Improved GPSR routing protocol based on weight function in shipborne ad hoc networks

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Abstract. The network topology of the shipborne ad hoc network changes rapidly, which leads to instability of the data transmission link. Therefore, finding a stable data packet transmission link has become a hot research topic. This paper improves on the basis of the original GPSR routing protocol, and evaluates the link quality by selecting four metrics, including direction of neighbouring ship, link risk, density of neighbouring ship and proximity. The analysis results show that the improved protocol is superior to the GPSR routing protocol in terms of packet delivery rate.

1. Introduction

With the rapid development of maritime trade, the number of ships in China is increasing day by day, laying a foundation for building the shipborne ad hoc network with ships as communication nodes. Through the shipborne ad hoc, human observations of the ocean can cover all key sea areas.

The technical basis for information communication in the ship network is the shipborne ad hoc network, namely Mobile Ad-hoc Networks. Mobile Ad hoc network is a typical communication network composed of mobile communication nodes. Due to the rapid mobility of the ship in the communication process, the network topology will also change constantly, and the established communication route is likely to be interrupted. Therefore, the research of related routing protocols has become the key research issue of current Ad hoc networks[1].

Literature [2] improves the GPSR algorithm and uses mobile information to improve the decision of the next forwarding node. The performance evaluation of the protocol lays a good foundation for designing a routing strategy suitable for automotive scenarios. Literature [3] comprehensively considers the network requirements based on the link established between the mobile nodes. In the process of searching for the route, the network requirements of the nodes are referenced, and the unstable channel is fully utilized to complete the task. Literature [4] proposes a routing protocol based on MM-GPSR. The neighbouring node with the largest communication time is selected as the next hop node. The concept of the minimum angle is introduced as the criterion for the optimal next hop node. Literature [5] considers the credibility in the routing process. Based on the subjective trust model Dy Trust, an objective trust model is used to measure the credibility of the nodes.

This paper proposes a GPSR routing protocol based on weight function. In the process of data transmission, factors such as direction of neighbouring ship, link risk, density of neighbouring ship and proximity are considered. The ship will select the ship with the highest weight function value in
the candidate neighbouring ship as the next hop to transmit information.

The second section of this paper introduces the establishment of the shipborne ad hoc network model, the third section introduces the GPSR routing protocol based on geographic location, the fourth section introduces the improved GPSR routing protocol of this paper, and the fifth section introduces the experimental simulation results. The sixth Section clarifies the shortcomings and shortcomings of the experiment.

2. The shipborne ad hoc network model

The assumptions of this paper are as follows:
1). Assume that the ship's communication radius is the same;
2). Assume that each vehicle is equipped with a GPS positioning system and an electronic map, and the vessel realizes the perception of the surrounding vessels through periodic broadcast status information, such as position, velocity, acceleration, and direction angle;
3). Assume that each vehicle can obtain its current position and speed information, including: speed, position and azimuth;
4). Assume that the ship is free to move within a certain area;
5). Assume that the energy of the ship in the ad hoc network is considered not exhausted and the energy consumed by the communication is negligible.

3. GPSR routing protocol overview

The GPSR routing protocol is a typical location-based protocol[6]. By loading a GPS or Beidou positioning system on the ship, the ship can obtain its own accurate position information. By sending a HELLO packet, the node can obtain information about all neighbouring nodes within its communication range[7].

When the source ship wants to send data to the destination ship, it can obtain the location information of its neighbouring node by periodically obtaining the Hello packet. By calculating the distance of each neighbouring ship to the destination ship, the neighbouring ship closest to the destination ship is selected as the relay ship to forward the data. This forwarding mechanism is called a greedy forwarding mechanism, as shown in Figure 2. The biggest advantage of this mechanism is that it can reduce the hop count of the source ship to the destination ship, greatly reduce the transmission delay [8].

However, the greedy forwarding mechanism also has certain shortcomings. The main disadvantage is that the distance between the relay ship and the destination ship is too much considered, thus neglecting the consideration of link stability. In addition, the greedy forwarding mechanism sometimes causes local optimization problems, causing routing holes. At this time, it is necessary to use the peripheral forwarding mechanism to forward the data packet.

In the process of transmitting data from the source ship to the destination ship, the rapid change of the network topology due to the rapid movement of the ship may cause the data link to break. This will cause the relay ship to find no next relay ship within its communication radius that can forward data. At this point, the relay ship will continue to carry the packet and wait for an opportunity. If the next relay ship that can forward the data packet is still not found after a certain time threshold is exceeded,
the relay ship will discard the data packet.

4. Overview of improved GPSR routing protocols

4.1. Position of neighbouring ship

In the process of finding the route, in order to avoid routing loops, reverse transmission and other issues, this paper introduces the direction of neighbouring ship. If a ship that is farther away than the current relay ship is selected as the next hop, it will cause a huge transmission delay and increase the packet transmission path, thereby increasing the packet loss rate.

This paper takes the cosine of the angle between the current relay ship \( A \), the neighbouring ship \( B \) and the destination ship \( D \) as the standard for measuring the index. Assuming \( \tau_0 \), the coordinates of the three points \( A,B \) and \( D \) are \((x_A(t_0),y_A(t_0)),(x_B(t_0),y_B(t_0))\) and \((x_D(t_0),y_D(t_0))\), as shown in Figure 3 below.

\[
\begin{align*}
\theta &= \arctan \frac{y_D(t_0) - y_A(t_0)}{x_D(t_0) - x_A(t_0)} \\
\gamma &= \arctan \frac{y_B(t_0) - y_A(t_0)}{x_B(t_0) - x_A(t_0)} \\
h_i &= \cos(\gamma - \theta)
\end{align*}
\]

![Figure 3. Position of the neighboring ship](image)

At this time, the direction of neighboring ship can be represented by \( h_i \). When \( \gamma - \theta \in \left[ -\frac{\pi}{2}, \frac{\pi}{2} \right] \), \( h_i \) is greater than 0, and the weight value can be increased. When \( \gamma - \theta \in \left[ -\pi, -\frac{\pi}{2} \right] \cup \left[ \frac{\pi}{2}, \pi \right] \), \( h_i \) is less than 0, which can reduce the weight value.

4.2. Link risk

In the process of packet forwarding, there must be a case where the selected next relay ship is at the edge of the ship communication radius. Due to the rapid movement of the ship, such a transmission link is very unstable, and the selected next relay ship is likely to be out of its communication range before the data packet arrives, causing the communication link to break, resulting in data packet transfer failed. The failure of the greedy forwarding mechanism caused by such malpractice is very common. Therefore, this drawback causes data to be retransmitted or lost, which degrades the overall performance of the ad hoc network.

The literature [9] studies the mathematical relationship between the communication distance between each communication node and the transmission validity. The study shows that when the communication distance between neighbor nodes is less than or equal to 0.9r, the success rate of data transmission is close to 100%. In this paper, the communication range less than or equal to 0.9r is called the stable area. However, as the distance between adjacent nodes gradually increases from 0.9r to r, the packet loss rate of data transmission increases rapidly, and the transmission link performance
at this time is very poor. In this paper, the communication ranging from 0.9r to r is called the danger zone. As shown in Figure 4 above.

In order to avoid the data link break caused by the selected next relay ship due to the long distance from the current relay ship, this paper increases the link risk degree when constructing the weight function. The specific expression is:

\[ D_1^* = \frac{1}{0.9r - D_{AR}} \]  

\( D_{AR} \) is the linear distance of the current relay ship to the neighboring ship. In this paper, the reciprocal of \( 0.9r - D_{AR} \) is used as the measurement index. If the neighboring ship is in the stable zone, \( 0.9r - D_{AR} \) is greater than zero, and the closer to the edge of the stable zone, then \( D_1^* \) is larger; if the neighboring ship is in the danger zone, \( 0.9r - D_{AR} \) is less than zero.

4.3. Density of neighboring ship

This paper strengthens the data packet transmission and forwarding optimization mechanism by considering the density of neighboring ship, and uses this as an important evaluation index of the weight function to optimize the search mode of the relay ship, thereby reducing the probability of routing holes and reducing the packet loss rate. In turn, improve routing performance[10].

In order to reduce the role of this value in the overall analysis of the weight function and to ensure the objectivity of the result, this paper normalizes the value. Its normalization formula is as follows:

\[ N_1^* = \frac{N_I - N_{\text{min}}}{N_{\text{max}} - N_{\text{min}}} \]  

Where \( N_I \) is the number of optional ships for each neighbor ship, \( N_{\text{min}} \) is the minimum value in \( N_I \), \( N_{\text{max}} \) is the maximum value in \( N_I \), and \( N_1^* \) is the value after normalization.

\[ \text{Figure 5. Proximity} \]

4.4. Proximity

In order to reduce the transmission delay and routing hops of data packets, this paper introduces a new measurement factor: proximity. The proximity characterizes the distance between each ship and the destination ship in the ad hoc network. This paper can be seen from Figure 5, \( S \) is the source ship, \( D \) is the destination ship, \( X_1, X_2, X_3, X_4 \ldots X_i \) are the numbers of other ships in the network.

The formula for calculating the proximity is as follows:

\[ \varphi_i = \frac{l_{SD} - l_{X_iD}}{R} \]  

Where \( l_{SD} \) is the distance from the source ship to the destination ship, \( l_{X_iD} \) is the distance from any ship \( X_i \) to the destination ship, and \( R \) is the communication radius of the ship. The closer the destination ship is, the smaller \( l_{X_iD} \) is, and the larger the \( l_{SD} - l_{X_iD} \) is, the larger the value of the
proximity \( \varphi_i \) is. Thus, the ship's weight value is also greater.

4.5. Construction of weight function

In this paper, direction of neighbouring ship, link risk, density of neighbouring ship and proximity are considered. A weight function is proposed. The formula is as follows:

\[
\mathbf{w}_i = w_1 \cdot h_i + w_2 \cdot D^*_i + w_3 \cdot N^*_i + w_4 \cdot \varphi_i
\]  

(7)

Where \( w_1, w_2, w_3, \) and \( w_4 \) are the weight values of the respective metric factors, and \( w_1 + w_2 + w_3 + w_4 = 1 \). On the basis of many simulation experiments, the four weight values of this paper are: \( w_1 = 0.21, w_2 = 0.13, w_3 = 0.13, w_4 = 0.53 \). In the process of selecting the relay ship, this paper will select the ship corresponding to the maximum value in \( \mathbf{w}_i \) as the relay ship.

5. Performance simulation and analysis

In this paper, the GPSR routing protocol based on weight function is implemented on MATLAB simulation software, and a new routing protocol GPSR-W is obtained. Compare it with the GPSR protocol and the GPSR-D protocol to observe the performance improvement brought by the new algorithm.

5.1. Performance

The indicators used in this paper to evaluate the network performance of the routing protocol are packet delivery rate, routing void rate, and average route hop count. Taking the ship freely sailing on the ocean as a simulation scenario, this paper builds two different modes of simulation environment. In scenario 1, the ship density is different, and the speed of each ship is randomly distributed; in scenario 2, the ship density is the same and the maximum speed of the ship is different.

5.2. Simulation environment

The software used in this simulation is MATLAB, and the parameters of the simulation environment are shown in Table 1:

| Parameter                  | Value                  |
|----------------------------|------------------------|
| Simulation tool            | MATLAB                 |
| Routing Protocol           | GPSR-W、GPSR-D、GPSR-D  |
| Number of nodes            | 20-60                  |
| Application Environment    | ocean                  |
| Movement speed / (m/s)     | 18-54                  |
| Simulation scenario / (km) | 100, 100               |
| Number of simulations      | 1000                   |
| Communication range / km   | 25                     |
| Packet size                | 4608bit                |
| Data transfer rate /Mbps   | 2                      |

5.3. Simulation result analysis

Figure 6 shows the effect of the number of ships in a fixed area on the group delivery rate. The horizontal axis represents the number of ships, and the vertical axis represents the group delivery rate. Compared with the other two protocols, the packet delivery rate of the GPSR-W routing protocol is about 5%-10% higher. This is because in the process of finding a route, the GPSR-W routing protocol comprehensively judges the stability of each link, and finally selects a path with high stability and good link performance.

Figure 7 shows the probability of a routing void in a packet during transmission. Among them, the horizontal axis represents the number of ships, and the vertical axis represents the routing void rate. As
can be seen from the figure, as the density of ships increases, the routing void ratios of the three protocols are decreasing. However, the routing hole rate of the GPSR-W routing protocol is relatively lower than that of other protocols. This is because the addition of neighbor ship density effectively avoids the occurrence of routing holes.

![Figure 6. Group delivery rate in scenario 1](image1.png)
![Figure 7. Routing void rate in scenario 1](image2.png)

![Figure 8. Average route hops in scenario 1](image3.png)
![Figure 9. Group delivery rate in scenario 2](image4.png)

Figure 8 shows the relationship between the average number of route hops and the number of ships during the transmission of a packet. The horizontal axis represents the number of ships, and the vertical axis represents the average number of route hops. As the number of ships increases, the average number of hops for the three protocols is decreasing. The average hops of the three protocols are concentrated between 7.0 and 8.0. However, the average route hop count of the GPSR-W routing protocol is slightly higher than the other two protocols.

Figure 9 shows the effect of the speed of the ship on the group delivery rate when the number of ships is constant. The horizontal axis represents the ship speed and the vertical axis represents the group delivery rate. As can be seen from the figure, as the speed of the ship increases, the packet delivery rate of the three protocols fluctuates within a certain range. However, the packet delivery rate of the GPSR-D routing protocol is higher than the other two routing protocols.

Figure 10 reflects the probability of routing void in the case of a certain density of the ship during the transmission of the data packet. The horizontal axis represents the ship speed, and the vertical axis represents the routing void rate. Compared with other protocols, the routing void rate of the GPSR-W routing protocol is lower than 5%, which effectively avoids the failure of packet transmission.

Figure 11 shows the relationship between the average number of hops and the speed of the ship during the transmission of the data when the ship density is constant. The horizontal axis represents the ship speed and the vertical axis represents the average route hop count. It can be seen from the figure that as the number of ships increases, the average number of hops of the GPSR-W routing protocol decreases, but the average number of hops is slightly higher than the other two protocols.
6. Conclusion
This paper proposes a method for finding a stable link of a mobile Ad hoc network based on the GPSR routing protocol. The simulation shows that the improved routing protocol has a certain improvement in packet delivery rate and routing void rate. However, this paper still has certain defects, the working environment is idealized and the average route hop count is large.

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