Initially, each node broadcasts a beacon message to inform its location information for its one-hop neighbors for every interval (min-Int). The beacon message format is {Node_ID, Location, Time-Stamp, ZN_{id}}. Each entry in the location table expires depending upon the inserted time stamp value. Each zone elects a zone leader (Z-ldr) among the cooperating nodes and maintains it within a zone consistently. For every interval (min-Int), each node sends beacon messages to the nodes in a zone, and only the Z-ldr enables the leader flag in the beaconB(node id, zone ID, Flag). When a node enters into a zone, it announces its existence by sending out a beacon message. The node waits for max-Int to receive the beacons from Z-ldr and other nodes. After the max-Int, each node ensures its neighbor table and elects the Z-ldr differently in the followingcases:

Case 1: A zone contains a single node

(1) It is selected as a leaderby itself.

Case 2: A zone contains multiple nodes

(1) In a zone, if flag bit of all the nodes is disabled, no nodes in the zone are selected as a leader. Therefore, the proposed system enables the node which is closer to the center of the zone as a Z-ldr and broadcasts the beacon message for announcing a Z-ldr role to all the nodes in its zone.

(2) If one node existing in the zone enables the flag, then the node set with the flag acts as Z-ldr.

(3) In the same zone, if more than one node enables the flag bit, the node with the highest node ID acts as a Z-ldr.

In case 2, a node closer to the zone center is selected as a Z-ldr. The accurate detection of the midpoint of the zone area needs six vertices of a zone, resulting in high computational complexity. To simplify the selection of Z-ldr, the LAMP enables each node to apply average distance measurement on all of its neighboring nodes with the same ZN_{id}. For every neighbor, the node estimates the average distance to the remaining neighboring nodes. If a node has a least average distance to the neighboring nodes, the node is located closer to the center of zone area. Thus, the node broadcasts the beacon message for announcing a Z-ldr role to all the neighboring nodes in its zone.

3.1.4 Multicast Session Initiation and Termination

Each node maintains a label that represents the role of the node in a multicast tree. "S" is the source and "MR" is the Multicast Receivers. In multicast session initiation, the node S sends a packet including all MR's identifiers, and thus the nodes become aware whether they are MR. On arrival this message, each multicast receiver labels it with "MR" and waits to take part in the multicast routing. On the initialization of multicast session MS, the source node S broadcasts the new session {MS: Z_{id}, Session_ID, Sequence Number, Time-Stamp} into the whole network to announce the existence of M. The zone of the source node is used as an H-Zone. When a node MR receives and interests in the new session message MS, initially it sends Join Request message to the Z-ldr and confirms the tree connection. The Join Request message includes the fields of {Member_ID, ZN_{id}, Session_ID, Sequence Number}. The sequence number is used for representing the freshness of the packet. Both the Session_ID and sequence number avoid the unnecessary transmission of delayed packets. Each group member maintains the membership table that contains an entry {M; H-Z_{id}; isAck}, where M is a zone member, H-Z_{id} is the H-zone id, and isAck is a flag which indicates the membership of a node in the multicast tree. The zone leader is responsible for maintaining the entries of the multicast table.

When a new session message arrives, the zone leader records the group ID and the H-Z_{id} in its multicast table. The source node begins data communication by establishing the inter-receiver zone depth and route consolidation mechanism. To terminate the session or re-initiate the session due to the mobility of the source node, it sends the End_ session message to the network. Moreover, after its movement, a source node sends the new session message with the current location information to re-initiate the session. Figure 6 shows the flow chart for the multicast initiation and termination processes.

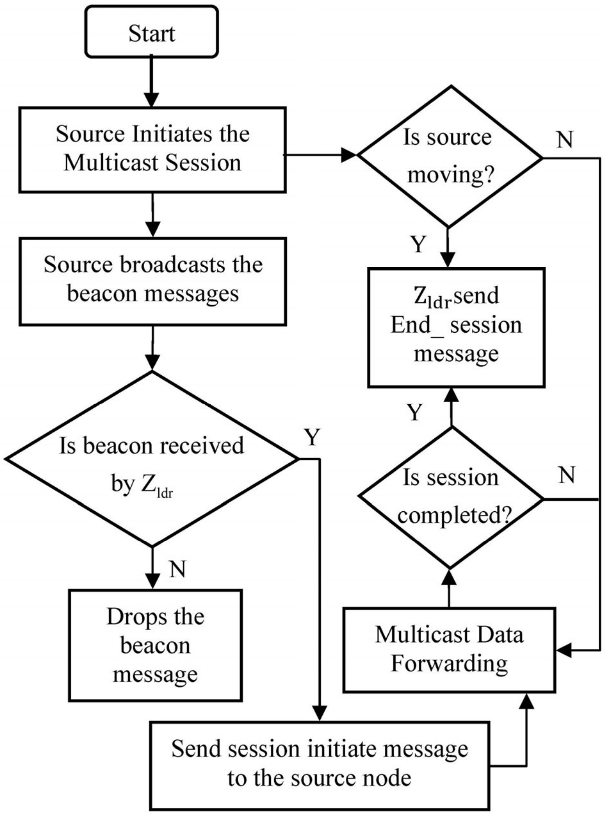


Figure 6. Flowchart for multicast session initiation and termination

3.2 Zone Supported Greedy Multicast Data Delivery

The proposed LAMP forwards the packets to destinations along the established multicast tree among the nodes. At branching points, packet copies are disseminated to all the branches. There are two conflicting properties in multicast communication: (1) The path length to the individual multicast receivers has to be as short as possible and (2) minimize the number of hops needed to advance the packet to all the multicast receivers. If the location coordinates of the nodes are known, the multicast tree significantly optimizes the first criterion using the shortest paths to all the multicast receivers, but the second criteria are yet to be addressed. There is a necessity to provide greedy adaptive routing for multicast scenario and to decide where the multicast receivers have to be grouped, or the packet has to be divided into several copies to reach all the receivers.

When a node S wants to send the data packets to a list of multicast receivers (MR1; MR2; MR3) as shown in Figure 7, it splits the network into three regions (W) with 120^0. Then, it splits off a copy of the packet to each region that contains the set of multicast receivers (MR_w). To find the greedy multicast zone in each region, it executes the function of zone depth, Fi for each neighbor zone (W_{zone}) to the zone of all multicast receivers MR_w, as shown in the equation (2). However, the multicast receiver is likely to be located in the sender zone, in such a case the sender node directly transmits the packet to the receiver. Thus, it excludes the receivers in its zone from the MR_w. For example, Figure 8 shows the data transmission through the multicast tree. Consider, the zone (1,2) as a sender, and it divides the network into three regions as shown in Figure 7(a). The blue color zones ((1,4),(2,3)) are the neighboring zones W_{zone} of the sender in region one as shown in Figure 7(b). Among them, the W_{zone} of (2,3) is identified as the ideal one to reach the multicast receivers in the region (W=1) with the ZNid of {(1,5),(2,5),(3,5),(2,3)} using the equations (2) and (3). Then, the sender node forwards the data packet towards the zone leader (Nh1) of the selected multicast greedy zone (2,3) to reach the multicast receivers of region 1. This process is repeated in all the regions until it reaches all the multicast receivers.

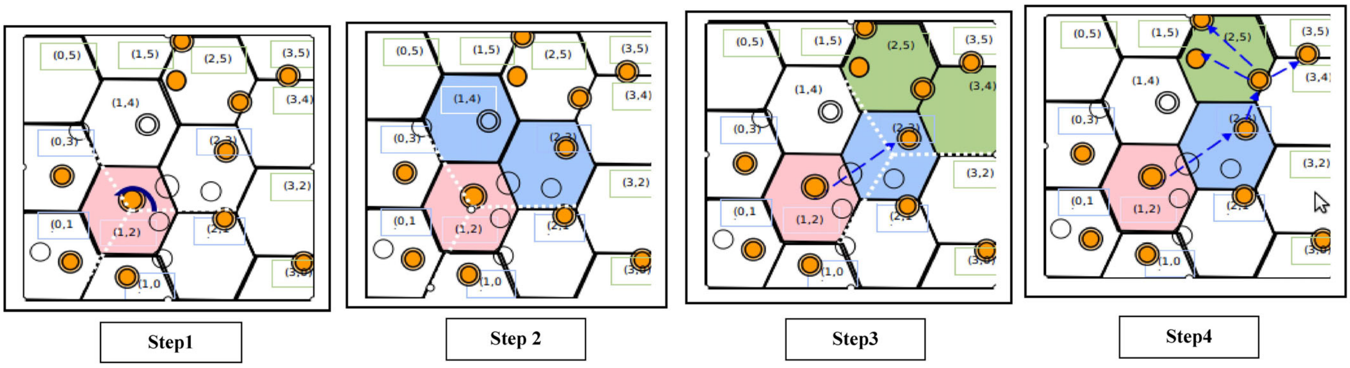


Figure 7. Greedy multicast routing in LAMP

$$C = a * (N_{zone} / N)$$

$$D = \left(\sum_{x=1}^{|MR_w|} (Dist(W_{zone}, MR_x)) / \sum_{x=1}^{|MR_w|} (Dist(Dist(s, MR_{W_x})) \right)$$

$$Fi(W_{zone}) = C + (1-a) * D \qquad \textbf{(2)}$$

The number of nodes in a zone of W (N_{zone}) is decided by the first section of the equation (2), and it is denoted as N_{zone}. The value of N_{zone} is normalized into [0, 1] by dividing it by the total number of nodes, N. The second section of equation (2) determines the id distance or zone depth from the location of a W_{zone}

leader to the multicast receivers of a particular region. It normalizes the value between [0, 1] by dividing it by the zone depth calculated from the source zones for the multicast receivers' zone of region W. The value of 'a' is always 0.5 since both the normalized N_{zone} and zone depth are important to ensure better connectivity and fast delivery respectively. In equation (3), x represents a candidate in MR_W, and $\{ZNid(i), ZNid(j)\}_{Wzone}$ and $\{ZNid(i), ZNid(j)\}_{MRWi(x)}$ represent the location coordinates of W_{zone} leader and $MR_{W(x)}$ respectively. By applying the location coordinates of $MR_{W(x)}$ in a distance measure, the equation (3) estimates the Distance between W_{zone} and MR_{Wi}.

$$A = (ZN_{id}(WZone)_i - ZN_{id}(MR_{W_x})_i)^2$$
$$B = (ZN_{id}(WZone)_i - ZN_{id}(MR_{W_x})_j)^2$$
$$Dist(WZone, MR_{w_i}) = \sqrt{A+B} \qquad \textbf{(3)}$$

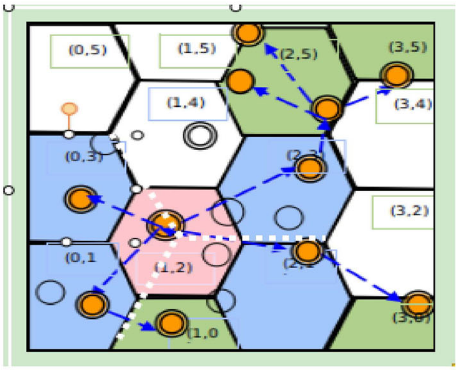


Figure 8. Greedy multicasting in LAMP

Before sending the data packets, each forwarder adjusts the region size when the region has the same multicast greedy zone selected by an adjacent region as greedy, and this adjusts the region size and can reduce the multicast delay. For example, the multicast receiver of the zone (1,0) is located in region 2, but it is joined with region3 according to this rule. Moreover, the source node attaches the list in the packet header. For instance, (Nh1: MR_{W11}, MR_{W12}, MR_{W13}, MR_{W14}, MR_{W15}; Nh2: MR_{W21}; MR_{W22}; Nh3: MR_{W31}, and Nh4: MR_{W31} and MR_{W32}), where Nh1 is the next hop node selected for the multicast receivers. MR1-MR5 in the region of W1 and Nh2 is the next hop node for two multicast receivers in W2. Moreover, the Nh3 is selected for the last two receivers in the region of W3. On arrival of the packet, a node retains it, if it is the destination or one of the next hop, otherwise, drops the packet. The neighboring nodes also follow the same rule as the source node to select the greedy zone to send data packets towards corresponding multicast receivers. The greedy multicast routing aims to deliver the packets to multiple receivers with less number of transmissions. When there is no such neighbor for a receiver, the perimeter forwarding mode is enabled to escape from the communication hole.

3.3 Mobility Adaptive Tree Maintenance

In a highly dynamic network topology, it is hard to manage the multicast tree structure. The mobility prediction is the best way to en-count the node failure. Even though the location assisted multicast routing can quickly re-establish the connection of the disconnected multicast member, the proposed multicast tree structure has to counter with two challenges due to mobility, such as zone member or leader movement among different zones and an empty zone. When a zone member moves from one zone to another, the leader corresponding to the new zone helps the member to rejoin the multicast tree. If a new mobile node takes over the leadership, the old leader has to hand over the multicast table to the new leader in the zone. In another case, a zone becomes empty, when the zone does not contain even a single member. In LAMP, the disconnected multicast zones due to the creation of an empty zone re-establish the connection with the multicast tree.

The mobility prediction mechanism significantly controls the frequency of the generation rate of the beacons to manage the node mobility. Each node broadcasts the beacon packets including its movement characteristics to the neighboring nodes. The nodes within a communication range track the movement of the nodes using simple linear motion equations. As the location of mobile nodes is changing dynamically, they need to forecast the location of its one-hop neighbors frequently. It is possible to assume that a node(i) follows a linear trajectory, and its next location is a function of time(t) and velocity(V) over a relatively short period, as shown in the equation(4).

$$Pos(t+1) = \begin{pmatrix} X_1 \\ Y_1 \end{pmatrix} + \left(\begin{pmatrix} V_x^1 \\ V_y^1 \end{pmatrix} * (t - t1) \right) \qquad \textbf{(4)}$$

$$ALC = \sqrt{\{(X_i - X_j)^2 + (Y_i - Y_j)^2\}} \qquad \textbf{(5)}$$

Where, X_i- X_j is the difference between x coordinates of the nodes at t time, V^x_i and V^x_j are the differences between x and y modules of speed vectors of monitored nodes. If an error occurs between the original and the predicted next location, it deviates the ALC value. In this event, a node (i) sends its original location information to the Z-ldr and informs all the neighboring nodes using the beacon packet while each node measures Acceptable Location Change (ALC) for Z-ldr. In the event of Z-ldr movement prediction, a node which is closer to the center point of the zone announces its leadership role through a beacon message.

The real time factors affecting the accuracy of mobility prediction are localization error and signal fading in the physical layer. To tolerate the impact of real time scenarios, an adaptive acceptable location change is measuredwith respect to the ratio of failed predictions (F_p). Initially, the LAMP fixes less ALC value. After that, the ALC value is updated periodically using F_p over time. When the F_p value increases, the scenario intimates the localization error or the region transition due to signal fading. The LAMP solves this problem by adjusting the ALC value using equation (6).

$$ALC_{t+1} = ALC_t + \{(R' - ALC_t) * F_p\} \tag{6}$$

In equation (6), the value of ALC is dynamically fixed based on the value of F_p. The multiplication of (R' - ALC_t) and F_p ensures that the ALC value is always in the range of R'. Thus, it significantly minimizes the routing overhead and impact of node mobility in real time MANET scenarios, and also improves the routing performance of LAMP significantly.

3.4 Analysis of Routing Overhead in LAMP

The quantitative analysis on per node cost of the LAMP protocol is measured as the average number of control packets used by a node per second. The per-node cost includes the overhead due to beaconing, tree construction, and maintenance.

3.4.1 The cost of Beaconing and Leader Election

The LAMP virtually forms the hexagonal zones in a distributed manner, as it excludes the additional control packets for informing the zone ID to each node. The nodes in a zone select a leader by exchanging the beacon messages periodically. Even though, the periodic beaconing impacts the per node cost, the mobility prediction reduces the per node cost significantly. Considering that every node has a $\rho\pi R^2$ average number of neighbors and among them, $\delta(t)$ is the probability of neighboring nodes that are predicted with an error more than that of the ALC at t time. Thus, the product of $\rho\pi R^2$ and "t/min-Int" gives the number of transmitted beacon packets at t time. The multiplication of "$\delta(t)$" in $\text{Cost}_{\text{beaconing}}$ deducts the beacon packets that are not transmitted due to the usage of mobility prediction.

$$Cost_{\text{beacoming}} = (\rho\pi R2 * \delta(t)) * (t/_{\text{min-Int}}) \tag{7}$$

3.4.2 The Cost of Tree Construction

The per node cost of the LAMP is associated with the control packets used inside the zone and between the zones. During tree construction, session initiation, member joining, and leaving procedures, the LAMP exploits additional control packets in MANET. Considering that every node in the network initiates the session by sending the message to all the N nodes in the network i.e. $2N^2$.

$$\begin{aligned} Cost_{\text{tree-construction}} &= Cost_{\text{initiation}} + Cost_{\text{Join-Req}} Cost_{\text{initiation}} \\ &\quad + Cost_{\text{Join-Rep}} \end{aligned} \tag{8}$$

$$\begin{aligned} Cost_{\text{tree-construction}} &= 2N^2 + 2\{(n+1)(X/3R)\} * \\ &\quad \{(AVG\ D/R) + 1\} \end{aligned} \tag{9}$$

$\text{Cost}_{\text{Join\_Req}}$ and $\text{Cost}_{\text{join_Re}}$represent the total cost for multicast group join request and reply session respectively. (n+1)(X/3R) represents the number of zones in the network. Considering a case that all the zones have at least one multicast receiver for a particular multicast session, then (n+1)(X/3R) is the number of multicast receivers. To reach each zone leader, the join request/reply packet should travel Avg D/R hops, and moreover, the zone leader takes one hop to deliver the multicast packets to the receivers. Twice that of $\text{Cost}_{\text{Join\_Req}}$ is equal to the summation of$\text{Cost}_{\text{Join_Req}}$ + $\text{Cost}_{\text{join\_Rep.}}$

3.4.3 The Cost of Tree Maintenance

The cost for tree maintenance includes zone member and leader movement, and empty zone handling. The first component includesthe cost of handling movement of zone leader and members. For a leader node movement, it sends multicast table to the new zone leader, before leaving the current zone. Then, the leader informs all the members located in a zone. Moreover, the leader delivers the message in a single hop, since the distance between old and new leader is less than R, during the packet transmission. For a member node movement, it sends a message to the old zone leader, only when the predicted location error is more than the ALC, and join request to the new leader. The new leader assists the member to rejoin in the multicast tree. The cost due to moving nodes across zones and empty zone handling is shown in the equation (11).

$$Cost_{\text{tree-construction}} = Cost_{\text{node-movement}} + Cost_{\text{empty-zone}} \tag{10}$$

$$Cost_{\text{tree-maintenance}} = 2 * \{(n+1)(X/3R)\} * \delta(t) \tag{11}$$

The term $\text{Cost}_{\text{empty-zone}}$ is the cost of handling a zone when all the members and zone leader are moving away from the zone. If only one node is located in the zone, it will act as a leader, and so the last moving node away from the zone is a leader node. The leader node should inform the neighboring zone leader, before leaving the zone. However, it is negligible, compared to the multicast joining process.

4 Performance Evaluation

The NS2 simulation is employed to evaluate the performance of the proposed Location Aided Multicasting Protocol. The simulation model consists of 400 randomly deployed nodes within the square network area of 1000m x 1000m. Each source generates CBR data packets at the rate of 8 Kbps with a data size of 512 bytes. The data flow begins at 30 seconds, and group membership management is initialized at 10 seconds and stopped at 480 seconds. The node transmission range is 200m. The overall simulation time utilized for performance evaluation is 500s. To show the advantage of the proposed algorithm LAMP, the performance comparison is evaluated between existing EGMP and the proposed protocol.

4.1 Simulation Results

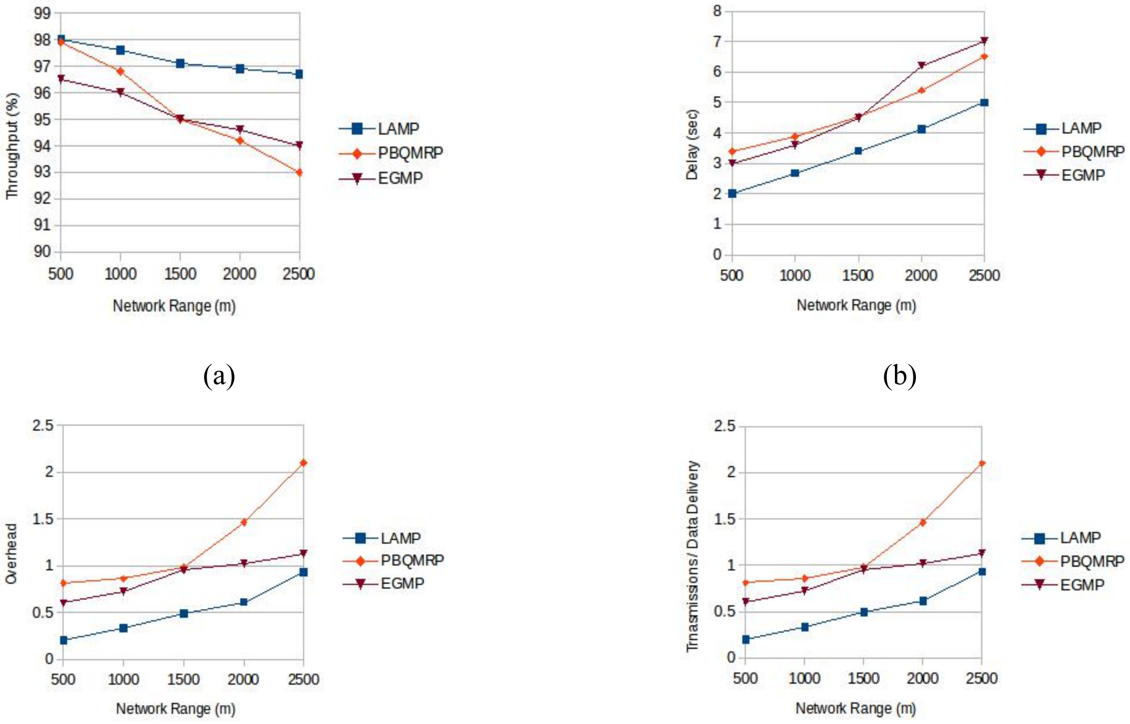
The following section illustrates the experimental results of the proposed protocol regarding throughput, delay, overhead, and data delivery/transmission.

4.1.1 Test 1: Varying the Network Range

To study the impact of the network range on the performance of LAMP, the square network range or side length is varied from 500m to 2500m.

Figure 9 shows the comparative performance of the proposed LAMP with the network range varied from 500 to 2500 m. From the Figure 9(a), the throughput of PBQMRP and EGMP decline remarkably as the network range increases while the throughput of LAMP decreases gently. The difference in throughput becomes apparent in a large scale network. The periodic local and network-wide multicast session message flooding in multicast routing protocols saturates the network capacity and reduces the network throughput. Compared to other protocols, the LAMP identifies the merged paths using the greedy multicasting technique which reduces transmissions per data delivery and delay as shown in Figure 9(d) and Figure 9(b) respectively, and efficiently utilizes the network capacity. Even though the PBQMRP follows the zone based multicast receiver grouping concept, the restricted directional flooding of route request and reply packets increases the packet dropping. For instance, in Figure 9(a), 98% of throughput is achieved at the point of 500m in LAMP, but it declines to 96.8% when the network range reaches 2500m.

The overhead is the main metric while evaluating the scalability of multicast routing protocols. In Figure 9(c), the control overhead of all the protocols rises with the increasing network range as more zones are involved in the membership management. With the large-scale network, a huge number of zones has a higher probability of being empty, and this problem increases the tree maintenance overhead. Compared to EGMP, the PBQMRP and LAMP utilize the advantages of the hexagonal zone structure effectively and reduces the overhead significantly. In a large network, the PBQMRP has realized slightly higher control overhead than that of others, as it more frequently uses route discovery messages when a sender wants to forward the multicast packets to receivers. For instance, when the network range is 2500m, the overhead of LAMP is 0.9, whereas the PBQMRP and EGMP reach 2.1 and 1.1 respectively.



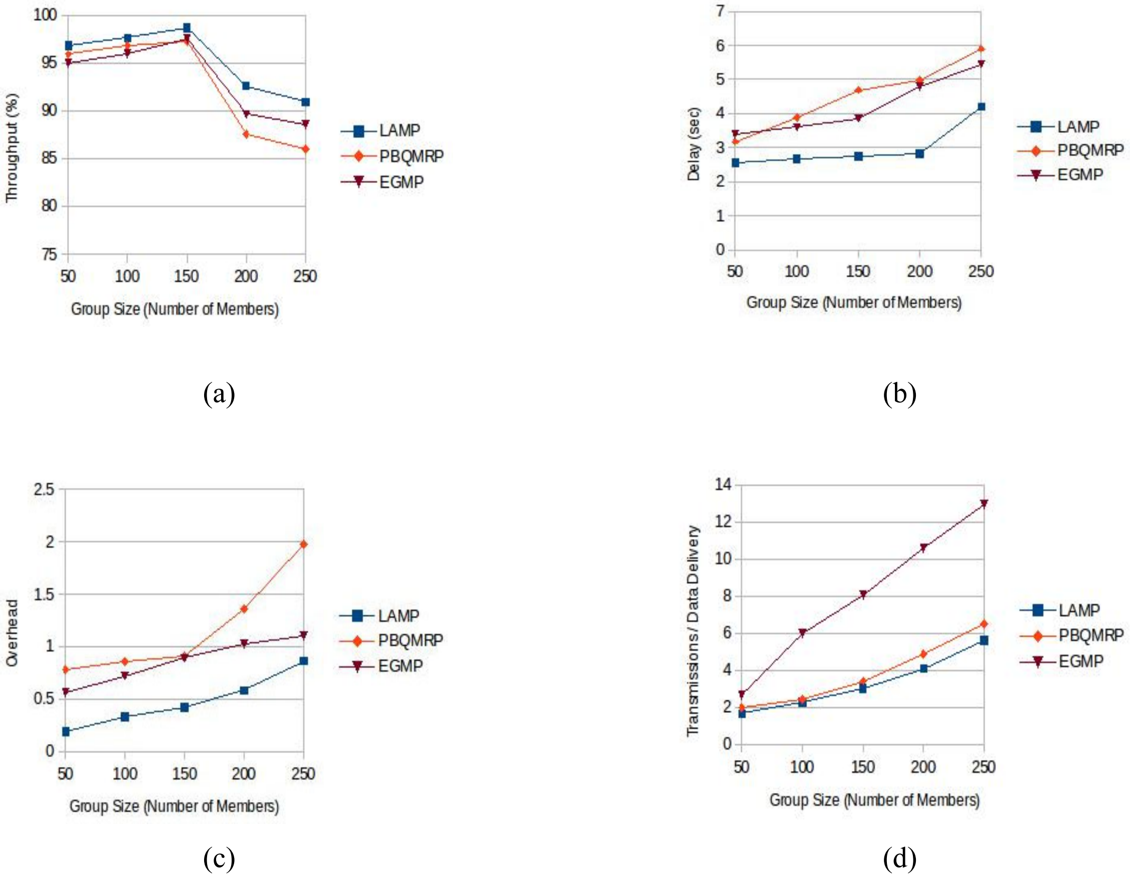
(a) (b)

(c) (d)

Figure 9. Test 1: performance with the varying network range

4.1.2 Test 2: Varying Group Size

In test 2, the proposed LAMP and the existing multicast protocols are compared by varying the group size or the number of multicast receivers. Figure 10 shows the result of throughput, delay, overhead, and transmissions per data delivery.



(a) (b)

(c) (d)

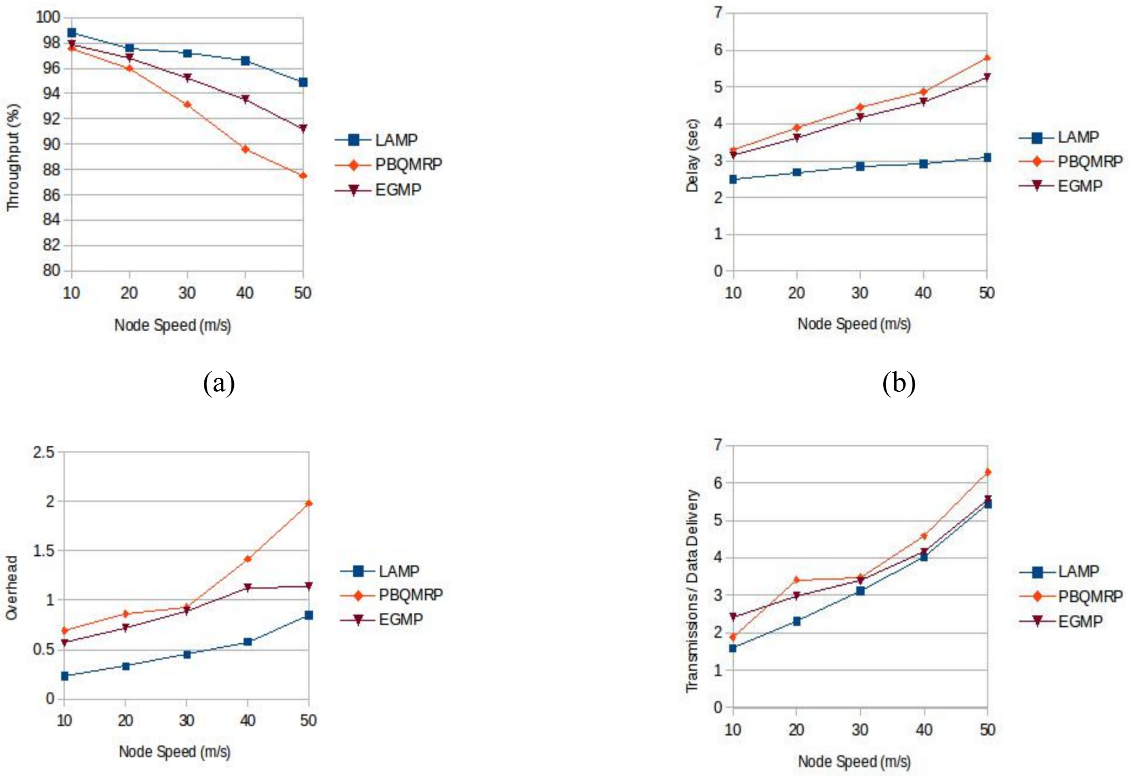
Figure 10. Test 2: performance with varying group size

Figure 10 reveals that LAMP is a potential protocol to scale up very well for a large group size and perform well with various numbers of multicast members. When the size of the group increases, the throughput of all the multicast routing protocols decline. Initially, the PBQMRP shows better throughput than that of EGMP, however, with a larger group size, a restricted flooding of route request packets and tree maintenance has an adverse impact on the packet forwarding, resulting in a slight reduction in the throughput. The LAMP achieves a better result; it is due to the mobility adaptive tree maintenance and the greedy multicast forwarding structure, which delivers the data efficiently to multiple receivers located in the same area. This process reduces the routing delay significantly, for instance, when the group size is 250, the LAMP delivers the multicast data packets in 4.1 seconds, whereas the PBQMRP and EGMP deliver in 6 and 5.5 seconds.

In Figure 10(c), PBQMRP and EGMP both indicate that they have high overhead when the group size is large, in PBQMRP, all the mobile nodes are involved in the flooding of route request messages, however, in EGMP the periodic flooding of beacon messages causes more unnecessary overhead. As similar as EGMP, the LAMP uses the knowledge of geographic forwarding and tracks the positions of multicast group members efficiently without using an external location server. Also, the minimum length multicast tree construction in LAMP with the hexagonal zone structure minimizes the number of transmissions while delivering a packet to all the multicast receivers. For instance, in Figure 10(d), the transmission per data delivery of LAMP reaches 1.9 when the group size is 50, and it increases to 5.9 with 250 group members.

4.1.3 Test 3: Varying Node Speed

In test 3, the proposed LAMP and the existing multicast protocols are compared by varying the node speed. Figure 11 shows that the LAMP provides better performance when varying the node speed from 10 to 50 m/Sec.



(a) (b)

(c) (d)

Figure 11. Test 3: performance with varying node speed

From the Figure 11(a), the throughput of all the protocols drops as mobility increases, wherein the throughput of PBQMRP drops much faster, as it is difficult to maintain the routing path to all the multicast receivers. At high speed, it is tough to track the node and group members in EGMP. In EGMP and PBQMRP, mobility induces frequent zone leader changes and more rejoining processes. This issue raises the normalized control overhead in EGMP and PBQMRP and causes more packet loss in the network queue. To overcome this issue, the LAMP utilizes the mobility adaptive tree maintenance, regulating the routing overhead and delay to be minimal. Moreover, to improve the routing performance, the virtual hexagonal zone-based structure is constructed with location information traced out from the GPS and the hexagonal zone structure covers a large area in a single transmission. For instance, when the node speed is 50m/s the LAMP delivers the multicast data packets within 3 seconds, whereas the PBQMRP and EGMP deliver in 5.9 and 5.2 seconds.

5 Conclusion

This study proposes the Location Aware Multicasting Protocol, LAMP to achieve improved scalability and provide mobility adaptiveness to the multicast routing. In LAMP, the adoption of hexagonal zone-based structure which is selected from the most efficient structure for multicasting considerably reduces the communication overhead and the propagation delay in performing the routing and tree maintenance. The zone supported greedy multicast forwarding scheme selects the greedy forwarder for a group of receivers located in a same geographical area and reduces the overall transmissions. Moreover, the mobility adaptive tree maintenance can optimize the performance of multicast routing by adjusting the tree structure to the topology changes. This optimization supports maintenance of the up-to-date positions of their neighbors and zone members and facilitates effective forwarding decision. Finally, this work has conducted an extensive simulation to evaluate the comparative performance of the proposed protocol LAMP with PBQMRP and EGMP on network range, group size, and node speed. The NS2 simulation results demonstrate that LAMP has significantly improved the throughput by 7.3% compared to EGMP.

There are several possible directions for the proposed work to extend in the future, and these directions are summarized as follows:

- The proposed multicast routing takes into account the distance (greedy routing) and in future, the consideration of multiple contextual factors is essential for routing decision.
- These protocols have only considered the node speed and direction. In future, the design of mobility prediction scheme applied to different mobility models is crucial.

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