An Efficient Zone-Based Multicast Routing Protocol for Ad Hoc Network

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Abstract: - This study presents a forwarding nodes selection scheme for zone-based multicast routing protocols to reduce transmission routing control overhead. The feasibility of the proposed scheme is demonstrated over mobile ad hoc networks (MANETs), and compared with the multicast zone routing protocol (MZR) in terms of the routing control overhead and packet delivery ratio. In this work, the proposed scheme represents a good reduction of forwarding packets. Furthermore, simulation results show that the proposed scheme presents effective forwarding nodes selection for reduction routing control overhead and increasing packet delivery ratio.

Key-Words: - Forwarding node selection, multicast routing, mobile ad hoc network, multicast zone routing protocol, routing control overhead, packet delivery ratio.

1 Introduction

Recently, mobile ad hoc network (MANET) [1] has been supported to the wireless sensor network and WLAN. The network architecture of MANET consists of a set of mobile nodes, is self-creating and self-organizing without using infrastructure such as base station and centralized administration [2]. Moreover, it can be deployed quickly to meet a wide variety MANET applications. Due to all mobile nodes are allowed to move randomly, the network topology is dynamically changed. Therefore how to ensure effective routing path, low routing control overhead, short end-to-end delay, high throughput and low energy consumption are the main challenges [3, 4].

Numerous researchers are interested in designing unicast routing schemes and many famous routing protocols have been proposed for MANET. These protocols can be classified into two categories: reactive and proactive routing protocols. Reactive routing protocols (such as AODV [5], DSR [6]) establish a route to a destination by source node only when it want to send data packets. In proactive routing protocols (such as OLSR [7], FSR [8], etc.), every nodes attempt to periodically maintain routes between every pair of nodes in the network. The advantage of the proactive routing protocols is that when a route to the destination is needed, it can be determined readily. However the protocols need additional bandwidth to periodically maintain route information. In reactive routing protocols, although the route construction suffers from long delay due to the on-demand route discovery, the protocols can be considered to have lower routing control overhead.

Zone routing protocol (ZRP) [9, 10] is a hybrid routing protocol, which combines the character of proactive and reactive routing protocols. The scope of the proactive procedure is limited to the zone radius. The ZRP applies intrazone routing protocol (IARP) to maintain routing information within zone radius. When source node needs to obtain a route to the destination not in its zone, it initiates interzone routing protocol (IERP) which works similar to flooding method [11] except that it involves only the border nodes of the source node and their border nodes and so on. The enhancement of reactive routing protocol has been studied by several investigators [12-14].

However, in a typical ad hoc environment, multicast communication [15] which incorporates the concept of group-oriented is more suitable than unicast communication [16], because most applications in MANET require distribution and collaborative computing. Multicast protocols have also been proposed for MANET, such as multicast zone routing (MZR) [17] and cluster-based multicast routing [18]. The MZR protocol applies the flooding method to construct multicast trees for the current wireless network topology. Therefore, the routing control overhead is proportional to the total number in the networks. Although these protocols can achieve the shortest path and the short end-to-end delay, they may cause the network congestion due to transmit the unnecessary flooding routing control packets and forwarding nodes to maintain time-varying network topology. Therefore, these protocols are not suitable for large scale and large multicast group size applications.

The above discussion motivates us to design an efficient selective forwarding nodes scheme, which can reduce the amount of routing control packets, decrease the size of forwarding group and increase the packet delivery ratio. In this paper, we propose a forwarding nodes scheme for zone-based multicast routing protocols, in which each source node applies the two-hop zone neighbor node information to selective proper forwarding nodes to create multicast tree.

This paper is organized as follows: Section 2 describes the model and notation of zone-based multicast routing protocol. In Section 3 we present route construction and maintenance phase. The forwarding node selection method will be specified in the route construction phase. Section 4 introduces the simulation and the performance in details. Finally, the conclusion will be discussed in section 5.

2 Zone-based Multicast Routing Protocol: Model and Notation

The main goal of this section is to describe the model and notation of the zone-based multicast routing protocol.

We assume that the routing zone radius is predefined as two. Each of the nodes collects the two-hop neighbor node information and creates a two-hop neighbor table, in which each record entry contents the fields of Neighbor_ID, Gateway_ID and Multicast_ID. Through the two-hop neighbor tables, each node can derive the following information:

$N(v)$: One-hop neighbors of node v, including multicast and non-multicast member neighbors.

$$N(N(v)) = \left\{ v_i \middle| v_i \in \left\{ \bigcup_{\forall v_j \in N(v)} N(v_j) \right\} - (N(v) \cup \{v\}) \right\}:$$

This set includes two-hop neighbors of node v, but excluding its one-hop neighbors.

$M(v)$: One-hop multicast neighbors of node v.

$$M(N(v)) = \left\{ v_i \middle| v_i \in \left\{ \bigcup_{\forall v_j \in N(v)} M(v_j) \right\} - (M(v) \cup \{v\}) \right\}:$$

This set includes two-hop multicast neighbors of node v, but excluding its one-hop multicast neighbors.

$$G(v_i, v) = \{v_j | v_j \in N(v) \cap N(v_i) \text{ and } v_j \in N(v) \cap \{v_i\}\},$$
$$\forall v_i \in N(v) \cup N(N(v)):$$

This set collects all the gateway nodes that connect node v_i and v.

An example of MANET topology is shown in Fig.1 The dotted circle represents the two-hop transmission range of multicast source node S. The gray nodes represent multicast members of source node S while the white nodes are non- multicast members.

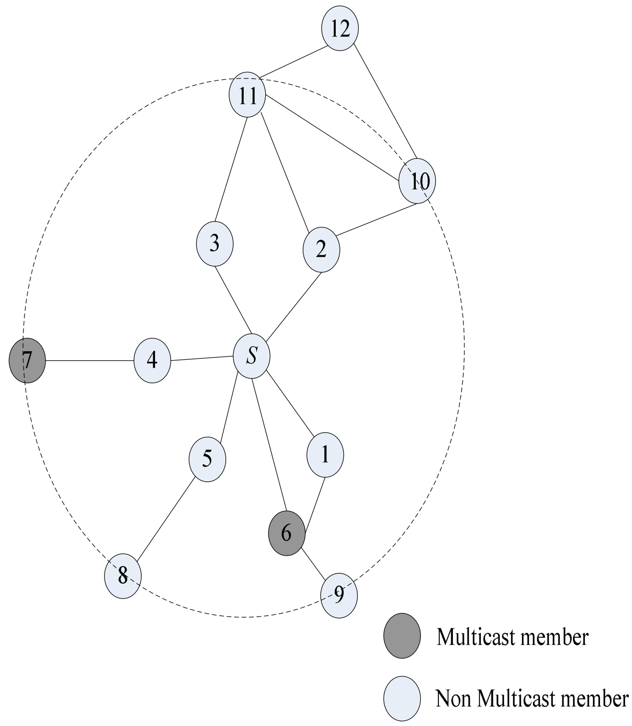


Fig.1. Multicast tree creation within a zone

From the above example, by using IERP, the two-hop neighbor table of multicast source node S can be obtained. The two-hop neighbor table is given in Table 1. According to the table, the multicast source node S can calculate the following information:

$N(S)=\{1,2,3,4,5,6\}$,

$N(N(S))=\{7,8,9,10,11\}$,

$M(S)=\{2,6\}$,

$M(N(S))=\{7\}$,

$G(1,S)=\{1\}, G(2,S)=\{2\}, G(3,S)=\{3\}, G(4,S)=\{4\}$,

$G(5,S)=\{5\}, G(6,S)=\{1,6\}, G(7,S)=\{4\}, G(8,S)=\{5\}$,

$G(9,S)=\{6\}, G(10,S)=\{2\}, G(11,S)=\{2,3\}$.

Table 1 Two-hop neighbor table

Neighbor_ID	Gateway_ID		Multicast_ID
1	1		Null
2	2		S
3	3		Null
4	4		Null
5	5		Null
6	1	6	S
7	4		S
8	5		Null
9	6		Null
10	2		Null
11	2	3	Null

3 Zone-based Multicast Routing Protocol

In this section, we describe the zone based multicast routing protocol in full detail. For this purpose, Section 3.1 discusses the route construction procedure. Section 3.2 presents a forwarding node selection scheme. Finally, the route maintenance procedure is discussed in Section 3.3.

In this paper, the zone-based multicast routing protocol described is a source-initiated, on-demand multicast routing protocol as MZR. The multicast tree is needed to be constructed when has multicast source node needs to send multicast data to all members. For each multicast data transmission session, multicast source node will construct autonomy multicast tree based on the network topology at the time. Our multicast routing protocol which is also based on zone-based routing mechanism, but using forwarding node selection process to select proper forwarding nodes transmitting routing control packets, instead of flooding them as MZR.

3.1 Route Construction Phase

The route construction phase is triggered at the time when source node wants to send multicast data packets to the multicast members. Meanwhile, the route request (RREQ) control packet is formed by the source node, and the source node and all border nodes need to execute both IARP and IERP. After forwarding nodes complete executing the IARP and IERP procedure, the route construction phase is done. In the IARP, the local multicast tree can be established by checking the Multicast_ID filed of the node's two-hop neighbor table. However, In the IERP, because the region between zones may heavily overlap and cause the sending of RREQ become unnecessary. Therefore, in the next sub-section, we proposed a forwarding node selection method to select the proper forwarding nodes to forward the RREQ control packets instead all border nodes.

3.2 Forwarding Node Selection Scheme

The forwarding nodes selection method is executed on the source node, selected forwarding nodes, and the associated gateways.

3.2.1 Forwarding Selection Method on Forwarding Nodes:

As to the part of forwarding nodes, we assume node v has received a RREQ control packet from gateway node g_0. The node v will execute the forwarding node selection method to select the forwarding nodes. As previous description, node v can obtain $N(v)$, $N(N(v))$, $M(v)$, $M(N(v))$, and $G(v_i, v), \forall v_i \in N(v) \cup N(N(v))$ from its own two-hop neighbor table. Through above information, the node v can also derive following information:

$A = M(N(v)) - N(g_0)$: A is a set of v's two-hop multicast neighbors.

$B = N(N(v)) - N(g_0) - A$: B is a set of v's two-hop non-multicast neighbors.

$C = M(v) - N(g_0)$: C is a set of v's one-hop multicast neighbors.

$D = N(v) - N(g_0) - C$: D is a set of v's one-hop non-multicast neighbors.

Note that the forwarding nodes must be the node v's two-hop neighbors. Among node v's two-hop multicast and non-multicast neighbors, the order in which the node v choose the forwarding nodes is important. The selection priority of the nodes from high to low is defined as:

1. Node v's two-hop multicast neighbor v_i where $G(v_i, v) \cap C \neq \phi$.
2. Node v's two-hop multicast neighbor v_i where $G(v_i, v) \cap C = \phi$.
3. Node v's two-hop non-multicast neighbor v_i where $G(v_i, v) \cap C \neq \phi$.
4. Node v's two-hop non-multicast neighbor v_i where $G(v_i, v) \cap C = \phi$.

The forwarding selection method on forwarding node v is summarized as follows:

1. Initialization step:
 Let node v's forwarding set $F(g_0, v) = [\ ]$
 $K_1 = \{G(v_i, v) | \forall\, v_i \in A \wedge G(v_i, v) \cap C \neq \phi\}$
 $K_2 = \{G(v_i, v) | \forall\, v_i \in A \wedge G(v_i, v) \cap C = \phi\}$
 $K_3 = \{G(v_i, v) | \forall\, v_i \in B \wedge G(v_i, v) \cap C \neq \phi\}$
 $K_4 = \{G(v_i, v) | \forall\, v_i \in B \wedge G(v_i, v) \cap C = \phi\}$
2. While($K_1 \neq \phi$)
 {
 Select a $G(v_i, v)$ from K_1 which has the least number of the elements and then random select an element g as gateway from $G(v_i, v) \cap C$
 $F(g_0,v) = F(g_0,v) \cup \{v_i\}$
 $C = C - \{g\}$
 $K_1 = \{G(v_j, v) | \forall G(v_j, v) \in K_1 \wedge g \notin G(v_j, v)\}$
 $K_3 = \{G(v_j, v) | \forall G(v_j, v) \in K_3 \wedge g \notin G(v_j, v)\}$
 }
3. While($K_2 \neq \phi$)
 {
 Select a $G(v_i, v)$ from K_2 which has the least number of the elements and then random select an element g as gateway from $G(v_i, v)$
 $F(g_0,v) = F(g_0,v) \cup \{v_i\}$
 $D = D - \{g\}$
 $K_2 = \{G(v_j, v) | \forall G(v_j, v) \in K_2 \wedge g \notin G(v_j, v)\}$
 $K_3 = \{G(v_j, v) | \forall G(v_j, v) \in K_3 \wedge g \notin G(v_j, v)\}$
 $K_4 = \{G(v_j, v) | \forall G(v_j, v) \in K_4 \wedge g \notin G(v_j, v)\}$
 }
4. While($K_3 \neq \phi$)
 {
 Select a $G(v_i, v)$ from K_3 which has the least number of the elements and then random select an element g as gateway from $G(v_i, v) \cap C$
 $F(g_0,v) = F(g_0,v) \cup \{v_i\}$
 $C = C - \{g\}$
 $K_3 = \{G(v_j, v) | \forall G(v_j, v) \in K_3 \wedge g \notin G(v_j, v)\}$
 }
5. While($K_4 \neq \phi$)
 {
 Select a $G(v_i, v)$ from K_4 which has the least number of the elements and then random select an element g as gateway from $G(v_i, v)$.
 $F(g_0,v) = F(g_0,v) \cup \{v_i\}$
 $D = D - \{g\}$
 $K_4 = \{G(v_j, v) | \forall G(v_j, v) \in K_4 \wedge g \notin G(v_j, v)\}$
 }
6. End of forwarding node selection method on the forward node.

3.2.2 Forwarding Selection Method on Gateway Nodes:

As to the part of gateway nodes, when gateway node g has received a RREQ control packet which is transmitted from node v to forwarding node t, gateway g will execute the forwarding node selection method to select the forwarding nodes as follows.

1. Initialization step:
 Let node g's forwarding set $F(v, g) = [\ ]$
 $A = N(g) - N(v) - N(t)$
2. While($A \neq \phi$)
 {
 Select a v_i from A which $N(v_i)$ has the largest number of elements
 $F(v, g) = F(v, g) \cup \{v_i\}$
 $A = A - N(v_i) - \{v_i\}$
 }
3. End of forwarding node selection method on the gateway node.

3.2.3 Forwarding Selection Method on Multicast Source Node *S*:

An example of proposed forwarding nodes selection method is demonstrated in Fig.2. The multicast source node S executes the forwarding node selection method to efficiently select forwarding nodes to send the RREQ control packet. First, According to the two-hop neighbor table of the node *S*, it can derive following information:

$A = M(N(S)) = \{7,13\}$,

$B = N(N(S)) - A = \{3,6,8,10\}$,

$C = M(S) = \{2\}$,

$D = N(S) - C = \{1,4,5\}$.

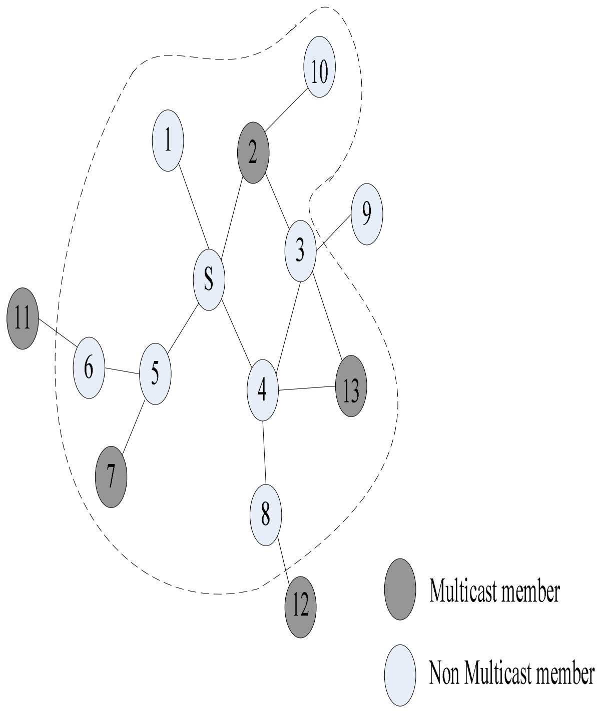


Fig.2. An example of forwarding nodes selection method

Then, similar to forwarding selection method on forwarding nodes, the multicast source node *S* executes following statements:

1. Initialization step:

$F(\phi, S) = [\ ]$

$K_1 = \phi$

$K_2 = \{G(7,S), G(13,S)\}$

$K_3 = \{G(3,S), G(10,S)\}$

$K_4 = \{G(6,S), G(8,S)\}$

2. $F(\phi, S) = [\ ]$

$K_2 = \{G(7,S), G(13,S)\}$

$K_3 = \{G(3,S), G(10,S)\}$

$K_4 = \{G(6,S), G(8,S)\}$

3. $F(\phi, g) = \{7,13\}$

$K_3 = \{G(10,S)\}$

$K_4 = \phi$

4. $F(\phi, g) = \{7,10,13\}$

$K_4 = \phi$

5. $F(\phi, S) = \{7,10,13\}$

6. End of forwarding node selection method on the source node.

After finishing the selection process, as shown in Fig.3, The multicast source node *S* will transmit RREQ control packets to forwarding nodes 7, 10 and 13 by corresponding associated forwarding gateway nodes 5, 4 and 2, respectively. For each of the forwarding gateway nodes, they will keep on selecting proper forwarding nodes when receiving the RREQ control packets from source node *S* to forwarding nodes 7, 10 and 13.

Forwarding Selection Method on Gateway 2:

1. Initialization step:

$F(S,2) = [\ ]$

$A = N(2) - N(S) - N(10) = \phi$

2. $F(S,2) = \phi$

3. End of forwarding node selection method.

Forwarding Selection Method on Gateway 4:

1. Initialization step:

$F(S,4) = [\ ]$

$A = N(4) - N(S) - N(13) = \{8\}$

2. $F(S,4) = \{8\}$

3. End of forwarding node selection method.

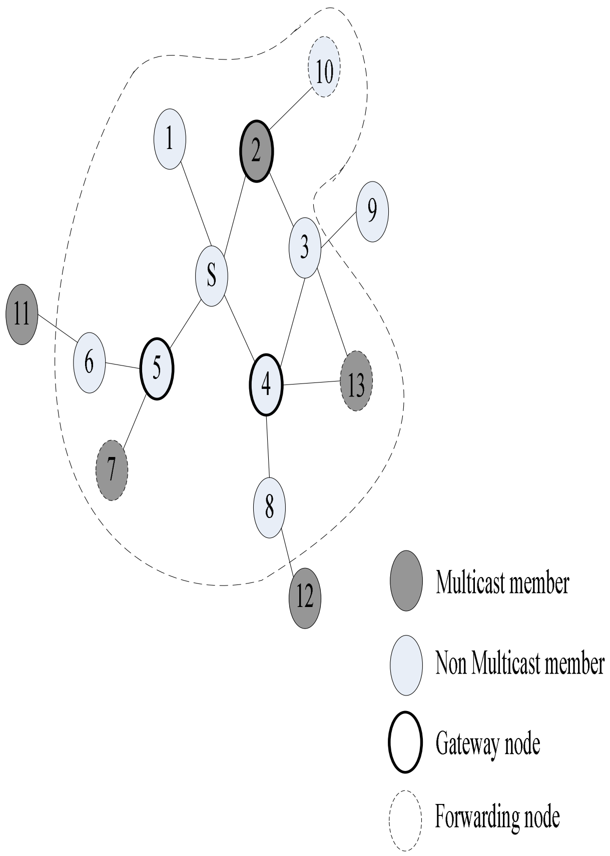


Fig.3. Example of forwarding node selection method

for multicast source node S

Forwarding Selection Method on Gateway 5:

1. Initialization step:

$F(S,5) = [\ ]$

$A = N(5) - N(S) - N(13) = \{6\}$

2. $F(S,5) = \{6\}$

3. End of forwarding node selection method.

Fig.4 shows the result after completely executing forwarding node selection method both on the source node and forwarding gateway nodes.

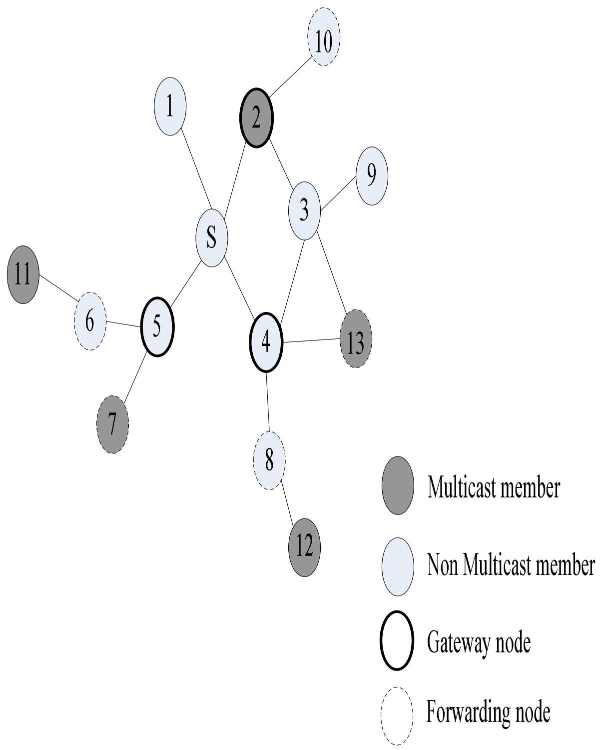


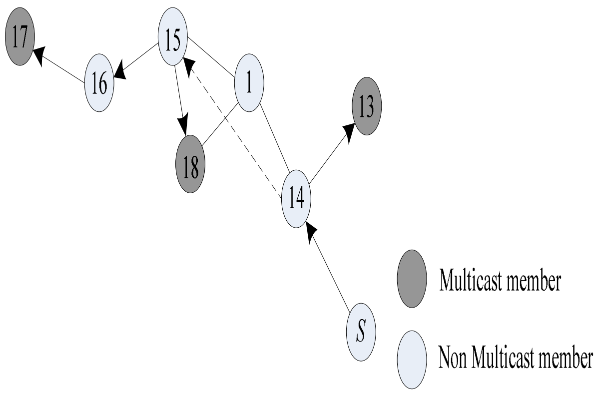
Fig.4. Example of forwarding node selection method for gateway nodes

3.3 Route Maintenance Phase

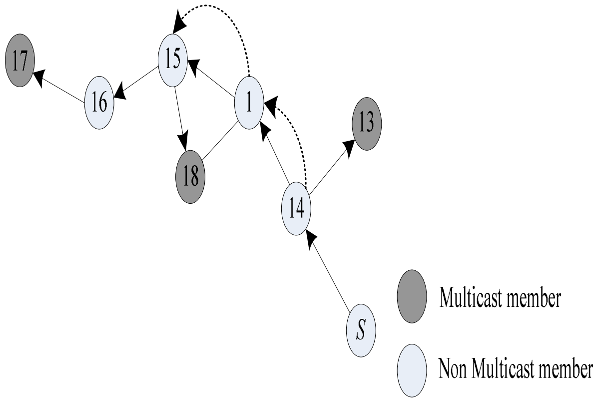
The route maintenance phase is indispensable for ad hoc routing protocols because the network topology is changing dynamically time after time. In this paper, the route maintenance phase was divided into two cases. One is that the movement of the node is within the zone radius range and another is beyond the zone radius range.

In the first case, the upstream node can fix up the broke-link by its two-hop neighbor table. The two-hop neighbor is periodically refreshed by IARP. Once the upstream node detects the downlink node which becomes two-hop neighbor by its two-hop neighbor table, it will find a valid gateway to reach the downlink in order to keep the route usability.

Fig.5 is an example of this case. As Fig.5-(a) shown, upstream node 14 can't directly communicate with its downstream node 15 due to the node's movement. After periodically up-to-date node 14's two-hop neighbor table, it can discover that node 1 can be the gateway between itself and its downstream node 15. Thus, Fig.5-(b) indicates the route will be fixed up by upstream node 14 which selects node 1 as a gateway to its downstream node 15.



(a)



(b)

Fig.5. An example of route maintenance

As to the other case, the upstream node can't fix up the broke-link by its two-hop neighbor table, if the movement of the downlink node is unpredictable. Once this case happens, the upstream node which discovers the downlink node is unreachable, and it will start the local re-route procedure. The local re-route procedure is similar to the route construction phase which we have described in previous section, but it starts with the node which detects the link break with its downstream node, instead of the multicast source node which can not fix up by its two-hop neighbor table.

4 Simulation Results

The network simulator (NS2) [19] is used for the implementation of zone-based multicast routing protocol. The physical radio interface of each node is chosen to approximate the Lucent/Agere WaveLAN/OriNOCO IEEE 802.11 product and the average transmission range is predefined as 250m. For the link layer, the IEEE 802.11 distributed coordination function (DCF) is applied. We simulate two zone-based multicast routing protocols. One is the proposed zone-based multicast routing protocol, and the other is MZR. The network scenario is consisted of 50 nodes. In addition, the movement model of each node is random waypoint. The maximum speed for each node is 20m/s, and constant bit rate (CBR) traffic type with the average data rate in 2048 bytes per second is considered. The simulation field is 1500m*300m. For each performance metric we set the 900 seconds simulation time which includes the pause time in 0, 30, 60, 120, 300, 600 and 900 seconds. The performance metrics considered in this paper are listed below:

1. Packet Delivery Ratio: the value is a number which is derived from the average number of data packets that received by multicast members divided by the number of data packets that sent from source. From this performance metric, we can obtain the routing protocol's packet delivery efficiency.
2. Control Overhead: sum of the control packets that are received by each node. It represents the number of control packets that will be transmitted in both route construction and maintenance phases.
3. Number of Forwarding Packets: sum of the data packets that are transmitted by each gateway node, excluding the multicast source and the members. The forwarding efficiency is evaluated by this metric.
4. End-to-End Delay: the value which indicates the average delay time that is spent when multicast source sends data packets to its multicast members.

Two different cases for each parameter metric are considered. In the first case, single multicast group in the simulation environment which has a multicast source with 10 multicast members. In another case, we consider three different multicast groups which have three different multicast source nodes. With each of these multicast source nodes, it has 10 different multicast members.

Fig. 6 and Fig.7 show the simulation result of packet delivery ratio for each case. In high mobility situation, we can observe that the proposed scheme has higher packet delivery ratio than MZR in both cases. This is because we modified the procedure of the route maintenance phase in order to speed up the route reconstruction.

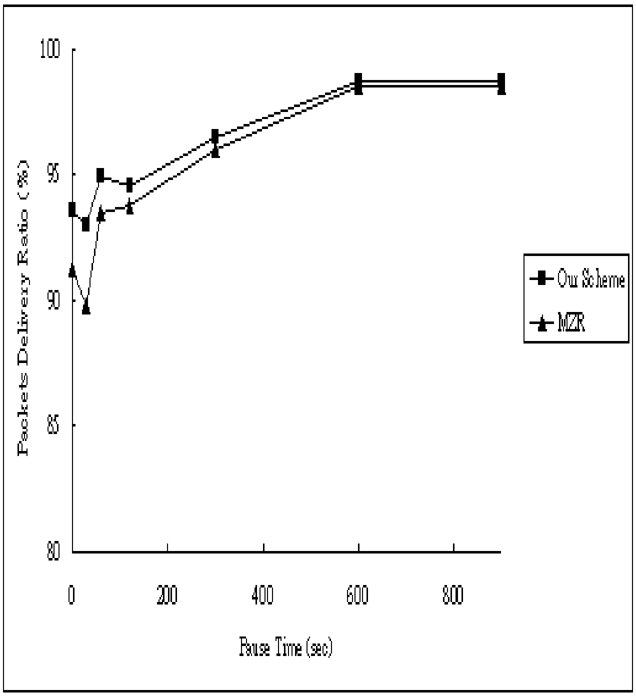


Fig.6. Influence of packet delivery ratio (1 multicast group, 10 nodes/multicast group)

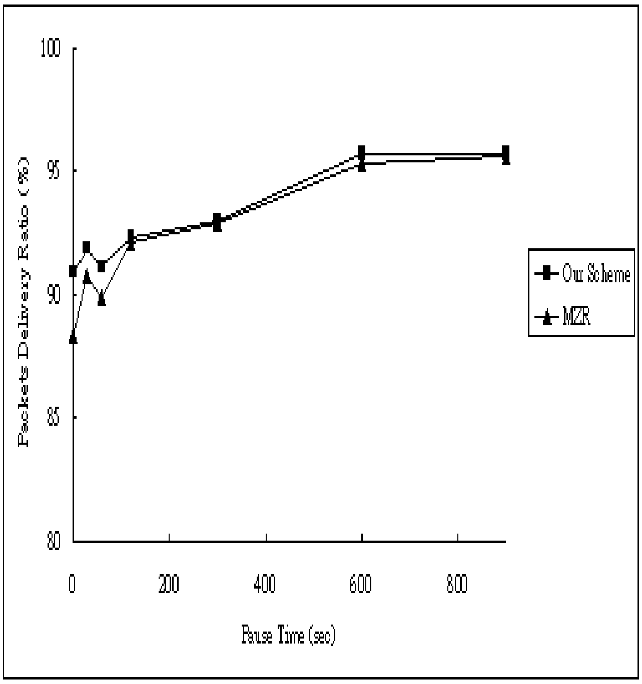


Fig.7. Influence of packet delivery ratio (3 multicast groups, 3 multicast source nodes, 10 nodes/multicast group)

Fig.8 and Fig.9 show the simulation result of control overhead ratio for each case. As mentioned before, we select some of the border nodes as forwarding nodes to retransmit the control packet instead of flooding it. It is easy to understand that our scheme made fewer control overhead than MZR.

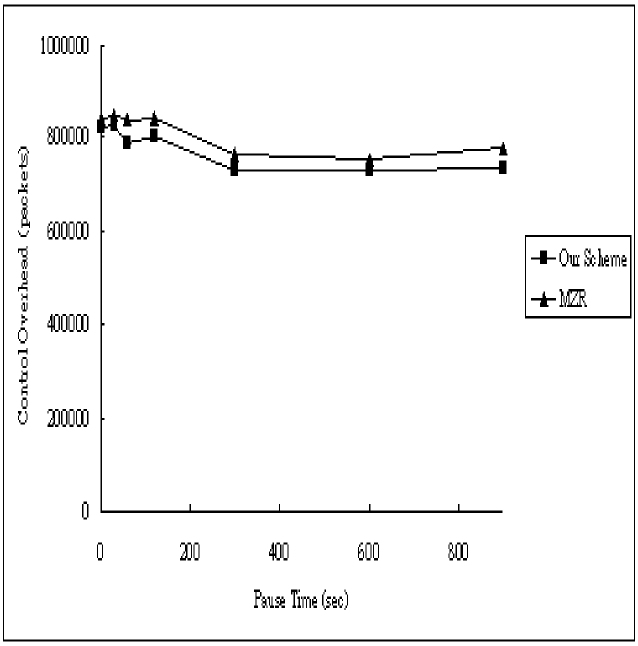


Fig.8. Total routing control overhead (1 multicast group, 10 nodes/multicast group)

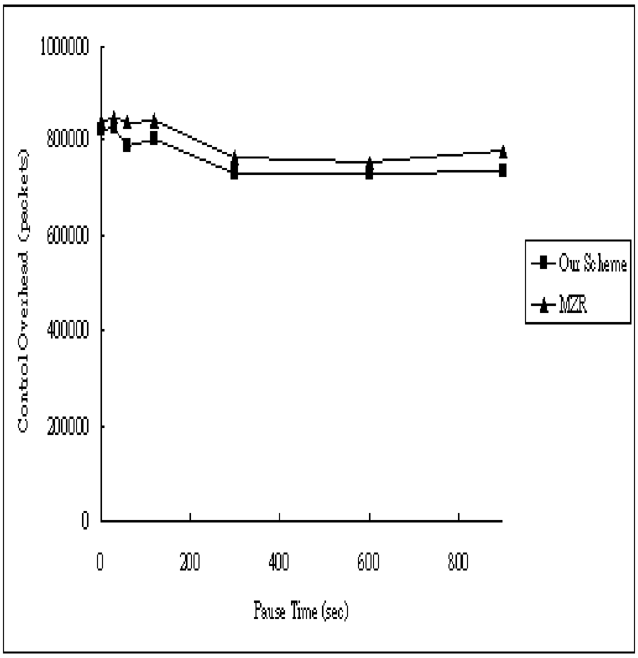


Fig.9. Total routing control overhead (3 multicast groups, 3 multicast source nodes, 10 nodes/multicast group)

The simulation result of number of forwarding packets for each case is shown in Fig.10 and Fig.11. In the proposed scheme, routing paths from multicast source node to its multicast members are often overlapped. However, in the MZR protocol, the multicast source node finds the shortest path to each of multicast members. It may lead to low probability to find overlapping paths and more forwarding nodes which are produced in the multicast tree. The more forwarding nodes forward the data packets, the more forwarding data packets there will be. Thus, as show in Fig.8 and Fig.9, in both of these two cases, our scheme is better than MZR.

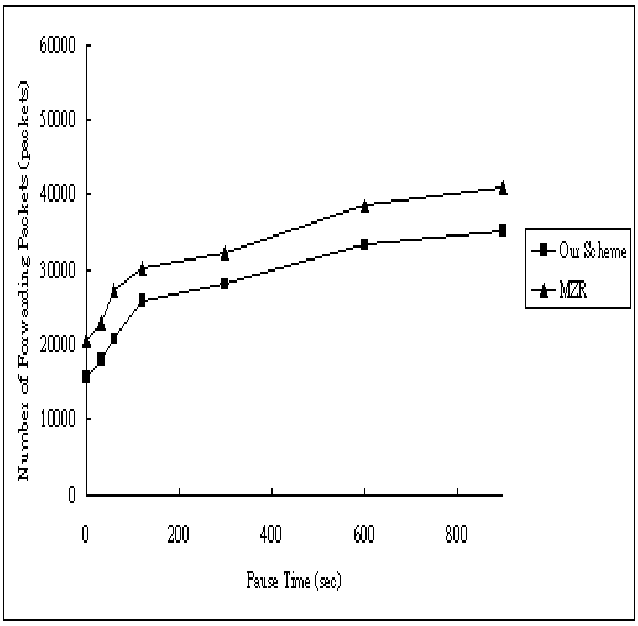


Fig.10. Total numbers of forwarding packet (1 multicast group, 10 nodes/multicast group)

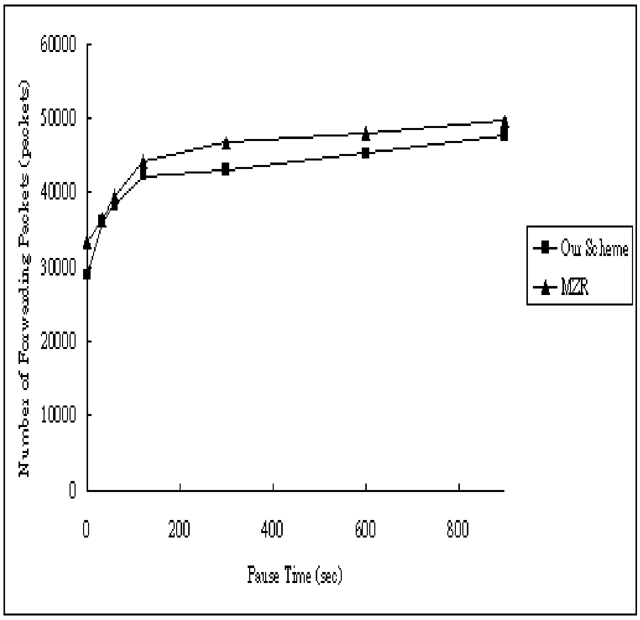


Fig.11. Total numbers of forwarding packet (3 multicast groups, 3 multicast source nodes, 10 nodes/multicast group)

The result of End-to-End Delay for each case is shown in Fig.12 and Fig.13. Obviously, MZR has better performance in this metric than our scheme.

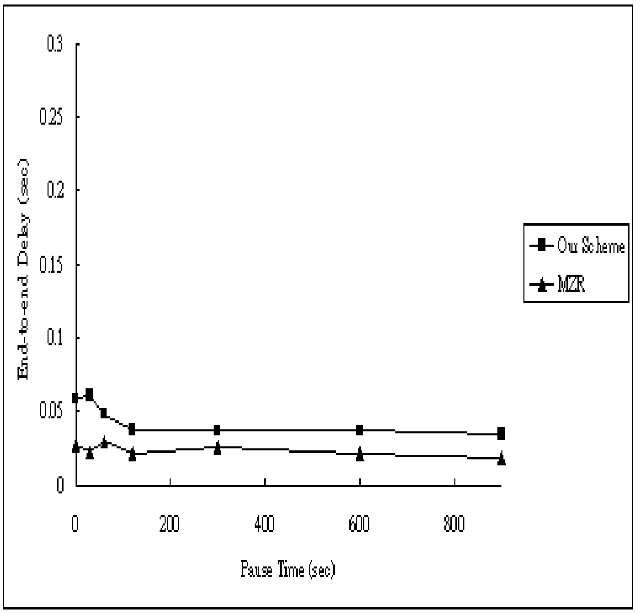


Fig.12. Performance of end-to-end delay (1 multicast group, 10 nodes/multicast group)

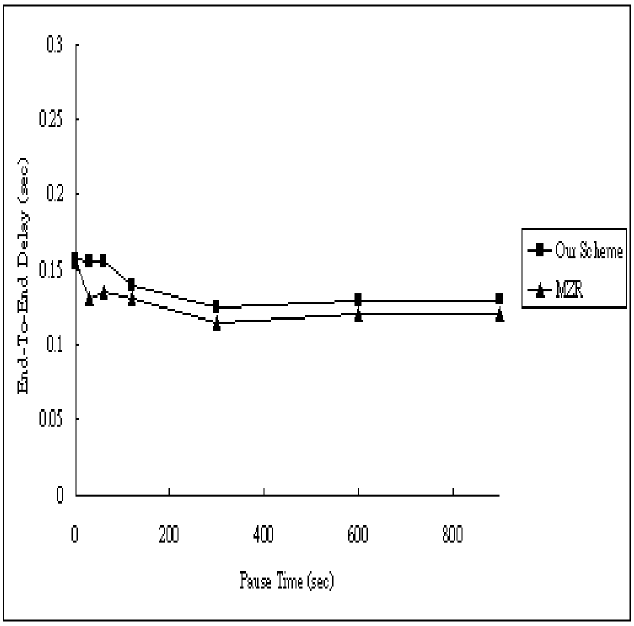


Fig.13. Performance of end-to-end delay (3 multicast groups, 3 multicast source nodes, 10 nodes/multicast group)

The multicast paths which constructed by MZR may find the shortest path from source node to each multicast member node. However the proposed scheme uses share path to deliver multicast data packets which may not be the shortest path from source node to each multicast member node. In our scheme, the average path to each multicast member node in shared path is longer than the shortest path which is found by MZR. Thus, it is reasonable to take more time in transmitting multicast data. Although it has longer end-to-end delay, our scheme is outstanding in other metrics, especially in reducing control overhead.

5 Conclusion

The flooding-based multicast routing protocols in MANETs sent many routing control packets unnecessarily to entire ad hoc network. Thus, a new zone-based multicast routing protocol, which efficiently select proper forwarding nodes to reduce routing control overhead and forwarding group size, is proposed in this paper.

The proposed scheme builds the multicast tree which is rooted on the multicast source and consisted based on multicast members. Under the connected network topology, our protocol guarantees the multicast tree can be completely constructed within a finite time. By using the proposed selection method it can also reduce control packets and forwarding group size. The simulation results imply that if all nodes in high mobility situation, the worst result of our scheme has the same performance compared with MZR, whereas the performance in low mobility situation is better than MZR.

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