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Scalable routing strategy for dynamic zones-based MANETs

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Abstract

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Scalable Routing Strategy for Dynamic Zones-based MANETS

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***Abstract*— This paper presents a new routing strategy for Mobile Ad Hoc Networks, called Dynamic Zone-based Topology Routing protocol (DZTR). We introduce new strategies to maintain up-to-date intrazone and interzone topology information at each node. We also propose a GPS-based location tracking mechanism, which reduces route discovery area and the number of nodes queried to find the required destination. Our routing strategy has been designed to work with dynamic zone, which contains a set of member nodes. Every node outside a zone is called a single-state node. We perform theoretical performance analysis, which shows that our network topology creation process has significantly fewer overheads than flooding approaches.**

I. INTRODUCTION

One challenging research area in Mobile Ad hoc Networks (MANETs), is to design a routing strategy, which is scalable as the size of the network and traffic increases. A scalable routing strategy must be adaptable to the dynamic nature of MANETs, ensure that routes are found with minimum amount of overhead and guarantee different levels of QoS for different users and applications. A number of different routing protocols have been proposed for MANETs. These protocols can be classified into three categories proactive, reactive, hybrid. In proactive routing strategies, each node in the network maintains up-to-date route information to every other node in the network. The route stored for each node is maintained in route tables and updated according to the route update strategy employed [1].

Reactive routing protocols reduce the overheads in proactive protocols by maintaining information for active routes only. This means that routes are determined and maintained for nodes requiring to send data to a particular destination [5].

Hybrid routing protocols are a new generation of protocols, which are both proactive and reactive in nature. These protocols are designed to increase scalability by allowing nodes with close proximity to work together to form some sort of a backbone to reduce the route discovery overheads. This is achieved by proactively maintaining routes to nearby nodes and determining routes to far away nodes using a route discovery strategy. Most hybrid protocols proposed to date are zone-based, which means that the network is partitioned or seen as a number of zones by each node. Zone-based routing strategies eliminate the single point of failure problem in cluster-based routing protocols by defining a hierarchical routing structure, which do not rely on a single node (such as a cluster-head) to coordinate data transfer or maintain a routing structure for a small area. Instead, a number of nodes work together in a defined area called a zone to perform routing. Zone-based networks can be classified into two categories: overlapping zones (such as ZRP[3]) and non-overlapping zones (such as ZHLS[4]). In overlapping zone-based routing protocols, each node determines its zone separately and maintains up-to-date routes to all nodes within its zone. In non-overlapping zone-based protocols, the network is divided into a number of zones, which form a grid. Each zone has a unique zone ID, which is used by each node to associate itself with a zone. It is also used to simplify the route discovery procedure and data transmission. The disadvantage of non-overlapping zone-based protocols such as ZHLS is that the zone partitioning is done at the design stage. This means that all nodes must have preprogrammed zone maps, which are identical for all nodes in the network, or they must obtain a copy of the zone map before routing can occur. Static zone maps can be used in environments where the geographical boundaries of the network is known (or can be approximated). However, in environments where the geographical boundaries of the network are dynamic, a static zone map cannot be implemented. In this paper, we propose a new routing strategy for dynamic zone-based networks, which is designed to reduce routing overhead and increase the scalability of MANETs. [1].

II. TOPOLOGY CREATION FOR ZONE-BASED NETWORKS

A. Intrazone Routing

The intrazone network topology is maintained proactively. Each node belonging to a zone (i.e. a member node) broadcasts its location information through its intrazone if it has travelled (displaced) a minimum distance. This distance is called Minimum Intrazone Displacement (MID). To determine their displacement, each node starts by recording its current location at the startup using a GPS device. It will then periodically check its location. If the distance between the current and the previous location is greater than or equal to MID, then the node will broadcast its location information through the intrazone and set its current location as the new previous location. We call this updating strategy, Minimum Displacement Update (MDU). The advantage of MDU is that updates are sent more frequently if the location of a node has changed significantly. The disadvantage of sending updates based on mobility alone is that if a node travels back and forward in a small region update packets are still disseminated, however, the topology may have not necessarily changed. Therefore, sending an update packet will be wasteful. Intrazone update packets will also be sent if any of the following conditions occur:

[1]Note that we do not describe how the dynamic zones are created. Since it is beyond the scope of this paper. Our zone creation algorithms for DZTR are described in [2]

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1) New node comes online
2) Node enters a new zone
3) Node travels more than MID within a zone
4) Intrazone-Update Timer (IUT) expires

In the first two cases, a location-update packet will be broadcasted through the intrazone by the new node, which contains its node ID, current location and a sequence number. The neighbouring nodes in the intrazone will record the new node location and node ID. They will then reply to the new node by sending their location information. Once, the replies are received by the new node, it will query the closest member node for its intrazone table to build its own intrazone table. Each neighbouring node will then forward the new nodes location-update packet through their outgoing links. Multiple forwarding of the same location update packet by a neighbouring node is avoided by comparing the sequence number of the location update packet received with the ones it has already seen. The nodes which have not sent any location-updates for the time specified in the IUT will also broadcast their location information in their intrazone. Therefore, the nodes which continuously change their location will update their intrazone more frequently than stationary nodes.

B. Interzone topology creation

When a gateway node learns about an existence of another zone, it will broadcast the zone ID of the new zone through its intra zone using an Inter zone-Update packet (IEZ). IEZ stores the gateway node's node ID, zone ID, location, velocity and learnt zone ID. This also allows other member nodes to update the information stored in their intrazone table about that gateway node. Hence, the gateways can reset their IUT timer each time they send one of these packets To illustrate how interzone packets are propagated, suppose that node B and node C form a bidirectional link in Fig. 1. Both these nodes will update the nodes in their intrazone about the existence of the other zone using interzone update packets as illustrated. Each gateway node can also learn about non-neighbouring zones by using the information stored in the control and data packet travelling through them or by overhearing other neighbours packets. This information is also broadcasted in the intrazone using IEZ packets. Each member node will then buildup (or update) their interzone topology table from these packets. Each member node also keeps a Temporary Members Table (TMT). Each time a new single-state mode node communicates with a member-node, it will send its location, velocity and zone degree[2]. The member-node will then update its TMT table and broadcast this information, using a temporary member update packet (TM-update) to its intrazone. Each receiving node will then update its TMT and forward the packet to the other nodes in the intrazone using their outgoing links. The temporary member-node will also record the zone ID of the member-node in its interzone table. For example, when node C and I (in Fig. 2) come in transmission range, node C will add the zone ID of node I to its interzone table and node I will add node C's information to its TMT and then broadcast it through its intrazone. All member-nodes also keep a Destination History Table (DHT). This table stores the node ID of the destinations, which the member node had communicated with or has overheard. A timer is set for each entry in the table. When this timer expires for a particular entry, it is deleted. Each entry timer can be refreshed every time the member node receives new information. Note that the nodes in the single-state mode, which are gateways to a zone do not maintain an intrazone table. However, they maintain all the other tables mentioned, and a neighbour table, which lists the nodes which are currently within its transmission range. These nodes perform routing by simply forwarding their queries (using their interzone topology table) to their neighbouring zones or send their data directly to the destination using their DHT.

[2]The zone degree is the number of known neighbouring zones

C. Interzone Migration

When nodes migrate from one zone to another they send a control packet to the previously visited zone, thus leaving behind a trail. The trail information includes the nodes current zone ID, location and velocity. The nodes which receive this trail information update their DHT table. Therefore, the nodes in previously visited zone can forward the location request or data packets for the migrating zone to its current zone. For example, suppose node M (see Fig. 3), wants to send data to node A. According to node M's DHT, node A is in Z1, but node A has migrated to Z2. Node M will start sending data packets to Z1. Node D will consult its DHT and forward the data packet to Z2 using the location trail sent back by node A. Therefore, node can still transmit data to node A without using a route discovery strategy. Location trails can be also used during location discovery to reduce the amount of overhead transmitted through the network.

III. Location discovery and Route Establishment

A. Location Discovery and Route Establishment

To illustrate how routing is performed in our routing strategy, we define a number of different routing scenarios:

(i) Destination is in the intrazone or a is temporary member.
(ii) Destinations ZID or location is known, and it is expected to be in its current zone.
(iii) Destinations ZID or location is known, but its velocity and location information suggest that it could currently lie a number of different neighbouring zones.
(iv) The location or the ZID of the destination is unknown.

When a source has data to send to a particular destination it firstly starts by checking if the destination is located in the intrazone or it is a temporary neighbour. This is done by checking the neighbouring table (for single state mode nodes) or the intrazone table and the TMT (for member nodes). If the destination is found in one of these tables (i.e. case (i)), the source starts sending data. Since the route to the destination has been predetermined proactively. Otherwise, the source node will consult its DHT. If an entry is found in the DHT, the source checks if the destination still maps in its current zone (using the destinations location, velocity and expiration time in the DHT), if the mapping suggest that the destination is still in its current zone (i.e. case (ii)), the source node will use its interzone table to forward the data packet to the next zone, which leads to the destination zone. For example, suppose that node S (Fig. 4) has an unexpired location information about node X, and based

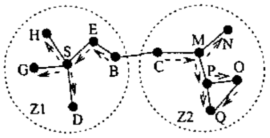

Fig. 1. Interzone update packet propagation

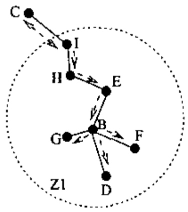

Fig. 2.A dding a temporary member to the zone

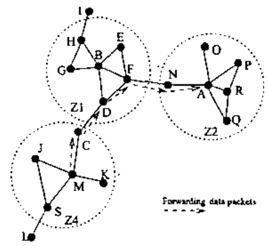

Fig. 3. Location discovery using location trails

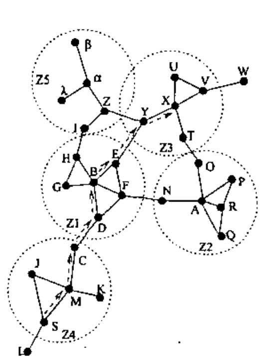

Fig. 4. Data forwarding with interzone and intrazone tables

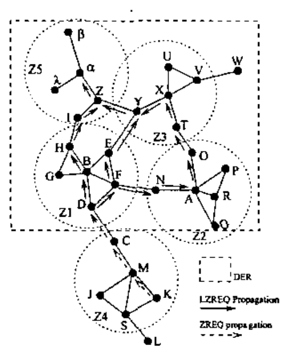

Fig. 5. LZREQ propagation in the DER

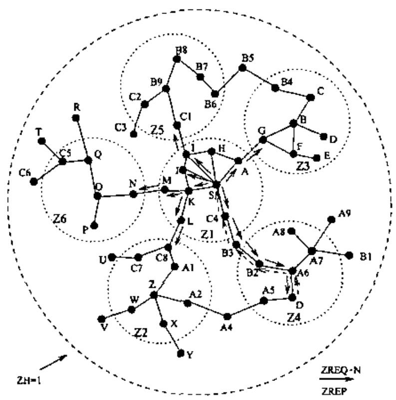

Fig. 6. ZREQ-N propagation using ZH=1

on node Xs velocity, it is still in Zone 3 (i.e. Z3). Node S will then start sending data towards the next zone, which leads to the destination zone, using its interzone topology table. Therefore, the data will travel from Z4 to Z1 and then Z3. When the destination zone is reached, the intrazone table is used to forward the data to the required destination. In (iii), to find the current zone ID (or location) of the destination, the source node unicasts a Zone Request packet with destinations previously recorded location information (i.e. ZREQ-L), to the zone in which the destination was last suspected to be in, using its interzone topology table. When the ZREQ-L packet reaches the destination's suspected zone, the gateway node which have received this packet will first check to see if the destination is still in the intrazone (or a temporary member). If the destination was not found and location trail is not available, the gateway node will calculate a region in which the destination could have migrated to. We call this the Destinations Expected Region (DER) , and it is calculated using the destinations previously known velocity and location information (similar to a request zone in [5]). When the DER is calculated, the gateway node will create a new packet, which includes the source node ID and zone ID, destination ID, a sequence number and the DER. This packet is called a Localised Zone Request (LZREQ). The gateway node forwards this packet to all the neighbouring zones which map into the DER. Each gateway node in the receiving zones will check their tables for the destination, if the destination is not found, they will forward this packet to their neighbouring zones which map into the DER. Note that each node only forward the same LZREQ (or ZREQ) packet once. However, each zone may be queried more than once from different entry points (i.e. gateways). This way if there is clustering within each zone, the zones can still be effectively searched. If the destination is found, the destination will send a ZREP packet back towards the source. For example, suppose that node K (Fig. 5) wants to send data to node α and node K's DHT states that node α is in Z1. However, node α's velocity and location information suggest that it could be in any number of zones surrounding Z1 (node α's currently resides in Z5 as shown in Fig. 5). To determine the current location of node α, node K forwards a ZREQ-L packet to Z1, where node α was last suspected to be in. Now, lets assume that no trail information is available in Z1 for node α from this zone. Hence, when the ZREQ packet reaches the gateway in Z1 (i.e. node D), it will calculate the DER for node α, then forwards a LZREQ packet to each neighbouring zone which lie in the DER. When the gateway in Z5 is reached, it will forward the LZREQ to node α. Node α will then send a ZREP back towards node K using its interzone table.

In (iv), to search the network effectively while ensuring that overheads are kept low, we introduce a new zone searching strategy called Limited Zone-hop Search with Multizone Forwarding (LZS-MF). In this strategy, the source node generates a ZREQ-N packet (N denotes no location information is available for the destination). This packet includes the source node ID, zone ID, location, sequence number, neighbouring zone list and a Zone-Hop (ZH) number. The zone hop number defines the number of zones in which the ZREQ-N packet can visit before it expires. To search for an unknown destination, the source node begins by setting $ZH = 1$, which means that only the neighbouring zones can be searched. Each time the ZREQ-N discovery produces no results, the source node increments the value of ZH to increase the search area, and the search in initiated again. This strategy continues until ZH = MAX-COVERAGE-AREA. The advantage of LZS is, if one of the nearby by zones have a trail to the destination (or hosts the destination), we avoid searching all zones in the network. Now, to ensure that not all nodes within each zone are involved in the routing, each time a gateway node in each zone receives a ZREQ-N packet, it uses its interzone topology table to forward the ZREQ-N packet to the nodes, which lead to the outgoing zones (neighbouring zones). We call this Multizone Forwarding (MF). In this strategy the source node starts by consulting its interzone topology table to determine the list of neighbouring zones. It will then store the list of neighbouring zones, along with the neighbouring nodes which lead to one these neighbouring zones. These are the only nodes, which can forward the ZREQ-N packet to the next neighbour leading to a neighbouring zone. When a ZREQ-N packet reaches a new zone, the receiving node, will first check its the intrazone, TMT and DHT tables to see if it has a location information about the destination. If location information is not found and it has not seen the packet before, it will consult its interzone table and forward the ZREQ-N packet with a new list of neighbouring zones and forwarding nodes. The process continues until the ZH limit is reached, the packet timer expires or the destination is found. When the destination is found, it will send a ZREP packet back towards the source node, indicating its current zone, location and velocity. For example, if node S (see Fig. 6), wants to send data to node D and it has no location information about node D. Node S will initiate LZS-MF (as described earlier) with $ZH = 1$. Here, a ZREQ-N packet is generated, with neighbouring zones Z2, Z3, Z4, Z5 and Z6 and forwarding nodes A, C4, L, M and I. Node S will broadcast the ZREQ-N packet and the forwarding nodes will send this packet to the neighbouring zones. The gateways receiving the ZREQ-N in each of the neighbouring zone Z2, Z3, Z5 and Z6 drop the packet, since the destination is not in their intrazone and they do not have location information. The gateway node in Z4 (i.e. B2) will forward the ZREQ to the destination. The destination sends back a ZREP to the source node in Z1.

B. Route Maintenance

In our routing strategy routing and data transmission can still be carried out if the topology of each zone changes. For example, in Fig. 5, if node Q wants to sends data to node P, it will forward the data through node R. However, if node R becomes unavailable, it can use node A to its data to node P. Now, if node A wants to send data to node X (which is in zone Z3), suppose that according to its interzone table, node X can be reached through node O. If however, the link between node O and node T breaks, node A can use node N to send data to node F (in Z1). This node will then use its interzone table to send the data to zone 3, through the gateway node E. Otherwise, if node F in Z1 cannot find any zone leading to Z3, it will send back a Zone Error (ZERR) packet back to node A. Node A will then wait

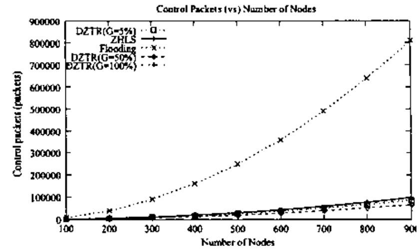

Fig. 7. Topology Overhead for M=9 and G = 5%, 50% and 100%.

until a gateway node is found to connect its zone to the other zones. When this is done it will initiate one of the route discovery strategies discussed in the previous section. The decision on which routing strategy to use will be based on the current state of the destinations recorded velocity, location and expiration time. Therefore, the intrazone topology or the interzone topology may not necessarily require another route discovery, which means that we minimise the amount of overhead introduced in to the network.

IV. Control Overhead Analysis

In DZTR, two types of control overhead packets are disseminated into the network. The first type of overhead is introduced for topology creation and maintenance, and the second is for routing. To determine a theoretical model for topology overhead, let the number of nodes in the network be N, the number of zones in the network be M and the number of gateways in each zone be G. Assuming that the nodes are evenly distributed through the network, each zone will have (N/M) nodes[4] and also equal number of gateway nodes Since each node generates a location update packet, propagating throughout its intrazone, if a gateway node sends an IEZ packet it resets its IUT and it does not need to send an intrazone update for $t = IUT$ unless their location changes by MID. Then the number of location update packets produced is $(N/M - G)^2$ for one zone and $M(N/M - G)^2 = (N^2/M) - 2GN + MG^2$ for all the zones in the network. The number of interzone packets per zone is $G(N/M) = GN/M$ and the total number of interzone packets for all the zones in the network is M(GN/M) = GN. Therefore, topology creation and maintenance overhead is

$$\begin{aligned} O_T &= N^2/M - 2GN + MG^2 + GN, \\ &= N^2/M - GN + MG^2 \end{aligned} \quad (1)$$

From equation 1 (also shown in Fig. 7), it can be seen that for $2 < M < N/2$ where[3] $G \leq (N/M)$, the size and the number of O_T will be less than [4] and [6], since the size of the location packets are smaller than link state packets. Furthermore, Fig. 8 and Fig. 9 show that DZTR produces fewer overheads that [4] for any number of zones. This is because interzone update packet are exchanged with neighbouring zones only rather than propagating through the entire network.

To determine the maximum possible routing overhead introduced into the network, let us look at the worstcase scenario,

[3] $G_{max} = (N/M)$ for evenly distributed gateway nodes per zone

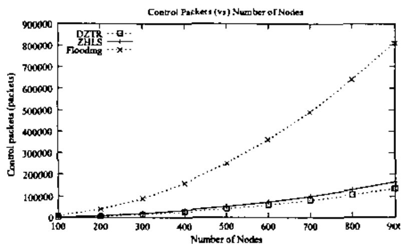

Fig. 8. Topology Overhead for M=5 and G=20%

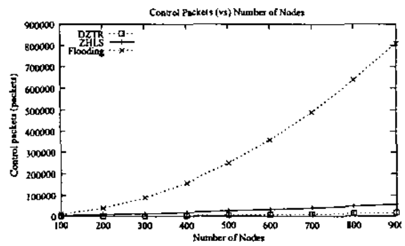

Fig. 9. Topology Overhead for M=40 and G=20%

where the source node does not have any location information about the destination and no location trails are left in the network (i.e. scenario (iv) is section A6). In this case, our routing strategy will initiate LZS-MF searching strategy. To determine the routing overhead introduced in this search strategy, let F be the number of forwarding nodes in each zone [4]. Then the number of routing packets transmitted through each zone is F and the number of packets transmitted (forwarded) in the network is $R_T = FM$. In the worstcase scenario where there is $M = N/2$ zones (since each zone must have at least 2 nodes per zone)and ZH is equal to the size of the entire network. If all the nodes in each zone are forwarding nodes, then the number of retransmissions will be $R_T = FM = 2(N/2) = N$. However, as the number of nodes in each zone increases, the number of forwarding nodes in each zone will start to decrease. Therefore, as $F \ll (N/M)$, then $R_T \ll M(N/M)$ or $R_T \ll N$. This means that LZS-MF will be more efficient that flooding for $F < N/M$ and $M < N/2$. To illustrate the efficiency of LZS-MF,we compare its performance against pure flooding and Multi-point relaying (MPR) [7] using Fig. 6. If node S wants to determine a route to node D, using LZS-MF 15 broadcasts (i.e. 10 ZREQ and 5 ZREP broadcasts) are generated, using the same scenario with MPR (Fig. 10), we find that 40 broadcasts are generated and with pure flooding 52 broadcasts are generated. Therefore, it can be seen that LZS-MF generates significantly lower amounts of overhead that the other two methods. With MPR, its performance will increase when the nodes in the network are evenly and more densely distributed, so that each node can calculate their MPR more effectively [7].

V. Conclusions

We presents a new routing strategy for zone-based mobile ad hoc networks called Dynamic zone-based Routing (DZTR).

[4] Assuming that all zones have equal number of forwarding nodes.

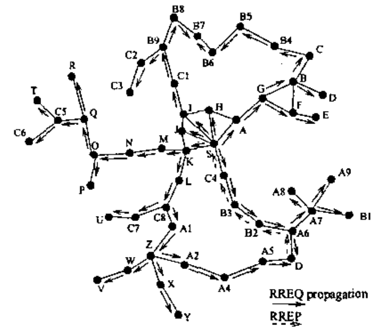

Fig. 10. Route request propagation using MPR

The idea behind this protocol is to allow the nodes in each zone to work together to perform efficient routing. By allowing groups of nodes to together to perform routing and data transmission, we eliminate single point of failure during data transmission, distribute network traffic through a set of nodes and avoid frequent route recalculation. The topology of each routing zone is maintained proactively and each zone member node is aware of the neighbouring zones through the gateway nodes. DZTR reduces routing overheads by reducing the search zone and allowing only selected nodes to forward the control packets. Each node that migrates between zones also leaves transient zone trails, which assist our proposed search strategy to find the destination more quickly and with fewer overheads. In the future, we plan to carryout a performance comparison between our routing strategy and a number of other currently proposed strategies

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