Team Multicasting Routing Protocol In MANETs

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Abstract:

Multicast applications for large-scale Mobile Ad hoc NETworks (MANETs) require an efficient and effective Quality of Service (QoS)-aware multicast model. The new requirements to guarantee QoS are high availability and good load balancing due to limited bandwidth and transmission power of Mobile Nodes (MNs). In this paper, multicast routing protocol namely Hypercube based Team Multicast Routing Protocol (HTMRP) has been proposed to address the scalability in mobile ad hoc networks In HTMRP team multicasting is proposed where the multicast group does not consist of individuals rather, member teams. This mechanism is common in ad hoc networks to accomplish collective tasks such as emergency recovery, battle field where team affinity model exist when the member teams has a common interest. In MANET the link failures due to mobility is a big concern and is addressed in HTMRP by incorporating a logical hypercube model. The HTMRP also has a mesh layer on top of the hypercube for effective fault tolerance. In addition to scalability, HTMRP also guarantee the new QoS requirements namely high availability and good load balancing by incorporating team, hypercube and mesh tiers. The HTMRP has been simulated and extensively analyzed for scalability, delivery ratio and control overhead. HTMRP provides better performance for the above evaluation parameters than the existing multicast routing protocol.

Keywords:
MANETs, HTMRP, Team Affinity model

1. INTRODUCTION

Ad hoc networks are self-organizing, rapidly deployable, and dynamically reconfigurable networks, which require no fixed infrastructure. Ad hoc networks in which the nodes are connected by wireless links and can be mobile are referred to as MANETs, where all the MNs function as hosts and routers at the same time. Two MNs communicate directly if they are within the radio transmission range of each other. Otherwise, they reach each other via a multi-hop route.

Many existing and forthcoming applications in MANETs require the collaboration of groups of mobile users. Communications in battlefield and disaster relief scenarios, video conferencing and multi-party gaming in conference room or classroom settings, and emergency warnings in vehicular networks are example applications. As a consequence, multicast in MANETs becomes a hot research topic in recent years. Multicast is a communication scheme for sending the same messages from a source to a group of destinations. MANETs are inherently ready for multicast communications due to their broadcast nature. However, limited bandwidth between MNs and highly dynamic topology due to unpredictable node mobility make the design of scalable and QoS-aware multicast routing protocols much more complicated than that in the traditional networks.

As MANETs are infrastructure-less, many virtual backbone-based routing schemes have been proposed to seek for similar capabilities of the high speed and broadband backbone in the Internet in supporting efficient data transportation. In the literature, two major techniques are used to construct a virtual backbone, i.e., connected dominating set [1,2] and clustering [3,4]. Because the search space for route discovery is reduced to the nodes in the virtual backbone consisting of the dominating set or the Cluster Heads (CHs) or agent, routing based on the virtual backbone scales better than that based on flat MANETs. However, the virtual backbone-based routing protocols still cannot scale well in large-scale MANETs when the number of nodes in the backbone becomes large.

In theory, a multi-tier hierarchy can potentially solve the scalability problem in the two-tier hierarchy. Therefore, a natural way is to further organize the backbone nodes into multiple tiers in large-scale MANETs. However, this scalability is not automatically guaranteed if too many tiers exist in the hierarchy. (1) Due to the mobility and failure of nodes, all the backbone nodes may join or leave the hierarchy at any time, which makes the maintenance of multi-tier routing tables quite challenging. (2) Most traffic load goes through the nodes in the higher tiers of the hierarchy, and these nodes become the bottlenecks. (3) There are some hardware limitations, e.g., different types of radio capabilities are required at different tiers. Although multiple radios in some backbone nodes are common practice in military applications, they may not be practical in many commercial applications if too many tiers of radios are required. Due to these reasons, one generally uses a backbone with only a few tiers (say, two) [30]. In order to solve the scalability problem in large-scale MANETs, researchers have developed many

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location-based routing protocols. Recent surveys on these protocols can be found in [5,6]. In location-based routing, each node determines its own location through the use of Global Positioning System (GPS) or some other type of positioning service. A location service is used by the sender of a packet to determine the location of the destination and to include it in the header of the packet. The routing decision at each forwarding node, is then based on the locations of the forwarding node's neighbors and the destination node. In this way, the location-based routing need not to maintain routing tables. Therefore, location-based routing can scale quite well in large-scale MANETs.

Basically, multicasting reduces the communication cost for the application that sends the same data to multiple destinations. In MANET, several tree based and mesh based multicast routing protocols have been proposed in the literature. Tree based multicast routing protocols construct a tree that connects all the members into the tree and provide single path between source and destination. Multicast ad hoc on demand distance vector routing protocol (MAODV) [7] and ad hoc multicast routing protocol are tree based protocols. On the other hand, mesh based protocols constructs a mesh structure between source and destination connecting each other. Because of mesh structure, the link failures can be quickly addressed by the redundant paths at the cost of excessive overhead. On-demand multicast routing protocol (ODMRP) [11] is mesh based protocol.

Existing multicast protocols [7,8,9,10,11] mainly addresses the multicast sessions with small group size and they do not scale well for large multicast sessions. Managing large multicast session in MANET is difficult because of the mobility of the members. Moreover, the existing multicast routing protocols do not exploit team affinity model [12, 13] where the members have collaborative mobility pattern and common interest.

Hence in this paper, a Hypercube based Team Multicast Routing Protocol (HTMRP) for MANETs is proposed. HTMRP address the team affinity model and scalability for large multicast group through team multicast [15] and hypercube architecture [14] respectively.

The proposed model is derived from n-dimensional hyper cubes, which have many desirable properties, such as high fault tolerance, small diameter, regularity, and symmetry. Due to these properties, the proposed model meets the new QoS requirements of high availability and good load balancing.

This model uses the mobility prediction and location based clustering technique in [4] to form stable clusters, which elects an MN as a CH when it satisfies the following criteria: (1) it has the highest probability, in comparison to other MNs within the same cluster, to stay for longer time within the cluster; (2) it has the minimum distance from the center of the cluster. Based on this technique, this model further abstracts a flat structure into three tiers: the mobile node tier, the hypercube tier, and the mesh tier, where each CH elected by their clustering algorithm can be simply mapped to a hypercube node at the hypercube tier.

2. RELATED WORK

2.1. Preliminaries of Hypercubes

An n-dimensional hypercube has 2^n nodes. Each node is labeled by a bit string k1 …..k_n (k_i {0, 1}, $1 \le i \le n$). Two nodes are connected by a link if and only if their labels differ by exactly one bit. The Hamming distance between two nodes u and v, denoted by H(u, v), is the number of bits in which u and v differ. An n-dimensional hypercube has many desirable properties: (1) High fault tolerance: The hypercube offers n node disjoint paths between each pair of nodes, therefore it can sustain up to n - 1 node failures; (2) Small diameter: The diameter of the hypercube is defined as the maximal Hamming distance between any pair of nodes in the hypercube, which is n; (3) Regularity: The hypercube has a very regular structure, in which every node plays exactly the same role, balancing; (4) Symmetry: The hypercube is symmetrical in graph terminology. In particular, any (k+1)-dimensional sub cube in the hypercube consists of two k-dimensional sub cubes for all $1 \le k < n$, each of which is also symmetrical

The hypercube is used to be a very hot research topic. It is originally proposed as an efficient interconnection network topology for Massively Parallel Processors (MPPs). In recent years, much research has been done to apply the hypercube to other network environments, such as multicast communications in the Internet [17,18], hypercube-like prefix routing in P2P networks [19, 20], and hypercube based overlay formation for P2P computing [21]. In [15], the authors propose the incomplete hypercube, which may contain any number of nodes. We generalize the incomplete hypercube by allowing any number of nodes/links to be absent due to many reasons such as mobility, transmission range, and failure of nodes.

2.2. Location-based Multicast Routing

Traditional unicast routing protocols designed for flat MANETs and hierarchical extensions, cannot scale well in large-scale MANETs. Similarly, traditional multicast routing protocols, e.g., flooding-based, tree-based, and mesh based, cannot scale well in large-scale MANETs either In recent years, location-based unicast routing has attracted much attention because it scales quite well in large scale MANETs. Accordingly, researchers have proposed to use location information in multicast routing protocols.

In the Dynamic Source Multicast (DSM) protocol [22], when a packet is to be multicast, the sender first locally computes a snapshot of the global network topology according to the location and transmission radius information collected from all the nodes in the network. A multicast tree for the addressed multicast group is then computed locally based on the snapshot. The resulting multicast tree is then optimally encoded and is included in the packet header. This protocol improves the scalability because it eliminates the maintenance of the multicast session state in each router, which has to be done in traditional multicast tree or multicast mesh based protocols. However, its scalability is still limited because the location and transmission radius information has to be periodically broadcast from each node to all the other nodes in the network.

In [23], the Small Group Multicast (SGM) protocol based on packet encapsulation is proposed. This protocol builds an overlay multicast packet distribution tree on top of the underlying unicast routing protocol. Different from the DSM protocol that computes the multicast tree at each sender, this protocol constructs the tree in a distributed way: each node only constructs its out-going branches to the next-level sub trees and forwards the packet to the roots of the sub trees. This process repeats until all the destinations have been reached. This protocol is more scalable than the DSM protocol because the nodes in a group need not to know the global network topology. Instead, they are only aware of each other in terms of the group membership and the location information of the group nodes. However, this protocol does not specify a method for dynamic joins and leaves in terms of location update among the group nodes. Therefore, this protocol is more suitable for the groups in which the group membership is static.

In [24], the Position-Based Multicast (PBM) protocol is proposed using only locally available location information about the destination nodes. This protocol provides a solution in order to approximate the optima for two potentially conflicting properties of the multicast distribution tree: (1) the length of the paths to the individual destinations should be minimal, and (2) the total number of hops needed to forward the packet to all the destinations should be as small as possible. If not properly handled, a greedy multicast forwarding may lead to a problem when a packet arrives at a node that does not have any neighbor providing progress for one or more destinations. This problem is solved in location-based unicast routing, such as using the right hand rule-based recovery strategy in [25]. This protocol extends the strategy to support the packet with multiple destinations. This protocol can deal with group members distributed in large-scale MANETs. However, it cannot scale well in terms of the number of group nodes due to the fact that the location and group membership information is required at each sender of the multicast group.

In [26], the Scalable Position-Based Multicast (SPBM) protocol is proposed to extend PBM. SPBM uses a hierarchical aggregation of membership information: the further away a region is from an intermediate node, the higher the level of aggregation should be for this region. This hierarchical scheme improves scalability. However, because all the nodes in the network are involved in the membership update, it still cannot scale well in large-scale MANETs. In this paper, we solve this problem by summarizing the group membership information in a novel way and disseminating this information to only a portion of nodes in the network. Therefore, our scheme can potentially scale well in terms of both the number of groups and the number of group nodes in each group in large-scale MANETs.

2.3. QoS-aware Routing Issues

Generally speaking, QoS is a loosely defined term. There are some metrics affecting QoS, such as delay, bandwidth, packet loss, and energy consumption. QoS-aware routing has been studied extensively in the wired networks such as the Internet. Due to the node mobility and the scarcity of resources such as energy of nodes and bandwidth of wireless links, it is much more difficult to provide QoS guarantee in MANETs than in the Internet. In fact, guaranteeing QoS in such a network may be impossible if the nodes are too mobile[27]. In the literature, there are only a few works tackling this problem in MANETs. In [28], a hard-QoS protocol based on the well-known IntServ model is proposed in MANETs, which searches multiple paths in parallel in order to find the most qualified one. In [30], the authors propose to use location information in QoS routing decisions, and consider connection time (estimated lifetime of a link) as a QoS constraint. In [9], the authors present a protocol for TDMA-based bandwidth reservation for QoS routing in MANETs. It solves the race condition and parallel reservation problems by maintaining three-state information (free/allocated/reserved) at each MN.

In [31], a soft-QoS protocol based on the well-known Differentiated Services model is proposed in MANETs. It extends the Dynamic Source Routing (DSR) protocol to embed the QoS constraints in the discovery, maintenance of routes, and the traffic management. In highly dynamic MANETs, soft-QoS protocols may have better overall performance than hard-QoS protocols due to the highly unpredictable topological change of the MANETs. In MANETs, network nodes/links may be broken sometimes, disrupting the continuity of an on-going session and potentially terminating the session, thus inducing the QoS problem. Many papers view the QoS as a scheme in providing fault tolerance [32, 33]. In particular, in [35], the authors propose to pre-compute some routes before existing routes break and thus avoid route re-computation delay. In this sense, the HTMRP model proposed in this paper helps to provide fault tolerance due to the high fault tolerance of hypercube.

The QoS problem is hard to tackle even in the wired network. In [34], the authors point out that high availability and even distribution of traffic over the network are a prerequisite for the economical provisioning of QoS. We complement that it is especially true in MANETs due to limited bandwidth and energy of MNs. Here high availability indicates that a network has the capability of hiding or quickly responding to faults, making users no sense of faults in the network; Load balancing indicates that traffic load be distributed evenly in the network to the greatest extent in order to eliminate hot spots in the network. Based on these, traditional QoS models, such as IntServ and DiffServ models, can perform much more effectively in MANETs.

3. HTMRP

In this section, we introduce the Hypercube based Team Multicast Routing Protocol (HTMRP), which combines the features of team multicast and hypercube to provide scalability, robustness, high availability and good load balancing in MANET.

3.1 Protocol overview

HTMRP is a hierarchical multicasting protocol, which organize the nodes with common interest into teams based on team affinity model. With such a hierarchy, HTMRP provides a three-tier multicast routing paradigm consisting of Landmark Tier, Hypercube Tier and Mesh tier which is shown in Figure.1.

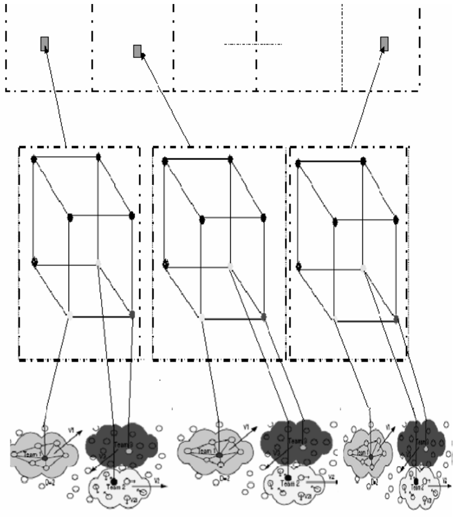

Figure 1. HTMRP layered model

3.1.1. Landmark Tier

Landmark Tier (LT) is the bottom most layer where the actual nodes are formed into teams.

These nodes have coordinated motion, i.e., they move together as a group. Each node in a team can randomly move with in a bounded area. Each team dynamically elects a team leader called Landmark and is responsible for broadcasting the message to other team members.

3.1.2. Hypercube Tier

Hypercube Tier (HT) is the middle layer which comprises of logical three dimensional hypercube whose nodes are actually team leaders of the Landmark Tier. HT provides QoS factors such as good load balancing and high availability to the proposed protocol. There is a one-to-one mapping relation between a team leader and a hypercube node. The hypercube is logical in the sense that the logical link between two adjacent logical hypercube nodes possibly consists of multi-hop physical links.

3.1. 3. Mesh Tier

The Mesh Tier (MT) is the top layer which is a mesh structure contains the hypercube as one mesh node. The link between two adjacent mesh nodes is logical and physically multi-hop.

3.2. HTMRP Algorithm

In HTMRP, the network nodes are divided into several teams Tn based on the commonality of interest of the nodes. The node which comes first into the team acts as team leader TL. The number of nodes and their ids in a team are maintained in In-list. A link from node i to node j is said to be present if node j lies within the transmission range of node i, i.e., link(i, j) = 1, if dist(i,j) <= Trange(i). We assume that all nodes in the team have uniform Trange and use omni-directional antennas. As and when a message is received, the TL broadcasts the same to the members of the team. Based on the number of team and team leaders, a logical hypercube is constructed. Let TL, TL $\subsetneq$ Tn denotes the team leader, TLS may be the source Team Leader which is the multicast source and TLR, TLR $\subsetneq$ Tn, is the set of receiver Team Leaders. Since the team leaders are the members of the hypercube, each team leader has a minimum three direct links to other team leaders. This arrangement helps in providing a better fault-tolerance through redundant path. As the multicast teams increase, the protocol needs to construct many such hypercube to accommodate all team leaders. In such case, a mesh is constructed to connect all the hyper cubes. Mesh structure inherently provides fault tolerance as it has alternate paths. For the entire multicast, the tree is constructed at hypercube and mesh level based on the number of teams involved. The entire protocol has been implemented using three different algorithms at three different tiers.

Landmark tier team construction algorithm:

```
// Nodes with common interest forms a team T; the first node in the team acts as team leader TL;

1. For each team Ti in Tn, $1 \le i \le Tn$, where Tn =
   {T1,T2,T3,…….Tn};

2. in-list = {} for each node Cj in Ti, $1 \le j$
   $\le |Ti|$ do in-list := in-list + {Cj};

3. list of neighboring nodes of A is {B1, B2, ….,
   Bx};
   for each neighboring node Bk, $1 \le k \le x$ do
   Compute the distance dk between A and Bk;

4. if $dk \le Trange$ then A and Bk are neighbors
   else find a multi-hop route between A and Bk

5. for each node Cj in in-list do
   TL broadcasts the message;
```

Hypercube tier tree construction algorithm:

```
1. for each team leader TLi in Tn, $1 \le i \le n$ do
   Source TLS sends the add initiates process
   if TLi requires to join multicast MG(S) then
   sends RREQ to TLS;

2. if TLS is in the same hypercube then
   Select the best path based on less hop count
   to construct hypercube tier multicast tree
   and sends RREP in the same path to TLi;
   else construct mesh tier multicast tree;
```

Mesh tier tree construction algorithm:

```
// Let TLhs be the Team leader in hypercube
   acting as  source and TLhr is the team leader
   in hypercube acts are receiver. TLs is the team
   leader source.

1. if $TL_{hr}$ sends RREQ to $TL_{hs}$ then $TL_{hs}$ sends to
   TLs;

2. Construct multicast tree at TLS and sends
   RREP back to TLhr;
```

3.3 Protocol Operation

Based on the above algorithms, HTMRP constructs the source-initiated multicast tree based on team multicast routing in which destinations are teams rather than individual nodes. This protocol has tree initialization and maintenance phases and is explained in the following section.

3.3.1. Tree Initialization Phase

The Source Team Leader (TLS) initiates the team multicast tree construction phase at hypercube by connecting a team. The process includes flooding by the source, replies by the receivers, best path selection by the source to the receivers. For creating the team multicast tree, initially the source TLS broadcasts multicast address along with its ID to inform all potential receivers. The team leader of the same hypercube, which wants to join in that multicast group (MGS) sends RREQ packet to source TLS. When an intermediate team leader receives the RREQ packet, it updates the path in its local routing table, increments the hop count, appends its ID to the RREQ packet and forward it to the next node.

After receiving RREQ packet through different paths the TLS selects the best path based on less hop count. If more than one path has same hop count then it checks the utility value of the paths and selects the path which has less utility value. Less utility value path has less congestion. The utility value is incremented by one whenever some TL uses the path. The TLS update the information into its multicast routing table and sends RREP packet in that path to the receiver in order to establish the hypercube tier multicast tree. After establishing team multicast tree TLS sends the data packets to the TLR and in turn the TLR broadcasts them to all its team members. When the team leader TLR, which is not present in the same hypercube wants to join in the multicast group, then it sends RREQ packet to its corresponding mesh node in order to construct mesh tier multicast tree. The mesh tier receiver MTR sends that RREQ to mesh tier source MTS where the source team leader hypercube HCS is the member to that MTS. Then MTS sends that RREQ to HCS where hypercube tier multicast tree is constructed as described above and the RREP is sent through that path.

3.3.2 Tree Maintenance Phase

Due to Team affinity model, tree maintenance is simple in HTMRP. Even though the nodes are moving in the team, there is no need to reconstruct the team multicast tree because only team leaders are presented in the multicast tree instead of nodes. Hence overhead and link breakages are less in the landmark tier. In the hypercube and mesh tiers the tree maintenance is done using a hard state approach. Each team leader maintains a table called

Neighbors - Neighbor Team Leader Table (NNTT) which has the information about the neighbor's neighbor. This table is periodically updated through packets.

In hypercube Tier, if receiver TLR1 moves from position A to B, link TLI1→TLR1 breaks. When a link break occurs, it's the responsibility of the downstream node (TLR1) to search for its upstream parent/super-parent node (TLI1). On detecting a link breakage, the downstream node TLR1 can refer its NNTT and find out a best alternate path (TLR1→ TLI2 →TLI1) to connect to the parent/super-parent node TLI1 immediately. This fast rerouting avoids the delay in the conventional Route Repair mechanisms i.e. the Route-Error propagation procedure. Since NNTT maintains two-hop neighbor team leader information, only a maximum of two consecutive link breakages can be locally repaired. Longer link breakages have to follow the conventional route repair mechanism.

4. SIMULATION RESULTS AND PERFORMANCE COMPARISON

The simulation models a dynamic mobile ad hoc network with hundred of nodes grouped into number of teams in a rectangular area. The maximum number of nodes in each team is 7. Every node has a uniform transmission range of 50m. The simulation has been run over 10 scenarios (topology information). In each scenario, the number of multicast sessions requested is varied in terms of 1, 2, 3, 4, 5… 10. The multicast source and receiver nodes are selected at random. Multiple runs are conducted for different scenarios and the collected data is averaged over these runs. The experiments were repeated with varying number of nodes. The performance of HTMRP has been extensively studied and compared with MAODV protocol

4.1 Performance Metrics

HTMRP has been evaluated using delivery ratio and control overhead metrics. Delivery ratio is the critical metric that is defined as the number of delivered packets to each member versus the number of packets to be received by each member. Control overhead is defined as the ratio of total number of control packets received against the total number of data and control packets delivered to each member.

4.2. Results Discussion

Based on the evaluation metrics, it is evident that HTMRP has better delivery ratio when the number of multicast sessions increases. This is because of the team multicasting technique. When the numbers of multicast sessions are less the performances of HTMRP and MAODV are almost similar.

Similarly, another set of results have been obtained to compare the control overhead performance. The control overhead of HTMRP is little more when the multicast sessions are very less. This is because of the control messages required to setup the hypercube and mesh tiers in addition to multicast tree construction in landmark tier.

In HTMRP, redundant paths are provided by hypercube architecture and mesh topology which considerably enhance the delivery ratio and reduce the overhead even with high mobility when compared with MAODV. This is because of less number of multicast tree construction is carried out in HTMRP since the teams are the members of the multicast tree, not the nodes. Hence the mobility of the nodes does not affect much the performance of the multicasting compared with MAODV. HTMRP performs better than the MAODV protocol when the network size grows or the number of multicast session

5. CONCLUSION

We have proposed a HTMRP to support QoS-aware multicast in large-scale MANETs. The proposed model is derived from n-dimensional hypercube, which have many desirable properties, such as high fault tolerance, small diameter, regularity, and symmetry. The proposed model uses the location information of MNs and meets the new QoS requirements: high availability and good load balancing. Firstly, in an incomplete logical hypercube, there are multiple disjoint local logical routes between each pair of CHs, the high fault tolerance property provides multiple choices for QoS routing. That is, if the current logical route is broken, multiple candidate logical routes become available immediately to sustain the service without QoS being degraded. Secondly, small diameter facilitates small number of logical hops on the logical routes. Thirdly, due to the regularity and symmetry properties of hypercube, no leader is needed in a logical hypercube, and every node plays almost the same role except for the slightly different roles of BCHs and ICHs. Thus, no single node is more loaded than any other nodes, and no problem of bottlenecks exists, which is likely to occur in tree-based architectures.

This paper thoroughly analyses the problems of scalability in large scale multicast routing with more nodes and large number of multicast sessions. Based on that, HTMRP is proposed and implemented. From the experimental results, it is proved that HTMRP outperforms the existing multicast routing protocols in terms of delivery ratio and control overhead. HTMRP also implements a combination of both team multicast and hypercube structure to provide high scalability and reliability.

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