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Multi Routing Metric AODV Protocol Based on Ant Colony algorithm

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Abstract: *With the rapid development of MANET(Mobile Ad Hoc Network) technology, the density of nodes in the network environment gradually increases, and the topology changes become more intense. The traditional AODV protocol can not effectively judge the congestion status of nodes and data transmission links in the network, nor can it effectively deal with the problem of route break. In order to solve these problems, this chapter proposes a multi path selection optimization algorithm based on ant colony optimization algorithm AM-AODV. In AM-AODV routing protocol, residual energy, congestion status and node density factors are added, and ant colony algorithm is combined to select a new path decision metric. This algorithm avoids involving nodes with heavy load in the route establishment process, thus effectively reducing the redundancy of route messages in the network, reducing competition and conflicts between nodes, and helping to effectively suppress network congestion. By introducing new routing criteria, AM-AODV can choose a communication path with less congestion and more stable links, thus improving the overall performance of the network.*

Keywords: *Mobile Ad Hoc Network; AODV; Residual energy; Congestion status;*

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I. Introduction

In the MANET environment, wireless self-organizing network nodes rely on wireless signal transmission for communication between nodes without fixed infrastructure support[1-2]. The high speed, random movement, and frequent topology changes of nodes pose a severe challenge to the stability and connectivity of the network[3-4]. At the same time, external environmental factors such as wireless channel attenuation, interference, and energy consumption of nodes also pose higher requirements for network performance. Traditional AODV routing protocols typically assume slow network topology changes, making it difficult to cope with dynamic and frequently changing MANET scenarios. Therefore, introducing an improved method based on ant colony optimization algorithm can fully utilize its global optimization, distributed processing, and strong adaptability, further improving the efficiency of routing protocols in MANET. This article proposes a multi routing metric AODV protocol based on ant colony optimization(AM-AODV), which can dynamically adjust routing selection strategies, optimize path discovery processes, and effectively balance network energy consumption, thereby improving data transmission efficiency and reducing latency in MANET.

II. Related work

Ant Colony Optimization[5-6](ACO) is an optimization algorithm based on swarm intelligence, which is inspired by ants' foraging behavior. Because ants can quickly adapt to environmental changes, if they encounter obstacles and the old path fails, they will choose the remaining new shortest path. The application of ant colony optimization algorithm in mobile ad hoc network routing protocol stems from the similarity between the natural communication mode of ant colony and the communication environment of MANET. Therefore, this process is applicable to mobile ad hoc networks with frequent link changes[7-9]. Based on the above analysis, the traditional GPSR protocol has the problems of single metric and insufficient consideration of energy consumption, etc. Improvements for the GPSR protocol are mainly focused on the greedy forwarding mode, and the routing nulling problem occurring in the greedy forwarding mode is also prone to lead to link breakage and reduce the network performance. To try to solve the above problems, this paper proposes a multi-metric GPSR protocol based on fuzzy control.

A multi route AODV ant routing algorithm(MRAA) is proposed in [10]. The MRAA algorithm reduces the end-to-end delay in packet transmission. Because this technology uses an alternate path for data transmission, it can send data packets to the destination node in a shorter time with lower overhead. In reference [11], an improved routing algorithm based on Ant Colony Optimization(I-ACO) is proposed. By using two models, the transition probability model and the directional probability model, the I-ACO algorithm routes data by utilizing updated pheromone information. This technique reduces the end-to-end delay of packets and improves the packet transmission rate. The reference [12] proposes a mobile sensing termite(MA-termite) routing scheme based on the mound-building mechanism of termites. The MA-termite scheme utilizes the coordinated adaptation mechanism of termites during the mound-building process to forward data packets to the destination node. The pheromone decay on the link is proportional to the distance between the nodes on the link. Neighboring nodes with high mobility cause rapid pheromone decay, while those with lower mobility experience slower pheromone decay. This technique results in fewer routing interruptions and lower overhead. In reference [13], a reactive routing protocol(E-Ant-DSR) combining Ant Colony Optimization and Dynamic Source Routing is proposed. The E-Ant-DSR routing protocol uses the ant colony algorithm to select the optimal path. Pheromones represent the probability of selecting a path, and the pheromone value is calculated by considering link metrics, congestion metrics, and hop count. By calculating the routing pheromone values, the route with the highest pheromone value is selected for data transmission. In reference [14], an Ant Colony Optimization-based Quality of Service Routing(QoRA) algorithm is proposed. The QoRA algorithm locally computes QoS parameters and avoids congestion during the data transmission process through two architectural components: the QoRA entity and the Simple Network Management Protocol(SNMP) entity. In reference [15], a cluster-based Ant Colony Optimization AODV routing protocol(AODV-R) is proposed. By using the ant colony algorithm to find multiple shortest paths, it reduces the likelihood of link failures when the network topology changes, allowing for better responsiveness to topology changes and improving link stability. In reference [16], an energy consumption method combined with an active MANET routing protocol is used. The routing protocol depends on the energy level and mobility of the nodes. Based on the calculation of node energy consumption levels, K-Means clustering and Ant Colony Optimization(ACO)-optimized AODV are used to estimate energy costs. Simulation results show that the proposed model achieves better performance in terms of packet delivery rate(PDR), end-to-end delay, latency, packet loss, and energy consumption.

In summary, since the search process of the ant colony algorithm is iterative, the convergence speed of the path is relatively slow, which may lead to delays. Additionally, the dynamically changing network can make the path unstable, and the decay of pheromones causes the quality of the path to decrease. In this paper, the influence of pheromones on path selection is increased in the improvement of AODV, allowing ants to find better paths in a shorter time. Furthermore, the pheromone update strategy is dynamically adjusted based on the node's load and path quality to avoid premature pheromone decay or delayed updates.

III. AM-AODV

3.1 AM-AODV algorithm design

In the AODV routing protocol based on ant colony optimization algorithm, "ants" explore, analyze and feedback the path information, and finally get the best transmission route. Therefore, it is necessary to modify the RREQ message and RREP message, and add information such as node residual energy, congestion status and node density to the original frame structure. Each node in the network will continuously calculate and update the pheromone according to the message information. By adding two entries to the original AODV routing table, a new routing table is designed to replace the original routing table.

(1) Pheromone

The specific calculation formula is:

$$PC_{ij} = \frac{1}{M_H \times M_E \times M_{CD} \times M_D} \tag{1}$$

Where PC_{ij} A represents the pheromone value of the link (i , j), and the four routing metric quantization indicators, M_H , M_E , M_{CD} and M_D are calculated based on formulas (2), (3), (4), and (5).

In the process of route establishment, the designed path selection factors are composed of hops, residual energy, node congestion degree and neighbor node density. These factors are quantitatively designed in the following way to follow the principle that the smaller the value, the better the path.

$$M_H = \frac{C_i}{C_0} \tag{2}$$

C_i represents the number of hops from the source node to the current node, and C_o represents the number of surviving nodes in the network.

$$M_E = 1 - \frac{E_r}{E_i} \tag{3}$$

E_r represents the residual energy value of the node itself; E_i represents the initial energy value of the node during network initialization.

$$M_{CD} = 1 - \frac{L_{free}}{L_{all}} \tag{4}$$

L_{free} represents the size of the idle receive queue and L_{all} represents the size of the total receive queue.

$$M_D = 1 - \frac{N_e}{N_o} \tag{5}$$

N_e is the number of hop neighbors of a node, and N_o is the total number of network nodes.

(2) Probability

According to (6), the probability value on node i at time t is:

$$P_{ij}^k(t) = \begin{cases} \dfrac{\left[PC_{ij}(t)\right]^{\alpha}\left[\eta_{ij}(t)\right]^{\beta}}{\sum_{S \in allowed_k}\left[PC_{is}(t)\right]^{\alpha}\left[\eta_{is}(t)\right]^{\beta}}, & j \in allowed_k \\ 0, & \text{其他} \end{cases} \tag{6}$$

Where, α and β are pheromone factors and heuristic factors respectively, and $\eta_{ij}(t)$ is the Euclidean distance from node i to node j.

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{7}$$

3.2 AM-AODV Algorithm Flow

Add Phermone Count to RREQ and RREP, Probability. The improved control message format is shown in Figure.1 and Figure.2:

```
Route Request (RREQ) Message Format
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type(8)     |J|R|G|D|U|       Reserved(11)    Hop Count(8) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           RREQ ID(32)                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Destination IP address(32)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Destination Sequence Number(32)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Originator IP address(32)                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Originator Sequence Number(32)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Phermone Count(32)                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Probability(32)                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure.1 RREQ of AM-AODV

```
Route Reply (RREP) Message Format
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type(8)     |R|A|     Reserved(9)    |Prefix(5)|  Hop Count(8)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Destination IP address(32)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Destination Sequence Number(32)                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Originator IP address(32)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Lifetime(32)                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Phermone Count(32)                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Probability(32)                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure.2 RREP of AM-AODV

(1) Route discovery

During route discovery, the source node will first send RREQs to its neighbors. When a neighboring node receives an RREQ, it will first check its routing table. If the path to the destination node already exists in the routing table, the data packet will be transmitted along this path. At this time, the neighboring node will discard the RREQ information, generate the RREP information, and return to the source node along the established path, so as to establish the link between the source node and the neighboring node and improve the entire route.

When the intermediate node receives the RREQ message, it will check whether it has a path to the destination node. If yes, the RREQ will continue to transmit along the path, and the hop count field carried by the RREQ message will increase by 1, which is stored in the hop count field corresponding to the routing table entry. Then, the pheromone value is calculated according to formula (1) using the four parameters of residual energy measurement, congestion measurement, node density measurement and hop count measurement, and the entries in the routing table, the initiator node and the pheromone value field corresponding to RREQ are replaced, and finally the routing request is broadcast.

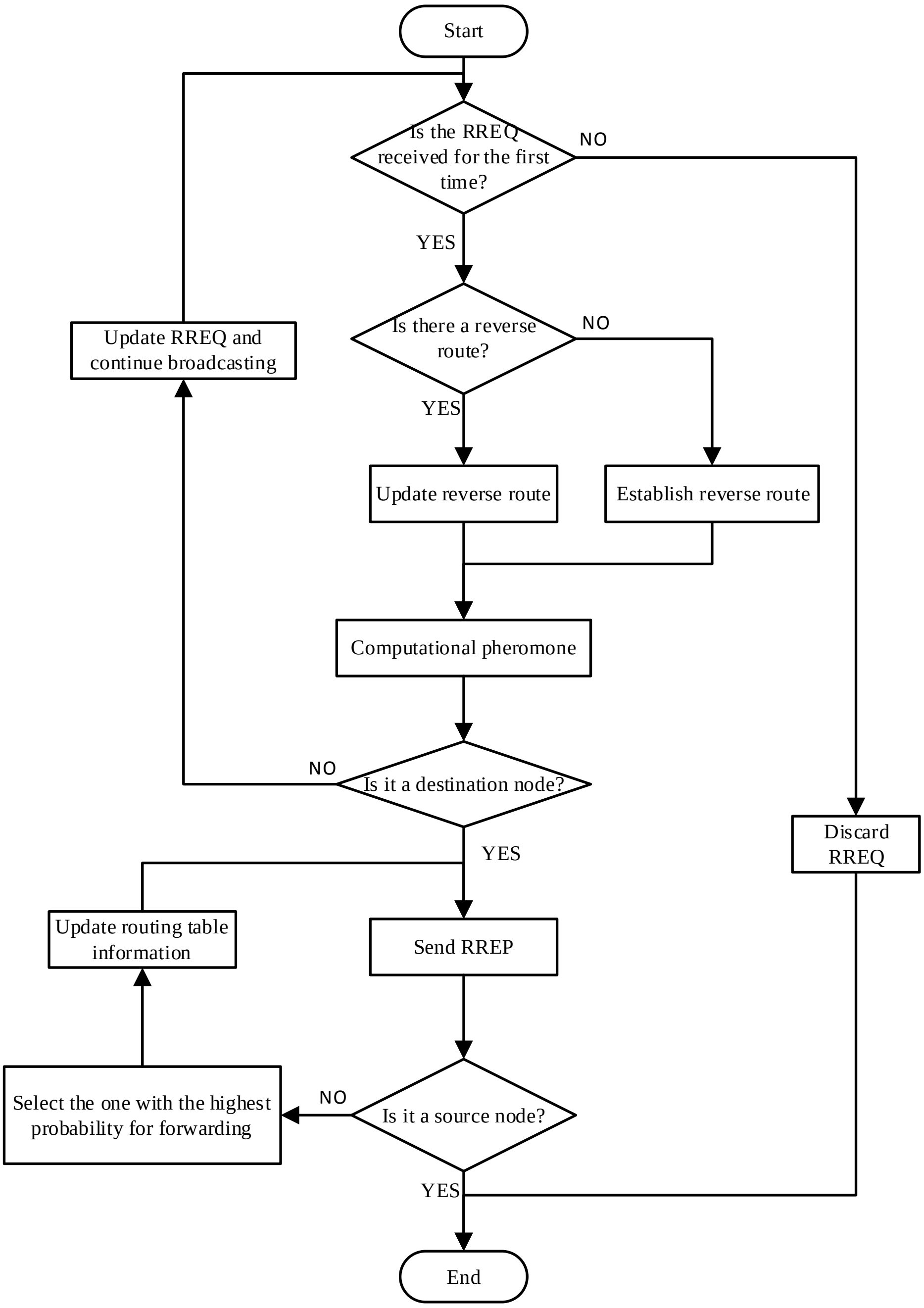

Figure 3 The routing construction process of AM-AODV

After the RREQ arrives at the destination node, it will not continue broadcasting. The destination node will send the RREP as a response. The path has been established before. According to the probability formula (6), the probability value of each adjacent node will be calculated and compared. This value reflects the residual energy and congestion of each path. The larger the Probability value, the higher the probability of selecting the path. Generally, the neighbor node with the largest Probability value is selected as the next hop.

In the process of RREP returning to the source node, the pheromone will be updated according to the information of the node according to the iteration rule every time it passes through a node.
The specific process is shown in Figure.3.

(2) Route maintenance

In order to determine whether the link can work normally, in the process of information transmission in the AODV routing protocol, the node not only broadcasts RREQ information, but also periodically broadcasts HELLO information to neighbor nodes. If the node does not receive HELLO information from neighbor nodes within the specified time, it means that the path between the node and neighbor nodes cannot work normally, and routing maintenance is required.

First, assume that the path (i , j) has the best best probability, and set the maximum response time as T_{MAX} . The node i does not receive the HELLO message from the node j within this time, which means that the path (i , j) cannot be used, and the energy, congestion degree and other information on the link will lose meaning. At this time, the routing table of the node i is updated, and the corresponding table items of the corresponding node j are set to Phrmone Count and Probability. At the same time, the RERR information is broadcast to the adjacent nodes, and the remaining nodes are notified to delete the information about the node j in their respective routing tables. Next, the node i needs to cache the packet queue to be sent to the node j , calculate the remaining link forwarding probabilities that can work normally according to the information in the routing table, find the link with the appropriate sub optimal forwarding probability, update the routing table of the corresponding node, and transmit the RREP with the new routing information to the source node. If the difference between the optimal forwarding probability and the optimal forwarding probability is too large, that is, when there is no suitable neighbor node to send information, an error message RERR is sent to the source node, and the source node will restart the route discovery process after receiving it.

IV. Simulation and Analysis

In order to analyze the performance of the proposed routing protocol, the simulation verifies the impact on the three performance indicators of the routing protocol packet delivery rate, average end-to-end delay, and throughput in different network scenarios, and makes a comparative analysis with ACA[17] routing protocol.

The simulation is carried out based on the NS-2 simulation platform. The simulation scenario is a 1200m × 1200m rectangular area. The link layer adopts IEEE802.11 MAC layer protocol, the node transmission radius is 120m, and the network bandwidth is 2Mbit/s. The impact of different network scenarios on the protocol performance is verified. The specific simulation parameter settings are shown in Table.1:

Table 1 Simulation parameters

Parameter Value	Parameter Value
MAC	802.11
Dissemination Model	TwoRayGround
Signal Channel	WirelessChannel
Physical Layer	WirelessPhy
Queueing Model	PriQueue
Queue Length	50
Logical Link Layer Model	LL
Number of Nodes	50
Simulation Time	200s
Simulation Scenario	1200m×1200m
Data Flow	CBR
Movement Model	RWP
Receive Power	200J
Receive Power	1.6W
Receive Power	1.2W

4.1 Influence of network topology changes on protocol performance

Change the mobile speed of nodes in the network to obtain the impact of the number of nodes on the protocol performance. The moving speeds of nodes are 10, 20, …, 50 m/s.

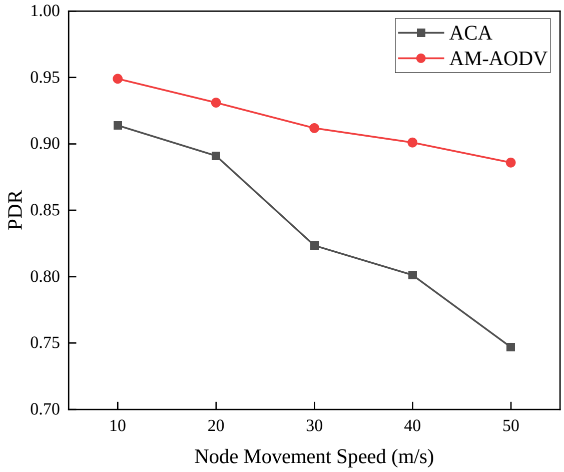

Figure.4 The impact of node movement speed on packet delivery rate

Figure.4 shows that both AM-AODV protocol and ACA protocol decrease with the increase of node speed. The increase of node speed will change the network topology, and the data transmission path will become unstable. When sending data packets, the route may break and the node cannot quickly capture the path information, resulting in more data packet losses. ACA is only based on ant colony search path and lacks dynamic optimization factors. Therefore, path failure is prone to occur in a highly mobile environment, resulting in a drop in packet delivery rate. The improved protocol takes the node density and residual energy as the factors of route selection. As the node speed increases, the route will not break frequently, and can adapt to higher node mobility and provide a more stable route path. Therefore, AM-AODV has a relatively higher packet delivery rate than ACA. When the node movement speed is 40m/s, AM-AODV protocol is 15% better than ACA protocol.

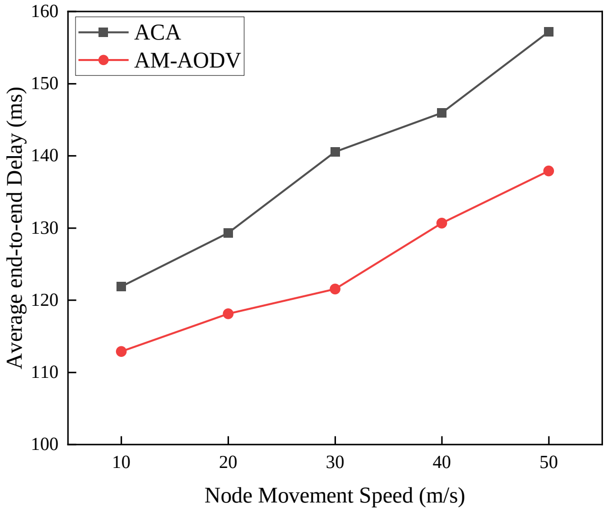

Figure.5 The impact of node movement speed on end-to-end average latency

Figure.5 shows that the average end-to-end delay of AM-AODV protocol and ACA protocol is increasing with the increase of mobile speed. Because ACA does not have the real-time adaptability to the node movement state, when the node movement speed increases, the path calculation and route update process may take more time, which will lead to an increase in end-to-end delay. AM-AODV protocol dynamically adjusts the routing path and updates the routing in time when the node moves, reducing the redundancy of the path and the delay in the selection process. When the node moving speed is 40m/s, AM-AODV protocol is 10% better than ACA protocol.

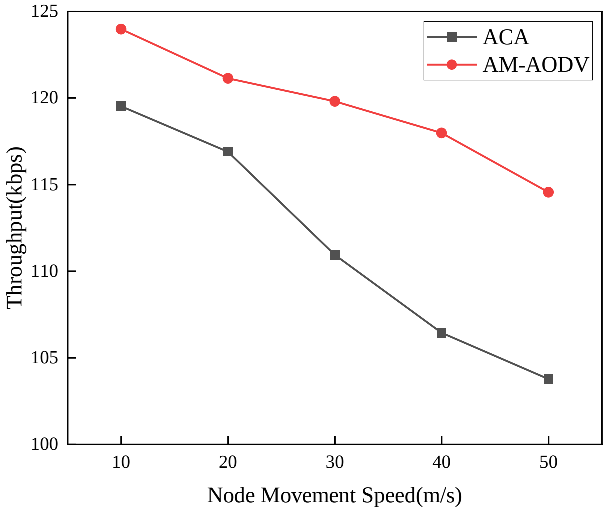

Figure.6 The impact of node movement speed on throughput

Figure.6 shows that with the increase of node speed, AM-AODV protocol and ACA protocol both show a downward trend. This is because with the increase of node movement speed, the network topology will change rapidly, and it is impossible to quickly grasp the destination route, resulting in the loss of links between nodes, and ultimately reducing the node throughput. Because the path selection of ACA is limited by the fixed strategy of the ant colony search algorithm, the path failure and frequent path reconstruction lead to a decline in throughput. AM-AODV optimizes path selection by combining node density, congestion status and other information. The selected path is more reliable than the path selected by ACA protocol, so that packets can be transmitted through a more efficient path, reducing packet loss rate and improving throughput. AM-AODV protocol is 11% better than ACA protocol when the node movement speed is 40m/s.

4.2Influence of node number on protocol performance

Change the number of nodes in the network to obtain the impact of the number of nodes on the performance of the protocol. The number of nodes is 20, 40, … , 100.

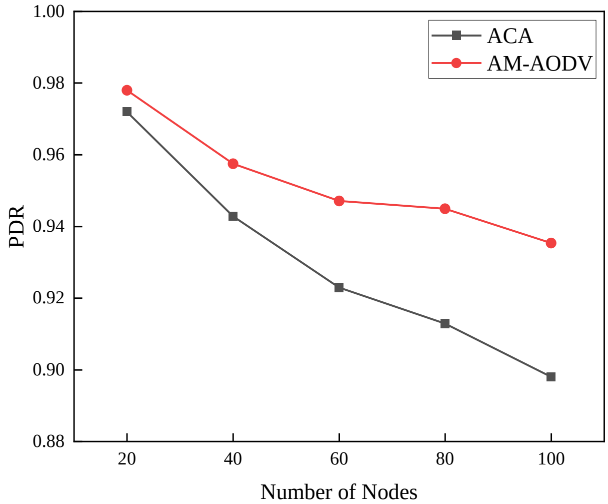

Figure.7 The impact of the number of nodes on packet delivery rate

Figure.7 shows that the packet delivery rate of AM-AODV protocol and ACA protocol gradually decreases with the increase of the number of nodes. An increase in the number of nodes will cause an increase in the number of cached packets in the path, resulting in packet loss. However, AM-AODV has a higher packet delivery rate than ACA protocol. When the network is congested and the node density is too high, ACA routing protocol may lead to some node failures or routing failures due to the lack of consideration of residual energy and congestion status, resulting in a drop in packet delivery rate. With the increase of the number of nodes, the improved AODV protocol can select routes more effectively in the case of high nodes, avoid excessive dependence on a single path, and enhance the robustness of the network because it introduces multiple measures such as residual energy, congestion status, node density and hops to optimize path selection. Its packet delivery rate usually shows good stability when the number of nodes increases. When the number of nodes is 80, AM-AODV protocol is 4% better than ACA protocol.

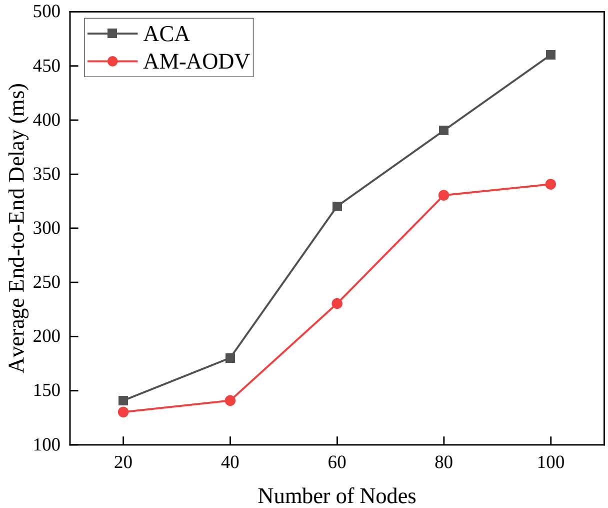

Figure.8 The impact of the number of nodes on end-to-end average latency

Figure.8 shows that as the number of nodes increases, the average end-to-end delay increases, but the end-to-end delay of AM-AODV protocol will basically flatten after a certain point. As path selection of ACA mainly depends on the "ant" search behavior of the path, the redundancy of path selection may occur when the number of nodes is large, especially when the network becomes more complex, it may increase the time for path search, thus improving the end-to-end delay. As the number of nodes increases, AM-AODV is more flexible and intelligent in selecting paths. Considering congestion and residual energy, it can reduce the delay caused by path failure or congestion, avoid congested paths, reduce the transmission time of data packets in the network, and thus reduce the end-to-end delay. When the number of nodes is 80, AM-AODV protocol is 15% better than ACA protocol.

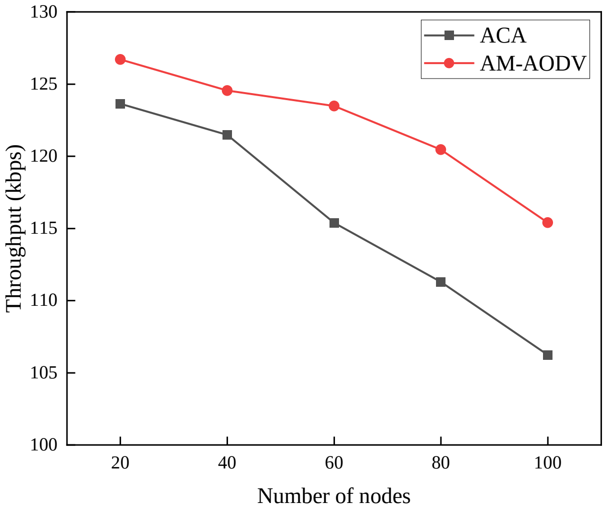

Figure.9 The impact of the number of nodes on throughput

Figure.9 shows that the AM-AODV protocol has higher throughput than ACA protocol when the number of nodes changes. ACA protocol does not pay enough attention to the load and energy of nodes. With the increase of the number of nodes, path selection will face more network load, resulting in a decline in the quality of the path, thus reducing throughput. AM-AODV protocol can select paths with less congestion and more energy, reduce the number of data packet losses and retransmissions, and maintain a high throughput in large-scale networks by optimizing route selection considering node density and congestion status. When the number of nodes is 80, AM-AODV protocol is 8% better than ACA protocol.

V. Conclusion

In order to solve the problem that traditional AODV can not effectively judge the congestion status of nodes and data transmission links in the network and deal with route break in the MANET network environment with dense nodes and dramatic topology changes, this chapter proposes a multi-path selection optimization algorithm AM-AODV based on ant colony optimization algorithm. In AM-AODV routing protocol, residual energy, congestion status and node density are introduced, and ant colony algorithm is combined to select a new path judgment metric. AM-AODV added pheromone to redesign the packet structure of RREQ and RREP and the routing table entries of the current node, and updated the receiving and processing flow of RREQ and RREP. AM-AODV algorithm avoids involving nodes with heavy load in the process of establishing routes, effectively reducing the redundancy of routing messages in the network, thus reducing competition and conflicts between nodes, and effectively restraining network congestion. In this paper, the introduction of new routing criteria helps to select a less congested and more stable communication path, which can improve the overall performance of the network.

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