ZBMRP: A Zone Based Multicast Routing Protocol for Mobile Ad Hoc Networks

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Abstract. In this paper, we propose a Multicast Routing Protocol termed ZBMRP (Zone Based Multicast Routing Protocol) for Mobile Ad Hoc Networks (MANETs). ZBMRP applies on-demand procedures to dynamically establish mesh-based multicast routing zones along the path from the multicast source node to the multicast receivers. Control packet flooding is employed inside multicast zones, thus multicast overhead is vastly reduced, and good scalability can be achieved. It will also be easier to secure multicast routing. ZBMRP fits well for MANETs where bandwidth is limited, topology changes frequently, power is constrained and security problem is serious. Simulation results are presented to support our claim.

1 Introduction

Mobile Ad hoc Networks (MANETs) is the cooperative engagement of a collection of wireless mobile nodes that also performs as routers. Nodes in MANETs communicate with each other through multi-hop transmission that does not need any existing infrastructure or communication supporting center. Topologies of MANETs may change quickly. Nodes in MANETs often perform a given task with other nodes together. This often leads to sending the same information to a group of members. Instead of sending data packets to each of the group members individually as unicast technique does, multicast technique allows the source node to send packets to a group of nodes as a single entity that will be sent only once on the shared path, greatly conserving network bandwidth on the shared path of the group member.

Multicast is one of the key techniques for group communication in MANETs. Among the existed multicast techniques proposed for MANETs, On Demand Multicast Routing protocol, ODMRP [1], stands as a good example. ODMRP is a mesh-based multicast protocol in which a collection (mesh) of nodes forwarding multicast packets is created between the senders and receivers. The main disadvantage of ODMRP is its excessive overhead incurred in keeping the forwarding group current and in the global flooding of the JOIN-REQUEST packets frequently [2]. Therefore, ODMRP may suffer scalability issue.

To overcome the disadvantage of ODMRP, we propose a new hybrid multicast routing protocol termed ZBMRP (Zone-Based Multicast Routing Protocol) for MANETs. In ZBMRP, when a node has multicast packets to send but no route information is available, it starts to create a forwarding mesh in the entire network as ODMRP does. Then, it creates multiple mesh-based routing zones, including source and branch zones, along the route from source node to multicast receiver nodes according to the distribution of source node, receiver nodes and forwarding group nodes in the forwarding mesh. Zone leaders are selected according to FDW (First Declaration Wins) principle which is responsible for creating and maintaining zones periodically. Inside each zone, a mesh-based multicast routing strategy similar to ODMRP is used. Zone size and the number of zones can be decided according to the network size and multicast nodes distribution. Tunneling technology is employed to deliver multicast packets among zones and other sporadic multicast receivers that are not included in any zone in which multicast packets are encapsulated in the unicast packet for transmission. Since control packets flooding is restricted inside multicast zones, multicast overhead will be vastly reduced, and good scalability can be obtained.

ZBMRP scheme integrates three advanced techniques: mesh-based, on demand, and zone based such as ODMRP[1], AODV[3], ZRP [4] respectively and has the characteristics of adaptive to network topology change, robust to nodal mobility, and good scalability. ZBMRP will provide adequate multicast service to MANETs where bandwidth is limited, topology changes frequently, and power is constrained.

The rest of this paper is organized as follows. Section 2 describes the operational details of ZBMRP. Section 3 gives a description of simulation environment for ZBMRP. Simulation results of ZBMRP are reported in Section 4. Section 5 is conclusions for ZBMRP.

2 Zone Based Multicast Routing Protocol Overview

2.1 Mesh Created in the Entire Network in the Establishment Phase

When a multicast source has packets to send but cannot find any route and group membership information, it broadcasts a member advertising and route request packet, termed RREQ, to the entire network. Only multicast receivers send back a route reply message, called RREP, in order to allow the source node to get the current routing information. Then ZBMRP uses the same strategy as ODMRP does [1] to establish a mesh of nodes for forwarding packets between a multicast source and receivers. The mesh is created using the forwarding group concept. The forwarding group is a set of nodes that are in charge of forwarding multicast packets. It supports shortest paths between any member pairs. A multicast receiver may serve as a forwarding group node if it is on the path between a multicast source and another receiver. In ZBMRP, we further classify forwarding group nodes into two categories: FG-F and FG-B. FG-F means a forwarding group node which only forwards packets to one other node. FG-B is a forwarding group node that should forward packets to more than one node (i.e., forwarding branches), as node C shown in Fig. 1.We call source node, FG-B, and multicast receivers as ZANs (Zone-Associated Nodes). For example, in Fig. 1, node B, C, R_1, R_6, are the nearest downstream ZANs of source node S. Node A is a FG-F node but not a ZAN.

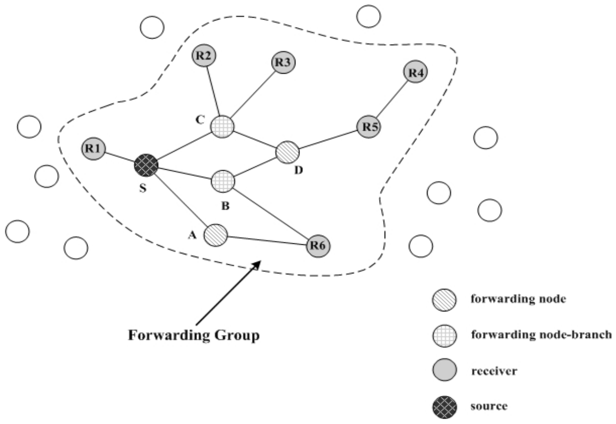

Fig. 1. Illustration of forwarding group nodes

2.2 Source Zone Creation

After the forwarding mesh between a multicast source and receivers is established in the entire network, mesh-based multicast routing zones are created according to the distribution of source node, FG-Bs, and multicast receiving member nodes, i.e. ZANs.

Multicast source node will firstly establish mesh-based multicast zone, named source zone. It collects the information of its nearest downstream ZANs from RREP messages that it receives. Such information includes IP address and distance (in terms of hop counts). If the source's nearest downstream ZAN is far away from itself, e.g., more than 3 hops away, and relatively sparse, then the source node will not establish source zone (or we can say the zone size is 0). It just tunnels multicast packets in the unicast packets to its nearest downstream ZANs. If the source node finds many ZANs within N hops, then it establishes source zone with a zone radius of N. Source node becomes the leader of this source zone. A zone leader is in charge of constructing and maintaining a zone. When N is no less than the size of the entire network, ZBMRP becomes ODMRP.

After source node selects the size of the source zone as N, it sets the TTL of the periodically flooded RREQ packet to be N, puts the zone ID, i.e. the IP address of the zone leader, in the reserved field of IP header, and then sends the IP multicast packet out. Inside the source zone, forwarding mesh-based routing strategy is used. Source node and ZANs inside zone communicate through a mesh of forwarding group nodes. For the sporadic ZANs of source node that is outside source zone, the source node will tunnel packet to them.

FG-B receiving packets from the source node with zone information just joins the source zone as a normal zone member, it will not build zone by itself. They find out whether their ZANs are in the source zone based on the source zone size (optimal zone size depends largely on node density and traffic load and its study is beyond the scope of this work). FG-B tunnels packets to its ZANs are that are outside of source zones if there are any.

If a downstream ZAN receives the same packets from both multicast source node and an upstream FG-B, it will send a message packet N-Tunnel (Not to Tunnel packet) to its upstream FG-B to notify the FG-B to stop sending packets to it.

2.3 Branch Zone Creation

If a FG-B gets data packets without zone information, which means it gets the packets through tunneling, it is outside upper level zone, then it has to create and maintain its mesh based routing zone according to the distribution of its nearest ZANs. We call this kind of zone as branch zone. Other FG-Bs inside this zone just join it and will not create the zone of itself as in FG-B IN source zone does. It is a kind of FDW (First Declare Win) strategy. This kind of work will continue until the far end of the network. There are no two or more FG-Bs to contend for building a same branch zone.

If a ZAN resides in multiple zones, it will receive multiple copies of the same multicast packet from several zone leaders with different zone ID. It then just discards the replicate packet. Note that, if this ZAN received a replicate packet tunneled from its upstream ZAN, it needs to send an N-Tunnel message packet to its upstream ZAN to save bandwidth. Upon receiving data packets without zone information, FG-B will start establish its zone. Thus along with the data packets delivering, multiple mesh based routing zones will be established along the path from the source node to multicast receivers.

In Fig. 2, we show an example of several zones created. Node S is the source node. The source zone has a zone radius of 1. The branch zone created by node C has a zone radius of 2. Note that the dashed lines represent tunneling transmissions. Therefore, nodes R2 and R3 receive their multicast data through tunneling.

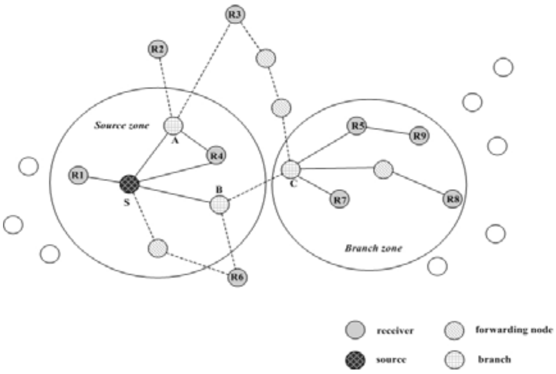

Fig. 2. Zone creation

2.4 Zone and Route Maintenance.

Zone leader periodically broadcasts RREQ message inside zone with TTL equal to N (zone radius). Every node inside zone that receives RREQ forwards RREQ until TTL becomes zero. It also sends RREP back to zone leader. With these, zone leader updates mesh routing inside zone.

For the sporadic ZANs that are not included in any zone, the upstream ZAN of it tunnels packets to it unless the upstream ZAN receives explicit N-Tunnel messages from these sporadic ZANs. A periodic positive update of tunneling membership is also possible. In this technique, the downstream nodes periodically send the upstream nodes a Tunnel message. Reception of such message indicates validity of the tunnel.

2.5 New Node Joining the Multicast Group

During the process of multicasting, if a new node wants to join the multicast group, it explicitly generates a RREP-R packet that will be broadcasted to its neighbors. This RREP-R message will be forwarded until it is received by a forwarding group node, or source node. Then this node will be added to the multicast group, through a zone or a forwarding route.

If the RREP-R is terminated at the normal forwarding group node with no branch, i.e. FG-F, then this FG-F node will become as a FG-B node which will update this information to its upstream ZAN and responsible for forwarding packets to this new group member.

2.6 Multicast Group Member Leaving the Group

Only the multicast group member node outside any zone needs to send an N-Tunnel message to its upstream ZAN to tell its leave. Other group member nodes need only to stop sending back any RREP or RREQ (for source node). It is a kind of soft leaving mechanism.

2.7 Process for Link Breakage

If the link for forwarding breaks, the downstream receiver needs to send RREP-R packet as a new node does to join the multicast group again, also to inform the downstream ZANs about this state. If one link inside mesh-based zone breaks, the packet may be sent to the receiver members through possible redundancy route. Besides, zone leader will broadcast RREQ packets periodically inside zone. The receiver with link breakage can send RREP packets after it receive the new RREQ to update route information with zone leader.

2.8 Unicast Capability

Unicast can be seen as a special case of ZBMRP, i.e. only one group receiver with unicast IP address. No zone will be created. Source node broadcasts RREQ to the entire network, unicast receiver sends back RREP and activates the nodes to join the forwarding group along the reverse route. After the unicast route is established, the source can send packets to the receiver until link breakage information is received which will trigger route finding again, i.e. sending RREQ and RREP again.

2.9 Tables Used in ZBMRP

Nodes build and maintain following tables on demand. First one is membership table for recording which groups they are joining. Second one is message buffer for saving recently received packet which will be used for checking out whether a replicate packet is received. Third one is routing table in which every entry records multicast address, forwarding flag, pointer pointing to its Nearest ZANs list, flag indicating multicast route valid or not, multicast route expire time, flag indicating zone created or not, zone ID, zone radius. Fourth one is the Nearest ZANs list for recording the information about the downstream nearest ZANs which will be used to establish mesh-based multicast routing zones.

3 Description of Simulation Environment

Simulations have been implemented in OPNET (version 10.5.a). In the simulations, a free space propagation model with a threshold cutoff is used in our experiments. In the free space model, the power of a signal attenuates as $1/r^2$, where r is the distance between radios. In the radio model, we assume the ability of a radio to lock on to a sufficiently strong signal in the presence of interfering signals, i.e., radio capture. If the capture ratio (the minimum ratio of an arriving packet's signal strength relative to those of other colliding packets) is greater than the predefined threshold value, the arriving packet is received while other interfering packets are dropped. The IEEE 802.11 Distributed Coordination Function (DCF) is used as the medium access control protocol. The scheme used is Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) with acknowledgments.

In our simulations, we investigated the performance of the ZBMRP scheme in networks with two different nodal densities: one network with 50 mobile hosts placed randomly within a 1000x1000 area; the other with 100 mobile hosts in the same network area. Radio propagation range for each node is 300 meters and channel capacity is 2 Mbps. Each simulation lasts 600 seconds of simulation time. Multiple runs with different seed numbers are conducted for each scenario and collected data is averaged over those runs. We are still working on other simulation scenarios and will report new results as they become available.

The source node sends data at the rate of 2 packets per second. The size of data payload is 512 bytes. The member nodes of the multicast group are chosen randomly. Members join the multicast group in the beginning of the simulation and remain as members throughout the simulation. Random waypoint mobility model [1] is used. A node randomly selects a destination and moves towards that destination at a predefined speed. Once the node arrives at the destination, it stays in its current position for a pause time between 0 and 10 seconds. After being stationary for the pause time, it selects another destination and repeats the same process. Mobility speed is varied from 0 km/hr to 72 km/hr.

We choose the following ZBMRP parameters in our simulations: The multicast route entry lifetime is 10 s. The number of multicast group is 1. The period of sending RREQ packet is 3 s. The ratio of ZANs to be included into a zone is 0.8 which means at least 80 percent of the nearest ZANs are included in the zone.

4 Simulation Results and Discussions

4.1 Packet Delivery Ratio for Different Node Mobility

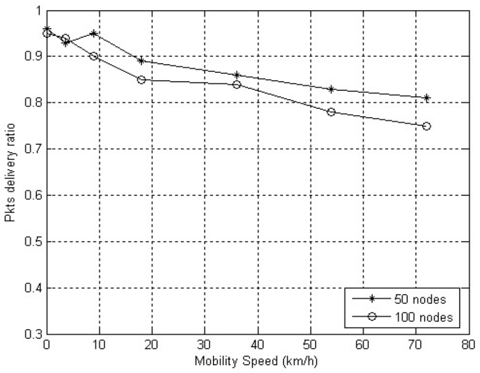

Fig. 3. Packet delivery ratio for different node mobility

Figure 3 shows the packet delivery ratio of ZBMRP as a function of node mobility speed. Packet Delivery Ratio is the number of data packets delivered to multicast receivers over the number of data packets supposed to be delivered to multicast receivers. We assumed 20 multicast receivers exist among the 50 (or 100) network nodes. As confirmed by Fig. 3, packet delivery ratio decreases as nodal speed increases. This is due to the higher probability of link breakage and topology change, which cause more multicast control packets to be transmitted, lowering the overall data delivery ratio. As the nodal density doubles, the packet delivery ratio only lowers slightly, indicating the good scalability of the ZBMRP scheme. Overall, a relatively high packet delivery ratio can be obtained.

4.2 Number of Data and Control Packets Transmitted per Data Packet Delivered

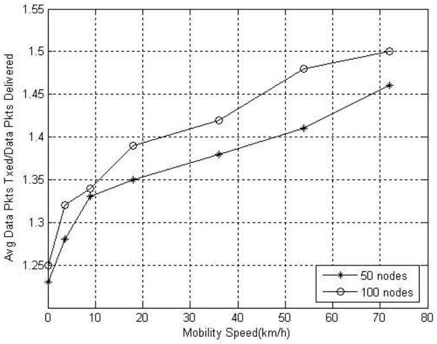

Fig. 4. Number of Total Packets Transmitted

Figure 4 shows the average number of total packets transmitted per data packet delivered. Total packets include data and control packets. Since most Medium Access Control (MAC) schemes used in MANETS are contention-based, it is crucial to be able to send one data packet with as less control packets as possible. When nodes contend less for the channel access, the probability of successful delivery of packets in a short time becomes higher. As suggested by Fig. 4, the average number of packet transmitted per data packet delivered maintain relatively in the range of 1.2-1.5, although it climbs up as the node mobility increases. Total packets sent in the network with 100 nodes are a little more than in the network of 50 nodes. Therefore, the control packet overhead introduced by the ZBMRP scheme is relatively low in both 50 nodes and 100 nodes networks which show good scalability of ZBMRP also.

4.3 Number of Control Bytes Transmitted Per Data Byte

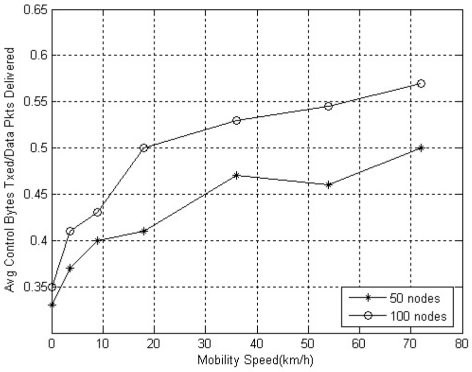

Fig. 5. Number of control bytes transmitted per data byte

The average number of control bytes transmitted per data byte delivered is shown in Fig. 5. Here, we choose to use a ratio of control bytes transmitted to data byte delivered to investigate how efficiently control packets are utilized in delivering data. In addition to bytes of control packets (e.g., RREQ, RREP, RREP-R, N-Tunnel), bytes of data packet headers are included in calculating control bytes transmitted. Thus, only bytes of the data payload contribute to the data bytes delivered.

We can find that the control overhead increases with the node mobility speed add. Two aspects results in the control overhead increment. One is the mesh-based routing which leads to redundancy route with more control overhead. Another one is link breaks more frequently as the nodes move faster which leads to more control packages, i.e., RREP-R and RRER will be sent. To deliver packets reliably to the destination, some control packets have to be sent. Protocol design has to make some compromise between efficiency and reliability. Fig.5 shows that ZBMRP gets high reliability with relative low control overhead in both 50 nodes and 100 nodes networks. It means good scalability also.

4.4 Multicast Group Size

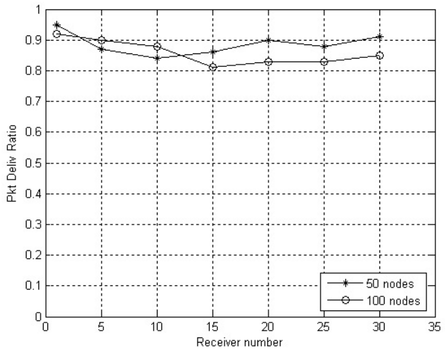

Fig. 6. Packet delivery ratio changed with group receiver numbers

One other indication of the performance of a multicast scheme is its deliverability as the number of multicast receivers of the same multicast group increases. A good multicast scheme should scale well even if a wide range of number of receivers “tap” to the multicast group. We present our simulation results of the ZBMRP scheme in this respect in Fig. 6. We can see that the packet delivery lowers slightly as receiver number increases from 1 to 15 (with 50 or 100 network nodes)，then climbs up slowly as receiver number increases from 15 to 30. When the receiver number equals to 1, it is similar to unicast which has high packet delivery ratio. When the number of multicast group member increases, but is not too much, mesh is established with few redundancies, packets are lost more frequently. When the number of receiver member is big, more redundancy routes exist. Packet delivery ratio becomes high also. Fig.6 shows packet delivery ratio does not change much with group receiver numbers changes.

5 Conclusions

In this paper, we have proposed a new multicast scheme, termed Zone-Based Multicast Routing Protocol (ZBMRP). It builds mesh-based multicast routing zones along the source node to multicast receivers on demand. Tunneling technology with link breakage repairing is used to deliver multicast packets between zones or levels which is not mesh based but a kind of tree. Only with this the overhead may be reduced a lot. And it is still robust for we have adopted link breakage repairing technique for it. A compromise of tree and mesh according the real network situation will get the best performance for ZBMRP. We will continue to research on how to do the compromise in the future.

With cohesive integration of the mesh-based, on demand, zone-based and tunneling techniques, ZBMRP scheme strives to provide adequate multicast service to MANETs where bandwidth is limited, topology changes frequently, power is constrained and security problem is serious. ZBMRP restricts RREQ control message flooding inside zones, thus get good scalability. ZBMRP uses RRER and RREP-R control message to repair link breakages and get good packets delivery ratio. ZBMRP lets only receiver member initiating to send back RREP message and get latest routing information. With zone structure, it will also be easier for ZBMRP to secure multicast routing compared with other scheme. Our simulation results show that ZBMRP scheme performs quite well in terms of data delivery ratio, overhead, and sensitivity to node speeds in different network scales and different multicast group sizes as well. ZBMRP can work well with unicast protocol such as AODV, etc. ZBMRP can also work without unicast protocol support.

In future work, we will further improve ZBMRP protocol. We will investigate how to secure our ZBMRP multicast routing protocol. We will also compare ZBMRP scheme with other related schemes, e.g., ODMRP. We will analyze ZBMRP scheme theoretically as well.

Acknowledgment

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