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A New Method of Mobile Ad Hoc Network Routing Based on Greed Forwarding Improvement Strategy

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ABSTRACT In resource-constrained mobile ad hoc network, geographical routing algorithms are relatively attractive routing algorithms. Due to the movement of nodes, energy exhaustion and the presence of obstacles, routing holes may occur. The existing routing algorithm only considers bypassing routing void through right-hand or left-hand criteria, and forwards data at the boundary of the hole. However, such a routing algorithm may lead to the expansion of the routing hole and even cause the paralysis of the network. This paper proposes a new greedy forwarding improvement routing method for mobile ad hoc network. In the greedy forwarding phase, the reliable communication area is calculated, and then the quality of the link is evaluated according to the relative displacement between the nodes and the maintenance time of the link. Then, according to the quality of the link, the distance between the candidate node and the destination node, and the number of the neighbor nodes, the metric value is obtained, and the node with the large metric value is selected as the next hop. When a routing hole occurs, the waiting forwarding mode is used for a period of time. After a period of time, when the current node is still a routing hole node, we can use the right-hand rule and the left-hand criteria, and the bypass mode is performed simultaneously. By considering three factors of the deflection angle and the maintenance time of the link and the remaining energy of the node, the forwarding node as the next hop with the highest priority value is selected in each direction. The experimental results show that compared with the existing GPSR,EMGR and EDGR, the proposed algorithm reduces the energy consumption of the network, improves the delivery rate of data packets, reduces the network delay and prolongs the network lifetime.

INDEX TERMS Mobile ad hoc network, greedy forwarding, bypass mode, link quality, energy consumption.

I. INTRODUCTION

Mobile Ad hoc Network (MANET) is widely used in military battlefields, traffic control, environmental monitoring, disaster relief, and smart cities, making routing protocols become the current research hotspot. The quality of the routing protocol determines the performance of the entire network [1]–[4]. Mobile ad hoc network is a self-created, self-organized and self-managed network composed of a group of wireless nodes or terminals. It does not need fixed infrastructure and uses distributed management,its sensor nodes communicate through the wireless structure. However, the node resources are limited, the storage capacity is limited, the nodes move frequently, and the network has no center, which makes the data access complicated. Therefor,mobile self-organization communication in the network is usually

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implemented in a hop-by-hop manner based on a distributed routing protocol. These features pose a great challenge to routing design [5]–[8].

In MANET, when the battery is exhausted, the link is broken, and the limited battery capacity of a mobile node affects network lifetime. Therefore, routing protocols that consider the energy of mobile nodes are critical to ensuring network connectivity and extending the lifetime of the network [9]–[11]. In MANET, the moving direction of the nodes is random, and the movement of the nodes may cause the link to be disconnected. Therefore, when the forwarding node is selected, the moving direction of the node is also an important parameter [13]–[15].

With the rapid development of positioning technology, mobile nodes can accurately obtain their own location information through technologies such as Global Positioning System (GPS). Therefore, geographical location based routing protocols have emerged [16]–[18]. The geographical location protocol uses the geographical location information as the main basis for routing, and sends the data packet from the source node to the destination node according to a certain forwarding policy. Greedy Perimeter Stateless Routing (GPSR) is a location-based routing algorithm [19], which uses greedy forwarding strategies to establish routes. If the source node requests the transfer of data, the next hop can be selected from the node closest to the destination node in its neighbor nodes, and then the neighbor node accepts the data packet, and the process is repeated until the data packet reach the destination node. The existing routing protocol only considers the distance of the destination node, which leads to the local minimum phenomenon easily. That is, the forwarding process stops at the hole boundary. Due to the movement of nodes, the exhaustion of node energy, and the existence of obstacles, routing holes exist. Energy holes refer to nodes in a space that are not closer to the destination node [20]–[22]. Based on GPSR, we propose a new routing method for mobile ad hoc network based on greedy forwarding improvement strategy.

The remainder of the paper is organized as follows: Section 2 introduces the related work; Section 3 introduces a new method of mobile ad hoc network routing based on greedy forwarding improvement strategy; We give the simulation results and comparison in Section 4; We make a summary and present the future work in Section 5.

II. RELATED WORKS

GPSR routing algorithm begins with a greedy mode typically, so node selects the next hop from the neighbor node closest to the destination. In the network without routing holes, the performance of geographic routing is good. Due to routing holes exist, this routing algorithm has a serious shortcoming. No adjacent node is closer to the target than the current node. Traditional approach turns off the usual greedy forwarding mode and tries to forward routing packets along the boundaries of the hole. But, this method may result in a high flow load on the nodes around the holes and expand the length of the routing path when has many holes [23].

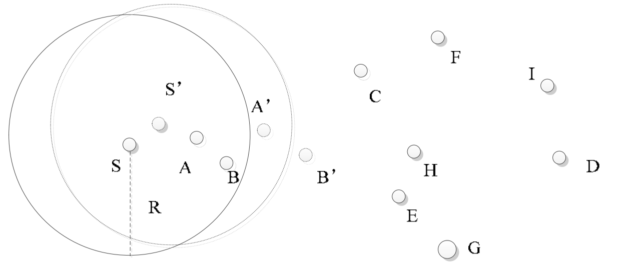

FIGURE 1. **The topology of moving nodes.**

The next hop is always selected from the neighbor node closest to the destination in GPSR. However, the node selected for the next hop is generally located at the edge of the communication range. Due to the rapid movement of the node, the location of the neighbor node changes rapidly, which may cause the next node to move out of the communication range of the current node before receiving the packet of the current node [24], [25]. In Figure 1, we use S to represent the current node and D to represent the destination node, and the node B is the node closest to D among the neighbor nodes of S. As the node moves, node S moves to the S' position, node B moves to the B' position, node A moves to the A' position, and in greedy forwarding, when B is selected as the next node, B has moved out of the communication range of S and reached position B'. So Node B cannot accept the packet. Eventually, the packet is re-transmitted or lost, which reduces the performance of the entire network.

In the existing research, Huang *et al.* [26] proposed an energy-aware dual-path geographic routing protocol(EDGR), which uses the nodes' location information, residual energy and energy consumption characteristics for routing decisions. EDGR uses two anchors that do not intersect with each other to achieve load balancing. Hu *et al.* [27] proposed an energy-aware multipath geographic routing protocol(EMGR). EMGR selects the next forwarding node according to geographic information, energy consumption characteristics, and uses a dynamic anchor list to transfer for load balancing. Yang *et al.* [28] proposed the max duration-minangle GPSR (MM-GPSR) routing protocol. In greedy forwarding [17], [29]–[34] of MM-GPSR, the stability of the node and the selection of the next hop node are determined according to the cumulative communication duration. If greedy forwarding fails, MM-GPSR will select the optimal next hop node by introducing the concept of minimum angle. Sun *et al.* [29] proposed a greedy perimeter stateless routing protocol (SU-GPSR) for WSN. The combination [35]–[39] of acceleration mode and greedy mode provides a scheme for data transmission in WSN. Select the potential next hop based on energy consumption.

In the existing research, most of the existing studies [7], [40]–[45] only consider the node's location information and the residual energy of the node, without considering the quality of the link.

III. DESCRIPTION OF THE ALGORITHM

In this paper, we propose a new mobile ad hoc network routing method based on greedy forwarding improvement strategy based on GPSR.

A. MODEL ESTABLISHMENT

1) NETWORK MODEL

Assuming that any two nodes are in different geographic locations, and all nodes are subject to a Poisson distribution at the initial location in the network. The moving direction of each node is arbitrary, and the node's location information can be got through its own GPS device. The node can also get the location information and energy information of the neighbor node by exchanging the beacon data packet. With the specific destination location service, the source node S gets the destination location. The node's location can be used as its ID and network address. Therefore, a separate ID setup protocol is not required. We only consider bidirectional links and assume that each sensor node can adjust its transmit power from 0 to its maximum transmit power.

2) ENERGY MODEL

The energy consumption of the node p transmitting a bit of data to the neighbor q consists of three parts. Let $Energy\quad(p, q)$ denote the energy consumption and $Energy\ \ (p, q)$ can be expressed as

$$Energy(p, q) = a \times (d_q^p)^{\mu} + b + c \times (d_q^p)^2 \tag{1}$$

where d_q^p is the distance between node p and node q. Because nodes periodically broadcast beacon packets, according to the following formula, the distance between nodes can be obtained

$$d_q^p = \sqrt{(x - x_q)^2 + (y\text{-}y_q)^2} \tag{2}$$

where (x, y) represents the location of the node p transmitting the beacon packet, and (x_q, y_q) represents the location of the one-hop neighbor node q of the transmitting node. μ represents the path loss constant, which varies from 2 to 5 according to the transmission environment. The constants a, b and c are related not only to the electronic characteristics but also to the characteristics of the wireless device. $a \times (d_q^p)^{\mu}$ is the path loss from nodes p to q, b represents the energy that is consumed by nodes p and q in processing the signal, and $c \times (d_q^p)^2$ is the energy that the node uses for reception within the transmission range of the sender. Suppose a, b, and c are the same for each sensor node. In this paper, we set the energy parameters to $\mu = 2$, $a = 100pJ/bit/m^{\mu}$, $b = 100nJ/bit$, and $c = 60pJ/bit/m^2$.

B. GREEDY FORWARDING STRATEGY

The traditional greedy forwarding strategy only considers the distance between the node and the destination node. In this paper, the improved greedy forwarding strategy handles the unsteadiness of the neighbor relationship by considering the following four parameters: neighbor node degree, link quality, distance, and reliable communication area.

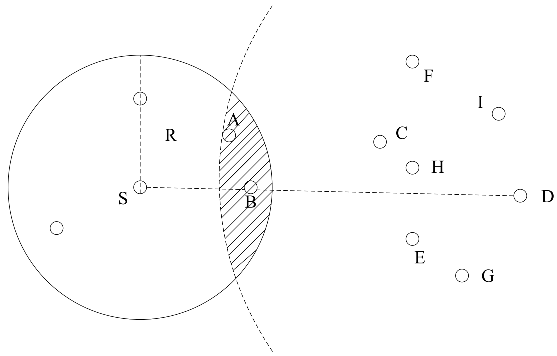

FIGURE 2. Schematic diagram of the reliable communication area.

1) RELIABLE COMMUNICATION AREA

As shown in Figure 2, for example, S, A, B, E, and C represent mobile nodes, and D represents a destination node. When S attempts to transmit a data packet to D, S will select the mobile node closest to the destination node from the neighboring neighbor nodes. The closest node to the destination node D is B. According to the distance between B and D, the maximum allowable hop distance is calculated. The communication stability between the neighbor nodes of S and S is evaluated by comparing the above several parameters, and we can get the most stable next hop node.

In Figure 2, S sends a data packet to D, (x_S, y_S) and (x_D, y_D) represent the coordinates of S and D. When a packet is sent in greedy mode, the source node S finds the node closest to D in its own neighbor list, and the nearest node is B with coordinates (x_B, y_B). We can obtain the d_{BD} from B to D and d_{BS} from B to S:

$$d_{BD} = \sqrt{(x_D - x_B)^2 + (y_D - y_B)^2} \tag{3}$$

$$d_{BS} = \sqrt{(x_S - x_B)^2 + (y_S - y_B)^2} \tag{4}$$

The overlapping region of two circles with D as the center, $d_{\max}$ as the radius, and S as the center, and the maximum communication distance R as the radius is a reliable communication area, and the shaded part represents a reliable communication area named RCA. The nodes in RCA are all within the communication range of node S and close to destination node D, so they can be selected as candidate nodes for next hop of S. $d_{\max}$ is calculated as follows:

$$d_{\max} = d_{BD} + \lambda \times d_{BS} \tag{5}$$

In equation (5), $\lambda \in [0, 1]$. It is easy to see that the size of the RCA is affected by λ. When λ approaches 1, the RCA will also increase, and the next hop in the RCA will be easier to select the node near S, however, the number of hops from the node to D may increase. When λ approaches 0, the RCA will also decrease, then the next hop will be easier to select the node near D, the distance between S and the node becomes longer, and the stability of link may be deteriorated, resulting in an increase in packet loss rate. By performing multiple experiments, when λ is set to 0.3, it has better performance in greedy mode.

2) LINK QUALITY ASSESSMENT

Because of the movement of the nodes, the network topology changes, which affects the stability of the link. The link stability between nodes is measured by the relative displacement variation between nodes. The relative displacement $L_{displacement}$ between the nodes is calculated as follows:

$$L_{displacement} = 1 - \frac{|d_i(t) - d_i(t-1)|}{R} \tag{6}$$

where R is the transmission radius of the mobile node. $d_i(t)$ is the distance from the node transmitting the beacon packet to the neighbor node i at time t. By considering the relative displacement between nodes, the smaller the $d_i(t)$, the better the link stability.

Due to the speed of the node and the direction of the movement will cause changes in the link topology, and the originally connected link is broken easily when the data packet is sent. Therefore, the link maintenance time is also an important factor. The node receives the beacon packet sent by the neighbor node. At this time, the link maintenance time T_i between the node and the node i is calculated as follows:

$$R^2 = ((x_i + v \times T_i) - x)^2 + ((y_i + v \times T_i) - y)^2 \tag{7}$$

where (x, y) is the location of the node transmitting the beacon packet, and (x_i, y_i) is the location of the one-hop neighbor node i of the transmitting node. R is the communication radius of the node, v is the relative speed of the two nodes, and v can be calculated as follows:

$$v = v_i - v_s \tag{8}$$

v_i represents the neighbor node's speed, and v_s represents the speed of the node that sent the beacon packet.

Therefore, we use the above mentioned relative displacement between nodes and the maintenance time of the link, the quality of the one-hop link can be obtained. Let $L_{quality}$ denote the quality of the one-hop link and we can express it by the following formula:

$$L_{quality} = \omega \times \frac{1}{L_{displacement}} + (1 - \omega) \times T_i \tag{9}$$

where ω is the weighting factor, $L_{displacement}$ is the relative displacement between the nodes, and T_i is the link maintenance time between the two nodes.

3) DISTANCE AND NEIGHBOR NODE EVALUATION

In the energy model, it can be known that the energy consumed in transmitting the data packets depends on the distance of destination node. Therefore, if the next hop node to be selected is a reliable and high quality of node, the distance of destination node should be fully considered when designing the forwarding strategy. The distance indicator between nodes is calculated as follows:

$$dis\tan ce(s, i) = \frac{d_D^S - d_D^i}{R} \tag{10}$$

where d_D^S represents the distance between the sending node and the destination node, and d_D^i represents the distance between the neighboring node i and the destination node.

In the greedy forwarding process, the quantity of neighbor nodes of the next hop node is also a crucial factor. If not considered, it may cause the next hop of the selected next hop node to have no suitable selection, resulting in a decline overall network performance. Therefore, we define the neighbor node degree to measure the next hop node. We use d_D^i to indicate the neighbor degree of the ith node, and can be calculated as follows:

$$\rho_{num}^i = \frac{n_i}{N} \tag{11}$$

where n_i is the quantity of neighbor nodes of the ith alternate node, and N represents the number of nodes from the source node to the destination node.

4) GREEDY FORWARDING NODE SELECTION STRATEGY

When greedy forwarding chooses the next hop node, only the distance between the next hop node and the destination node is considered, which may cause the link between the selected next hop to be unstable and affect the performance of the network. Therefore, when we choose the next hop node in greedy forwarding, we consider three performance indicators of link quality, node distance and neighbor node degree in the reliable communication area. It can not only increase the delivery rate of data packets, but also reduce the transmission delay.

In this paper, we define Pri as a measure to measure the choice of the next hop greedy forwarding node. In the reliable communication area, the node with the largest Pri value is the next hop forwarding node, which can be got from formula 12.

$$\Pr i = \begin{cases} A, & dis\tan ce(s, i) > 0 \\ 0, & dis\tan ce(s, i) \leq 0 \end{cases} \tag{12}$$

where $A = \alpha \times \rho_{num}^i + \beta \times L_{quality} + \gamma \times dis\tan ce(s, i)$ and ρ_{num}^i is the neighbor node degree of the ith node, which can be obtained by exchanging beacon data packets, $L_{quality}$ is the link quality of the one-hop node, and $dis\tan ce(s, i)$ represents the distance from the sending node to the neighboring node. At the same time, $\alpha + \beta + \gamma = 1$.

The weights of these three indexes are estimated by Analytic Network Process(ANP). ANP was formally proposed by the US operational research scientist T.L.Saaty in the middle of 1970s. ANP divides system elements into two parts: the first part is called the control layer element, which includes the objective of the problem and the criteria of decision-making. All decision criteria are dominated by the target elements, in which the control layer elements can have no decision criteria, but at least one goal. The goal of this paper is to find the best next hop forwarding node. The criteria for decision-making are good link stability, low energy consumption and data delivery rate. The weight of each criterion can be obtained by using the traditional AHP method. The second part is the network layer. It is composed of all elements dominated by the control layer. The elements are interdependent and interdependent. The elements and levels are not independent. Each criterion of hierarchical structure dominates not a simple internal independent element, but a network structure of interdependence and feedback. Control layer and network layer constitute a typical ANP hierarchy.

The principle of ANP is to compare the elements in the network layer according to their influence, that is, to construct a judgment matrix under the criteria. According to the results obtained, a comparison matrix is constructed and its consistency is checked. The local weight vector matrix Wij of elements and element sets can be obtained by calculating the eigenvectors of the comparison matrix. For the established judgment matrix, vector $\alpha = (\alpha_1, \alpha_2 \ldots \alpha_i)^{\mathrm{T}}$ is obtained by summing up the elements in each matrix, and the unweighted hypermatrix is obtained by summing up each vector:

$$\alpha_{\mathrm{i}} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \ldots & \alpha_{1i} \\ \alpha_{21} & \alpha_{22} & \ldots & \alpha_{2i} \\ \ldots & \ldots & \ldots & \ldots \\ \alpha_{i1} & \alpha_{i2} & \ldots & \alpha_{ii} \end{bmatrix}$$

Then normalize every vector in the unweighted hypermatrix,define $\omega_i = \alpha_i / \sum_{i=1}^{m} \alpha_i$, where α_{i} is the vector value of the corresponding element, $\sum_{i=1}^{m} \alpha_i$ is the sum of M vectors, and the eigenvector corresponding to the maximum eigenvalue obtained is $\omega = (\omega_1, \omega_2 \ldots \omega_i)^{\mathrm{T}}$:

$$\omega_{\mathrm{i}} = \begin{bmatrix} \omega_{11} & \omega_{12} & \ldots & \omega_{1i} \\ \omega_{21} & \omega_{22} & \ldots & \omega_{2i} \\ \ldots & \ldots & \ldots & \ldots \\ \omega_{i1} & \omega_{i2} & \ldots & \omega_{ii} \end{bmatrix}$$

Then, on the basis of weighted hypermatrix, the stability of weighted hypermatrix is treated by formula $\lim_{m\to\infty} (1/m) \sum_{i=1}^{m} \omega i$.That is, the matrix multiplies itself until it reaches a stable state. Finally, the weights can be obtained by normalizing the values. In this paper, we adopt the super decision software to solve the problem. What is the convenience of the software to solve the complex ANP network, and the results are more intuitive.The weights used in this paper are 0.301, 0.587 and 0.112, respectively.

When $\Pr i > 0$, in the reliable communication area, the forwarding node of the next hop is selected; when $\Pr i \leq 0$, the routing hole is considered to exist. Considering the randomness of the mobile node, the network topology is constantly changing. Therefore, the wait forwarding mode is adopted.

C. BOUNDARY FORWARDING STRATEGY

The traditional GPSR algorithm uses the right-hand rule and adopts bypassing mode. Although routing holes can be bypassed, the path is usually not optimal. We believe that it is not enough to consider the distance factor. Here, we consider the angle factor, node's remaining energy, and the duration of the link.

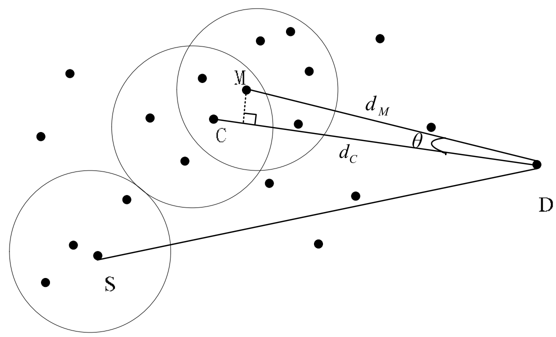

FIGURE 3. Angle diagram.

1) GREEDY FORWARDING NODE SELECTION STRATEGY

Different from the traditional GPSR, we adopt the right-hand rule and the left-hand rule to bypass the route hole from two directions. Taking the right-hand rule as an example, after entering the bypass forwarding mode, calculate the angle θ between the current node C and the candidate node, assuming that the coordinates of the node C is (x_C, y_C), the coordinates of the candidate node M is (x_M, y_M), and the coordinates of the node D is (x_D, y_D). As shown in Figure 3, the distance of the node M to the CD is represented by $d_{M\to CD}$ and can be expressed as follows:

$$d_{M\to CD} = \frac{\left|(x_C - x_M)y_D + (y_M - y_C)x_D + x_M y_C - x_C y_M\right|}{\sqrt{(y_M - y_C)^2 + (x_C - x_M)^2}} \tag{13}$$

Therefore, we can get

$$\theta = \arcsin(\frac{d_{M\to CD}}{d_M}) \tag{14}$$

2) RESIDUAL ENERGY LEVEL ASSESSMENT

Due to the node with low energy is selected, it may cause the node to run out of energy, causing the size of the routing hole to increase. We also consider the node's remaining energy and try to select the node with high residual energy for forwarding. Let E_{level} represent the energy level and it can be calculated as follows:

$$E_{level} = \frac{E_{residual}}{E_{init}} \tag{15}$$

where $E_{residual}$ represents the current remaining energy and E_{init} represents the initial energy of the node.

3) BOUNDARY FORWARDING NODE SELECTION STRATEGY

When the bypass forwarding mode is used, the priority value AEL of all candidate nodes are calculated and compared. The current node chooses the next hop node that has the largest AEL, and the formula of AEL is as follows:

$$AEL = p \times \frac{\theta}{2\pi} + q \times E_{level} + f \times L_{quality} \tag{16}$$

In equation (16), p, q, and f are the bypass mode weighting coefficients of the angle factor, the residual energy level, and the link quality factor, respectively, and $p+q+f=1$, $L_{quality}$ is the same as equation (9). In this paper, $p=q=f=1/3$, according to the method proposed in this paper, selecting the next hop node with large deflection angle can increase the probability of jumping out of routing holes, avoiding increasing the size of routing holes, selecting nodes with high relative energy and relatively stable link, which can improve the survival time of the entire network.

When a route hole is encountered, both the right-hand rule and the left-hand rule are taken, and two paths from the routing hole node to the destination node are found.

D. DESCRIPTION OF THE ALGORITHM

The GFR(Routing Based on Greed Forwarding) protocol adds a mechanism based on the energy level, link quality, forwarding angle and neighbor node degree based on the GSPR protocol.

Algorithm: The steps of GFR are described as follows:

Step 1: The location and residual energy of the neighbor node are obtained by transmitting the beacon packet. If the source node has a request to send data, check whether there is a destination node in its neighbor node firstly. If there is a destination node in the neighbor node, the data is sent to the destination node directly. Otherwise, the second step is performed.

Step 2: According to formula (5), the transmitting node calculates the value of $d_{\max}$ to obtain a reliable communication area, and then all the reliable nodes in the reliable communication area are the next hop nodes. At this time, the relative displacement between the nodes and the link maintenance time are calculated. According to formula (9), the quality of the link is evaluated. Then, according to formula (13), the distance between the candidate node and the destination node and the neighbor node degree, the value of *PRI* is obtained, and the node with large *PRI* value is selected as the next hop node. When there is no larger *PRI* value than the current node, we believe that a routing hole has occurred.

Step 3: When a routing hole occurs, we use the wait forwarding mode to set a MAX_WaitTime. After this time, if the current node is still a routing hole node, the right-hand rule and the left-hand rule are used to perform bypass mode simultaneously.

Step 4: According to equation (14), calculate the deflection angle, and then calculate the *AEL* value by considering the node's remaining energy and the maintenance time of the link. In each direction, select the neighboring forwarding node with the large *AEL* value as the next hop until there is a node that is better than the routing hole node, and then convert it into the greedy mode or up to the destination node.

Step 5: When data transmission is performed, a path with a long link lifetime and high residual energy is selected for data transmission.

The pseudo code for the algorithm (Mobile Ad Hoc Network Routing Based on Greed Forwarding Improvement Strategy) is as follows:

```
initialize E_init, λ, N, Source Node S and Destination
        node D
do
  If the node encounters a routing hole
    do
        Update θ according to formula (14)
        Update E_level according to formula (15)
        Update AEL according to formula (16)
    while there is a node closer to D
  else
    do
        Update and according to
          formula (6) and (7)
        Update according to formula (9)
        Update and according to
          formula (10) and (11)
        Update Pri according to formula (12)
    while there are no nodes closer to D
    Select the next hop according to AEL or Pri
while arrived at D
```

Theorem 1: The path formed by GFR is no loop.

Proof: In the greedy forwarding strategy, each next hop node selected is in the reliable communication area, so that it is closer to the destination node than the last hop node, so no fallback is generated to the source node. Therefore, there is no loop. In the bypass mode, the routing hole is bypassed, and the left-hand rule and the right-hand rule are used for forwarding on both sides, and the angle of the deflection is considered, and the path is not rolled back. Therefore, the path formed by the GFR is route free.

E. THEORETICAL ANALYSIS OF THE COMPLEXITY OF THE ALGORITHM

In this part, we analyze the complexity of the GFR and explain it from two aspects: time complexity and space complexity.

Theorem 2: GFR algorithm's time complexity is $O(n)$.

Proof: GFR algorithm's time complexity is mainly decided by the path established by greedy strategy and the path established by right-hand rule and left-hand rule. Routing is the basic operation of N nodes in the whole network. The worst case is that each remaining node in the network is utilized from the source node to the destination node, so the worst time complexity is $O(n)$. In the greedy mode, several parameters between the candidate node and the node are calculated, assuming that the time complexity of this process is $O(n_1)$. In the bypass forwarding strategy, the right-hand rule and the left-hand rule are used to forward the boundaries of nodes encountering routing holes. n_2 and n_3 are used to represent the number of intermediate forwarding nodes. Let $n=n_1+n_2+n_3$, so the time complexity of the GFR algorithm is $O(n)$.

Theorem 3: GFR algorithm's space complexity is $O(n^2)$.

Proof: In the large sparse mobile ad hoc network, the frequent movement of nodes will generate the link and link disconnection continually. Thus, it is more appropriate to use the adjacency matrix of the graph to represent nodes. Each node in this protocol stores the information and routing of neighbor nodes, thus $O(n^2)$ is the space complexity.

IV. PERFORMANCE EVALUATION

A. TEST ENVIRONMENT AND PARAMETER SETTINGS

In this part, we use NS-2.35 platform for simulation experiments, and analyze the protocol proposed in this paper. The GFR is compared with the classic GPSR protocol and the proposed EMGR and EDGR algorithms. In Table 1, we give the simulation parameters. The simulation time for each experiment was 500s, and the simulation results were averaged 40 times.

TABLE 1. Simulation parameters.

Parameters	values
Size of topology	1000m*1000m
MAC Channel	MAC/802.11
Mobility model	Random way point
Number of nodes	400,500,600
Traffic type	CBR
Transmission range	40m
Initial energy	1J
Routing protocols	GPSR, EMGR, EDGR, GFR
Speed of nodes	10m/s

The proposed protocol is evaluated by changing the density of network nodes and the number of communication sessions, using four performance indicators of energy consumption, network lifetime, packet delivery rate and end to end delay.

We consider the energy consumed by all the sensors involved in data transmission to be the total energy consumption. We can use this indicator to measure the energy consumption of sensor nodes in communication.

The network lifetime is from the beginning of the simulation to a certain point in time, and the node exhausts 20% or more of the energy in the network. This metric represents the degree of load balancing between participating nodes in the communication.

The packet delivery rate is defined as the ratio between the number of successfully transmitted data packets and the number of data packets generated by the source node. This indicator reflects the efficiency of data transmission.

The end to end delay is defined as the time delay from packet generation to delivery to the destination. This metric indicates the speed at which the target receives after the packet is sent from the source node.

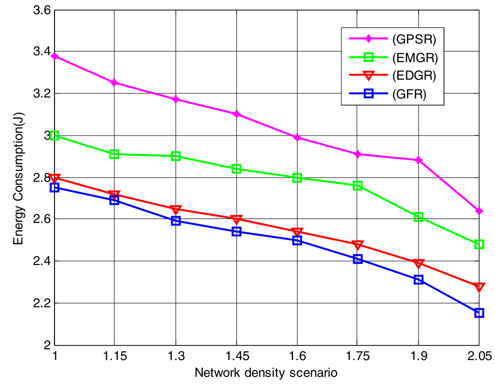

FIGURE 4. The relationship between different network density and energy consumption.

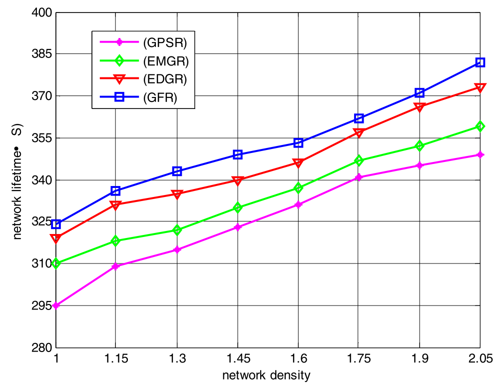

FIGURE 5. The relationship between different network density and network lifetime.

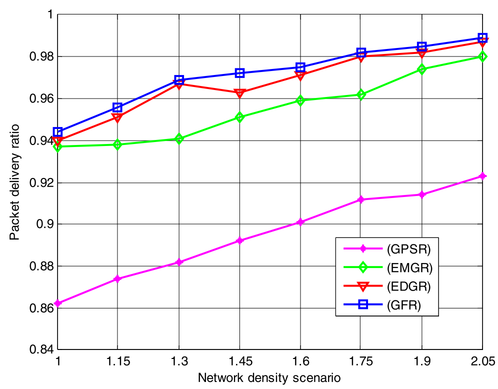

FIGURE 6. The relationship between different network density and packet delivery rate.

B. EXPERIMENT TESTS BASED ON SIMULATION AND ANALYSIS

In Figure 4, Figure 5, Figure 6 and Figure7, the network performance of the four routes is compared under the condition of changing the network density. The nodes move at the same speed, both at 10m/s, and the direction of movement is random.

As can be clearly seen from Figure 4, with the increase of network density, the energy consumption of the four

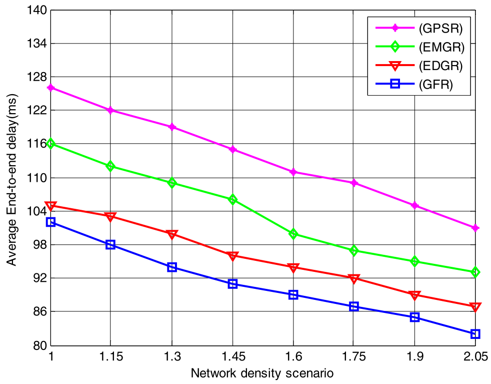

FIGURE 7. The relationship between different network density and end to end delay.

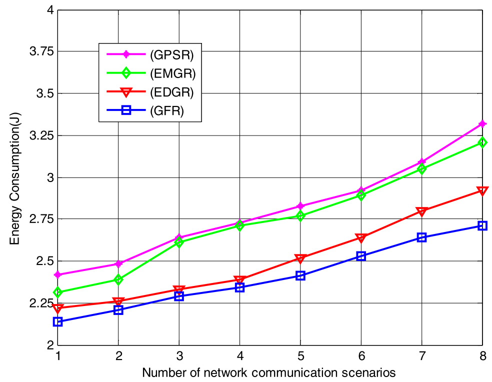

FIGURE 8. The relationship between different the number of communication and energy consumption.

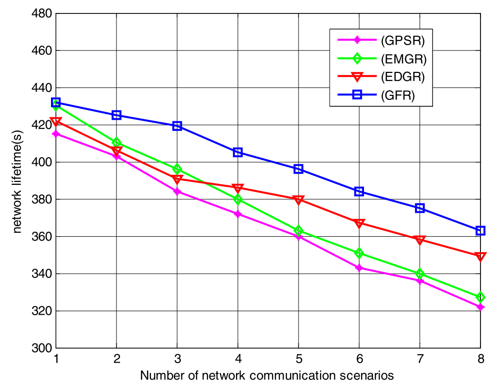

FIGURE 9. The relationship between different the number of communication and network lifetime.

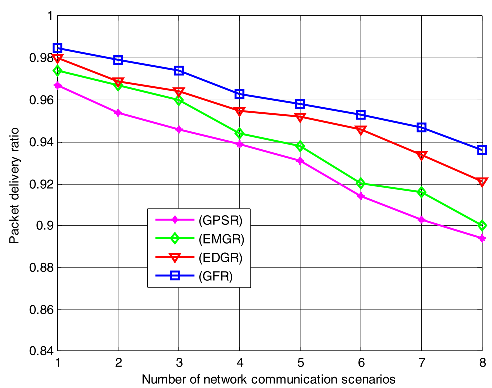

FIGURE 10. The relationship between different the number of communication and packet delivery rate.

algorithms GPSR, EMGR, EDGR and GFR all show a downward trend.However, with the increase of network density, the total energy consumption of the GFR algorithm proposed in this paper decreased from 2.75j to 2.15j, the energy consumption of EMGR decreased from 3.0j to 2.48j, the energy consumption of EDGR decreased from 2.8j to 2.28j, and the energy consumption of GPSR decreased from 3.38j to 2.64j. We can clearly see that the total energy consumption of GFR algorithm is always lower than the other three algorithms under the same network density. Experiments show that the GFR algorithms outperforms the other three algorithms in terms of energy consumption under different network densities.

Figure 5 indicates that with the increase of network density, the network lifetime of the four algorithms GPSR, EMGR, EDGR and GFR are all increasing. The network lifetime of the GFR algorithm proposed in this paper increase from 324s to 382s, EMGR increases from 310 s to 359s, EDGR increases from 319s to 373 s, and GPSR increases from 295s to 349s. Obviously, the network lifetime of the GFR algorithm is significantly higher than the other three algorithms.

From Figure 6 we can see that with the increase of network density, the delivery rates of the four algorithms are all increasing. The data delivery rate of the GFR algorithm proposed in this paper increased from 0.944 to 0.989, the EMGR increased from 0.937 to 0.98, the EDGR increased from 0.94 to 0.987, and the GPSR increased from 0.862 to 0.923. Experiments show that the delivery rate of the GFR algorithm packet is higher than the other three algorithms.

In Figure 7, we show that as the network density increases, the network delays of the four algorithms decrease. The network delay of the GFR algorithm proposed in this paper is reduced from 102ms to 82ms, the EMGR algorithm is reduced from 116ms to 93ms, the EDGR algorithm is reduced from 105ms to 87ms, and the traditional GPSR algorithm is reduced from 126ms to 101ms. Experiments have shown that GFR outperforms the other three protocols in terms of network latency.

As shown in Figure 8, Figure 9, Figure 10 and Figure 11, the performance of the four algorithms is verified by changing the number of communication sessions. The number of communication sessions is gradually increased from 1 to 8. At this time, the network node density remains unchanged, the speed of nodes are identical, and set to 10m / s.

Figure 8 shows the total energy consumption of the four algorithms with different communication sessions. Obviously, the energy consumption of the EDGR and GFR algorithms is much lower than the other two algorithms. Due to both the EDGR and GFR algorithms establish two different

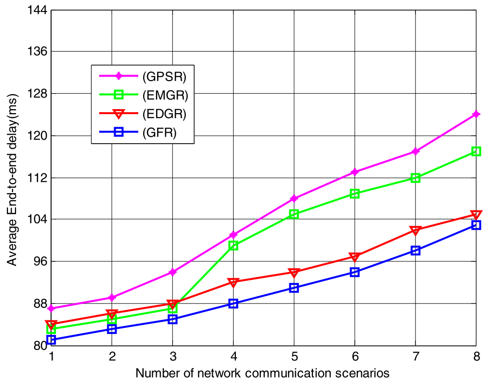

FIGURE 11. **The relationship between different the number of communication and end to end delay.**

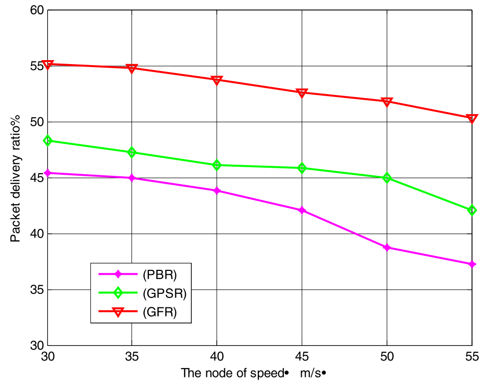

FIGURE 12. **The relationship between different moving speeds and test data packet delivery rate.**

routes to the destination node. In this way, the probability of packet re-transmission is reduced. Therefore, it saves energy consumption.

From Figure 9, we can get the network lifetime of four algorithms with different number of communication sessions. Compared with other algorithms, the GFR algorithm considers the nodes' energy consumption and candidate nodes in the bypass forwarding strategy, and finds two different paths. Therefore, as the number of communication sessions increases, the lifetime of the proposed GFR network is better than that of other protocols.

Figure 10 depicts the delivery rate of packets under different communication sessions. When the number of communication sessions increases, the packet delivery rate decreases. Because the GFR and EDGR algorithms can divide data packets into two sides of the routing hole, the probability of data collision is relatively low, that is, the packet delivery rate is not significantly reduced.

Figure 11 shows the end to end delay with a different number of communication sessions. Simulation experiments show that with the increase of the number of communication sessions, the GFR algorithm proposed in this paper has the lowest latency. Because, the proposed protocol establishes two paths, which can reduce data collisions occurring in data transmission, thereby reducing the number of re-transmissions and reducing transmission delay. And, the protocol proposed in this paper selects the node with more energy as the candidate node of the next hop node, which reduces the possibility of link failure.

C. INTERSECTION SCENARIO TEST

To verify the practicability of the GFR algorithm, the GFR algorithm is applied to the internet of vehicles, and the vehicle is regarded as a moving node, using 30 vehicles. The average speed of the vehicle is between 30km/h and 50km/h, and experiments are carried out at the intersection. Compare the performance of GFR, PBR [17] and GPSR algorithms.

Figure 12 shows the impact of different node movement speeds on the data packet delivery rate at the intersection. As the speed of vehicles increases, the data packet delivery rate decreases, mainly because the speed becomes larger, which makes the link to disconnect easily. The GFR protocol maintains good performance.

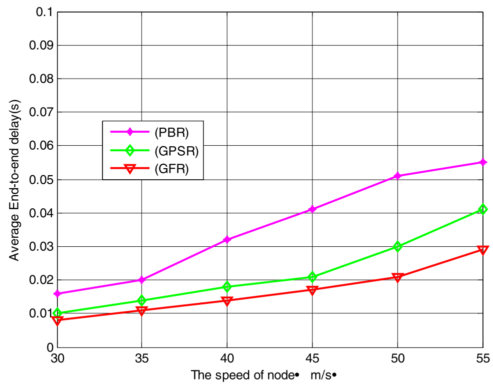

FIGURE 13. **The relationship between different moving speeds and average end-to-end delay.**

Figure 13 shows the average end-to-end delay at different speeds. The experimental results show that the average end-to-end delay increases with the increase of vehicle speed. This is because the speed is increased, and the network topology is more likely to change. The existing path may not meet the communication requirements, resulting in restarting the route discovery process. But compared to the other two algorithms, GFR has better performance.

V. CONCLUSION

In this paper, we propose a mobile ad hoc network routing method based on greedy forwarding improvement strategy, which is optimized and improved in the greedy forwarding and bypass forwarding phases. In the greedy forwarding phase, a reliable communication area is established. By considering factors such as link quality and distance, the metrics of the candidate nodes are obtained, and the nodes with large metric values are selected for forwarding. In the bypass forwarding phase, considering the energy and deflection angle of the node, the priority values of the candidate nodes are obtained, and the routes distributed on both sides of the routing hole are found. Simulation and experimental results show that compared with the existing GPSR,EMGR and EDGR, the proposed algorithm reduces the energy consumption of the network, improves the delivery rate of data packets, reduces the network delay and prolongs the network lifetime.For the geographic routing strategy, only the node is considered to be in two-dimensional space. To some extent, it has certain limitations. The next step is to expand the algorithm into three-dimensional space, so as to be more suitable for emergency disaster.

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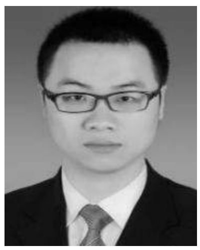

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