Zone-based Two-level Routing Protocol for Wireless Mobile Ad Hoc Networks: A Fully Reactive Approach

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Abstract: This paper presents a novel zone-based routing protocol for wireless mobile ad hoc networks, which is named as Reactive Zone-based Routing Protocol (RZRP). The main objective of this protocol is to reduce the traffic overhead caused by proactively maintaining local or global neighbourhood routing information and frequent gateway node elections in high mobility and large-scale network situations. To this end RZRP utilises a pure reactive solution for zone-based routing protocol.

1. Introduction

Wireless mobile ad hoc network (MANET) is a network that consists of mobile devices, and each mobile device communicates to others via radio channels without presence of fixed network infrastructure. To effectively apply MANETs into various applications, many challenges are still in need to be solved. Routing, as a critical mechanism for MANETs, is such a challenge despite the enormous effort that has been put in. Hierarchical or cluster-based routing is widely regarded as an efficient way of routing, especially in large-scale wireless networks.

Most recent literature utilises hierarchical routing which show their efficiency in reduction of storage and communication overhead over flat routing structure [1-5]. The protocols presented in [1] and [2] described the zone as physical distance which is a fixed non-overlapped geometrical area based on location coordinates with pre-defined size, whereas [3], [4] and [5] describe the zone as nodal connectivity by pre-defining a zone radius in hops and any node whose distance in hops to the central node is less than or equal to the zone radius will be treated as local neighbours of the central node therefore the node is in the routing zone of the central node, and any node who requires packet transmission must form its own routing zone, hence the routing zone may be created dynamically and overlapped to each other. Moreover, some of hierarchical protocols require the existence of gateway node or cluster head in each zone for central administration and packet relay. The cluster head concept improved routing performance but may result in fast power depletion of head nodes and extra communication cost is also required for head election and cluster structure maintenance. Whatever approach been used, one common aspect can be found amongst these protocols is the utilisation of hybrid strategy, i.e. a combination of proactive and reactive solutions. By using hybrid routing strategy, the local or global topological information is maintained proactively, and route discovery packet will be initiated reactively. As in a large-scale network, not every zone has the equal probability to become an active relay zone, the network resources such as bandwidth and energy may be utilised inefficiently in these zones. Therefore, RZRP proposed a pure reactive two-level routing approach for zone-based routing protocol in terms of meeting all of the requirements of scalability, robustness, bandwidth efficiency and energy efficiency simultaneously.

As a zone-based protocol, the partitioning procedure of RZRP is similar to that in [1]. However, the maintaining of local and global topological information and route discovery are both carried out in reactive manner, via a two-stage operation: Interzone Route Discovery and Intrazone Route Discovery. The former is to establish routing path between source zone and destination zone in zone-to-zone manner, whereas the latter is only used to confirm the existence of destination node in the zone and connectivity status of the zone with its neighbouring zones. Different from that in the interzone route discovery, the routing path established within a zone is on a node-to-node basis.

The rest of this paper is organised as follows. After a presentation of the preliminaries in Section 2, Section 3 details the operations of the proposed RZRP. Based on the numerical analysis in Section 4, Section 5 illustrates the performance of RZRP. The paper concludes in Section 6.

2. Preliminary

As RZRP utilises location information to partition the network, all nodes in RZRP are assumed to be equipped with GPS receiver or equivalent equipment to get information like geographic location coordinates, current time, node moving speed and direction. Link between two nodes is assumed to be symmetric. We also assume that all nodes in the network already know the partition information such as zone ID and scope of each zone via some simple calculation if given the side lengths of zones.

Before any nodes join the network it must be associated with a Zone ID by mapping its current location to the zone map. The location coordinates of each node will be checked periodically in order to refresh its zone ID. As all zones are pre-partitioned based on their geographical information, these zone IDs can be used to represent current location of nodes, so that it may be transmitted over network instead of transmitting location coordinates. Since the length of zone ID is much smaller than coordinates, the overhead introduced by transmitting location information can be reduced.

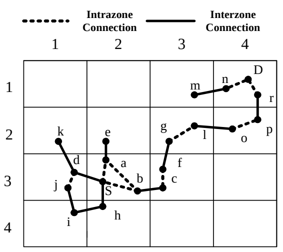
The structures of major control packets used in RZRP are as follow:

- Interzone RREQ: *<RREQ_ID, SourceNode_ID, SourceZone_ID, DestNode_ID, NeighbouringZone_List, RouteZone_List>* where RREQ_ID and SourceNode_ID are used to identify this packet. NeighbouringZone_List is the list contains IDs of neighbouring zones which currently connected with. Finally, the RouteZone_List contains the IDs of zones which will be used to forward this packet.
- Intrazone RREQ: *<RREQ_ID, InitiatorNode_ID, InitiatorZone_ID, DestNode_ID, LastHop_Location, Route_List>* where LastHop_Location is reserved for future using which contains location information about the last hop node. Route_List contains a set of nodes which will be used to forward this packet.
- Interzone RREP: *<RREP_ID, ReplierNode_ID, Route_List>* where Route_List contains the complete path between source node and destination node in zone-to-zone manner.
- Intrazone RREP: *<RREP_ID, ReplierNode_ID, ReplierZone_ID, Route_List>* where ReplierZone_ID tells the initiator that which zone it has connected with. Route_List is the complete path to the replier's zone in node-to-node manner.

A table is also utilised to store the ID of each packet, and its structure is: *<Packet_ID, Initiator_ID, Destination_ID, Packet_Type, Time>*.

3. Protocol Operations

When a source node wants to transmit packets to a destination node, it firstly checks its cache, if there is no valid path it then initiates an Intrazone RREQ. If the Intrazone RREQ cannot find the destination node in the same zone, an Interzone RREQ is then initiated and sent out to neighbouring zones by source node following the paths established by Intrazone RREQ. When a node receives an Interzone RREQ, it processes the packet following the pseudo code in Procedure 1. The first node in the zone receives an Interzone RREQ from its neighbouring zone and finds there are no valid paths to its other neighbouring zones or destination node it then initiates an Intrazone RREQ. When a node receives an Intrazone RREQ, it processes the packet following the pseudo code in Procedure 2. The Interzone RREQ will be forwarded when the node receives Intrazone RREPs to confirm the connectivity from its neighbouring zones. In such a manner, a route can be found as illustrated in the figure aside. Once the route between source node and destination node is established, the source node put the complete route in zone-to-zone manner into the data packet's header and sends it to the next-hop zone following the routing path in its cache. If a node detects its next-hop neighbour is no longer available it will select another path to the same neighbouring zone, if no such path can be found in its cache, it then initiates another Intrazone RREQ.




```
Procedure processInterRREQ (InterRREQ packet) {
If (myPktTable.contains(packet)==false){
   addToMyPktTable(packet);
   If(myNode_ID == packet.DestNode_ID || findPath(DestNode_ID)!=null) {
  send(Interzone_RREP);      }
  else if (findPath(Neigh_Zones)!=null) {
                      forward(packet);    }
else if (packet.Route_List.contains(myZone_ID)==false{
    addMyZoneID(packet.Route_List);
    initiate(myIntrazone_RREQ);}
else if (packet.Route_List.contains(myZone_ID)){
   drop(packet);}
 } else drop(packet);
}
```

Procedure 1 Processing Interzone RREQ

```
Procedure processIntraRREQ (IntraRREQ packet) {
If(myPktTable.contains(packet.pkt_ID)==false){
  If(myNode_ID==packet.DestNode_ID) {
    send(Interzone RREP);}
else {
  If(myZone_ID==packet.InitiatorZone_ID){
    Path P = findPath(DestNode_ID);
    If (P!=null) {
     send(Interzone_RREP);}
    else forward(packet);}
  else send(Intrazone_RREP);} }
  else {
  If(packet.Route_List.contains(myNode_ID) {
   drop(packet);}
 else updateMyCache(packet.Route_List); }
}
```

Procedure 2 Processing Intrazone RREQ

4. Numerical Analysis

In this section, the end to end delay and the number of control packets are to be analysed for both RZRP and ZHLS [1]. The reason why ZHLS is chosen as the benchmark is that ZHLS also utilizes the zone concept and the way zones are partitioned is same as that in RZRP. And ZHLS shows improved performance than other cluster-based routing algorithms [1].

The parameters will be used are: *N* (total number of nodes), *M* (total number of zones), *R* (route creation request rate per second), γ_z (breaking probability of zone level connectivity), γ_n (breaking probability of node level connectivity), *l* (average number of zones in a route), *T*(average process delay on node), *t*(average propagation delay on node), *Q*(percentage of active routes in a zone),*w*(probability of find valid path in cache), *f*(broadcast interval), *r*(transmission request rate per second).

4.1 End To End Delay

The end to end delay in a routing protocol is the time taken to establish routing path plus the time taken to deliver the data packet during propagation. In ZHLS, a destination zone ID searching packet must be broadcasted to all zones before sending data packet, hence, the end to end delay of ZHLS is

$$D_{ZHLS} = \sum_{j=1}^{M} S_j + \sum_{i=1}^{Q \times \frac{N}{M} \times l} d_i \quad (1)$$

where $S = T + t \times Q \times \frac{N}{M}$ is the delay caused by destination zone ID searching and $d = t$ is the delay caused by propagation. RZRP may has longer delay than ZHLS as two-level discovery is utilised, therefore, the end to end delay of RZRP is

$$D_{RZRP} = \sum_{j=1}^{M} (S_j \times (1 - w_{Inter}) + \sum_{i=1}^{\frac{N}{M}} s_{ij} (1 - w_{Intra})) + \sum_{i=1}^{Q \times \frac{N}{M} \times l} d_i \quad (2)$$

Where $S = t \times Q \times \frac{N}{M}$ is the delay caused by interzone discovery and $s = (T + t)$ is the delay caused by intrazone discovery.

4.2 Total Number of Control packets

The control packets in ZHLS include Node Link State Packet, Zone Link State Packet and Query Packet. As the node LSP and zone LSP are broadcasted periodically, every node maintains consistent view of network connectivity, therefore, the source node only needs to find the zone ID of destination node in order to select routing path from its cache for packet transmission. Hence, the total number of control packets will be generated by ZHLS within a specific time *P* is

$$O_{ZHLS} = \sum_{j=1}^{M} (L_j \times (1 + \gamma_n) + Z_j \times (1 + \gamma_x)) \times f \times P + \sum_{i=1}^{M-1} q_i \times R \times P \times r \quad (3)$$

Where $L = (\frac{N}{M})^2$ is the number of node LSPs generate in a zone, $Z = N$ is the number of zone LSPs generated in a zone, and $q = Q \times \frac{N}{M}$ is the number of query packets propagated in a zone.

In RZRP, only two types of control packet are initiated on-demand. Therefore, the total number of control packet generated by RZRP within a specific time *P* is

$$O_{RZRP} = \sum_{j=1}^{M} (u_j \times (1 + \gamma_z) \times (1 - w_{Inter}) \times R \times P \times r + v_j \times (1 + \gamma_n) \times (1 - w_{Intra})) \quad (4)$$

Where $u_j = Q \times \frac{N}{M}$ is the number of Interzone RREQs propagated in a zone and $V_j = \frac{N}{M}$ is the number of Intrazone RREQs propagated in a zone.

5. Evaluation Results

Figure 1 shows the end to end delay as the total number of nodes increases. The increase of total number of nodes in network implies that both the node density and network congestion in each zone will increase. There are two reasons that could cause the reduction of end to end delay. One reason is that involving fewer nodes in route discovery which implies both the route discovery delay and propagation delay of data packets can be reduced. The other reason is prolonged lifetime of route, and it implies that the route discovery delay can be reduced due to the reduction of route discovery requests. As show in Figure 1, RZRP suffers longer delay than ZHLS when the total number of nodes less than

800. This is reasonable in that reactive protocols usually have longer end to end delay than proactive protocol as the routing path to destination node and neighbouring zones are created on-demand rather than pre-decided on a periodic basis. When the total number of nodes is greater than 600, it shows a trend that end to end delay of RZRP close to ZHLS. When the total number of nodes is greater than 800, the end to end delay of RZRP is smaller than ZHLS. It is caused by the second reason as the more nodes exist in the network the more connections will be established to neighbouring zones, making the connectivity between neighbouring zones more robust. As a result, the number of requests for intrazone route discovery is reduced. This evaluation implies that RZRP enjoys "stressful" situation rather than a "loose" network situation.

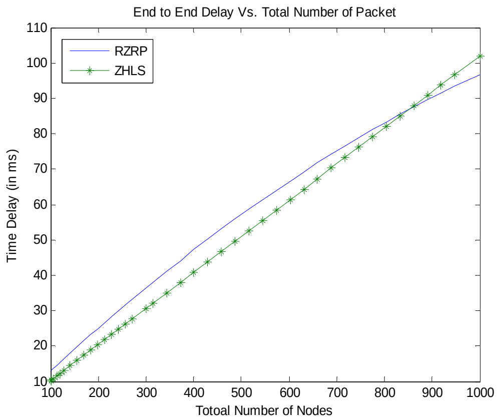


Figure 1 end to end delay Vs. total number of nodes

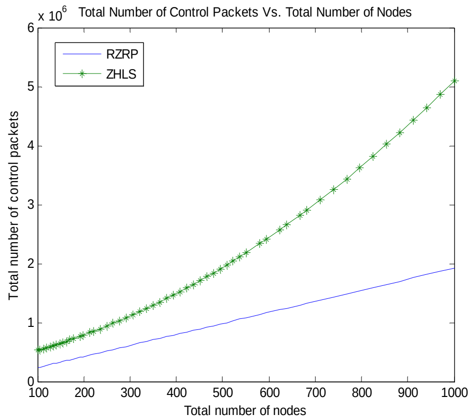


Figure 2 total number of packets Vs. total number of nodes

In terms of communication overhead, we calculated the total number of control packets. Figure 2 illustrates the total number of control packets versus the total number of nodes for each algorithm. Theoretically, as the total number of nodes increase, the total number of control packets generated by ZHLS should sharply increases due to both the increases of node density and transmission requests, whereas, RZRP should keeps a steady increase as it is insensitive to the increase of node density and only react to the increase of transmission requests. As Figure 2 shows, ZHLS generates significant amount of packets due to periodically broadcast node LSPs and zone LSPs, whereas, RZRP generates fewer packets as the control packets are only initiated on-demand, which implies that RZRP consumes less bandwidth and energy than hybrid protocols.

6. Conclusion

This paper presents a pure reactive zone-based two-level routing protocol for MANETs. By using purely reactive strategy in hierarchical networks control overheads can be largely reduced, especially in large-scale networks. In contrast, the end to end delay is prolonged. Through our evaluation, we find that by using efficient caching mechanism and location-aid routing strategy, the shortcomings may be improved. Therefore, our future development is to investigate how efficient caching mechanisms can be used in RZRP.

7. References

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