A Geographic Packet Forwarding Approach in 3D Mobile Ad Hoc Networks

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Abstract. In high dynamic 3D mobile ad hoc network, the mobility of node is the main factor that causes the topology change and the route instability. In this paper, we proposed a novel geographic forwarding approach based on node mobility features (FBMF) and selection of the relay node via distributed cooperation among receivers for highly dynamic 3D Ad hoc networks. Node mobility features are defined as the mobility factor which considers not only the individual node mobility but also the relative mobility of the other node. The proposed forwarding approach make use of node mobility features to select relay node. Simulation results show that compared with other methods, the proposed approach is more efficient in terms of packet delivery ratio and end-to-end delay, in other words, the stability of route is promoted in the highly dynamic mobile environment.

Keywords: 3D Ad hoc network · Geographic route · Greed forwarding
Random forwarding · Mobility factor

1 Introduction

In recent years, with the research and application of mobile Ad hoc networks, the application scenario has been extended from the traditional terrestrial 2D scene to the spatial 3D scene. Therefore, some new research areas have emerged, such as the Ad Hoc Network [8], UAV network [3], and underwater ad hoc network [2] and so on. The general characteristics of these networks are high-speed movement of nodes in 3D space, large-scale network distribution scenario and highly dynamic topology, which belong to 3D mobile Ad Hoc Networks (3D MANET). 3D MANET routing protocol is one of the important technologies to realize the out-of-sight transmission between network nodes, which has aroused the concern of researchers. The routing protocol based on geographical position information could realize the packet forwarding only by keeping the position information of the destination node. So the node does not maintain the end-to-end route, which is more suitable for such large-scale 3D MANET.

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References [1, 4, 5, 7, 9] proposed a variety of routing protocol for 3D MANET based on the position information. This kind of routing protocol adopts the greedy forwarding approach. However, when a candidate node closer than the current relay node to the destination does not exist, a routing hole problem of the greedy forwarding approach would happen, which could degrade the protocol performance. In [6, 10], a random forwarding approach based on position information is proposed, which uses the distance between the relay node and the destination node as the route metrics to select next-hop node set (CNS). In this approach, the broadcast characteristics of the channel were used to realize multiple potential relay nodes to compete and decide whether to become the relay node autonomously. It improves the performance of the protocol.

However, the forwarding approach in the above-mentioned protocol only considers the static characteristics of the nodes. When selecting the relay nodes, the neighbor nodes are usually selected nearest to the destination nodes. This usually causes the selected relay nodes to be located near the communication radius of the source node. In the highly dynamic network such as 3D MANET, when the above-mentioned forwarding approach is used, the mobility of the node will cause the link to be switched on and off frequently. In this kind of network, the distance between nodes couldn't fully reflect the path quality, that is, the stability of the route is also affected by the link duration (lifetime) between relay nodes. Node mobility will affect the establishment of reliable routing, and thus affect the reliability of packet delivery performance and delay performance.

In this paper, we propose a geographic forwarding approach based on mobility features of the nodes (FBMF). In the selection of relay nodes, the mobility of nodes is taken into full account. The position information and the stability factor which is the function of the mobility of nodes and their neighbors are used as the routing metric to provide the basis for the selection of relay nodes. Because the mobility characteristics of the node are fully considered in the process of relay node determining, compared with the other geographic forwarding approach, the performance (which main parameters are the packet delivery ratio and the end-to-end delay) of the proposed forwarding approach have improved. Finally, the simulation results prove this point.

2 Positioning Service and Forwarding Policy

In this section, we define notations and terms used throughout this article. Then the proposed geographic packet forwarding approach is presented. We assume that:

1. Each node knows its geographic position.
2. Each node knows the geographic position of all other nodes, including the target node.

We further assume that the geographic position of each node is unique. In general, the geographic position of the node can be obtained by GPS or any other positioning algorithms. The position information of neighbor nodes is distributed by the beacon exchange between each other. The positioning service is essential to accomplish packet forwarding in the proposed geographic routing protocol.

We need to get the position information of the destination node through position service on account of the node mobility. With a focus on the impact of node mobility on packet forwarding performance, this work assumes that each node has implemented position service.

The relay node selection scheme is shown in Fig. 1. The communication radius of all nodes in the network is R. That is, when the distance between two nodes is less than R, the two-way communication link can be established. When the distance is larger than R, the link is broken. The nodes are moving at constant speed V. The direction of the node is unchanged during the move; The movement speed and direction of nodes are independent of each other.

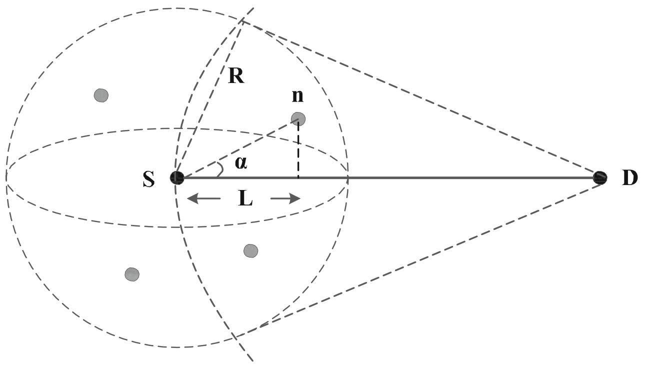

Fig. 1. Illustrations of the scheme used to select neighbors as forwarders

As shown in Fig. 1, P_s is the position information of the source node S, which is represented as (x_s, y_s, z_s). The position information of the destination node D is P_d, which is represented as (x_d, y_d, z_d). N is defined as the neighbor nodes set of source node, which is represented as $N = \{n_1, n_2, \ldots, n_m\}$.

N' is defined as candidate next-hop node set

$$N' = \{n_i : L_{min} \leq L_i \leq R\}, \tag{1}$$

and $N' \subset N$. L_{min} is defined as the minimum advance value, which is the condition to select the relay node set. L_i is the distance from the source node S to the destination node D when the node n_i is chosen as the relay node, which is represented as

$$L_i = \sqrt{(x_s - x_{n_i})^2 + (y_s - y_{n_i})^2 + (z_s - z_{n_i})^2} \cdot \cos\alpha. \tag{2}$$

In order to avoid repeating forward, the candidate next hop nodes that received a packet wait for a back-off time before forwarding the packet. $T_f^{n_i}$ is the back-off time of node n_i, which is computed on the position of node n_i, source node position, destination node position and the metrics M_{n_i}, following Eq. (3)

$$T_f^{n_i} = k \cdot \max_{n_i \in N'} \left\{ \frac{1}{d(P_s, P_d) - d(P_{n_i}, P_d)} - \frac{1}{d(P_{n_i}, P_s)} \right\} \cdot M_{n_i}. \tag{3}$$

The triangle inequality asserts that candidate next-hop nodes could hear packet forwarding each other. The metrics M_{n_i} is determined by the stability factor and the distance information. The short back-off time should mean good position advancement and high relatively stable.

FBMF Forwarding Process

- The source node S selects the candidate next-hop node set N', according to the position information P_d of the destination node D.
- Sending the packet to the candidate next-hop node set, which includes the *ID* of the source node *S*, the *ID* of the destination node *D*, the position information and the speed information.
- The node that received the packet calculates the back-off time according to the position information and the metrics in the received packet. Equation (3) shows that the shorter the back-off time, the higher the probability that the node will be selected as the relay node, which could cooperate with the other relay nodes to decide the forwarding order/priority. The metrics information is determined by the stability factor and the distance information, the calculation method of metrics information is shown in the following section.

In this forwarding approach, when the candidate relay node receives the packet, it sends it in the order of the back-off time. Obviously, a node with a short back-off time has high priority than a node with a long back-off time. After the other candidate relay node has heard the packet has been forwarded, it discards the local corresponding packet. When the candidate relay node does not detect that the packet is forwarded within a certain period of time, it thinks the packet fails to be forwarded, and then forwards the packet automatically. Therefore, this method does not require message loss recovery mechanism. Compared to the greedy forwarding strategy, it could reduce the feedback information. On the other hand, this method is easier to extend than the GeRaF approach [10], which is based on the handshake mechanism of MAC protocol to cooperative between the candidate relay nodes' order/priority.

3 Calculation of Metrics

The selection of the candidate next-hop node set is the key factor which would affect the performance of the forwarding protocol. The node based on GeRaF [10] measures the geographical distance, and it only needs to know the position of neighboring nodes and the destination node. It uses the distance from each neighbor to the destination node as a measure to select the set of relay nodes. The proposed method uses a static factor *S* and distance parameter *L* as the standard of metrics *M* calculation. The great value of the node-static factors and the close to the destination node would mean the node is in the high the forwarding priority, and the node is more likely to be selected as a relay node. The metrics *M* takes into account the mobility of the nodes and the group mobility of their neighbors (represented by the static factor S), and the distance parameter L_d, which is a function of both. The following is a detailed calculation process.

3.1 Static Factor

The three velocity components of a node n_i in the relay node set N' are v_{ix}, v_{iy}, v_{iz}, respectively.

The different between the average speed of the node n_i and the average speed of the source node S are

$$\Delta v_{2i} = \sqrt{(v_{ix} - v_{sx})^2 + (v_{iy} - v_{sy})^2 + (v_{iz} - v_{sz})^2} \tag{4}$$

The average velocity components of the group of neighbor nodes of node n_i are v_x, v_y, v_z, respectively.

And

$$v_x = \frac{1}{m}\sum_{i \in I} v_{ix}, v_y = \frac{1}{m}\sum_{i \in I} v_{iy}, v_z = \frac{1}{m}\sum_{i \in I} v_{iz},$$

where I is the neighbor nodes set of node n_i, and m is the number of the neighbor nodes.

The difference between the average speed of the node n_i and the neighbor group is

$$\Delta v_{1i} = \sqrt{(v_{ix} - v_x)^2 + (v_{iy} - v_y)^2 + (v_{iz} - v_z)^2} \tag{5}$$

The static factor S_i is defined as follows

$$S_i = \frac{\Delta v_{1i} + \Delta v_{2i}}{2|V|} \tag{6}$$

It represents the relative motion stability of a single node n_i relative to the source node and its neighbor node set.

From the Eq. (6), the small the relative speed of the source node, and the small the dynamics of the whole neighbor group, would mean the node n_i is relatively stable.

3.2 Calculation of Routing Metrics

The metrics M_i of the node n_i takes into account the static factor S_i and the distance parameter L_{d_i}.

The formula is:

$$M_{n_i} = (S_i + 1)^{L''_{di}} \tag{7}$$

L''_{d_i} is the normalized distance, which is defined as:

$$L''_{d_i} = \frac{L_{d_i}}{L_{sd} - L_{min}} \tag{8}$$

The influence of the static factor S and the distance parameter L_d on the metrics parameters is shown in Fig. 2. As it can be seen from Fig. 2, the great the static factor S and the great the distance result to the great the metrics. According to Eq. (3) the node has the longer back-off time, which would have the lower forwarding priority. Since node only calculates their own metrics *M*, it may determine the forwarding order/priority in a distributed manner.

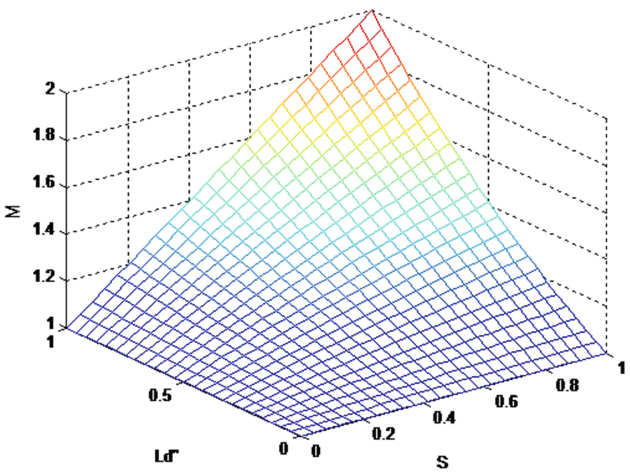

Fig. 2. Influence of S and L''_{d_i} on M

From the calculation process of the metric *M*, the algorithm actually weighs the mobility and position characteristics of the nodes and chooses the node with low mobility and near to the destination node as the relay nodes.

4 Simulation Results

Comparison of three methods of 3D Greedy forwarding (3DGF), 3D random forwarding (3DRAF) and the forwarding approach based on mobility features (FBMF) proposed in this paper are carried out. The simulation environment is as follows: 50 nodes are randomly distributed in the $\sqrt{L^2 + H^2/2} \times \sqrt{L^2 + H^2/2}$ 3D space. L is the maximum length and width of the node distribution range, the value is 15 km. H is the maximum height of the node distribution range, the value is 10 km. The node's velocity component is given by $(-V, +V)$, and V is the maximum velocity of the node movement. After the node reaches the boundary of the region, it returned to the simulation area at the original speed. The bounce angle is randomly selected between $[0, 2\pi]$. Since 3DRAF forwards based strategy of RTS/CTS, the simulation using the

IEEE 802.11 MAC protocols, the data transfer rate is 2 Mbit/s. Traffic model is the continuous bit rate (CBR), traffic packet length is 1024 bits, packet interval is 0.1 s. Each source node randomly selects the nodes in the simulation region as the destination node.

Figure 3 shows the results of the packet delivery ratio of three forwarding approaches under different moving speeds. When the node speed is 0, the network is a static, and the packet delivery ratio of the three methods is all higher than 85%. Due that 3DRAF and FBMF methods take into account the broadcast characteristics of the wireless channel and adopt the relay node cooperation mechanism, they achieved higher packet delivery ratio than 3DGF method. With the increase of the node's moving speeds, the dynamic of the network increases gradually, then the packet delivery ratio of 3DGF and 3DRAF decreases obviously. However, FBMF considers the mobility of the nodes in the selection of relay nodes, the node with low relative mobility (high stability) is selected as the relay node, thus maintaining a stable high packet delivery ratio.

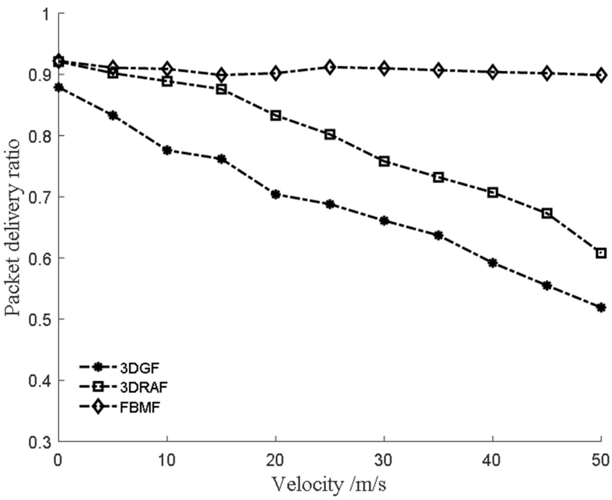

Fig. 3. Packet delivery ratio

Figure 4 shows the comparison of average end-to-end delay. Since FBMF chooses a node that is close to the destination node and with a smaller relative mobility (high stability) as the next-hop forwarding node, it reduces the possibility of routing holes (no next-hop nodes) which would increase the number of forwarding. Therefore, under dynamic network conditions compared to the other two forwarding approaches to get a lower average end to end delay.

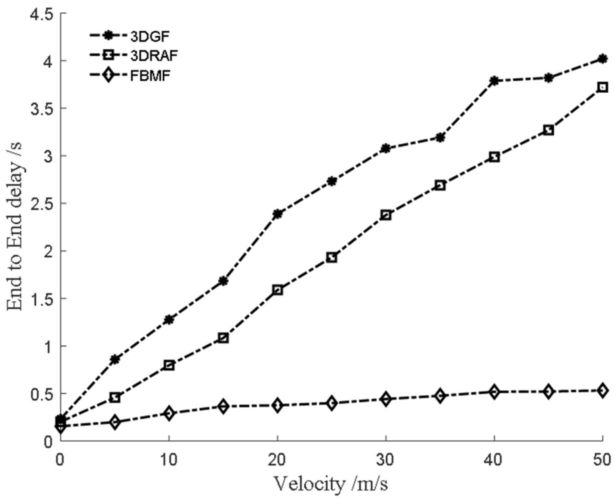

Fig. 4. End to end delay

5 Conclusions

In high dynamic 3D mobile ad hoc network, the mobility of node is the main factor that causes the topology change and affects the route stability. Therefore, taking node mobility into consideration in the process of relay node selection and path maintenance can improve the performance of routing algorithm. In this paper, we proposed a routing metrics based on node mobility, then presented a forwarding strategy make use of the routing metrics. The simulation results show that the packet delivery and end-to-end delay are better than the other two types of forwarding approaches when the node moves at high speed. Therefore, the performance of this approach under high dynamic conditions has obvious advantages.

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