Node-Disjoint Multipath Routing with Zoning Method in MANETs

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Abstract

Multipath routing is one of the most important research directions in the area of network routing. However, it is very difficult to achieve node-disjoint multipath routing in Mobile Ad-hoc NETworks (MANETs), especially in large scale MANETs. We propose a Multiple Zones-based routing protocol (M-Zone for short) to discover node-disjoint routing paths segment-by-segment in large scale MANETs effectively. M-Zone uses a multiple zoning method based on location to guarantee that the nodes in multiple routes are different apart from the source and the destination. We propose two approaches to maintain the routes: one is local route maintenance and the other is global route maintenance. Simulation studies show that the average path length of M-Zone is close to that of GZRP, which combines the Zone Routing Protocol (ZRP) and Global Positioning System (GPS). The average packet delivery ratio of M-Zone is significantly higher than that of GZRP.

Keywords: MANETs, multipath routing, node-disjoint, location, zoning method

1. Introduction

A Mobile Ad-hoc NETwork (MANET) consists of a set of mobile nodes. Each node acts as both a host and a router.

Existing routing protocols in MANETs are generally classified into topology-based routing and location-based routing. Topology-based routing protocols can be further categorized into proactive, reactive and hybrid approaches. Destination Sequenced Distance Vector (DSDV) routing [1] is a typical proactive routing protocol. Dynamic Source Routing (DSR) [2] and Ad-hoc On-demand Distance Vector (AODV) [3] are examples of reactive routing protocols.

The Zone Routing Protocol (ZRP) [4] is a hybrid routing protocol that combines the proactive and reactive approaches. Each node maintains an up-to-date routing table of a zone, which is approximately a circle. ZRP has many query messages. To solve this problem, GZRP is proposed in [5]. GZRP is a hybrid protocol that combines the ZRP protocol and the Global Positioning System (GPS). It outperforms ZRP by significantly reducing the number of route query messages and increasing the efficiency of the network load.

Location-based routing protocols have good scalability such as Terminodes routing [6] and Segment-by-Segment Routing (SSR) [7]. However, they encounter the local optimum problem when the nodes forward packets in a greedy way. Greedy Perimeter Stateless Routing (GPSR) [8] and Hole Shadowing Routing (HSR) [9] provide two different

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ways to handle this problem.

To establish more efficient routing, several multipath routing protocols have been proposed. Ad-hoc On-demand Multipath Distance Vector (AOMDV) [10] and Ad-hoc On-demand Distance Vector Multipath (AODVM) [11] are extensions to AODV. AOMDV finds node-disjoint or link-disjoint multiple paths, but only link-disjoint paths are guaranteed. AODVM does not allow intermediate nodes to reply route requests so that the destination can select node-disjoint paths. Split Multipath Routing (SMR) [12] and Multipath Source Routing (MSR) [13] are extensions to DSR. SMR can find an alternate route that is maximally disjoint from the shortest delay route between the source and the destination. MSR distributes load among multiple paths based on the measurement of Round Trip Time (RTT). Reference [14] presents a multipath routing protocol based on DSDV.

The aforementioned protocols are typical protocols used to find disjoint paths but they can hardly find node-disjoint multiple paths in large-scale networks efficiently. In this paper, we propose a Multiple Zones-based routing protocol (M-Zone for short) to discover node-disjoint multiple paths using a location-based multiple zoning method. M-Zone combines the advantages of proactive routing (short delay) and location-based routing (good scalability) and is particularly effective in large scale MANETs by virtue of segment-by-segment route discovery. The paths are distributed in multiple zones, ensuring that each path is mapped to a distinct zone. The zone is strip-shaped shown in Figure 1, not approximately circular like in GZRP. The multiple zones move periodically as the nodes move, so we use a zoning method to emphasize the change of the zones. Local route maintenance and global route maintenance are proposed to maintain the routes. We will describe the M-Zone protocol in detail in the following section.

The remainder of this paper is organized as follows. Section 2 describes the network model. Division of regions is given in section 3. Section 4 presents the design of the proposed M-Zone protocol. Section 5 presents the simulation studies. Finally, we conclude the paper and describe our future work in section 6.

2. Network Model

There exist only a small number of node-disjoint paths between any two arbitrary nodes in moderately dense networks [12]. We assume a network with comparatively high density, where each node is uniformly distributed and knows its own location by GPS. We also suppose that the source knows the location of the destination via some location service, e.g. [15].

Each node maintains a *k*-hop vicinity routing table, where *k* is a system parameter. Figure 1 illustrates a 2-hop vicinity of node *S*. *P* belongs to the vicinity because the minimum hops from *S* to *P* is 2. *U* is not in the 2-hop vicinity since the minimum hops from *S* to *U* is 3.

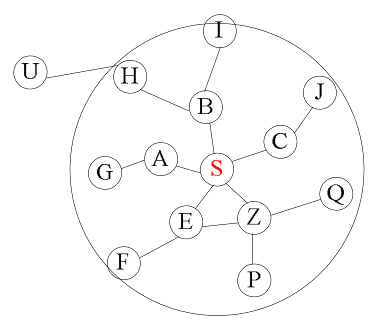

Figure 1. A 2-hop vicinity of node *S*

3. Division of Regions

3.1. Division of Zones

The region between the source and the destination is divided into *N* strip-shaped zones to discover *N* node-disjoint paths, where *N* is the number of node-disjoint paths.

Let the coordinates of the source and the destination be (x_1, y_1) and (x_2, y_2) respectively, and the straight line *L* between the source and the destination is given by the equation $Ax+By+C=0$, where $A=y_2-y_1$, $B=x_1-x_2$, and $C=x_2\times y_1-y_2\times x_1$.

A zone is a strip-shaped region bounded by two lines based on their distance to L and the zone width d is determined by the value of k and the number of multiple paths. A node obtains its distance to L using the following formula:

$$\text{Dist}=\left(Ax_i + By_i + C\right)\Big/\sqrt{A^2+B^2} \quad (1)$$

where (x_i, y_i) denotes the location of the node. The distance can be negative from Formula (1) in order to confirm which zone the node belongs to.

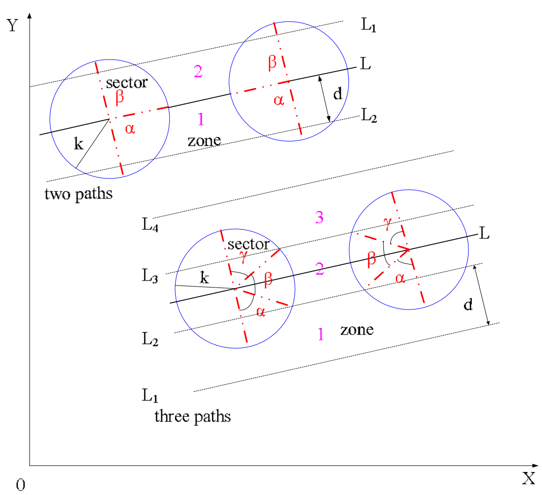

Figure 2. The division of zones

As shown in Figure 2, for two paths, the ranges of the two zones are as follows:

1 $(-d, 0)$; 2 $(0, d)$.

For three paths, the ranges of the three zones are as follows:

1 $(-3\times d/2, -d/2)$; 2 $(-d/2, d/2)$; 3 $(d/2, 3\times d/2)$.

We consider zone 1 with the three paths case as an example to describe the method of zone division more clearly. Zone 1 is within the range $(-3\times d/2, -d/2)$, where $-3\times d/2$ is the distance from the boundary L_1 to L and $-d/2$ is the distance from the boundary L_2 to L. Any nodes whose distance to L is within the range of a certain zone belong to the corresponding zone.

According to the two ways of dividing odd and even paths, we deduce that the boundaries of a zone can be described by the range $((-N/2+j)d, (-N/2+j+1)d)$ where $(0<=j<=N-1)$. In this way, the lengths of the paths are not only close to each other, but also close to the shortest path length.

Since the nodes can be mobile at will, we periodically recalculate the multiple zones according to the new location of the source and the destination and it looks like the multiple zones move periodically along with the movement of the nodes.

3.2. Division of Sectors

The aim of dividing the sectors is to ensure that the nodes in the k-hop vicinities at the source and the destination will be different from each other. For simplicity, we divide the sectors at the source and the destination symmetrically.

As shown in Figure 2, in the three paths case, sector α is mapped to zone 1, sector β is mapped to zone 2, and sector γ is mapped to zone 3. The N sectors are periodically recalculated according to the N zones.

4. The M-Zone Protocol

4.1. Route Discovery

When the destination is in the k-hop vicinity of the source, it uses proactive routing for route discovery. Otherwise, route discovery has three phases: the source to anchor phase, the anchor to anchor phase, and the anchor to destination phase. An anchor is the node nearest to the destination in the corresponding zone and within the k-hop vicinity of the previous anchor. Selecting anchors in this way ensures that the path length is as short as possible. The sub-path within the k-hop vicinity is called a segment and is obtained by using proactive routing.

In the source to anchor phase, the source chooses an anchor in each zone within the k-hop vicinity of the source. The N segments from the source to N anchors belong to N distinct sectors and are built from the k-hop vicinity routing table maintained by the source.

As for the anchor to anchor phase, each anchor chooses the next anchor in the same zone. The intermediate nodes in the segment from an anchor to the next anchor are selected according to the k-hop vicinity routing table of the former, and are located in the same zone as the anchor. This phase continues until the destination is within the *k*-hop vicinity of an anchor.

Finally, for the anchor to destination phase, the segment from the anchor to destination can be computed according to its *k*-hop vicinity routing table and the sector of the destination. Since the sectors at the source and the destination are symmetrical, the sector of the destination *D* can be easily obtained.

Figure 3 presents the route discovery procedure. A source *S* needs to discover three disjoint paths to send packets to a destination *D*. Here, *D* is not within the *k*-hop vicinity routing table of *S*. *S* obtains the location of *D* by querying the location service, and includes the location in the header of the packets. According to the locations of *S* and *D*, the straight line *L* and three zones are computed and included in the packets.

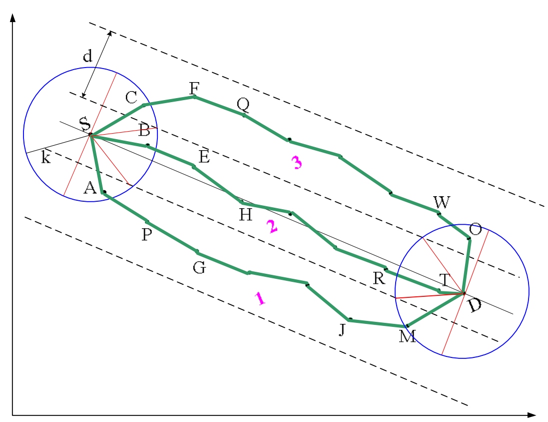

Figure 3. Route discovery

Source *S* broadcasts the packets in its *k*-hop vicinity and determines three anchors *A*, *B*, and *C* respectively in three corresponding zones. *S* builds a segment to each anchor based on its *k*-hop vicinity routing table. Each segment passes through a distinct sector of *S*.

The segment from *A* to its next anchor *P* is built according to the *k*-hop vicinity routing table of *A* and all the intermediate nodes in the segment belong to zone 1. Other Anchors determine their next anchors in the same way.

This procedure continues until the anchor nodes *O*, *T* and *M* find that *D* is in their *k*-hop vicinity routing tables. When *M* finds that *D* is in its *k*-hop vicinity routing table, it builds a segment to *D* within the corresponding sector.

In this way, the three node-disjoint routing paths from *S* to *D* can be built.

4.2. Route Maintenance

Local route maintenance and global route maintenance are proposed to maintain the routes. In the local route maintenance, the source records its next anchor and next-to-next anchor, and the destination records its previous anchor and previous-to-previous anchor. Each anchor in the routing paths records its next anchor, next-to-next anchor, previous anchor and previous-to-previous anchor.

When the movement of the source *S* results in its next anchor *A* moving out of its *k*-hop vicinity, the source *S* will select another node, which is in the same zone as *A* and is within the *k*-hop vicinity of both *S* and *A*, as its next anchor. Then *A* becomes the next anchor of the new anchor.

When an anchor *F* moves out of the *k*-hop vicinity of its previous anchor *C*, *C* will select a new anchor, which is in the same zone and within the *k*-hop vicinity of both *C* and *Q*, to replace *F*. *Q* becomes the next-to-next anchor of *C*.

When the movement of the destination *D* causes its previous anchor *M* to move out of its *k*-hop vicinity, *M* will choose another node whose *k*-hop vicinity contains the destination. This node will forward the packets to *D*.

If the M-Zone protocol uses local route maintenance for a long time, the path length may be greatly increased and the zone region may not be optimal. To resolve this problem, we use global route maintenance, which initializes route discovery periodically. Each node in the network maintains a *k*-hop vicinity routing table and the rediscovery time can be configured according to real situations.

5. Simulation Studies

We use C++ to simulate the M-Zone protocol in a rectangular area, where nodes are distributed uniformly. We forward packets through the path located in the zone that contains the source and destination, and when this path is broken, we switch to another backup path to forward packets. The transmission range *R* is 250m and Table 1 lists the simulation parameters.

Table 1: Simulated parameters

Region	Number of nodes	Maximum velocity	Pause time
1500m×1500m	300	10m/s	10s
4000m×4000m	2500	10m/s	10s

The following three performance metrics are used in the simulation.

Average path length: the average number of hops from the sources to the destinations.

Average packet delivery ratio: the number of packets received divided by the number of packets sent.

Relationship between zone width d and hop number k: Given *k*, it shows what value of *d* can make the average path length shortest.

Figure 4 shows the relationship between hop number *k* and zone width *d*. Generally, as *d* increases, *k* increases. We also see that at higher values of *k* e. g. *k*=4 and 5, the change in *d* is less than that at lower values and as the value of *N* increases the change in *d* at higher values of *k* increases. This means the larger *k* is, the less influence *k* has on *d*. For a given *k*, *d* decreases as the node-disjoint path number *N* increases. However, when *k* equals to 4 or 5, the zone width *d* for *N*=3 is larger than that of *N*=2. There are two reasons for this result, one is that different methods of zone division are used, and the other is that as *k* increases, the change in *d* decreases as *N* decreases.

GZRP can discover the best path (the shortest length) and both GZRP and M-Zone are location-based and discover routes segment-by-segment. The radius *k* plays an important role in the performance of GZRP and M-Zone. We carry out a performance study of GZRP and M-Zone and compare the average path length and the average packet delivery ratio.

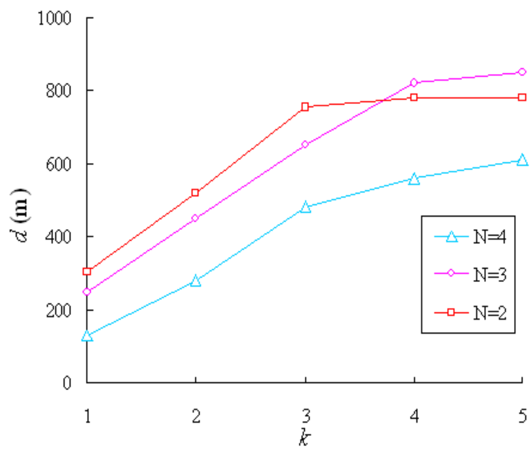

Figure 4. The relationship between *k* and *d*

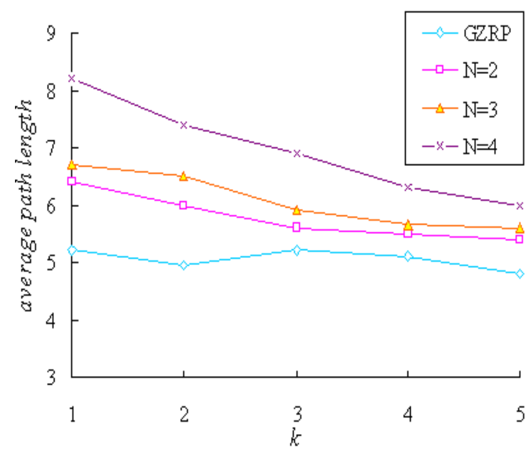

Figure 5. Average path length in region: 1500m×1500m

Figure 5 and Figure 6 present the results of average path length at two network sizes. When *k*=1, the average path length of M-Zone is longer than that of GZRP, especially for *N*=4. The average path length increases with an increase in the number of node-disjoint paths. The path length for *N*=2 is close to that for *N*=3 because of the different ways of dividing odd and even zones. As *k* increases, the average path length of M-Zone is closer to that of GZRP. The reason is that as *k* increases, the *k*-hop vicinity routing table maintains more nodes information so that much better routes can be provided.

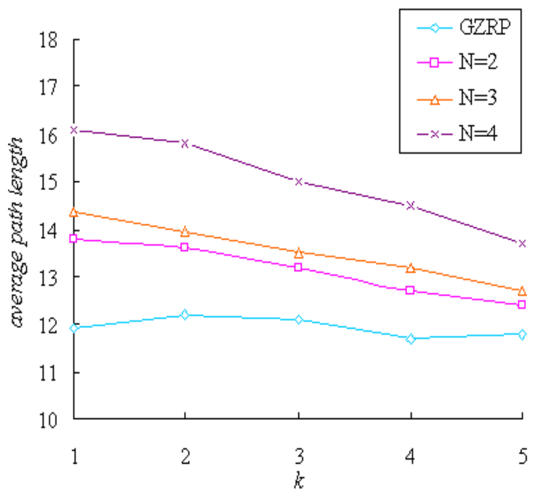

Figure 6. Average path length in region: 4000m×4000m

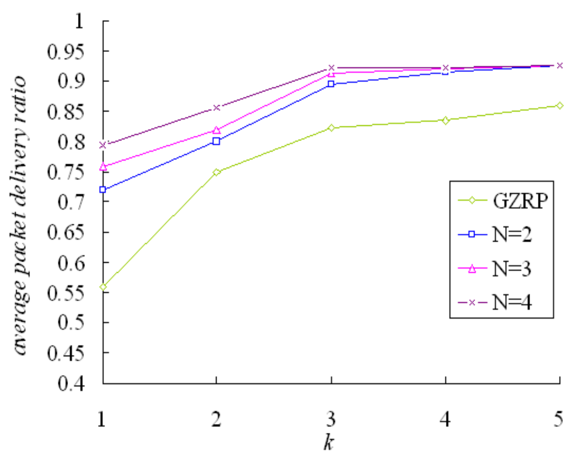

Figure 7. Average packet delivery ratio in region: 1500m×1500m

Figure 7 and Figure 8 show the results of average packet delivery ratio at two network sizes. M-Zone has a much higher average packet delivery ratio than that of GZRP. In M-Zone, the paths are node-disjoint, so when a routing path is broken, another effective node-disjoint routing path can be used to forward packets. The local maintenance used in M-Zone ensures that the broken path is repaired quickly and global route maintenance initializes route discovery periodically. These mechanisms guarantee a high average packet delivery ratio for the proposed M-Zone protocol.

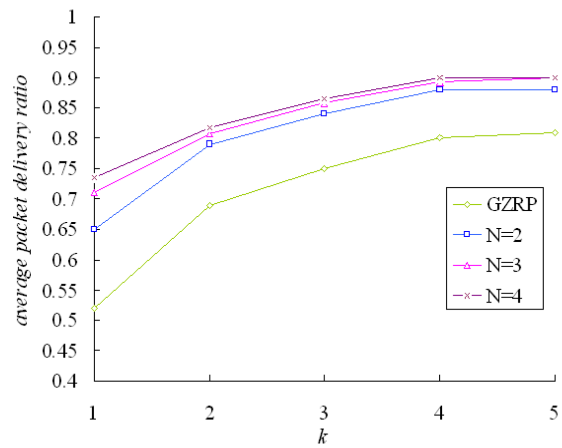

Figure 8. Average packet delivery ratio in region: 4000m×4000m

M-Zone has lower average packet delivery ratio in a network within area 4000m×4000m than that in a network within area 1500m×1500m, but it achieves nearly 90% packet delivery ratio in a network with area 4000m×4000m. Hence we can conclude that M-Zone has good performance in large scale MANETs.

6. Conclusions and Future Work

In this paper, we proposed an M-Zone routing protocol which uses a multiple zoning method to find node-disjoint multiple paths in MANETs. M-Zone combines the advantages of topology-based routing and location-based routing and can be used in large scale MANETs using segment-by-segment route discovery. We divide the region between the source and the destination into multiple zones to find node-disjoint multiple paths and use two route maintenance approaches to maintain the routes. Compared with GZRP, the average path length of M-Zone is close to that of GZRP and the average packet delivery ratio is improved significantly.

The proposed protocol works well when the nodes are uniformly distributed in the network with comparatively high density. When there are holes (voids) in the network, however, our protocol is not so adaptive. As our future work, we are trying to find better solutions to tackle this problem.

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