Journal of Computers Vol. 33 No. 4, August 2022, pp. 205-213
doi: 10.53106/199115992022083304017

Improvement and Optimization of a Mobile Multi-agent AODV Routing Protocol

Quan-Hai Wang[1], Shao-Feng Lan[2], Jing Feng[2], Yi-Qun Wang[2], Wen-Bai Chen[2*]

[1] Northeast University at Qinhuangdao,
[2] School of Automation, Beijing Information Science and Technology University,
chenwb@bistu.edu.cn

Received 1 June 2022; Revised 8 July 2022; Accepted 8 August 2022

Abstract. In the scenario of node failure in mobile multi-agent, Ad hoc On-demand Distance Vector (AODV) routing protocol fails in network information transmission due to the damage of communication link. In addition, the existing AODV multipath routing protocol node load balancing mechanism is imperfect. In order to solve the low network survivability caused by the above problems, an improved responsive multipath routing protocol MD_AODV (Multipath Destroy-resistance AODV) is proposed. The protocol is optimized in three aspects: multi-channel concurrency mechanism, node load balancing mechanism and shortest path maintenance mechanism. The simulation analysis of the modified AODV multipath routing protocol is realized on OPNENT simulation platform. The simulation results show that compared with AODV protocol, the improved multipath routing protocol can enhance the utilization of network resources and has better link redundancy. Moreover, the modified routing protocol not only enhances the reliability and fault tolerance of the path, but also increases the network aggregation bandwidth.

Keywords: AODV protocol, multipath routing, network survivability, OPNENT simulation

1 Introduction

Mobile multi-agent is a multi-agent system that draws attention to the qualities of agent mobility, autonomous decision-making, self-adaptation and asynchronous execution [1]. Mobile multi-agent systems such as unmanned aerial vehicles have been widely used in military, environmental monitoring, emergency disaster relief and other aspects. It is the current technological development trend that mobile multi-agents form self-organizing networks, and the routing problem of task-oriented mobile multi-agent networks has always been one of the core research issues. The currently proposed routing protocols suitable for mobile multi-agent systems can generally be divided into three categories: proactive routing protocols, reactive routing protocols and hybrid routing protocols [2]. A commonly used protocol in reactive routing protocols is AODV protocol [3]. The AODV protocol is widely used in different scenarios, but it is a single-path protocol. Whenever the link is disconnected, the routing request process needs to be reinitiated, which increases the frequency of routing initiation and the end-to-end delay. In recent years, many schemes have been proposed to improve the performance of the AODV protocol. Zhang et al. [4] proposed a new protocol (SAODV) to improve AODV, in which multiple routing information is considered before routing selection. In SAODV (Statistical Ad hoc On-Demand Distance Vector), the selected routes are modified by combining different routing standards. These combinations include the length of the path and information from network conditions. Based on this, the new route is optimized for the target application. Alebeed et al. [5] proposed a routing protocol called Ad hoc On-demand Multipath Distance Vector (AOMDV), which is an extension of the AODV protocol.

However, for the application scenario of dynamic topology changes of mobile multi-agent network, the protocol still needs to be optimized. The existing AODV multipath routing protocol node load balancing mechanism is not perfect, and the routing update of multipath single-shot routing protocol is not timely, which is difficult to adapt to the application scenario of mobile multi-agent network topology dynamic change. In this paper, the AODV routing protocol is analyzed from the perspective of route design and implementation. An improved responsive multipath routing protocol MD_AODV is designed, and the design ideas and design processes of the protocol are described. The difference between this algorithm and the existing multipath routing algorithm is that the node load balancing mechanism, the multi-channel parallel transmission mechanism and the optimal routing maintenance mechanism in the routing establishment process. The main process for the implementation of the

* Corresponding Author

improved multipath routing protocol is route discovery and route maintenance. Based on the OPNENT simulation platform, the three routing protocols of AODV, AOMDV and MD_AODV are modeled and simulated. The improved multipath routing protocol has good performance in terms of network throughput and link redundancy, and has a good anti-destruction potential under the scenario of frequent changes in network topology.

2 Analysis of AODV Routing Protocol

AODV is reactive routing, that is, it only initiates routing discovery when the node has data to send, so that it is not necessary to periodically broadcast routing information to maintain communication between nodes, which can greatly reduce network overhead. However, with the deepening of research, many shortcomings of AODV have also been exposed, such as long delay, excessive consumption of energy of a node, inability to dynamically select the optimal route, broadcast storm and other problems. Therefore, it is necessary to improve the AODV routing protocol to better adapt to Ad Hoc network.

AODV route discovery process, as shown in Fig. 1, the source node first checks whether the local route has an effective route to the destination node before each packet is sent. If there is, it does not perform route discovery and sends data directly. If there is no effective route to the destination node, the RREQ (Route Request) message is broadcast to the surrounding neighbor nodes. If the surrounding node has received the same RREQ_ID message, the forwarding of RREQ is abandoned. If it has not received the RREQ message, the forwarding of RREQ is continued. Among them, the intermediate node also needs to query the local routing table to confirm whether there is reached in the RREQ corresponding destination node routing. If there is, it sends a RREP (Rout Reply) message to the source node and establishes a reverse route. When the node confirms itself as the destination node, it immediately establishes the reverse route and sends RREP to the previous hop node in the received RREQ. The other nodes do this repeatedly and finally sends RREP to the source node along a limited path. At this point, route discovery is completed.

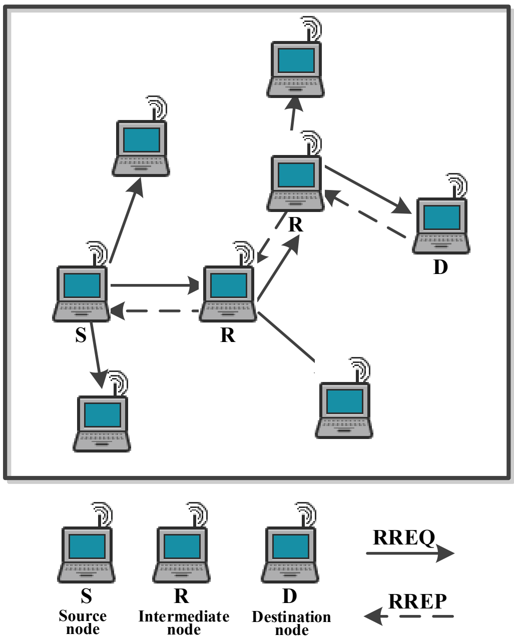

Fig. 1. AODV route discovery process diagram

AODV routing maintenance process, as shown in Fig. 2, the node periodically broadcasts HELLO messages to the surrounding neighbors to confirm whether the link between the neighbor node and the node is intact. When the routing maintenance node finds that the neighbor node has not carried out the ACK of HELLO messages for many consecutive times, it is considered that the link between the neighbor node and the routing maintenance node is disconnected, and the routing maintenance node sends RRER (routing error) to other neighboring nodes and upstream nodes. When the neighbor node and the upstream node receive RRER, they delete the unreachable routing information of the destination node corresponding to themselves. If the network based on AODV suffers from packet loss [6], node failure, path congestion [7] and other issues in the communication process, the data transmission from the source node to the destination node will not be guaranteed, because the AODV routing protocol belongs to the single-path routing protocol of end-to-end communication [8].

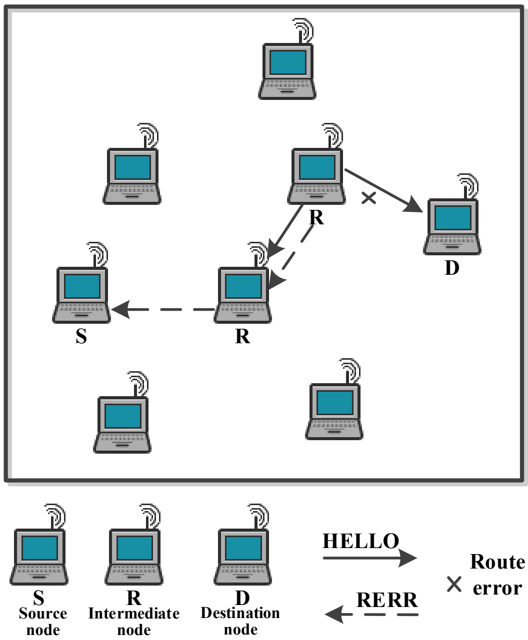

Fig. 2. AODV Route maintenance process diagram

At present, there are many studies on AODV routing protocol, mostly focusing on the balance of network energy consumption and the fault tolerance and reliability of paths. AOMDV is a multipath routing protocol based on AODV routing protocol. Generally, the multipath routing protocol has better performance than single-path routing protocol [9] in routing discovery frequency, average delay, network fault tolerance, etc. However, the current research on the invulnerability of mobile multi-agent multipath routing protocol is not perfect in the scenario of node failure leading to network damage, and AODV routing is a typical single-path routing protocol with better invulnerability. Therefore, it is necessary to further study the optimization of network invulnerability of AODV routing with single-path transmission in the scenario of node failure.

3 Improved MD_AODV Multipath Routing Protocol

3.1 Routing Protocol Improvement Ideas

In the scenario of node failure, AODV routing protocol fails to transmit network information due to the damage of communication link, and the existing AODV multipath routing protocol node load balancing mechanism is not perfect. In addition, the routing update of multipath single routing protocol is not timely, and it is difficult to adapt to the application scenario of dynamic topology change of mobile multi-agent network. In order to solve the low network survivability caused by the above problems, this paper designs an improved multipath routing protocol based on the following three improvement ideas.

1) Multi-channel Concurrency Mechanism

When the source node needs to send data to the destination node, the source node sends the application layer data in parallel from the multiple routes found each time. MD_AODV adopts this link redundancy mechanism. When the mobile multi-agent network is interfered and some nodes fail, for the transmission reliability of the same application layer data, the probability of data transmission failure will be inversely proportional to the number of effective paths. This mechanism can effectively improve the success rate of data transmission in the network.

2) Node Load Balancing Mechanism

When the node receives RREQ during the process of establishing a route, the network will first determine whether the node is already the intermediate route of the same type of RREQ. If so, the RREQ data will be discarded to avoid forming a route intersected by nodes; if it is not the same type the RREQ determines whether the number of local valid routing tables of the node reaches the maximum threshold. If it reaches the maximum threshold, the RREQ is discarded to prevent the load of the node exceeding the upper limit of the load of the node itself. The final network is a node load balancing network system in which nodes do not intersect in the same type of routing.

3) Shortest Path Maintenance Mechanism

In the process of route repair, AODV adopts the mechanism of local repair, while MD_AODV route adopts the mechanism of source node repair, and always selects the smallest hops as the available route when routing discovery. After the route is disconnected, repairing from the source node can make the effective path from the source node to the destination node update a current best route in time, that is, the route with the smallest hops. For the network with node failure, from the analysis of probabilistic events, the fewer nodes passed in the network link, that is, the smaller the hops, the lower the probability of damage to the link; the smaller the number of routing hops, the lower the network transmission delay, and the overall link quality of the network will be improved.

3.2 Improved Routing Protocol Design Process

The overall process of MD_AODV routing protocol implementation is described as follows:

Step 1: Initialize the state variables of the routing protocol, mainly including obtaining the relevant ID and node address within the node, obtaining the memory area of the data cache queue for the MD_AODV subprocess, and obtaining the number of nodes. Initialize the node serial number, initialize the RREQ_ID, initialize the times of RREQ retransmissions, initialize the RREP sending handle, create the multipath cache queue, initialize the RREQ sequence number received by the node, initialize the routing table and the neighbor node table, initialize the RREQ request queue, set the maximum number of paths, and set the maximum threshold of node load.

Step 2: Wait for and process the data coming from the upper and lower MAC, mainly including determining the node corresponding to the destination address of the packet, setting the packet domain and size of the data packet, counting the packets that need to be transmitted, refreshing the routing table entries, data packets delivery, and handling the lower data packet.

Step 3: Data and network maintenance, mainly including RREQ retransmission after RREP timeout, periodic HELLO packet sending, RRER processing and route repair after link disconnection.

The main process of the improved multipath routing protocol is route discovery and route maintenance.

1) Route discovery

The source node needs to send data to the destination node. When the source node has multiple paths cached to the destination node, the data will be sent from multiple paths in parallel. When there is no effective path to the destination node, the source node will broadcast RREQ. The node receives RREQ packets to judge whether the number of effective paths loaded by the node reaches the set threshold, whether the RREQ packet reaches the maximum broadcast hop, and whether the repeated RREQ packets are received. If the above conditions are not met, the RREQ package is further processed. Record the packet sequence number (RREQ_ID) and set the address of the first hop (First_Hop), update the local node to the source node routing. If the node is the destination node, the RREP response packet will be fed back. If it is not the destination node and does not reach the maximum broadcast range, the RREQ message is continued to be forwarded. The routing algorithm flow of updating the local node to the source node is shown in Table 1. Based on the effective paths cached from multiple source nodes to destination nodes in the above routing discovery, the destination node sends packet data immediately after receiving RREP, and sends multiple packet data correspondingly after receiving multiple RREPs. The MD_AODV routing discovery mechanism is shown in Fig. 3. In the process of route discovery, the node load balancing mechanism is realized by judging the number of effective paths loaded by the node and selecting the node disjoint link when the route is updated.

Table 1. Routing algorithm flow of updating local node to source node in RREQ

Algorithm 1. Routing algorithm for updating local nodes to source nodes in RREQ

Input: RREQ data received by the node, source node routing list in RREQ data

```
1   IF: source node serial number in RREQ > destination node serial number in routing table corresponding to
        the source node address in RREQ
    {
2       Clear the routing sequence information corresponding to the source node address in RREQ;
3       Write the latest next address, the next hop address after the group, the number of hops, and the lifetime
        to the routing sequence;
4       Add the updated routing sequence to the routing list corresponding to the source node address in RREQ;
    }
5   ELSE IF: source node sequence number in RREQ == destination node sequence number in the routing table
             corresponding to the source node address in RREQ
    {
6       IF: The number of routes corresponding to the source node address in the RREQ > the maximum
            number of unicast paths (Path_num)
        {
7       |   Discard RREQ packets;
        }
8       FOR: j=0;  j < The number of paths (Path_size) to the destination node corresponding to the source
             node in the RREQ
        {
9       |   IF: There is no node intersecting link between the local path and the original link of the routing
        |   |   table
        |   |   {
10      |   |   |   FOR: j=0; j < Path_size; j++
        |   |   |   {
11      |   |   |   |   IF: Route hop count (HopCount) in RREQ < hop count in the routing sequence
        |   |   |   |       corresponding to the destination node address in RREQ
        |   |   |   |   {
12      |   |   |   |   |   Update routing sequence;
13      |   |   |   |   |   Add the updated routing sequence to the routing list corresponding to the
        |   |   |   |   |   source node address in RREQ;
        |   |   |   |   }
        |   |   |   }
        |   |   }
14      |   ELSE
        |       {
15      |       |   Discard RREQ packets;
        |       }
        }
    }
16  ELSE
    {
17      Discard RREQ packets;       // expired RREQ information
    }
```

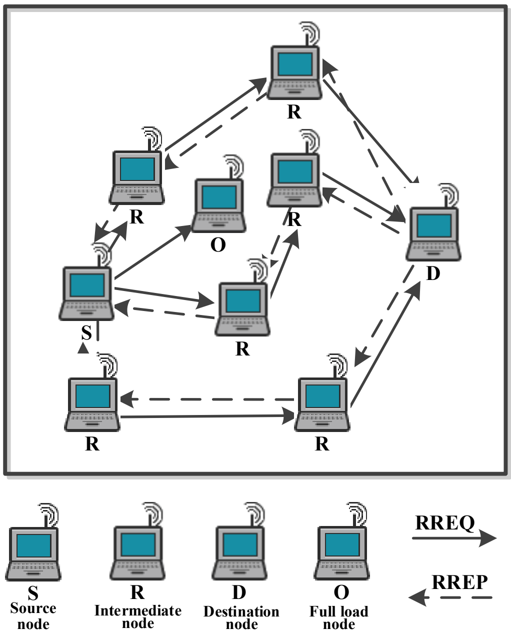

Fig. 3. MD_AODV routing discovery process diagram

2) Route maintenance

In the initial stage of route maintenance, similar to the AODV mechanism, it periodically broadcasts HELLO messages to determine whether to send RRER messages. When a node receives an RRER, it notifies its neighbor node and the last hop node, deletes the routing with the node as the next hop, and establishes the routing when the data application layer sends the data again. Table 2 is the process of RRER packet information processing. At this time, there is no local routing repair and destination node routing repair. The reason is that in the scenario where the node fails and the topology of the mobile multi-agent network changes frequently, the locally repaired route is often not the shortest route from the current destination node to the source node. Based on the basic characteristics of passive routing, the source node repair is not carried out at this time, but when the source node retransmits RREQ, so as to realize the path maintenance from the source node to the destination node. The MD_AODV route maintenance process is shown in Fig. 4.

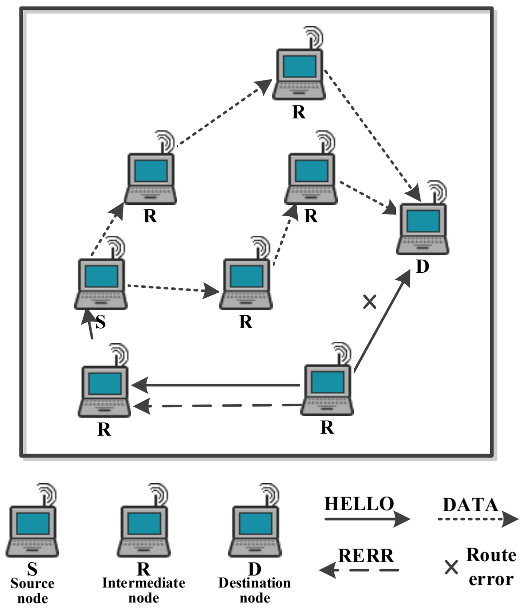

Fig. 4. MD_AODV routing maintenance process diagram

Table 2. RREP packet data processing algorithm flow

Algorithm 2. RREP packet data processing algorithm

Input: RREP data received by the node, source node data and destination node data in RREP data

```
IF：Node receives RRER packet data
{
    Get the source node address (Source_addr) and destination node address (Dest_addr) in RRER;
    Destroy the RRER packet data;
    IF：The number of broadcast hops (Broadcast_HopCount) corresponding to the destination node
        address in the RRER < the total number of nodes in the network + 1
    {
        Path_size = the number of paths corresponding to the destination node address (Dest_addr.path)
        in RRER;
        FOR: j = Path_size-1; j ⩾ 0; j—
        {
            Get the routing sequence information in the path (Path_info);
            IF：Next hop address in Path_info (Next_addr) == Source_addr
            {
                Delete the routing information corresponding to Dest_addr in Path_info;    //The path
                corresponding to the destination node address in RRER has been updated
            }
        }
        IF: The number of paths corresponding to the destination node address (Dest_addr.path) in RRER
            == 0 && Path_size > 0
        {
            WHILE：The forward address corresponding to the destination node address
                   (Dest_addr.Precursor_addrlist) in RREQ > 0
            {
                Clear the predecessor node (Pre_node_addr) corresponding to
                Dest_addr.Precursor_addrlist;
            }
            Source node address (Source_addr) in RRER = local node address (My_node_addr);
            Regroup RRER number;
            Send the RRER packet information to the MAC for processing;
        }
    }
}
```

4 Simulation Results and Analysis

4.1 Simulation Parameter Setting

1) Simulation scene parameter setting

As shown in Table 3, the mobile agent nodes are randomly deployed in the network area, and the agent nodes move randomly within the deployed network area. The creation of random movement model is as follows, open the Mobility Config module, in its Attributes, enable Mobility Modeling Status. Register a custom random movement path in the Random Mobility Profiles, setting the name of the random movement path as Default Random Waypoint. The range of lateral positions for random movement is set to (0, 2000) m, the range of longitudinal positions is (0, 2000) m, and the movement speed obeys uniform distribution of (0, 10) m/s. Every 10s of the node moves, the movement time is suspended for 100s, until the network operation ends the node completely stops moving randomly. After the random move attribute is established, select the agent node that needs to be configured with random movement, and configure the same random move attribute for all mobile agent nodes. Card Toplogy → Random Mobility to select the previous custom random movement model, and then click Set Trajectory Created from Randdom Mobility, and select the VECTOR path in the node path attribute, so as to complete the random movement attribute modeling of the selected node.

Table 3. Improved parameter setting of multipath routing simulation scene

Parameter	Setting value
Scene range	50 km×50 km
Number of nodes	50
Simulation time	20 min
Node movement scene	Random movement
Maximum communication distance of nodes	3000 m
Data transfer rate	1 Mbps

2) Simulation running parameter settings

In the simulation process, three simulation sequences are set up to simulate the three routing protocols AODV, MD_AODV and AOMDV respectively. The running time of the simulation is set to 20 minutes. Before the simulation, the number of MD _ AODV maximum effective paths is set to 3, the number of MD _ AODV maximum effective paths that any node can load is set to 50, and the packet delivery rate in the network is 1pkts/s, that is, a data packet per second; AODV and AOMDV routing protocols are implemented according to the standard, and the packet sending rate is also 1pkts/s.

4.2 Results Analysis

1) Comparison of the number of valid paths

Fig. 5 shows the comparison of the number of effective paths of the mobile multi-agent network based on MD_AODV, AODV and AOMDV routing after running the simulation. As can be seen from the figure, the number of effective paths generated by MD_AODV is always higher than that of AODV and AOMDV during network operation. It can be seen that the link redundancy of MD_AODV is obviously better than that of AODV and AOMDV.

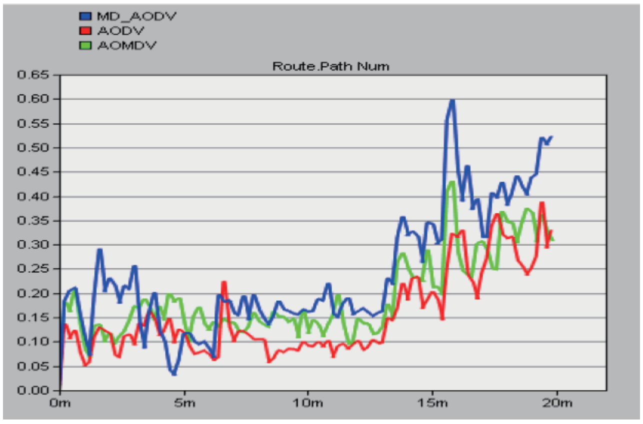

Fig. 5. Comparison of effective path number

2) Network throughput

Fig. 6 shows the comparison of network throughput of mobile multi-agent networks based on MD_AODV, AODV and AOMDV routing after running simulation. Network throughput refers to the amount of data that can be successfully transmitted per unit time in the network. The greater the network throughput, the better the network communication ability. It can be seen from the figure that with the advancement of simulation time, the network throughput persistence of MD_AODV is better than that of AODV and AOMDV. From the perspective of network throughput, the data transmission capacity of the mobile multi- agent network based on MD_AODV routing is better than that of AODV and AOMDV in the case of frequent network topology changes.

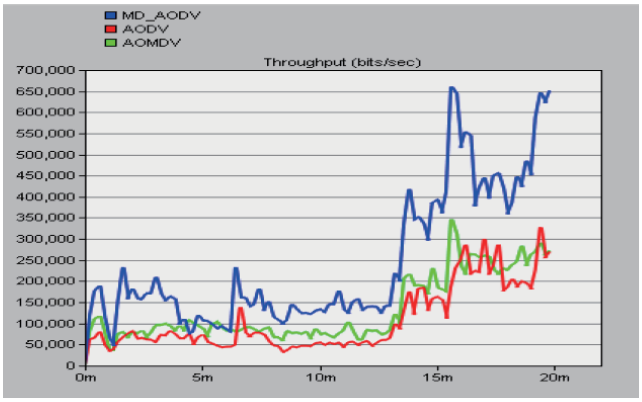

Fig. 6. Network throughput comparison

5 Conclusion

Based on the improved mobile multi-agent multipath routing protocol of AODV, this paper analyzes the basic mechanism of AODV routing protocol, puts forward the idea of routing improvement, and introduces the key algorithm implementation of the modified protocol in detail. Based on the above theoretical research, this paper establishes the mobile multi-agent node model based on the multipath routing protocol through OPNET simulation platform, and analyzes the performance of the improved multipath routing protocol, AODV routing protocol and AOMDV routing protocol based on the established model. The results show that the improved multipath routing protocol has good performance in network throughput and link redundancy. It can be seen that the improved multipath routing protocol has preferable survivability potential than AODV routing and AOMDV routing in the scenario of frequent changes in network topology. But there are still some limitations. For example, we did not conduct in-depth research on the invulnerability of routing protocols in different network damage scenarios. Therefore, the invulnerability of the improved multipath routing algorithm in the network damage scenario will be further studied through different network damage models. At the same time, we believe that we should consider more factors, combined with the agent cooperative control algorithm, topology evolution and network reconfiguration technology, to study the invulnerability of the agent network is an important research direction.

References

[1] M.-Y. Li, R.-B Wang, Key Technologies of Collaborative Work Based on Multi-agent, Computer Applications and Software 36(6)(2019) 21-25.
[2] J. Wang, C. Liu, W.-F. Li, K.-Y. Li, Heterogeneous multi-mode access in smart grid using BeiDou communication, Microprocessors and Microsystems 47(2016) 244-249.
[3] H. Moudni, M. Er-Rouidi, H. Mouncif, B.E. Hadadi, Performance analysis of AODV routing protocol in MANET under the influence of routing attacks, in: Proc. 2016 International Conference on Electrical and Information Technologies, 2016.
[4] W.-B. Zhang, X.-Q. Xiao, J.-J. Wang, P. Lu, An improved AODV routing protocol based on social relationship mining for VANET, in: Proc. 4th International Conference on Communication and Information Processing, 2018.
[5] H. Alebeed, a spectrum decision scheme for cognitive radio ad hoc networks, [dissertation] TRNC: Eastern Mediterranean University, 2016.
[6] J.-Y. Feng, G.-Y. Lu, Z.-Q. Bao, A survey on cognitive radio security, Journal of Xi’An University of Posts and Telecommuniations 17(2)(2012) 47-52.
[7] M.K.D. Barma, R. Chowdhuri, N. Debbarma, S.K. Sen, S. Roy, Enhancing the Performance of AODV Using Node Remaining Energy and Aggregate Interface Queue Length, in: Proc. IEEE 2013 International Symposium on Computational and Business Intelligence, 2013.
[8] D.-Y. Zhang, J.-L. Wang, Research on Performance Comparison among Improved AODV Routing Protocols, Computer Technology and Development 20(1)(2010) 67-70.
[9] L.-G. Wang, Z.-P. Jia, X. Li, Performance analysis and comparison of AODV and AOMDV routing protocols, Journal of Computer Applications 30(3)(2010) 740-744.