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# A Survey on Scalable Multicasting in Mobile Ad Hoc Networks

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**Abstract** Mobile ad hoc networks (MANETs) have gained significant interest and popularity since they have enormous potential in several fields of applications. Infrastructure-free, self-configuring and mobility are the main reasons behind this popularity. Recently, group-oriented applications over MANET gains high popularity. Multicast communication is the ideal communication technique for supporting these types of applications. However, multicast routing in large-scale networks faces several difficulties and challenges that need to be addressed. These challenges include dynamic MANET topology, multicast packet forwarding and shared wireless medium. During the last years, active research work resulted in a variety of proposals. A number of protocols, each with a particular property and often optimized for a specific application area, have been designed. They follow different design principles and exhibit substantial variations in performance depending on various parameters. In this paper, most of the existing scalable multicast routing protocols in MANETs are briefly discussed and analyzed to provide a comprehensive understanding of these protocols and pave the way for further research.

**Keywords** MANETs · Ad hoc networks · Multicast routing · Survey · Position-based · GPS

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## 1 Introduction

MANETs are composed of a collection of mobile nodes that communicate with each other over wireless links in the absence of any infrastructure or centralized administration. MANETs have gained significant interest and popularity since they have enormous potential in several fields of applications.

The multicast concept for packet forwarding has been widely studied during the past years due to the rapid increase in a wide variety of applications that need cooperation between team members. These include battlefields and disaster recovery areas, scheduled audio/video distribution, multimedia conferencing, collaborative computing and communications in smaller areas (such as buildings, organizations and conferences), distance learning and multiplayer games where participants share information dynamically using their mobile devices. These applications lend themselves well to multicast operation. So they need support for group communication protocols. Multicast routing has many benefits. It is more efficient as it builds a multicast delivery infrastructure, which allows the multicast source to transmit only one copy of the information and the intermediate nodes will duplicate the information when needed. Only nodes that are part of the targeted group will receive the information. So multicasting plays an important role in MANETs [1].

Recently many efforts have been made to develop multicast protocols for MANETs. These include conventional tree-based protocols and mesh-based protocols. However, it is very difficult to maintain the tree structure in mobile ad hoc networks, and the tree connection is easy to break and the transmission is not reliable. on the other hand, The mesh-based are proposed to enhance the robustness with the use of redundant paths between the source and the set of multicast group members, which incurs a higher forwarding overhead. It's a big challenge to support reliable and scalable multicast in a MANET, as it is difficult to manage group membership, find and maintain multicast paths with constant network topology changes.

This paper presents a recent survey of multicast routing protocols in MANETs. The scalability of multicast routing is the main issue in this paper due the increased demand for scalable multicast routing protocols. The scalability of this kind of protocols is considered as a hot research topic in the research community. In the following subsections we present an introduction about routing protocols classification, scalability in MANETs and multicast routing protocols.

### 1.1 Routing Protocols Categories

Routing protocols for Ad hoc networks can be classified into many categories considering different criteria. In general, they can be classified based on how routing information is acquired and maintained by mobile nodes. Mainly, routing decisions are depends on the neighbor relations in the network.

Depending on how the protocol calculates its routes, routing protocols can be divided into two main categories: *topology-based* and *position-based* [2]. *Topology-based routing protocols* use information about links that exist in the network to perform packet forwarding. They are, in turn, divided into three categories: *proactive* (table-driven or periodic) protocols, *reactive* (demand-driven or source-initiated) protocols, and *hybrid* (hierarchical or (reactive/proactive) protocols [3].

In *proactive routing protocols*, the nodes are required to maintain the network topology information in the form of routing tables by periodically exchanging the routing information. Therefore, the route to every destination is available, so no additional time is needed to discover the route. Thus, there is little or no initial delay when first sending data [4]. However, proactive method requires periodic updating of the routing tables, so if only a few routes need to be determined then the overhead of table update and maintenance may be large. Proactive routing protocols are less suitable for Ad hoc wireless networks because they consume nodes' resources, regardless of the presence of network activities. Also they are not designed to track frequent topology changes [5]. Destination Sequenced Distance Vector protocol (DSDV) [6] is an example of proactive routing protocols.

*Reactive routing protocols* are more appropriate for wireless environments compared with proactive routing protocols, because they initiate a route discovery process only when data packets need to be routed [7]. Once the route is established, the route must be maintained until it is no longer needed or the destination node becomes inaccessible. This eliminates the overhead of maintaining routing tables for routes not currently in use. In reactive routing, route calculation process is divided into route discovery and route maintenance. The route discovery process is initiated when a source needs a route to a destination. The route maintenance process deletes failed routes and re-initiates route discovery in the case of topology change. An example of reactive routing is Ad hoc On-Demand Distance Vector (AODV) [8] protocol.

Since proactive protocols use excess network bandwidth to maintain routing information, while reactive protocols involve long route request delays. *Hybrid routing protocols* aim to address these problems by combining the best properties of both approaches; reducing the delay associated with reactive routing as well as limiting the overhead associated with proactive routing [2]. An example of hybrid routing protocols is Zone Routing Protocol (ZRP) [3].

Apart from topology-based routing protocols, *position-based protocols* use information about the position of mobile nodes to perform packet forwarding. This requires that a node is able to obtain its own geographical position. In an outdoor scenario, GPS receivers are the most famous way for a device to determine its location [9]. For an indoor scenario, systems can be used to obtain the geographic position such as RADAR [10], SpotON [11] and MoteTrack [12]. Also, the geographical position of the destination need to be obtained through using location services algorithms [13,14].

In some MANET applications, the information about the nodes' locations is very useful. Military applications are one example of these applications. For clarity, suppose that an army has a special mission in the desert and this army consist of several battalions. Each battalion has its commander. Here, each commander must know the location information of each soldier. There are different kinds of position-based protocols that are categorized into three main groups: *greedy forwarding, restricted directional flooding*, and *hierarchical routing protocols* [15].

In *greedy forwarding,* up-to-date local topology is required. In order to enable the nodes to do this, nodes periodically broadcast small packets (called beacons) to announce their positions and enable other nodes to maintain a one-hop neighbor table [15,16]. A source node tries to forward the packet to one of its neighbors that has the best progress towards (or closer to) the destination than itself. Similarly, each intermediate node selects a next hop node until the packet reaches the destination. If no closer neighbor exists, new rules are included in the greedy strategies to find an alternative route such as the strategies proposed in [17,18]. Greedy approach is scalable since it does not need routing discovery and maintenance [19]. Greedy forwarding also works well in dense network. However, its performance degrades in sparse networks. Hence, the forwarding node may not find a node that is in the way to the destination, so the data packets are dropped. Moreover, proactive beaconing of one-hop neighbors has to be maintained in a neighbor table at each node; which creates a lot of congestion in the network and consumes nodes' energy [16,20]. In addition, greedy forwarding requires complex computation at the nodes and hence, will incur more delay at the intermediate nodes.

In *restricted directional flooding*, the flooding region is limited based on distance, angle and distance covered by the next intermediate node. Based on the distance, only nodes that are nearer to the destination will participate in the route discovery. Nodes that are further away from sender node will not participate in packet forwarding [21]. In particular, the sender will broadcast the packet to all single hop neighbors towards the destination. The node which receives the packet compares its distance to the destination with the distance of the previous hop to the destination. If the receiver node was nearer to the destination, it retransmits the route request packet. Otherwise, the packet is dropped [15].

In *hierarchical position routing protocols*, two levels of hierarchy are used to provide routing scalability. If the destination node is close to the sender (in number of hops) packets will be routed base on a proactive distance vector, on the other hand, greedy routing is used in long distance routing [15]. Table 1 shows the categorization of routing protocols in MANET based on routing topology.

In the following subsections, scalability and multicast routing in MANETs are presented, then we presents a classification of multicast routing protocols.

### 1.2 Scalability in MANETs

As the scale of Ad hoc networks continues to grow, one of the most critical design issues of a routing protocol is its applicability in large-scale deployments, i.e. the protocol scalability [22,23]. The scalability of a routing protocol is a measure of its ability to support the increase of one or more network parameters (such as network size, network density, mobility rate and data generation rate) without degrading the network performance [24].

The multi-hop nature of Ad hoc networks and the scarce bandwidth makes the scalability of these networks directly related to the used routing protocol [25,26].

Designing a reliable and scalable routing protocol for Ad hoc networks is a challenging task, especially due to the continuous change in the network topology [13]. Also, the scarce bandwidth makes the scalability of these networks directly related to the used routing protocol [25,26]. This makes the absolute protocol scalability [24] very hard to be defined in mobile environments.

The common characteristic among all topology-based routing protocols is that performance degrades as network density increases, leading to a scalability problem [27]. For example, global broadcast of control packets may generate overhead and consume most of the bandwidth, causing scalability problems in large-scale networks [25]. Thus, reducing routing control overhead becomes a key issue in achieving routing scalability [28]. In proactive routing, for example, the routing protocol periodically broadcasts routing information throughout the network, so that, every node keeps routing information about every other node, leading to lack of scalability [29].

Position-based routing protocols, on the other hand, are an attractive scalable alternative [30]. In position-based routing, geographical location information is used to localize the control message propagation and to help the routing layer scale to support very large networks [20]. Position-based routing is scalable to large networks, since it uses only knowledge of the source and the destination locations and is independent of network topology and size.

Clustering algorithms and hierarchical routing are proposed in Ad hoc networks as attractive approaches to improve routing protocol scalability [31]. A clustering algorithm is usually used to divide the network into smaller sub-groups. In general, clustering can reduce

**Table 1** Categories of MANET routing protocols based on used technique for routing decision

| Category | Approach | Strengths | Limitations |
|---|---|---|---|
| Topology-based routing protocols | Proactive | 1. Every node in the network maintains routing information to every other node in the network even before it is needed | 1. Not suitable for larger networks, as they need to maintain node entries for each node in the routing table of every node |
| | | 2. Routing information is constantly updated which minimize the end-to-end delay of sending data packets | 2. More overhead in the routing table leading to wasting the limited wireless bandwidth |
| | | | 3. Not suitable for highly mobile networks |
| | Reactive | 1. Routes are only constructed when they are needed | 1. Source node has to wait for the route to be discovered before starting communication |
| | | 2. Scale to medium size networks with moderate mobility<br>3. Minimize control overhead and power consumption since routes are only established when required | |
| | Hybrid | 1. Combines the advantages of both proactive and reactive approaches; reduce the overhead of proactive and reduce the delay of reactive. | 1. In large routing zone it inherits the disadvantages of proactive protocols, and inherits those of reactive ones for small routing zones |
| Position-based routing protocols | Greedy | 1. Scalable since it does not need routing discovery and maintenance | 1. Degrades in sparse networks; the forwarding node may not find a node closer to the destination |
| | | 2. Works will in dense networks | 2. Proactive beaconing creates a lot of congestion in the network and consumes nodes' energy |
| | Restricted directional | 1. The flooding region is limited based on distance, angle and distance covered by the next intermediate node | 1. Route request packet is managed by several nodes (higher routing overhead than greedy, but less than that of topology-based protocols) |
| | Hierarchical | 1. Control overhead is reduced compared to proactive protocols | 1. Inherits disadvantages of proactive protocols for large routing zone, and those of greedy ones for small routing zones |
| | | 2. Eliminates disadvantages of beacons packets used in greedy ones | |

the exchange of control packets and improve the network capacity. This is essential in networks with large number of nodes (e.g. hundreds or thousands). Whenever multicast routing applied in large-scale networks, the problem will become worse if all nodes maintaining routing tables. Thus, clustering overcome other routing protocols and assist in improving scalability.

In cluster-based routing schemes that depend on virtual division, the network topology is divided into an arbitrary number of non-overlapping virtual clusters of any shape (square, triangle and hexagon). So, by using repetitive regular cell structures, the geometric properties for that shape can be used to utilize some routing algorithms. Each cluster has a cluster head node to manage the cluster activities. The cluster heads have to cover all nodes of the network. Therefore, it is important to select the cluster heads that survive the longest possible time, which will keep the network construction stable as possible.

After formation of the cluster, some techniques are required to maintain the cluster organization. Cluster organization involves handling nodes movement in and out the network, nodes movement between clusters, re-election of cluster heads, hand-over with new elected cluster head, cluster membership as well as handling corrupted and destroyed nodes. Therefore, maintaining a stable network structure is one of the main design challenges that face clustering protocols in MANETs. Also, as nodes are mobile, they can move between clusters. This requires a self-mapping algorithm that enables each mobile node to know exactly the cluster it belongs to during the network life time.

### 1.3 Multicast Routing Protocols in MANETs

Multicasting is defined as a scheme for delivering the same data from a source to a group of zero or more hosts identified by a single destination address [2,32]. Multicasting is intended for group-oriented computing, where the senders and receivers form the multicast group. To held multicasting session, some way is needed to define the multicast groups. In conventional multicasting algorithms, a multicast group is considered as a collection of nodes, which register to that group. This means that, if a particular node wants to receive a multicast packet, it has to join a particular group first. Whenever a particular node wants to send a packet to any group, it simply multicasts the packet to the address of that group. Then, all the group members receive that packet. The members of the multicast group are free to join and leave the multicast as desired. The member may be a participant of more than one group at a time. Also, the member have to send packets to the group members in order to be a member in the group [33,34].

Utilizing multicasting in MANETs can efficiently support a wide variety of applications that need cooperation between team members such as communications in battlefields and disaster recovery areas, scheduled audio/video distribution, multimedia conferencing, collaborative computing and communications in smaller areas (such as buildings, organizations and conferences), distance learning and multiplayer games [35,36]. On the other hand, the conceptual shift in the features of mobile systems (global roaming capability and coordination with other network structures) satisfies the user needs. By combining the features of MANETs with the efficiency and advantages of multicast routing, it will be possible to realize a number of envisioned group-oriented applications [35,36]. Extending multicasting to MANETs can enhance the performance and utilize the resources.

Many proposed multicast routing protocols for Ad hoc networks (such as MAODV [37] and ODMRP [38]) are designed with small network and flat topology in mind [39]. These protocols can scale reasonably well to dozens of nodes because their focus is mainly on performance in relatively small networks, and less on scalability. However, the widespread of mobile devices and the deployment of large-scale Ad hoc networks for military, rescue and commercial applications, that may consist of hundreds or possibly thousands of nodes, raise the scalability issue of routing protocols [40]. Hence, the development of large-scale Ad hoc networks has drawn a lot of attention and the scalability of Ad hoc networks has been the subject of extensive research [26].

Recently, many multicast routing protocols were proposed depending on the existence of clustering for efficient and scalable multicast message delivery. These protocols along others will be discussed in Sect. 2. Examples of these protocols include QMRP-H [41], EGMP [42] and LACMQR [43].

### 1.4 Classification of MANETs Multicast Routing Protocols

The most popular classification of multicast routing protocols is based on their delivery structure and how to maintain connectivity among multicast group members. Figure 1 shows the classification of these routing protocols. In this section, a brief introduction about each category is given along with some examples of the existing approaches.

One straightforward multicast method in MANETs is through flooding [33,44]. Flooding is considered as the easiest way to perform multicasting. This is because it eliminates the need to maintain explicit infrastructure for multicast forwarding. In flooding, when the source initiates the multicast session, it broadcast the request packet to its neighbors. The participating nodes simply broadcast the received packet to all their neighbors if it is not received before. Otherwise, the packet is dropped. This process is repeated until the packet is flooded throughout the network [33].

In flooding, the data packets are quickly propagated in the network; flooding offers the lowest control overheads. However, this comes in the expense of generating very high data traffic in the wireless environment. This is because there are duplicate packets in the network, which increases the network contention and wastes the bandwidth. The problem becomes worse when the network gets larger. In other words, the networks that rely on flooding do not scale well for large-scale networks.

In tree-based multicast routing protocols, the multicast tree is constructed starting from data source and connects all the receivers. There exists only single path between a source-destination pair. Depending on the number of trees per multicast group, a tree-based multicast can be further classified as a source-tree multicast and shared-tree multicast.

In source-tree protocols, the tree is rooted by the source node, whereas in shared-tree protocols, a single tree is shared by all the sources within the multicast groups and is rooted at a node denoted as the core node. In source-tree protocols, each multicast packet is forwarded through the most efficient path from the source node to each multicast group member, but this method incurs a lot of control overhead to maintain many trees. At heavy loads, source-tree protocols perform better than shared-tree protocols due to efficient traffic distribution [2].

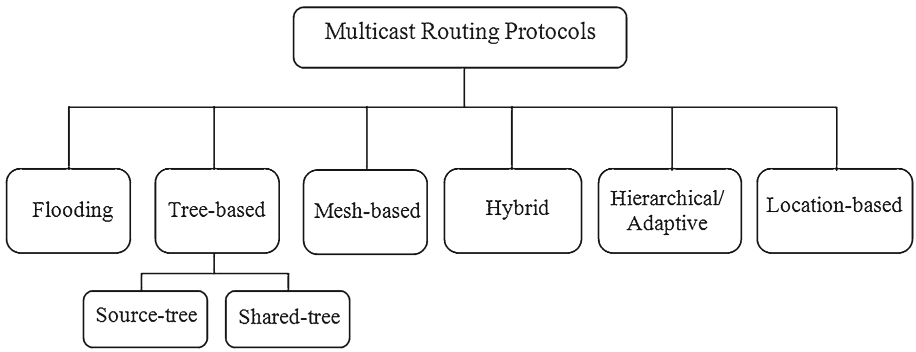


**Fig. 1** Classification of multicast routing protocols in MANETs

While, shared-tree protocols are more scalable and have lower control overhead because they maintain only a single tree for a multicast group. However, shared-tree protocols suffer from the single point of failure (core node), which affects the performance of the multicast routing protocol. Compared to flooding, tree-based multicast protocols are more efficient in terms of bandwidth consumption. However, they are not robust enough to operate in highly mobile networks because only single path between source-receiver pair is available.

Examples of source-tree protocols are Multicast Core-Extraction Distributed Ad hoc Routing (MCEDAR) [45] and Multicast Zone Routing Protocol (MZRP) [46]. Some examples of shared-tree protocols include Multicast Ad hoc On-demand Distance Vector routing protocol (MAODV) [37] and Shared-Tree Ad hoc Multicast Protocol (STAMP) [47].

Unlike tree-based multicast protocols, mesh-based protocols allow the data packets to be forwarded to the same destination through more than one path [2]. Using multiple paths between any source and receiver pair provides increased protection against topological changes, which increases the chance of successful delivery [33]. However, mesh-based protocols provide lower multicast efficiency compared with tree-based protocols due to redundant routes.

Mesh-based approaches are used in situations where network topology changes frequently. When the primary link is broken due to node mobility it may not trigger a reconfiguration of the network due to the availability of redundant paths. This avoids frequent network reconfigurations, which minimizes disruptions to ongoing multicast sessions and reduces the control overhead to reconstruct and maintain the network structure. Route discovery and mesh building are accomplished by using broadcasting to discover routes or by using core or central points for mesh building [33]. There are several protocols that rely on mesh-based multicast construction such as the Core Assistant Mesh Protocol (CAMP) [48], On-demand Multicast Routing Protocol (ODMRP) [38] and the Forwarding Group Multicast Protocol (FGMP).

Dynamic topology of MANETs makes designing the multicast protocols a challenging task. Therefore, the ideal multicast protocol should adapt to different environment conditions. In view of this, hybrid and hierarchical protocols are employed to provide robustness, efficiency and scalability.

Hybrid-based multicast routing protocols try to achieve better performance by combining the advantages of both tree-based and mesh-based approaches in order to provide efficiency and robustness [33,44]. Like mesh-based approaches, multiple paths are constructed to enable all data packets to reach the destination through different paths. Tree-based is used in route setup to provide multicast efficiency. Ad hoc Multicast Routing protocol (AMRoute) [49] and Efficient Hybrid Multicast Routing Protocol (EHMRP) [50] are instances for hybrid-based multicast routing protocol.

Hierarchical multicast routing protocols try to reduce the number of participating nodes by arranging the network nodes into a certain hierarchy to provide scalability. Here, a set of nodes are used to form a cluster or a dominating set of nodes. Hierarchical Differential Destination Multicast (H-DDM) [39] is an example of hierarchical multicast routing protocols.

Adaptive multicast routing protocols adapt their performance to different environmental conditions. For example Adaptive Demand-driven Multicast Routing protocol (ADMR) [51] adapts its performance to network mobility. ADMR switches to flooding when the network mobility becomes very high to overcome link break problem.

Location-based multicast routing protocols are based on the availability of relative location information of the network nodes. The geographical information for each node is determined using GPS receivers or other positioning service. In location-based multicast routing protocols, a location service is needed to determine the positions of the destination nodes. Then, forwarding of packets between nodes is based on the location information of the direct neighbor nodes and the intended destinations. Using this forwarding strategy, the nodes that have better progress towards the destinations are selected, which reduces the number of participating nodes.

Recently, location-based multicast routing protocols have attracted the attention of many researchers because these protocols scale quite well in large wireless networks in addition to the commercial proliferation of GPS devices. However, extending location-based unicast routing to location-based multicast routing faces many challenges. In location-based unicast routing, the destination's position is carried in packet header during packet forwarding, which is not efficient in multicast routing. This is because multicasting deals with group of members. So, carrying the positions of all multicast members in the packet header causes scalability problem. Also, maintaining the positions of a large number of destinations need to be performed efficiently.

## 2 Review of Existing Multicast Routing Protocols

This section presents some proposed multicast routing protocols and highlights their strengths and weaknesses. Section 2.1 discusses hybrid/hierarchal and adaptive routing protocols. Then, location-based protocols are discussed in Sect. 2.2.

### 2.1 Hybrid/Hierarchical and Adaptive Multicast Routing Protocols

Hybrid protocols adapt their performance to maintain efficient and robust multicast routing. These protocols combine the advantages of both tree-based and mesh-based protocols. The hierarchical multicast protocols place nodes into groups, often called clusters to improve scalability. In this subsection, some of the recent hybrid protocols are presented such as QMRP-H [41] and GMZRP [52].

#### *2.1.1 Hierarchical QoS Multicast Routing Protocol in MANETs (HQMRP)*

In HQMRP [41], the network is organized into multiple domains. The 0-level represents the nodes themselves. In the first-level each cluster contains at least one node and does not overlap with any other first-level cluster. The upper levels are formed by grouping the down levels into domains. The clusters with the same level are connected using bridge nodes as shown in Fig. 2.

This protocol considers the bandwidth and delay as QoS metrics and assumes that each node periodically measures the delay of outgoing links and broadcasts it to cluster members. Similarly, the bridge nodes measure the delay of the outgoing links and broadcast this information to bridge nodes in the same level.

The multicast tree is constructed by sending a *JOINReq* message with QoS metrics by the first member to its parent bridge node. The first entry in the array is set to the address of this member. If the bridge node is not aware of the multicast tree, it adds itself to the array and forwards the request to its parent bridge node. If the multicast tree is not found, the request will arrive to the bridge node at top-level domain. The top bridge node sends a multicast generation (*MT generation*) message towards the first member node. When the new member receives this message it replies by sending a *MT update* message to its parent bridge node to generate the tree. Each bridge node maintains the address of all on-tree nodes within the domain and bridge addresses of the lower level domains containing on-tree nodes.

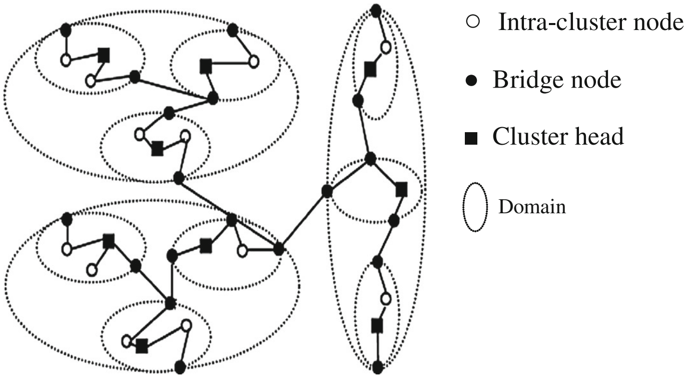


**Fig. 2** Network topology of HQMRP [41]

When a new node wants to join a multicast group, it sends a *JOINReq* message to its parent bridge node. If the message arrives at a bridge node that is aware of the multicast tree, it forwards the message to all on-tree nodes or bridge nodes of the sub-domains having on-tree nodes. Otherwise, the bridge node forwards the message to its parent bridge node. When the *JOINReq* arrives at an on-tree node, the node initiates a *SF* message. This message is flooded towards the new node by sending it to some neighbors which in turn forward the message to their neighbors.

HQMRP is scalable for large area networks due to its hierarchy of domains. Also, it enables local nodes to maintain local multicast routing information instead of global network states, which reduces the traffic overhead. However, using periodic messages to construct the neighbor table introduces considerable control overhead. Also, using subscribing to handle changes in the domains requires excessive communication and message processing specially in high mobility networks.

### *2.1.2 Geography-aided Multicast Zone Routing Protocol (GMZRP)*

GMZRP [52] is a hybrid source-based tree on-demand multicast routing protocol that combines the advantages of both topology and geographic routing schemes. GMZRP is inspired from the unicast protocol ZRP [3]. In this protocol, the network is partitioned into small equal circle shape zones starting from the network center and spreads outwards. Each circle contains a hexagon with same side length as the circle radius. The hexagon zones are not overlapping and covering the network as shown in Fig. 3. It is assumed that the network nodes are equipped with GPS devices. This geographical information is used to estimate the center of the network where the partitioning is initiated.

GMZRP maintains a multicast forwarding tree at two levels of granularities: zone granularity and node granularity. Zone granularity looks like source routing where the source keeps a zone ID chain connecting the source to each receiver. Intermediate nodes also keep zone ID chain connecting its own zone to each downstream receiver zone. On the other hand, at node granularity, the source and the intermediate nodes only keeps information about its child nodes.

When a source has data to send for a multicast group and there is no entry about this group in the Source-Table, it initiates a new entry in that table and initializes a request packet (MRREQ). The propagation of MRREQ packet is done in two steps: inter and intra zone. In inter-zone stage, an algorithm is proposed based on the geographic partition of the network.

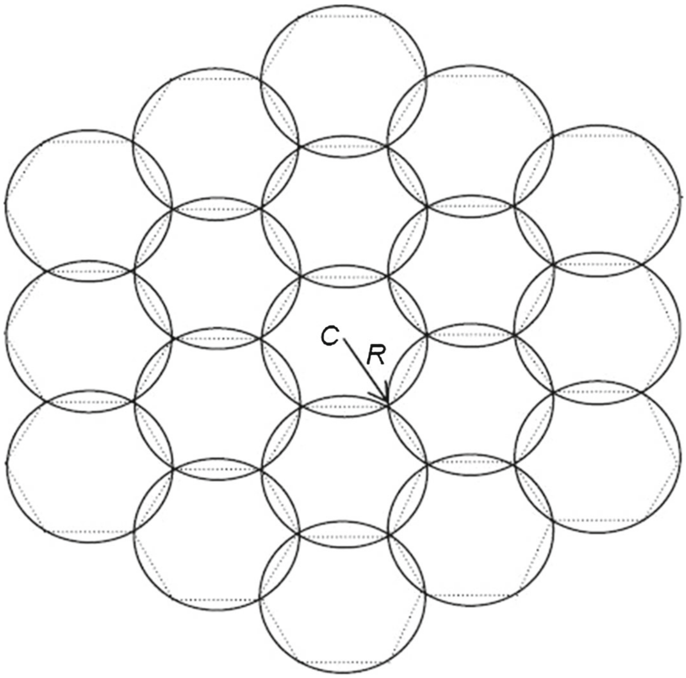


**Fig. 3** Illustration of network partition of GMZRP [52]

In this algorithm, the intermediate zone forwards MRREQ packet based on its own position and the source zone position. This algorithm ensures that each zone will be queried only once which limiting the discovery overhead. While in intra-zone stage, when a node receives the MRREQ packet destined to its own zone, it broadcast this packet within its own zone if it is received for the first time. Also, the receiving node compares the hop count entry in the Node-Table for the same source, group and broadcast ID. If the hop count is larger than that stored in the Node-Table, this node updates the entry in the Node-Table (hop count, node ID, zone ID), increments the hop count, copies its own ID and zone ID and forwards the MRREQ packet.

When a node receives a MRREQ packet and it is interested to be a member in the multicast group, it replies with MRREP packet and sets the receive flag in its Member-Table. The nodes in the path back to the source are considered as forwarding nodes. When a forwarding node receives MRREP packet, it creates entry in its Member-Table sets the forwarding flag. When the source receives MRREP packet, it records the node ID and zone ID from which it receives the packet and the chain carried with the packet.

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

### *2.1.3 Comparative Analysis of Hierarchal/Hybrid Multicast Protocols*

Table 2 summarizes the discussed hybrid/hierarchical multicast routing protocols. The discussed protocols are proposed to support scalable multicast routing based on the hierarchal design and utilizing the network area.

**Table 2** Summary of reviewed hierarchal/hybrid multicast protocols

| Protocol name | Approach | Strengths | Limitations |
|---|---|---|---|
| HQMRP [41] | 1. Builds a hierarchical topology by providing clusters and bridges | 1. HQMRP is scalable for large area networks due to its hierarchy of domains | 1. Using periodic messages to construct the neighbor table introduces a considerable control overhead |
| | 2. Considers delay and bandwidth as QoS constraints | 2. Reducing the message overhead by selecting a fewer on-tree routers to flood towards the host router | 2. Using subscribing to handle changing the domain requires excessive communication and message processing specially in high mobility networks |
| | | 3. Local nodes maintain local multicast routing information instead of global network states | |
| GMZRP [52] | 1. Combines both topological and geographic routing | 1. Works independently of any geographic unicast protocol | 1. The dynamic membership management cause large overhead |
| | 2. Partitions the network area into small zones and guarantees that each zone is queried only once | 2. Propagation of packets between geographic zones is efficient in eliminating duplicate packets and reducing the length of the discovered routes | 2. GMZRP performance is degraded in mobile networks |
| | | 3. GMZRP works will in quasi-static networks | 3. GMZRP performance is expected to incur large overhead when it is evaluated under small networks due to packet broadcast |

HQMRP [41] allows a node to maintain only local multicast information and a summary of other clusters; it does not require knowledge of the global network. This construction reduces the network traffic and makes the protocol more scalable. Also, the multicast tree construction allows a multicast group member to join or leave a multicast session dynamically, which should not disrupt the multicast tree and reduce the message processing overhead. HQMRP [41] satisfies the multiple QoS constraints and least cost's (or lower cost) requirements, which makes it efficient for multimedia application traffic. The simulation results show that HQMRP supports efficiently large networks constructed of heterogonous nodes.

GMZRP [52] uses geographic partitioning to perform route discovery. Since position based routing protocols are efficient in utilizing the network resources. The simulation results show that GMZRP gains high performance in large networks (up to 900 nodes) and in a network of large number of multicast members (from 15 to 75 member). GMZRP does not consider QoS metrics in route discovery and does not search for routes with available resources, which reduces its reliability in transmitting multimedia traffic.

## 2.2 Location-Based Multicast Routing Protocols

Recently, location-based routing has been used to eliminate network flooding and provide more scalable and robust packet transmissions. These protocols are uses a location-aware approaches to provide scalability for both network size and group size. In this section, several location-based multicast routing protocols are presented such as LGT [53], PBM [54], EGMP [42], SPBM [55], LACMQR [43] and HVDB [56].

### *2.2.1 Effective Location-Guided Overlay Multicast in Mobile Ad Hoc Networks (LGT)*

A location guided overlay multicasting protocol (LGT) is proposed in [53]. LGT is a stateless scheme based on packet encapsulation in unicast envelops to be transmitted to group of nodes. It builds an overlay packet distribution on top of the underling unicast routing protocol based on the geometric locations of the group nodes only. Authors presented three algorithms to construct the multicast tree that is rooted from the source node and spans over all the multicast members. In all the algorithms the sender node included the list of destination nodes in the multicast packet. In Location-Guided $K$-array (LGK) tree, the source node selects the nearest $K$ destinations to be its children, and then group the rest of the nodes to the $K$ children according to close geometric proximity. The multicast packet is replicated $K$ times and forwarded using unicast protocol to the source children nodes using greedy forwarding. After the children nodes receive the packet, they run the tree construction algorithm to further forward the packet down to other destinations.

In Location-Guided Directional (LGD) tree, the sender partitions the space into multiple cone areas centering around itself and selecting the nearest node in each cone area as its child. The sender then forwards a copy of the packet to each child with all the other nodes in the child's cone area as its destinations. The third algorithm is Location-Guided Steiner (LGS) tree. The Steiner tree is used to construct the multicast tree by initially containing only the source node. At each iteration, the nearest unconnected destination to the partially constructed tree is found and the least-hop path between them is added to the tree. The distance is usually measured by the number of network-level hops. This tree construction process is repeated until all destinations are included in the tree.

These previously mentioned algorithms suffer from some ambiguity in the way of performing their location service algorithm and how to get the up-to-date information. Also, in LGD when a single node is located in a core area and in the same time it is close to the nodes in the neighbor core. So it needs a standalone unicast forwarding, while it is better to be a member in the neighbor core. The address compression mechanism is used for the group members only, while it is difficult for the other nodes in the network to distinguish among these nodes. In LGS, if there is no neighbor of the current node that is closer to the root of the sub-tree the algorithm will fail.

### *2.2.2 Position-Based Multicast Routing for Mobile Ad Hoc Networks (PBM)*

A generalization of position-based unicast forwarding has been discussed in [54]. PBM uses the locally available location information about the destination nodes to make decision to find next nodes to forward the multicast packet. In this protocol, the sender includes the addresses of all the destinations in the packet header.

The multicast tree is constructed by applying a greedy neighbor selection approach. Based on the nodes' position information, each relay node receiving the multicast message evaluates a cost function for each subset of its neighbors to decide on the best subset to forward the multicast message. The set of neighbors is evaluated to optimize the progress of the packets towards the destinations and to optimize the usage of the bandwidth. To find the next hop nodes, formula (1) is evaluated in each node that receives a multicast message [54].

$$f(w) = \lambda \frac{|w|}{|N|} + (1-\lambda) \frac{\sum_{z \in Z} \min_{m \in w} \left(d\left(m, z\right)\right)}{\sum_{z \in Z} \left(d\left(k, z\right)\right)} \tag{1}$$

where $k$ is the forwarding node, $N$ is the set of all neighbors of $k$, $W$ is the set of all subsets of $N$ and $Z$ is the set of destination nodes. Also, $d(x, y)$ is a function which measures the distance between nodes $x$ and $y$, $w$ is the set of next hop ($w \in W$), and $\lambda$ is an optimization parameter. The first part of the equation determines the number of next hop neighbors and the second part determines the remaining overall distance from the next hop nodes to the destinations.

After selecting the neighbor set for each destination, the destinations are partitioned based on the identified sub-set; each neighbor in this sub-set becomes the forwarding node for this packet towards the corresponding partition. When the current node selects more than one next hope node, then the multicast packet is split. Also, when there is no direct neighbor to make progress toward one or more destination a repair strategy is used.

PBM is limited to groups with small number of nodes since the location and group membership information for each sender is required to be included in the data packets. Also, when there is a large number of neighbors and destinations, PBM suffers from high cost because each possible sub-set of the neighborhood has to be considered. Moreover, determining the optimal value of $\lambda$ is not a trivial task as it depends on the number of neighbors and the distribution of the destinations [57,58].

#### *2.2.3 Scalable Position-Based Multicast for Mobile Ad Hoc Networks (SPBM)*

SPBM [55] is designed to provide scalability for PBM protocol [54]. The network is subdivided into quad-tree with a predefined level of aggregation. The top level is the whole network and the bottom level is constructed by basic squares. The higher level is constructed by larger squares with each square covering four smaller squares at the next lower level. All the nodes in a basic square are within each other's transmission range. In a basic square, a node periodically broadcasts its position and membership information. At each level, the membership of every square is periodically flooded to its upper level square. This periodic flooding is repeated for every two neighboring levels and the top level is the whole network.

Each node has an aggregate view of the position of the group members. SPBM uses the geographic positions of the nodes from global and local member tables provided by group management scheme to make the forwarding decision of the data packets. The forwarding algorithm checks if the current node is a member of the multicast group in order to deliver the data packet to that node.

The main focus of SPBM is scalability for the group management through using hierarchical aggregation of membership information. However, SPBM relies on unicast geographic routing for each destination, which makes it fails to provide efficient multicast forwarding. In this protocol, to determine the most suitable next hop for a packet to a given destination, the source compares the geographic progress for each of the neighbors in respect to the destination and picks the neighbor with the highest progress.

In SPBM, the use of periodic messages to update the membership information increases the control overhead specially in large area networks. Also, the interchange of routing tables between neighbors causes the protocol not to scale well to the number of multicast groups as PBM [59].

### 2.2.4 An Efficient Geographic Multicast Protocol for MANETs (EGMP)

A zone-based protocol is proposed in [42]. This protocol is proposed to improve scalability of location-based multicast protocols. EGMP divides the network topology into geographical non-overlapping square zones, and a leader is elected in each zone to serve as a representative of its local zone on the upper tier. The leader collects the local zone's group membership information and represents its associated zone to join or leave the multicast sessions as required. At the upper tier, the leaders of the member zones report the zone memberships to the sources directly along a virtual reverse-tree-based structure or through the home zone.

The position information is used to implement a hierarchical group membership management. EGMP maintains the tree by introducing a concept called zone depth, which is the depth of the member zone and root of the tree. The sender node sends the multicast packet directly in the tree, and then it will flow along the multicast tree at the upper tier. When a zone leader receives the packet, it will send the packet to the group members in its local zone. Nodes inside the same zone are within each other's transmission range and forwarding nodes are used for the communication between nodes in different zones.

In this protocol the location service is combined with the hierarchical zone structure. So, the packet is forwarded to the center of the destination zone and then it is forwarded to the specific zone or broadcasted depending on the message type. The multicast session is initiated by flooding a message into the whole network and the node that is interested in the multicast group can join this session. The flooding of the multicast session initiation is easy to be implemented but it introduces a large overhead. Also, the size of the multicast message is large as it contains the list of next hop for all destinations in addition to the destination list.

### 2.2.5 Location-Aware Cluster Multicast QoS Routing Protocol (LACMQR)

In [43], a cluster-based QoS multicast routing protocol has been proposed. This protocol partitions the network into square clusters and the nearest node to cluster center is elected as a cluster-head. A gateway node is selected between the adjacent clusters to rely the packets when the adjacent cluster-heads are out of the effective transmission range of each other (refer to Fig. 4.)

The source node starts the multicast session by sending a *PROPE* packet to the cluster-head. If the destination is in the same cluster, the cluster-head will forward this *PROPE* packet to the destination node directly. The cluster-head then forwards the *PROBE* packet to its gateway nodes. The gateway forwards this packet to the proper neighbor cluster until either the destination or an intermediate node with a valid route to the destination is reached. The destination or the intermediate node selects the optimal route using best predecessor replacement strategy [61]. When an intermediate node receives a *PROPE* packet, it compares the accumulated metric (e.g. delay and cost) of the current probe packet with that of the previous probe packets. If the value of the constructed metric of the new *PROPE* is better than that of the previous probe, the node changes its predecessor to the node that forwarded the new *PROPE* packet. As a better path has been found, the *PROPE* will be forwarded; otherwise, the *PROPE* packet is discarded. When the source receives the *ACK* reply packet, it starts data transmission.

This protocol uses only cluster-head, source, gateway and destination nodes in routing. However, only the gateway is responsible for packet forwarding. Thus, the gateway selection

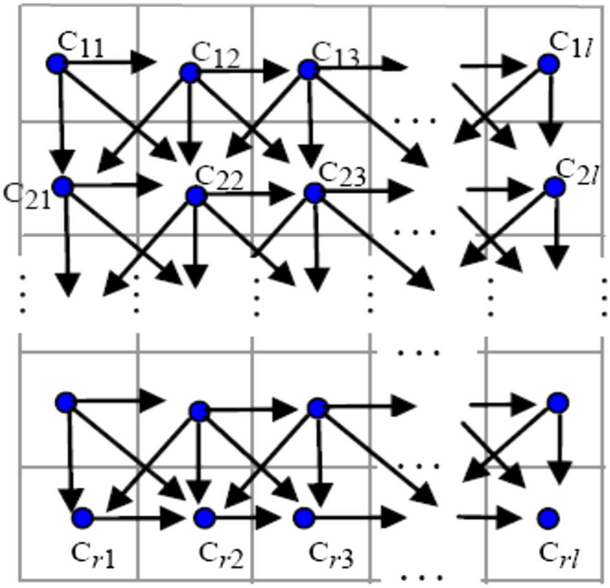


**Fig. 4** Entire topology of LACMQR [60]

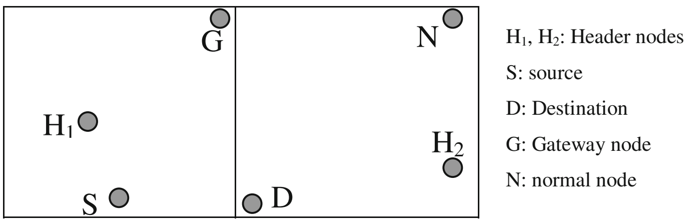


**Fig. 5** LACMQR in sparse network

becomes the key point of this protocol. Furthermore, authors did not discuss the needed network structure maintenance, which may produce significant traffic. Another drawback appears when the network is sparse, in this case the gateway nodes may fail to reach the neighbor cluster-head and then the route cannot be established as shown in Fig. 5. As shown in Fig. 5, the source $S$ needs to contact with node $G$ to forward the packets. Since the network is sparse, $G$ cannot reach $H_2$ directly although there are many routes from $S$ to $D$ such as $S$-$H_1$-$G$-$D$ and $S$-$H_1$-$G$-$N$-$D$).

### *2.2.6 Hypercube-Based Virtual Dynamic Backbone (HVDB)*

In [56], a hypercube-based model for QoS-aware multicast communication has been proposed. In *HVDB*, the clusters are formed using the mobility prediction and location-based technique used in [62].

As shown in Fig. 6, the structure is abstracted into three tiers: mobile node (*MN*), hypercube tier (*HT*) and mesh tier (*MT*). The network area is partitioned into overlapped circular shapes and a cluster-head (*CH*) is elected for each circle. The *CH* is mapped to a hypercube node at the *HT* tier. Each hypercube is mapped as one mesh node at the mesh tier. The nodes periodically

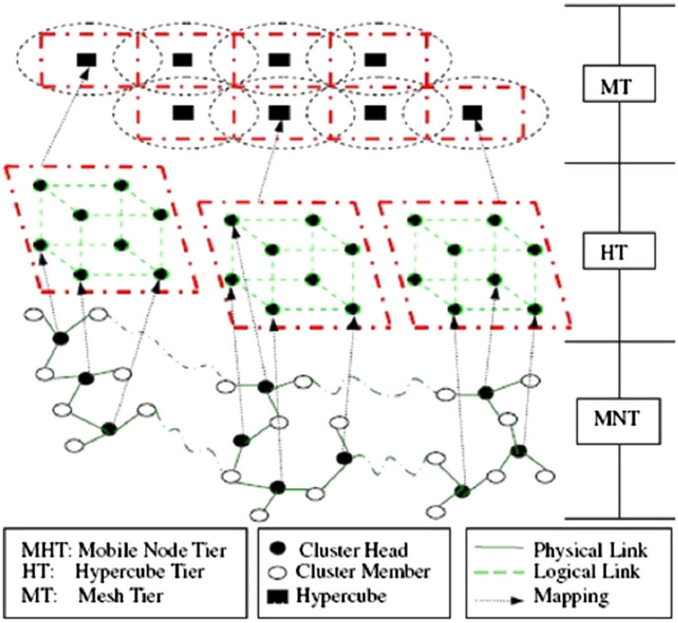


**Fig. 6** HVDB structure [56]

send the local memberships to their *CH*. Each *CH* periodically sends the group memberships to all *CH*s within the hypercube. Moreover, one of the *CH*s periodically broadcasts the membership to all the clusters in the network.

In *HVDB* [56], the multicast tree is built at the mesh tier, and each node in the tree is a mesh node, i.e., a logical hypercube. When a node has data to send to group members, it sends the data to its *CH*. Then, the *CH* checks the summarized membership to determine the hypercubes that maintain the members of this group. The logical locations of these hypercubes are used to compute a multicast tree. The information about the multicast tree is encapsulated into the messages. A location-based unicast protocol is used to send the packets between *CHs* in the same hypercube. When the packet enters a hypercube, it is forwarded to hypercube nodes that contain the group members.

*HVDB* protocol is scalable and provides fault tolerance property. However, it suffers from high communication overhead due to periodic messages in the three tiers. Also, the overlapping circles bring extra overhead for the cluster-heads. Additionally, the mapping between the tiers and the selection of border and inner cluster-heads increases the overhead.

### *2.2.7 Comparative Analysis of Location-Based Multicast Routing Protocols*

Table 3 summarizes the discussed location-based multicast routing protocols. We tried to discuss some of the latest proposed protocols to support scalable multicast routing.

LGT [53] builds an overlay packet delivery tree on top of the underlying unicast routing protocol, and multicast packets are encapsulated in a unicast envelop and unicasted between the group members to minimize the overall bandwidth cost of the tree. LGT requires each group member to know the locations of all other members, which makes it suitable for small multicast groups and not suited for large receiver groups. Since LGT requires long delay time

**Table 3** Summary of reviewed location-based multicast proposals

| Protocol | Approach | Strengths | Limitations |
|---|---|---|---|
| LGT [53] | 1. Stateless protocol based on packet encapsulation | 1. Using stateless scheme eliminates maintaining multicast routing tables | 1. Each group member has to know the locations of all other group members |
| | 2. Packets are forwarded using unicast routing in an overlay fashion | 2. LGT overlay topology is more robust against network traffic and mobility | 2. Location service algorithm and how to get the up-to-date position information is ambiguous |
| | 3. Proposes two overlay multicast trees: a bandwidth-minimizing LGS tree and a delay-minimizing LGK tree | 3. Minimizes the bandwidth cost | 3. LGS algorithm will fail if there is no neighbor of the current node that is closer to the root of the sub-tree |
| | | | 4. LGT is not scalable for large multicast groups |
| | | | 5. Packet header is large in size |
| PBM [54] | 1. PBM studies the rules for splitting a multicast packet's path and a repair strategy for situations where no direct neighbor exists that makes progress toward one or more destinations | 1. Global distribution structure is not necessary because the next hops are selected by the neighbor nodes | 1. PBM is limited to groups with a small number of nodes |
| | 2. The positions of the destination nodes are assumed to be known to the sender node | 2. Efficient in case that the destinations are distributed in large scale area | 2. PBM suffers from high cost when there are a large number of destinations due to the fact that location and membership information is required at each sender |
| | 3. Uses greedy forwarding | 3. Uses only locally available location information about the destination nodes to reduce the length of the path to each individual destination | 3. PBM is not scalable in terms of group size because the location and group membership information for each sender is required to be included in the data packets |
| EGMP [42] | 1. Network is divided into square zones | 1. EGMP is scalable | 1. The flooding of the multicast session initiation introduces large overhead |
| | 2. A zone-based bi-directional multicast tree is built to connect zones having group members | 2. Combine location service with membership management | 2. The size of the multicast message is high because it contains the list of next hop for all destinations in addition to the destination list |
| | 3. Hierarchical group membership management | 3. EGMP does not use any network flooding | |
| | | 4. Robust against node mobility | |

**Table 3** continued

| Protocol | Approach | Strengths | Limitations |
|---|---|---|---|
| SPBM [55] | 1. Defines a static hierarchy by dividing the network into a quad tree with a predefined level of aggregation | 1. SPBM is scalable in terms of group size because it uses hierarchical group management | 1. SPBM uses flooding in hierarchical group management |
| | 2. Manages the multicast members in a scalable way | 2. Robust against dynamic network topology | 2. The hierarchy structure increases the delay of information update which makes SPBM not scalable for node mobility |
| | | 3. Analytical model is provided to examine the protocol performance | 3. Not efficient in multicast delivery due to using a separate unicast protocol for each destination |
| LACMQR [43] | 1. Divides the network into clusters | 1. The use of end-to-end probing does not require the network state, and the available resources are estimated based on the ability of the receiving node | 1. The gateway is responsible for packet forwarding. Thus, the gateway selection becomes the key point |
| | 2. Uses location information to discover and maintain routes | 2. Shows better performance compared with ODMRP protocol | 2. The network performance is poor in sparse network |
| | 3. Bases on a distributed cluster-based QoS multicast routing algorithm | | 3. Relies on location-based unicast routing algorithm |
| | | | 4. The simulation results do not show the performance in large-scale networks |
| HVDB [56] | 1. Uses hypercube-based virtual backbone. Nodes are grouped into clusters, clusters into hypercubes and hypercubes into a mesh to build logical routes | 1. Hypercube architecture provides fault tolerance to address the availability issue | 1. Incurs high communication overhead due to the periodic messages in the three tiers |
| | 2. Studies availability and load balancing as QoS metrics | 2. Provides regularity and symmetry to address the load balancing issue | 2. Mapping between the tiers and the selection of border and inner cluster-heads, increases the overhead |
| | | | 3. Overlapping circles bring extra overhead for the cluster-heads |

to acquire the location information of the receivers; it is inefficient in applications sensitive for delay like voice and video applications.

PBM [54] builds a multicast tree by applying a greedy neighbor selection approach. PBM uses information about the positions of the destinations and its own neighbors to determine the next hops that the packet should be forwarded to and is thus very well suited for highly dynamic networks. PBM provides efficient multicast forwarding and reduces the interchange of routing tables between neighbors which can support reliable data transmission. However, PBM needs to include all the destinations positions in the multicast data packet which limits its scalability in networks of large number of receivers.

SPBM [55] uses the geographic position of nodes to provide a scalable group membership scheme and to forward data packets. The multicast groups are managed into a way to provide scalability and separate geographic multicast forwarding was used for each destination. This reduces the efficiency in multicast packet forwarding and increases the routing tables exchange between neighboring nodes which reduces SPBM's scalability regarding increased number of receivers compared with PBM [54]. The periodic multilevel message flooding in SPBM and the network-wide flooding in its membership management increase its control overhead much more as the network size gets larger which reduces its efficiency in large scale networks.

EGMP [42] supports scalable and reliable membership management and multicast forwarding through a two-tier virtual zone-based structure. EGMP does not use any interrupted network-wide flooding, thus it can scale to mutually the group size and network size. In EGMP, the multicast tree is formed in the granularity of zone with the guidance of location information, which significantly reduces the tree management overhead and utilizes the network bandwidth. In fast changing network conditions, EGMP performance can adapt very fast to maintain the membership change and the movement of individual members which can be implemented in high mobility networks.

LACMQR [43] uses cluster-based routing to search for routes that satisfy the QoS metrics (e.g. delay and cost) using the best predecessor replacement strategy which may be suitable for multimedia traffic. The protocol discovers the routes but after high network traffic and high control overhead. The high overhead makes the protocol fails to scale in large networks with large number of multicast members.

HVDB [56] is a hybrid mesh based multicast routing protocol that contains mainly clusters, with cluster heads in each cluster. The mobile nodes find information like position velocity and direction using GPS and periodically send information to the cluster head to construct the hypercube structure. Also, the cluster heads store and exchange the summary of local nodes with the other cluster heads. The multicast tree is constructed among the hypercube nodes in a mesh based structure which provides high tolerance due to the availability of multiple links to the hypercube. This structure is efficient to QoS traffic in large scale networks. However, it will require more time to construct the network which may affect the performance of delay-sensitive applications.

## 3 Discussion

Multicasting is an ideal communication scheme that can efficiently support wide variety of applications that are characterized by close collaboration. The design of a multicast routing protocol depends on the application requirement, design goals, respective assumptions and network properties. The following points summarize our findings from the conducted literature review:

1. Proactive routing protocols are not applicable in a dense and dynamic network due to the large amount of broadcast messages initiated with topology changes. While reactive protocols allow deploying large networks at the cost of increased route acquisition latency.
2. Topology-based multicast protocols are difficult to scale due to many reasons. First, group membership changes frequently as each node may join or leave a multicast group

randomly. This group management becomes harder as the group size or network size increases. Second, construction and maintenance of multicast structure (tree-based or mesh-based) should be done wisely to reserve network resources especially when the group size is large.

3. Tree-based structure is difficult to maintain in frequent mobility scenarios and due to continuous changes in multicast group membership. While mesh-based protocols are more robust against topology changes at the cost of extra consumption of network resources.
4. Flooding is considered as the most reliable scheme and it outperforms other approaches in terms of packet delivery ratio. However, flooding-based networks are not scalable and incur high overhead especially when the network size is large.
5. QoS guarantee in MANETs is not easy task as these networks are characterized by multi-hop, limited bandwidth resources and dynamic network topology. These characteristics make QoS provision in MANETs more complex compared to traditional wired or wireless networks.
6. In heterogeneous MANETs there may be differences in nodes' transmission ranges, nodes' capabilities, channel capacity and perspectives of the multicast members. Therefore MANET researchers are confronted with new challenges.
7. Hierarchical and clustering approaches are proposed to facilitate multicast delivery, location management, network management, multicast group management and QoS support. However, maintaining stable cluster structure is hard to achieve in high mobility networks.
8. Many issues need to be considered when using virtual construction to improve protocol performance. These issues include leader election, handling nodes mobility and failure and reducing packet loss during movement between grids.
9. In greedy forwarding, the data packets are sent only to the next node that has the best progress towards the destination. This method suffers from single point of failure, extra processing in the intermediate nodes, overhead of the periodic beaconing and it fails when it is deployed in sparse networks. Moreover, the location-based protocols that use greedy forwarding may not be able to support QoS. This is because the main elements of QoS multicasting are QoS routing, resource estimation, admission control and resource reservation. In greedy forwarding, there is no route discovery step and hence it is difficult to estimate the bandwidth previously.
10. On the other hand, restricted flooding is a promising forwarding technique to support QoS in location-based protocols. This is because restricted flooding avoids network flooding and the packets are sent to many nodes that are located closer to the destination. This will significantly reduce not only the consumed nodes' energy but also the probability of packets collision. Also, restricted flooding helps in increasing the probability of finding multiple paths and being robust against the failure of individual nodes and position inaccuracy.
11. Despite the fact that there are numerous available multicast routing protocols, a satisfactory solution for MANETs is still not evident and there still exist a number of issues and unresolved problems that need further investigation and research. Some of these issues are reliability, security and power consumption [63].

## 4 Conclusion

In short, this paper has presented a detailed survey on some recent network-layer multicast solutions for MANETs. Based on this survey, the limitations of the existing protocols may considered in designing new protocols. From the conducted survey, it was observed that most of the existing protocols do not take scalability into consideration when holding the multicast session, especially in QoS multicast protocols. A common problem with these protocols is that the control overhead could be large when the network gets dense, large and with large number of destinations. Despite the availability of numerous multicast routing protocols, a satisfactory solution is still not evident and a number of issues remain open problems that require further research and investigations. Some of these issues are reliability, scalability, security, QoS support, and power consumption. Hence, in this research, the scalability and efficiency of multicast routing protocol that supports multimedia applications are highlighted.

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