

MZRP: An Extension of the Zone Routing Protocol for Multicasting in MANETs

XIAOFENG ZHANG AND LILLYKUTTY JACOB

Centre for Internet Research School of Computing

National University of Singapore

3 Science Drive 2, Singapore 117543

E-mail: {zhangxi4, jacobl}@comp.nus.edu.sg

In recent years, a variety of unicast and multicast routing protocols for Mobile Ad hoc wireless NETWORKS (MANETs) have been developed. The Zone Routing Protocol (ZRP) is a hybrid unicast protocol that proactively maintains routing information for a local neighborhood (routing zone), while reactively acquiring routes to destinations beyond the routing zone. In this paper, we extend ZRP for application to multicast routing and call it the Multicast Zone Routing Protocol (MZRP). MZRP is a shared tree multicast routing protocol that proactively maintains the multicast tree membership for nodes' local routing zones at each node while establishing multicast trees on-demand. It is scalable to a large number of multicast senders and groups. IP tunnel mechanism is used to improve the data packet delivery ratio during transmission. Detailed simulations were performed on the NS-2 simulator. Its performance was also compared with that of ODMRP.

Keywords: MANETs, multicasting, zone routing, performance evaluation, wireless networks

1. INTRODUCTION

Ad Hoc networks are wireless networks that do not need any communication infrastructure. They are characterized by a dynamic topology due to node mobility, limited channel bandwidth, and the limited battery power of nodes. In a typical ad hoc environment, group-oriented communication is more popular than one-to-one communication, and multicast has naturally been considered the ideal technique for use with group communication. Multicast protocols used in static networks do not perform well in ad hoc networks due to node mobility and limited channel bandwidth. Thus, many new multicast routing protocols have been exclusively proposed for ad hoc wireless networks. Some of them are tree-based multicast protocols, e.g., the Reservation-Based Multicast (RMB) routing protocol [5], the Lightweight Adaptive Multicast (LAM) algorithm [12], the Ad-hoc Multicast Routing Protocol (AMRoute) [3], the Ad hoc Multicast Routing protocol utilizing Increasing Id-Numbers (AMRIS) [18], and the Multicast Extension of Ad Hoc On Demand Distance Vector (AODV) routing protocol [17], while others are mesh-based, e.g., the Core-Assisted mesh Protocol (CAMP) [16] and the On-Demand Multicast Rout-

Received October 15, 2003; accepted November 15, 2003.

Communicated by Ten-Hwang Lai, P. Sadayappan, Yu-Chee Tseng and Yi-Bing Lin.

Routing Protocol (ODMRP) [13, 14]. The mesh-based scheme can support a more robust route through multiple redundant routes. However, resources are wasted as a result of unnecessary forwarding of duplicate data. With the tree-based scheme, resource usage is optimized; however, the node's mobility induces a major tree reconstruction overhead and latency. Mesh-based multicast routing protocols show better overall performance than the tree-based protocols in [15] do.

In this paper, we extend the Zone Routing Protocol [6, 11] for application to multicast routing in ad hoc networks. The remainder of this paper is organized as follows. Section 2 gives a brief overview of ZRP. Section 3 describes our Multicast ZRP. The simulation environment, results and a comparison with ODMRP are presented in section 4, and a conclusion is given in section 5.

2. OVERVIEW OF ZONE ROUTING PROTOCOL

The Zone Routing Protocol (ZRP) is a hybrid ad hoc routing protocol which limits the scope of the proactive procedure to the node's local neighborhood. It is composed of an IntraZone Routing Protocol (IARP) [10], IntErzone Routing Protocol (IERP) [9] and Bordercast Resolution Protocol (BRP) [8] with a query-control mechanism. We will describe each of them briefly in this section. For more details, please refer to [6-11].

2.1 IntraZone Routing Protocol

IARP is a limited scope proactive routing protocol. The scope of IARP is defined by the routing zone radius: the distance in hops that IARP route updates are relayed. The routing zone for a node X is defined as the set of nodes whose minimum distance in hops over which X is no greater than a parameter referred to as the zone radius. An important subset of the routing zone nodes is the collection of nodes whose minimum distance to the central node is exactly equal to the zone radius, and these are called peripheral nodes. Every node will broadcast its local routing information within its own routing zone. This causes each node to maintain a local routing table, which contains the routes to the nodes in its routing zone. By using IARP, a node can get a route without any delay if the destination is within its routing zone.

2.2 IntErzone Routing Protocol

IERP is the global reactive routing component of ZRP. When a node needs a route which is not yet available, IERP will help to find it. IERP initiates a route discovery process; instead of flooding the request, it uses 'Bordercast' along with a query control mechanism, which will be described in the following subsections.

2.3 Bordercast Resolution Protocol

Bordercasting makes use of the information that IARP provides and directs the route request outward, via multicast, to a set of surrounding peripheral nodes. Then the peripheral nodes perform bordercasting again if they cannot reply to this query. Finally, the

query spreads throughout the network. There are two approaches to performing the bordercasting: one is called root directed bordercast; the other is called distributed bordercast. The root directed bordercast needs the source node and the peripheral nodes to construct their multicast trees and append forwarding instructions to the routing query packet. This results in additional routing overhead and increases when the zone radius increases, thus obscuring the benefits of ZRP. The distributed bordercast needs each node to maintain an extended routing zone, which increases the number of local routing information exchanges. However, it also reduces the requirement for route discovery.

2.4 Query-Control Mechanism

ZRP also needs an efficient query control mechanism in order to generate less control traffic than purely proactive route information exchange or purely reactive route discovery do. The query control mechanism includes Query Detection (QD1/QD2), Early Termination (ET), and Random Query Processing Delay (RQPD). Every node along the bordercast tree can detect the query (QD1) and keep the query from reappearing in the routing zone of a node that has already bordercast the query. Any node within the transmission range of a relaying node can overhear the query. This extended query detection is called QD2 and can be implemented by means of IP and MAC layer broadcasts. When a node relays a query, it can prune any downstream branch that either leads to the peripheral nodes that have been covered or leads to the peripheral node that it has already relayed the query to, which is called "ET." RQPD gives the relaying node another chance to prune the downstream branches. It is performed prior to bordercasting tree construction and ET.

3. MULTICAST ZONE ROUTING PROTOCOL (MZRP)

The proposed MZRP is a shared tree multicast routing protocol. Group leader messages are broadcast throughout the network so as to inform nodes of the existence of a multicast group and a group leader. By adapting IARP to MIARP, MZRP is able to keep track of group information in each node's local routing zone. And by adapting IERP to MIERP, it is able to construct a shared tree for a multicast group. An IP tunnel is used for data packets delivery while a broken link is being repaired by MZRP, which benefits the protocol as if there were redundant paths between tree members.

3.1 Group Leader Messages

The first member of a multicast group becomes the leader of the group until it decides to leave that group or until two partitions of the multicast tree merge. The group leader is in charge of broadcasting group leader messages periodically to the whole network.

3.2 Multicast IARP (MIARP)

In a multicast tree, there are two kinds of nodes: multicast forwarding nodes and multicast group members. The functions of multicast forwarding nodes are to intercon-

nect multicast group members and to forward packets in a multicast tree. Multicast tree membership messages are broadcast within a node's local routing zone if that node is a multicast tree member. Thus, nodes keep track of the groups and group members within their local routing zones. This helps a node to join a group with less route request routing overhead if there is a group member in its routing zone. This message can be sent separately or piggybacked on an original IARP packet, periodically or event-triggered.

3.3 Multicast IERP (MIERP)

3.3.1 Multicast route request procedure

A node that wishes to join a multicast group and is already a multicast forwarding node for that group switches its status from that of a multicast forwarding node to that of a multicast group member. Any other node that has data to send to a multicast group and does not have a route to that group sends a multicast route request (MRREQ) message. There are two kinds of MRREQs, unicast MRREQs and bordercast MRREQs, depending on the information the source node (the node that wants to join a multicast group or wants to send data to a multicast group) has. If the source node has a valid route to a multicast tree (i.e., to any node on the tree) and it wants to join that group, it sends a unicast MRREQ along the route to the multicast tree and waits for a multicast route reply (MRREP). The intermediate nodes forward the unicast MRREQ, and reverse paths are set in their multicast routing tables. When the destination (the tree member to which the source has unicast the MRREQ) receives the MRREQ, it sends an MRREP. If the unicast MRREQ fails or the source node does not have a valid route to that group, it initiates a bordercast MRREQ. This bordercast MRREQ is sent via the bordercast tree of the source node. When the bordercast MRREQ reaches the peripheral nodes, they check whether they have a valid route to that multicast group or group leader. If they do, they send unicast MRREQs instead of bordercast MRREQs and wait for the MRREPs. Otherwise, bordercast MRREQs are sent via the bordercast tree of the peripheral nodes, and so on. Reverse paths are established among the intermediate nodes. If the source does not receive an MRREP before timing out, it sends a bordercast MRREQ up to *mrreq_retries* times. After those request attempts, the source node assumes that there is no such multicast group in the network. It becomes the group leader of that group and starts to send group leader messages.

3.3.2 Multicast route reply procedure

When a destination node receives an MRREQ for a multicast group, if it is a multicast tree member of that multicast group, it sends MRREP to the source and waits for the multicast route activation (MRACT) message from the source node to activate the new branch of the multicast tree. The MRREP is sent to the source along the reverse path.

3.3.3 Multicast route activation procedure

The source may receive more than one reply after it sends an MRREQ. The source node waits for *wait_for_more_reply* msec after receiving the first reply, chooses the best

reply according to certain metrics and then sends an MRACT to that destination node. Other destination nodes that fail to receive MRACTs purge the inactive routes from their routing tables.

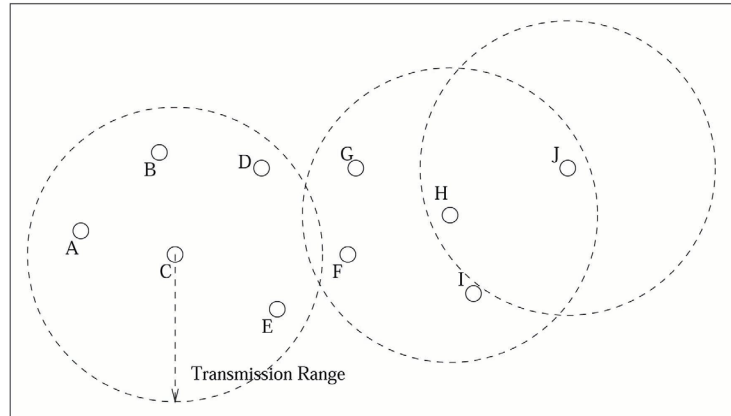


Fig. 1. Before multicast tree construction.

Example: In Fig. 1, the routing zone radius is 2. Suppose that node C wants to join a multicast group (say, MG1), and that there are no group members so far. Then, C bordercasts an MRREQ along its bordercast tree. When the peripheral nodes F and G receive the MRREQ, they re-bordercast the MRREQ using their bordercast trees. Because there is no group member of that multicast group in the network, C will not receive any reply to its MRREQs. After *mrreq_retries* attempts, C elects itself as the group leader and starts to broadcast group leader messages to the network as well as broadcast multicast tree membership messages within its local routing zone. Therefore, all the nodes know that the group leader of group MG1 is C after receiving group leader messages from C. Nodes A, B, D, E, F, and G (the nodes within the routing zone of C) know that there is a multicast tree member of multicast group MG1 in their routing zones after receiving multicast tree membership messages from C. Suppose that node J now wants to join MG1. It bordercasts an MRREQ since it does not know of a route to MG1 or the group leader. Both F and G have routes to node C when they receive the MRREQ from J, and both send unicast MRREQs to C. C replies to both of the MRREQs. Thus, source J receives two replies to the same MRREQ. It chooses one of them and sends an MRACT to the destination node. In this example, node J chooses the reply from node G. A new multicast tree branch is added, and nodes D, G, and H become multicast forwarding nodes for group MG1. After that, nodes D, G, H, and J start to broadcast their multicast membership messages within their local routing zones. When node F wants to join MG1, it has many choices of paths. It can choose one or more of them to send unicast MRREQs. In this example, F chooses one node, G, to send a unicast MRREQ. After the reply and activation procedure, another new branch is added to the multicast tree. If H wants to join the multicast group, it just switches its status from that of a forwarding tree member to that of a multicast group member because it is already in the multicast tree. Fig. 2 shows the resulting multicast tree.

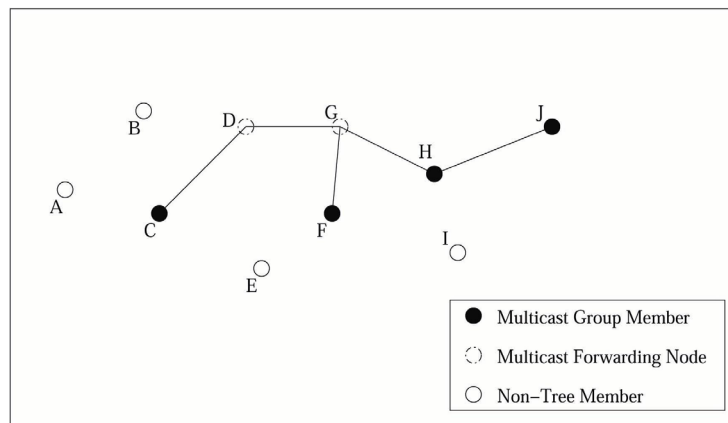


Fig. 2. After multicast tree construction.

3.4 Multicast Tree Maintenance

3.4.1 Pruning procedure

Suppose a multicast group member decides to leave the group. If it is a leaf node of the tree, it prunes itself from the multicast tree by sending a multicast prune message (MPRUNE), along with the ‘prune’ flag set, to its unique upstream node (i.e., the node that is closer to the group leader in terms of the number of hops in the multicast tree). The upstream node also prunes itself from the tree if it is not a group member, and it now becomes a leaf node. Otherwise, the pruning procedure stops. If the node which wants to leave the multicast group is not a leaf node, it just switches its status to that of a forwarding node. Suppose that the group leader wants to leave the group; it sends an MPRUNE to one of its downstream nodes, setting the ‘new_leader’ flag and, if necessary, the ‘prune’ flag as well. This pruning procedure continues until no more forwarding nodes need to be pruned and a multicast group member becomes the new group leader. The new group leader broadcasts a group leader message, along with the ‘update_leader’ flag set, to indicate that a new group leader has been elected, and then sends normal group leader messages periodically.

3.4.2 Repairing link breakages

A link breakage is detected if no packets are received from the neighbor during the time period $hello_interval \times (1 + allowed_hello_loss)$. Other neighbor detection mechanisms may also be applied to accomplish the same purpose. When a broken link is detected, the downstream node is in charge of repairing it. This prevents a loop from being formed during the repair process. When the downstream node has a valid route to the group in its routing zone, a local link repair is performed by sending a unicast MRREQ along with the ‘repair’ flag set. If the downstream node cannot find a route in its routing zone, MRREQs are bordercast in the network. The multicast tree members whose hops to the group leader are fewer than or equal to that from the downstream node may reply to

the MRREQs, which also prevents a loop from being formed during the repair process. If no MRREPs are received at the downstream node after *mrreq_retries* attempts, the downstream node assumes that the network has been partitioned. In this case, a new group leader is elected as described in the “pruning procedure.” On the other hand, the upstream node of the broken link may prune itself if it becomes a leaf node and forwarding node after *route_expiration* msec.

3.4.3 Reconnecting partitions

Group leader messages can be used to detect the reconnection of partitions. When a multicast tree member receives a group leader message of the same group but from a different group leader, it reports this to its group leader if the new group leader’s IP address is larger. Otherwise, the node ignores this group leader message. The group leader with a smaller address may receive more than one reports from different multicast tree members at the same time. It asks only one of them to perform reconnection, which prevents the formation of a loop. The border node (that gets permission from its group leader to reconnect) reports to the group leader with a smaller address when reconnection is successful. Upon receiving the reports, that group leader sends group leader message with the “*update_leader*” set to be true.

3.5 Using an IP Tunnel in Data Packet Transmission

Data packets may get dropped at the MAC layer either due to a broken link or due to RTS/CTS failure in the media access contention. A broken link is detected if no packets are received from the neighbor during the time period $hello_interval \times (1 + allowed_hello_loss)$. In high mobility scenarios, link breakages may not even be detected because of the relatively shorter durations during which the link is down. Because of the absence of redundant routes in a tree-based multicast protocol, severe performance degradation can occur under the above mentioned conditions: RTS/CTS failure, shorter but frequent link breakages, and relatively long durations of broken link repair performed by the multicast routing protocol. Use of an IP tunnel under these conditions can improve the performance significantly. With a routing zone ≥ 2 , there may be one or more nodes in the overlapping area between the two nodes that fail to send packets to each other. An IP tunnel can be temporarily created between these two nodes via a node in the overlapping area. Let us examine the feasibility of using an IP tunnel. Refer to Fig. 3. The overlapping area is given by $2(\pi/3 - \sqrt{3}/4)R^2$. Suppose that the area of the network is S , the number of mobile nodes is N , and the transmission range is R . The link between nodes A and B has just broken. If there is a node in the overlapping area, nodes A or B can send packets to each other through that intermediate node by using an IP tunnel. The probability that “*there is at least one node in the overlapping area*” is approximately

$$1 - \left(1 - \frac{2\left(\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right)R^2}{S} \right)^{N-2},$$

where we have approximated the distance between A and B to be R . If the transmission range is 250 m, the network size is $1000 \times 1000 \text{ m}^2$, and the number of nodes is 50, this probability is 97.84%. This means the use of an IP tunnel in such cases will benefit the performance significantly.

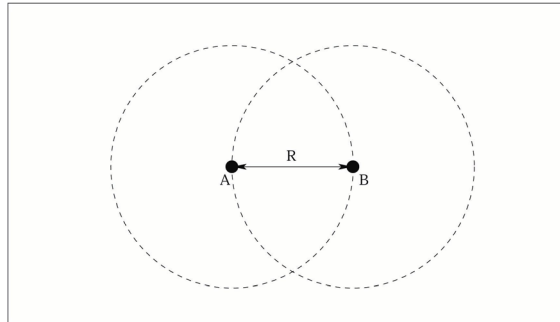


Fig. 3. IP tunnel feasibility illustration.

4. SIMULATIONS

4.1 Simulation Environment and Performance Metrics

Simulations were performed on the ns-2 simulator with wireless components that were developed by the Monarch research group at CMU. Details about the ns-2 simulator and the physical, data link and MAC layer models can be found in [2] and [4].

In our MZRP implementation, we adapted the link state routing protocol and AODV, respectively, for the MIARP and the MIERP, according to our multicast algorithms. The multicast tree membership information was added into the original link state packet. The distributed bordercast approach was implemented for bordercasting. The query-control mechanism described in section 1, which includes Query Detection and Early Termination, was also implemented. A HELLO message was used to detect the existence of neighbors. The distributed coordination function (DCF) mode of the IEEE 802.11 standard was used as the MAC layer, which used CSMA/CA, and RTS/CTS/data/ACK dialog. In all the simulations, 50 mobile nodes moved around a square region of size $1000 \times 1000 \text{ m}^2$ according to the random waypoint mobility model [4]. Constant bit-rate (CBR) traffic sources were used, and the data packet size was 64 bytes. The numbers of multicast groups and multicast members were varied to change the offered load in the network. All the simulations were run for 200 simulated seconds, and each point in a plot represented an average of seven runs with different random number streams. The on-demand multicast routing protocol (ODMRP) was compared with our MZRP. The implementation of ODMRP is described in [1]. For details about ODMRP and its performance, please refer to [13-15]. Table 1 gives the values of the essential parameters used with the two protocols in our simulations.

Four important performance metrics were used to evaluate the effectiveness and efficiency of the protocol as well as to compare its performance with that of ODMRP.

Table 1. Simulation parameters.

(a) Network parameters.

Simulation time	200 seconds
Network Size	1000 × 1000 (m ²)
Number of Nodes	50
Transmission Radius	250m
Transmission Rate	2 Mbps
Data Packet Size	64 bytes
Data Generating Rate	2 pkts/sec/sender
Multicast Groups	Variable
Multicast Group Members	Variable
Node Speed	Variable

(b) ZRP parameters.

hello_interval	1.0 s
link_state_interval	3.0 s
allow_hello_loss	3 pkts
GI_interval	10 s
Mrreq_retries	4
wait_for_more_reply_interval	50 ms
zone radius (hops)	variable

(c) ODMRP parameters.

join query refresh interval	3 sec
join reply acknowledgement timeout	25 ms
maximum join reply retransmissions	3

- Packet delivery ratio – the ratio of the number of data packets actually delivered to the destinations to the number of data packets are supposed to be received.
- Normalized multicast routing overhead – the ratio of the total number of multicast routing packets transmitted to the number of data packets delivered. For multicast routing packets sent over multiple hops, each transmission of a multicast routing packet (each hop) is counted as one transmission.
- The number of data packets transmitted per data packet delivered – “data packets transmitted” means the sum of all the individual data transmissions sent by each node over the entire network. This total includes the transmissions of packets that are eventually dropped and retransmitted by intermediate nodes.
- Multicast route discovery delay – the time interval between the instant when a node initiates a route query and the instant when it finally becomes a multicast member. This includes request, reply, and activation procedures. The average multicast route discovery delay was plotted. Only successful multicast route discovery requests were considered.

4.2 Results and Discussion

4.2.1 Varying node mobility

First, we performed a series of simulations, with the maximum speed ranging from 1 m/s to 20 m/s. Only one multicast group was used and there were 5 senders sending data among 20 multicast group members.

In Fig. 4, zr-0 represents a zone radius of zero, where no link-state packets are broadcast in the network. The multicast group information is not being broadcast, either. Therefore, MZRP becomes a pure reactive multicast routing protocol. Furthermore, the use of the IP tunnel is insignificant since a node may not have a valid route to replace the broken link in its routing table in most cases. zr-1 represents a zone radius of one, where link-state packets are broadcast if and only if a node is a multicast tree member. However, these link-state packets only contain multicast tree membership information, no link-state information. The use of the IP tunnel is again not significant for the same reason noted above. zr-2 represents a zone of radius two, where link-state packets are broadcast with multicast tree membership information if a node is multicast tree member. The IP tunnel is useful this time since there are valid routes to use when needed. zr-3 is similar to zr-2 where the zone radius is equal to 3.

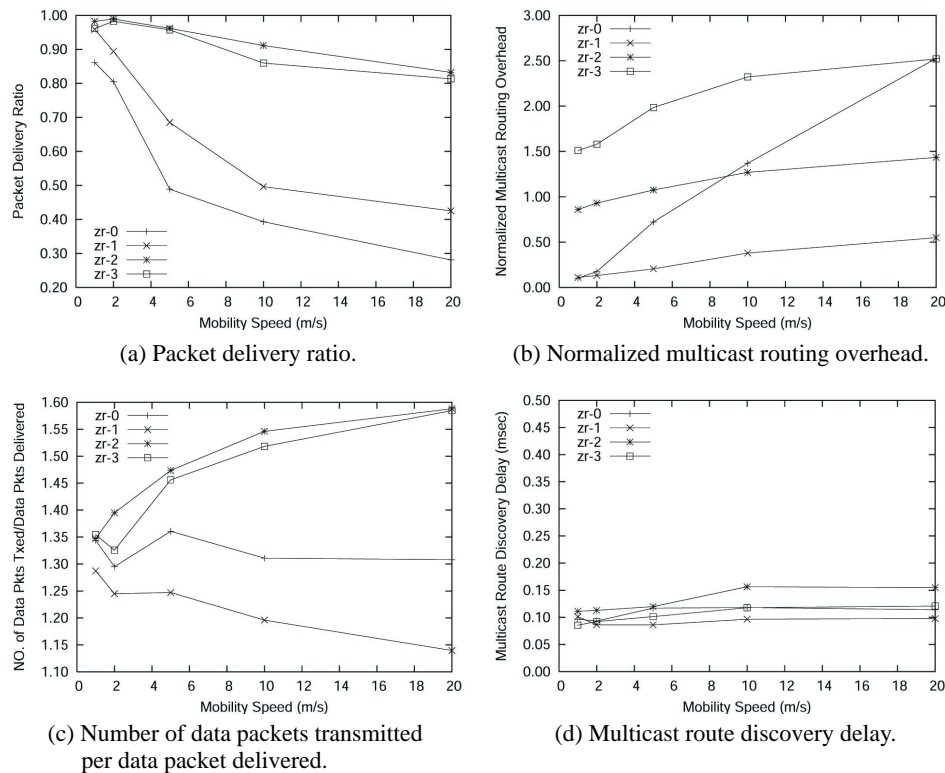


Fig. 4. Various performance metrics vs. mobility speed (20 multicast members, 5 senders, and 2 pkts/sec/sender).

As shown in Fig. 4 (a), zr-2 delivered the maximum number of data packets compared to the other zone radii. The delivery ratio of zr-3 was slightly worse than that of zr-2. This was due to more MIARP routing overhead when the zone radius was larger, especially with the distributed bordercast approach, where the extended routing zone is nearly two times larger than the original one [8]. zr-0 and zr-1 performed worse than zr-2 and zr-3 in all cases, especially when the mobility was high. Benefiting from multicast tree membership information learned from neighbors, zr-1 performed better than zr-0. In the case of zr-2, the average numbers of data packets sent via the IP tunnel in each running were (382, 1 m/s), (773, 2 m/s), (2317, 5 m/s), (3874, 10 m/s), and (5431, 20 m/s). Those in the case of zr-3 were (327, 1 m/s), (901, 2 m/s), (2621, 5 m/s), (3719, 10 m/s), and (5034, 20 m/s).

Fig. 4 (b) shows the performance achieved under the normalized multicast routing overhead. One can see that as the mobility increased, the normalized multicast routing overhead also increased. However, for zr-0, it increased most dramatically. This was because the normalized multicast routing overhead was a function of the routing overhead and delivered data packets. Under high mobility, the delivery ratio of zr-0 was very low, and the number of route requests was high, which caused the normalized multicast routing overhead to increase rapidly. Again, since zr-1 benefited from the multicast tree membership information learned from neighbors, the number of route requests was smaller. This made the curve more smooth than that of zr-0. In the case of zr-2 and zr-3, the values mainly depended on the proactive routing overhead. Thus, zr-2 had less normalized multicast routing overhead.

The other two metrics are shown in Figs. 4 (c) and 4 (d). zr-2 and zr-3 had similar numbers of transmissions, which were higher than those of zr-0 and zr-1. The use of the IP tunnel affected the values because at least one more hop was needed when the IP tunnel was used to replace the broken link. The multicast route discovery delays were very similar in all cases. zr-1 showed the best performance in most scenarios while zr-2 had the longest delay.

4.2.2 Varying group size and multicast senders

We fixed both the number of groups and the number of senders at 1, and varied the number of receivers from 1 to 25. Fig. 5 shows the results. We found that the packet delivery ratio and multicast route discovery delay were almost always the same regardless of the multicast group size. The packet delivery ratios for zr-2 and zr-3 were better than those for zr-0 and zr-1 due to use of the IP tunnel. The normalized multicast routing overhead decreased when the group size increased. When the zone radius was greater than 1, the overhead of MIARP was determined by the MIARP interval and the number of nodes. Therefore, when the group size was small, in spite of the high delivery ratio, the total number of delivered data packets was small. This led to a large normalized multicast routing overhead. However, it decreased rapidly when we increased the group size (see Fig. 5 (b)). The number of data packets transmitted per data packet delivered decreased when the group size increased (Fig. 5 (c)).

Next, we varied the number of senders in the group. We noticed that the packet delivery ratio decreased rapidly when there were 10 or more senders in the group. This was because the network loads were close to the network capacity. However, the normalized

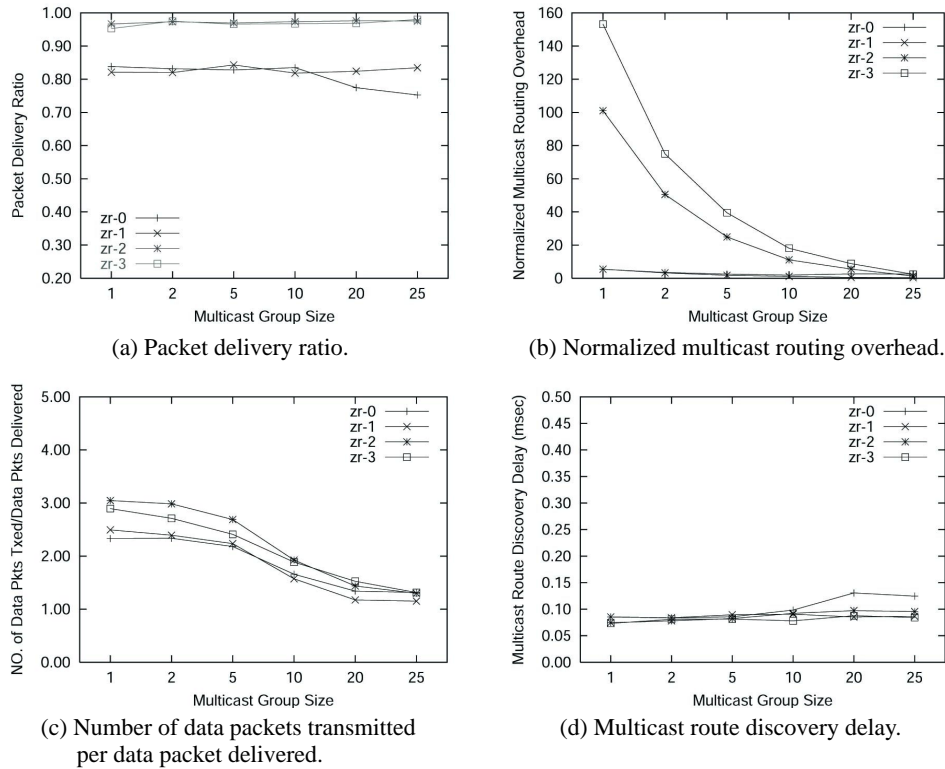


Fig. 5. Various performance metrics vs. multicast group size (1 sender, 5 m/s mobility speed, 2 pkts/sec/sender).

routing overhead still decreased when there were more senders. Remember that the normalized routing overhead is the ratio of the total number of multicast routing packets transmitted to the number of data packets delivered. With more data packets delivered, this value decreased. The other two performance metrics produced similar results when the number of senders changed (see Fig. 6).

4.2.3 Comparison with ODMRP

Finally, our protocol with ODMRP, which performed well among the other multicast routing protocols in most of the experiments in [14, 15]. For MZRP, we set the zone radius to be equal to 2, and varied the number of multicast groups and the nodes' degree of mobility. Each group had ten members, and three of them were senders. Figs. 7 (a) - 7 (c) show the results for low mobility, where the maximum speed was 2 m/s, and Figs. 8 (a) - (c) show the results for high mobility, where the maximum speed was 10 m/s. Figs. 7 (b) and 8 (b) show similar results for a normalized multicast routing overhead. When the number of groups increased from 1 to 3, ODMRP suffered from excessive control overhead. When the number of multicast groups increased, the total number of senders increased, and ODMRP did not scale well. This was due to the multicast route and mesh

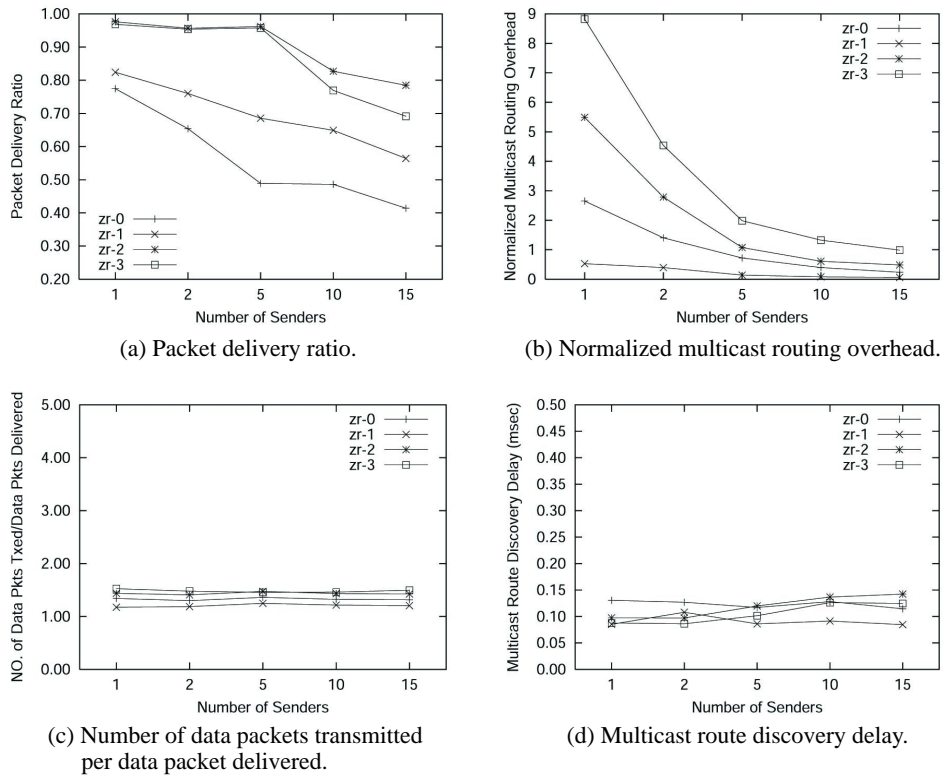


Fig. 6. Various Performance Metrics vs. Number of Senders (20 multicast members, 5 m/s mobility speed, 2 pkts/sec/sender).

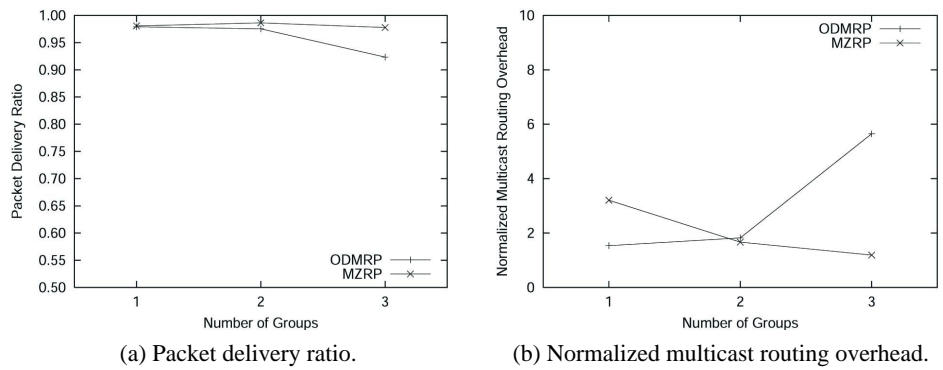
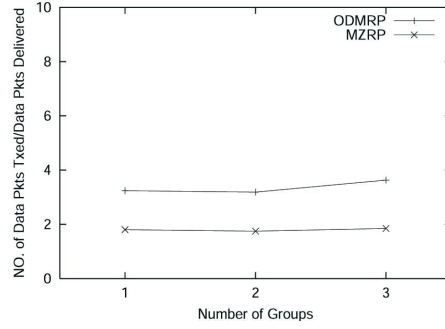
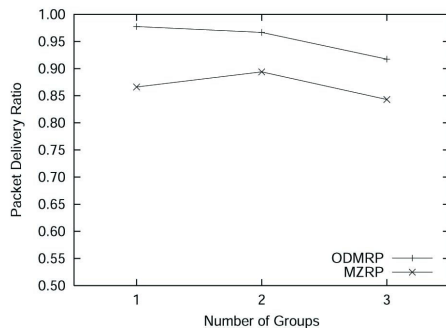


Fig. 7. Comparison of MZRP with ODMRP for different numbers of multicast groups. (Each group had 10 multicast members, 2 senders, 2 pkts/sec/sender, and a mobility speed of 2 m/s).

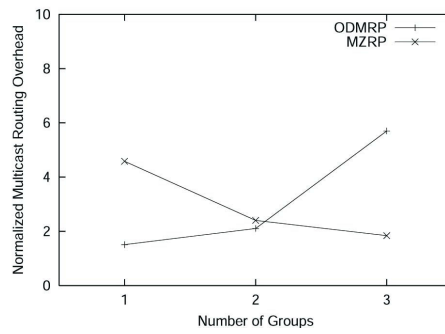


(c) Number of data packets transmitted per data packet delivered.

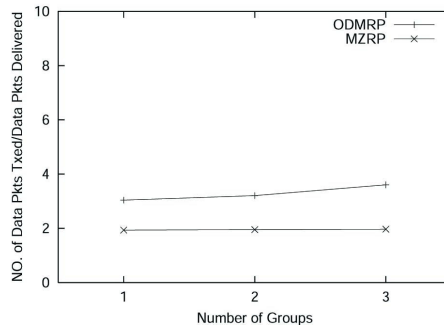
Fig. 7. (Cont'd) Comparison of MZRP with ODMRP for different numbers of multicast groups. (Each group had 10 multicast members, 2 senders, 2 pkts/sec/sender, and a mobility speed of 2 m/s).



(a) Packet delivery ratio.



(b) Normalized multicast routing overhead.



(c) Number of data packets transmitted per data packet delivered.

Fig. 8. Comparison of MZRP with ODMRP for different Number of Multicast Groups (Each group had 10 multicast members, 2 senders, 2 pkts/sec/sender, and mobility speed is 10 m/s).

creation mechanism that ODMRP uses. However, our MZRP performed better when the number of groups increased. Note that the routing overhead of our MZRP is mostly determined by the proactive routing overhead, i.e., MIARP, which was not affected by the number of multicast senders. That is, no matter how many senders there were, the MIARP traffics was almost the same. Therefore, with more multicast senders, more data packets were delivered. Also, the normalized multicast routing overhead decreased at the same time. Clearly, in low mobility cases (Figs. 7 (a) - 7 (c)), MZRP performed better in all three performance metrics when the number of groups was greater than 1. However, in high mobility cases (Fig. 8 (a)), ODMRP performed better in terms of the packet delivery ratio due to the availability of alternative paths, which allowed multicast datagrams to be delivered to all or most of the multicast receivers even if links failed. Figs. 7 (c) and 8 (c) show that our MZRP transmitted fewer data packets per data packet delivered than ODMRP did. This was the reason for the shared tree structure versus mesh structure.

5. CONCLUSIONS

In this paper, we have presented a multicast zone routing protocol, which is shared tree based. It proactively maintains multicast tree membership information, and makes on-demand route requests by means of MIERP using an efficient query control mechanism. Because the IP tunnel used in data packet transmission, the data packet delivery ratio is improved a lot. MZRP achieved good performance in our evaluations. We compared ODMRP with our MZRP in our simulations. ODMRP is an on-demand, mesh-based protocol, and it performed well in most of the experiments reported in [14, 15]. By comparing our protocol with ODMRP, we have shown that not only mesh-based protocols, but also tree-based protocols may provide good routing performance in multicast environments. Our MZRP is scalable to a larger number of multicast groups and senders, and has a smaller normalized multicast routing overhead than dose ODMRP.

REFERENCES

1. "The implementation of ODMRP," [http:// www.monarch.cs.rice.edu/multicast_extensions.html](http://www.monarch.cs.rice.edu/multicast_extensions.html).
2. K. Fall and K. Varadhan, "The network simulator (ns-2) manual," <http://www.isi.edu/nsnam/ns/ns-documentation.html>.
3. E. Bommaiah, M. Liu, A. McAuley, and R. Talpade, "AM-route: ad-hoc multicast routing protocol," Draft-talpade-manet-amroute-00.txt, Internet-Draft, IETF, 1998.
4. J. Broch, D. A. Maltz, D. B. Johnson, Y. C. Hu, and J. Jetcheva. "A performance comparison of multi-hop wireless ad hoc network routing protocols," in *Proceedings of ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM '98)*, 1998, pp. 85-97.
5. M. S. Corson and S. G. Batsell, "A reservation-based multicast (RMB) routing protocol for mobile networks: initial route construction phase," *ACM/Baltzer Wireless Networks*, Vol. 1, 1995, pp. 427-450.

6. Z. J. Haas, "A new routing protocol for the reconfigurable wireless networks," in *Proceedings of IEEE International Conference on Universal Personal Communications (ICUPC '97)*, 1997, pp. 562-566.
7. Z. J. Haas and M. R. Pearlman, "The performance of query control schemes for the zone routing protocol," *IEEE/ACM Transactions on Networking*, Vol. 9, 2001, pp. 427-438.
8. Z. J. Haas, M. R. Pearlman, and P. Samar, "The bordercast resolution protocol (BRP) for ad hoc networks," Draft-ietf-manet-zone-brp-02.txt, Internet-Draft, IETF, 2002.
9. Z. J. Haas, M. R. Pearlman, and P. Samar, "The Interzone routing protocol (IERP) for ad hoc networks," Draft-ietf-manet-zone-ierp-02.txt, Internet-Draft, IETF, 2002.
10. Z. J. Haas, M. R. Pearlman, and P. Samar, "The intrazone routing protocol (IARP) for ad hoc networks," Draft-ietf-manet-zone-ierp-02.txt, Internet-Draft, IETF, 2002.
11. Z. J. Haas, M. R. Pearlman, and P. Samar, "The zone routing protocol (ZRP) for ad hoc networks," Draft-ietf-manet-zone-zrp-04.txt, Internet-Draft, IETF, 2002.
12. L. Ji and M. S. Corson, "A lightweight adaptive multicast algorithm," in *Proceedings of IEEE Global Telecommunications Conference (GLOBECOM '98)*, 1998, pp. 1036-1042.
13. S. J. Lee, M. Gerla, and C. C. Chiang, "On-demand multicast routing protocol," in *Proceedings of IEEE Wireless Communications and Networking Conference (WCNC '99)*, 1999, pp. 1298-1304.
14. S. J. Lee, W. Su, and M. Gerla, "On-demand multicast routing protocol in multicast wireless mobile networks," *ACM/Baltzer Mobile Networks and Applications*, Vol. 7, 2002, pp. 441-453.
15. S. J. Lee, W. Su, J. Hsu, M. Gerla, and R. Bagrodia, "A performance comparison study of ad hoc wireless multicast protocols," in *Proceedings of IEEE INFOCOM '00*, 2000, pp. 565-574.
16. E. L. Madruga and J. J. Garcia-Luna-Aceves, "Scalable multicasting: the core-assisted mesh protocol," *ACM/Baltzer Mobile Networks and Applications*, Vol. 6, 2000, pp. 151-165.
17. E. M. Royer and C. E. Perkins, "Multicast operation of the ad-hoc on-demand distance vector routing protocol," in *Proceedings of ACM/IEEE International Conference on Mobile Computing and Networking (MOBICOM '99)*, 1999, pp. 207-218.
18. C. W. Wu and Y. C. Tay, "AMRIS: a multicast protocol for ad hoc wireless networks," in *Proceedings of IEEE Military Communications Conference (MILCOM '99)*, 1999, pp. 25-29.



Xiaofeng Zhang received his B.S. degree in Computer Science from Fudan University, Shanghai, China, in 2001. Currently, he is pursuing his M.S. in Computer Science at the National University of Singapore. His research interest is ad hoc wireless networks routing issues.



Lillykutty Jacob obtained her B.S. Engg. degree in electronics and communication from the Kerala University, India, in 1983. M.Tech. degree in electrical engineering (communication) from the Indian Institute of Technology (IIT) at Madras in 1985, and Ph.D. degree in electrical communication engineering from the India Institute of Science (IISc), in 1993. She was with the department of computer science, Korea Advanced Institute of Science and Technology (KAIST), as a research associate during 1996-1997, and was with the department of computer science, National University of Singapore (NUS), as a visiting faculty during 1998-2003. Since 1985, she has been with the National Institute of Technology (formerly Regional Engineering College) at Calicut, India, where she is currently an assistant professor. Her research interests are in communication networks, protocol engineering, and performance analysis.