An AODV Routing Algorithm Based on Energy Consumption

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Abstract—The mobile Ad Hoc network solves the problem of quickly establishing a temporary Ad Hoc network without the need for fixed facilities. However, problems such as network performance degradation, delay increase, and link interruption are endless. Aiming at the problem of shortening the survival time of Ad Hoc network nodes, this paper proposes an improved AODV routing algorithm RE-AODV based on energy consumption. RE-AODV takes energy as the starting point, determines the time extension according to the remaining energy of the current node, balances the energy consumption of each node, and extends the net-work lifetime. The network simulator NS-3 is used to realize the effectiveness of the RE-AODV routing algorithm. The simulation results show that the RE-AODV routing optimization algorithm can effectively extend the network survival time, reduce the number of dead nodes, and effectively solve the wireless Ad Hoc network compared with the AODV routing protocol. The problem of energy consumption can improve the overall performance of the network.

Keywords—Ad Hoc networks, Energy consumption, NS-3 simulation, RE-AODV protocol.

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1. Introduction

WITH the explosive growth of network scale, the diversified development of new services and the continuous upgrading of intelligent terminals. Wireless Ad Hoc networks began to enter a period of rapid development, and the mobile Ad Hoc network [1] defined by the standard has become a research hotspot in the network field. Researchers have studied Ad Hoc routing protocols from different angles [2-7]. Among them, Ad Hoc on-demand distance vector routing (AODV) has attracted extensive attention of re-searchers because of its low routing overhead, simple routing control and good expansibility. However, the source node only executes the route discovery process when the protocol needs routes, and only maintains active routes. There are some problems, such as long route discovery time and short network survival time. In recent years, many scholars have optimized AODV Routing Protocol in different aspects [8-16]. Literature [14] proposed an improved AODV routing protocol based on energy balance and congestion, which further improved the routing performance, but when the nodes in the network move violently, the nodes with less energy will be discarded. Literature [15] proposed a mesh network packet forwarding mechanism based on AODV, which is optimized in terms of protocol overhead and end-to-end delay. However, frequent use of packet forwarding may result in insufficient node energy. Literature [16] proposed an AODV routing protocol that prioritizes nodes with high energy and high signal strength. Even if the original route is broken, the backup route will be activated immediately, but the possibility of route breakage will increase. Therefore, in order to reduce the number of node deaths and prolong the survival time of the network, this paper proposes a routing algorithm based on energy consumption, RE-AODV. By balancing the energy consumption of each node, it solves the problem of small nodes being discarded, insufficient node energy and routing broken. And other issues.

2. Related Work

2.1 Basic AODV Routing Protocol

AODV protocol is a commonly used on-demand routing protocol in Ad Hoc networks. It is proposed after adding on-demand routing mechanism on the basis of table driven routing protocol DSDV and improving it. The routing protocol was developed by Charles E. Perkins of Nokia Research Institute, Elizabeth M. Belding-Roryer of State of California, Samir R. Das of Cincinnati University. At present, it has been added to RFC 3561 standard by Internet Engineering Task Force.

The AODV protocol executes the route discovery process by the source node when routing is needed, and only maintains active routes, so new destination routes can be quickly discovered without maintaining inactive routes. It can effectively avoid periodic updates of routing information and save network overhead. The AODV routing protocol will send different routing protocol packet messages under different circumstances. The routing protocol packet messages include: routing request RREQ message, routing response RREP message, routing error RERR message, and routing response confirmation ACK message.

2.2 Limitations of AODV Routing Protocol

AODV adopts new on-demand routing, so that each node in the network will not maintain the routing table containing the entire network route, and only execute the route discovery process when data transmission is needed but there is no unreachable routing path. Its limitations are summarized as the following four points:

•The impact of the two-way transmission channel: As the route discovery process requires the establishment of a reverse route and two-way communication, the use environment must be able to send data in both directions.

• The impact of frequent changes on performance: In order to prevent loops, the node routing table can only have one path to the destination node. Therefore, whenever the network topology changes, it is necessary to re-find the path.

• The impact of timeout deletion: Because the AODV protocol uses a timeout deletion mechanism, no matter whether the sending path is damaged or not, it will be deleted as long as the timeout expires.

• The impact of node energy is not considered: the protocol itself does not calculate energy consumption, making key nodes easy to die and leading to largescale changes in the network topology. Therefore, the level of energy consumption must be added to improve the AODV protocol.

3. Node Model Based on Energy Consumption

3.1 Node Energy Consumption Model

In the process of Ad Hoc node transmission, energy consumption mainly comes from data transmission and reception. At the same time, node energy will also be consumed as the communication distance increases.

(a) Energy Consumption for Sending Data

When the source node is sending data, in the case of a data transmission process where the transmission distance is d and the amount of data sent is *s* bits, two different transmission modes can be set: when $d < d_0$, the free space energy consumption model is adopted; when $d \geq d_0$, the multi-channel attenuation energy consumption model is adopted.

The calculation method of sending data energy consumption is as follows:

$$E_{Tx}(s,d) = E_{Tx-elec}(s) + E_{Tx-amp}(s,d) = \begin{cases} sE_{elec1} + s\varepsilon_{fs}d^2, d < d_0 \\ sE_{elec1} + s\varepsilon_{amp}d^4, d \geq d_0 \end{cases} \tag{1}$$

In formula (1): E_{Tx} is the energy consumed by sending data; (*s*, *d*) is the situation when the transmission distance is *d* and the amount of data is *s* bits; $E_{Tx-elec}$ is the energy consumed by the node to monitor the data; E_{Tx-amp} is the energy consumed by the transmitter signal amplification; E_{elec1} is the energy consumed by the node to send each bit of data; ε_{fs} is the acceptable error rate for free space transmission; ε_{amp} is the acceptable error rate for multipath fading transmission, and d_0 is the threshold. The calculation method of the threshold is shown in formula (2):

$$\mathrm{d}_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \tag{2}$$

(b) Energy Consumption for Receiving Data

When the destination node receives data, when the transmission distance is d and the transmitted data is s bits, its energy consumption is:

$$E_{Rx}(s,d) = E_{Rx-elec}(s) = sE_{elec2} \tag{3}$$

In formula (3): E_{Rx} is the energy consumed to receive data; $E_{Rx-elec}$ is the energy consumed by the receiver to monitor; E_{elec2} is the energy consumed by the node to receive each bit of data.

3.2 Node Remaining Energy

In the process of forwarding route request messages, frequent use of route discovery will result in insufficient node energy, resulting in a waste of node energy. Therefore, it is inevitable to consider the node energy factor. By selecting nodes with large remaining energy for routing message forwarding, the problem of insufficient node energy can be effectively solved.

The calculation method of the remaining energy at time t is as follows:

$$RE_t = RE_{t-1} - E_{Tx}(s,d) - E_{Rx}(s,d) \tag{4}$$

In formula (4): RE_t is the energy consumed by the routing of the node at *t*; $RE_{t\text{-}1}$ is the energy consumed by the routing of the node at *t*-1.

$$RE_{CR} = \frac{E - E(t)}{E} = \frac{RE_t}{E} \tag{5}$$

In formula (5): RE_{CR} is the ratio of remaining energy consumption, *E* is the initial energy of each node in the initial stage of the network; *E (t)* is the energy consumed by the node routing within *t*.

When a node forwards an RREQ message, if the node receives the message for the first time, it will decide whether to delay forwarding it to the next node based on the remaining energy consumption ratio of the node's RE_{CR}. When RE_{CR} is greater than or equal to a constant λ, the operation of forwarding RREQ messages is performed; when RE_{CR} is less than a constant λ, RREQ messages are not forwarded.

$$Forward(P, RE_{CR}) = \begin{cases} 1, & RE_{CR} \geq \lambda \\ 0, & RE_{CR} < \lambda \end{cases} \tag{6}$$

In formula (6): P is the data packet generated by this node, and *Forward* is the forwarding function used by the AODV protocol, and λ is the threshold.

4. AODV Routing Protocol Algorithm RE-AODV Based on Energy Consumption

4.1 The Basic Idea of RE-AODV Algorithm

At present, there are two main types of routing algorithm ideas for reducing energy consumption in Ad Hoc networks:

(1) sending data with the least energy as much as possible;

(2) trying let the network survive longer.

The first routing algorithm idea is to use the routing with the smallest transmit power to save the energy consumed by sending data. The disadvantage of this algorithm is that if the network topology has not changed or there are uncompleted data packets, this path will be reused. Some key nodes die due to energy exhaustion, leading to network fragmentation, which will affect the timeliness and stability of the routing network to a certain extent.

The second routing algorithm idea is proposed to solve the above problems, by protecting nodes with less remaining energy to prolong the network survival time and reduce the probability of network fragmentation.

The algorithm in this paper is based on the above two points, combined with minimizing the cost of each packet and minimizing the energy level difference of nodes, and proposes a routing algorithm based on energy consumption, RE-AODV. This routing algorithm is suitable for use on Ad Hoc networks. The algorithm adopts an on-demand query method, which can effectively reduce node energy consumption and prolong node survival time.

4.2 RE-AODV Algorithm Design

Step 1: When the node receives the RREQ message, it detects the neighbor node list around it, and if the neighbor node is the destination node, it immediately forwards the RREQ message.

Step 2: If the surrounding nodes are not the destination node and cannot directly reach the destination node, they will not forward the RREQ message immediately, and judge whether to forward the RREQ message according to the remaining energy of the node. If the remaining energy is RE, the RREQ message is immediately forwarded and the node energy is consumed. Otherwise, the RREQ message is not forwarded.

Step 3: If the surrounding nodes are not the destination node and can directly reach the destination node, the RREQ message will not be forwarded immediately, but the delay will be dynamically increased according to the current energy consumption value of the node, and then the message will be forwarded.

Introduced the energy consumption decision mechanism, improved the shortcomings of the traditional AODV protocol, and generated an improved RE-AODV routing algorithm. The pseudo code of the RE-AODV algorithm is shown in the figure below.

1. For（List of all neighbor nodes）
2. IF（This node is the destination node）
3. THEN
4. Forward RREQ messages immediately；
5. ELSEIF（The node is not the destination node&& Can't reach the destination node directly）
6. THEN
7. Don’t forward RREQ messages immediately AND Determine whether to forward RREQ messages according to RE_{CR}
8. IF ($RE_{CR} \geq \lambda$)
9. Forward RREQ message to all neighbor nodes
10. ELSE
11. Don’t forward RREQ messages
12. ELSEIF（The node is not the destination node&& Can reach the destination node directly）
13. THEN
14. Don’t forward RREQ messages immediately && Dynamically increase the delay according to the *RE*, and then forward the RREQ messages

4.3 Routing Discovery

When the source node needs to send a data packet to the destination node, it must first consider whether there is an effective route directly to the destination node. If there is no effective route, a route discovery process needs to be started. The flow chart of route discovery is shown in Figure 1.

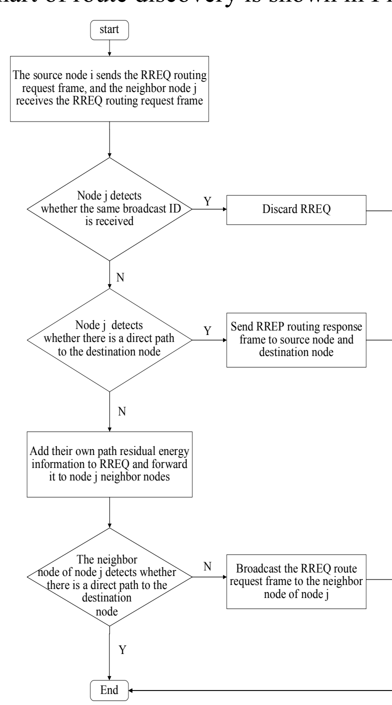

Fig. 1 Route discovery process

The route discovery steps are as follows:

(1) Suppose that the source node i first broadcasts the RREQ route request packet to its neighbors and is received by the neighbor node j.

(2) After the neighbor node j receives the RREQ route request packet, it first detects the broadcast identifier. If the same identifier has been received before, the RREQ is discarded. If the same identifier is not detected, it is determined whether there is a direct path to the destination node.

(3) If there is a direct path to the destination node, directly send RREP control packets to the source node and the destination node. Otherwise, add the remaining energy information of its own path to the RREQ routing request packet and forward it until the RREQ is sent to the destination node.

(4) If the above conditions are not met, the route discovery process will continue until the RREQ is sent to the destination node.

5. Experiments Results and Discussion

5.1 Simulation Environment

The parameters in the script are set as follows: The required (default 40 nodes) of the experiment are generated in the script. The random direction-2d-mobility-model is used to determine the movement direction and speed of the nodes. It's 500m by 500m.The initial energy is 10 joules. In the script, 4 packets are sent per second, the packet size is 1024 bytes, and the bandwidth is 6m; and the node sending radius is 200m by default; the free space energy consumption model is adopted.

Other settings: The wireless model uses the basic IEEE 802.11 DFC (Distributed Coordination Function) with Ad Hoc mode, and the channel is Wifi Channel.

Experimental environment: VM virtual machine, LINUX system, NS-3, eclipse C++ editor.

5.2 Experimental Results and Discussion

Under the same conditions of setting other environments, by setting the number of different nodes and initial energy, the impact of the new algorithm on the average delay, packet delivery rate, network lifetime, etc. is examined.

(a) Average delay

As shown in Figure 2, the fixed initial energy is 10J, the simulation step is 20, and the number of nodes is increased from 20 to 100, and the average delay change is measured. It can be seen that when the number of nodes is small, the network topology does not change in time, and the time delay between the two tends to be close; when the random movement of the node causes the network topology to dynamically change, because the RE-AODV algorithm takes into account the energy consumption of the node, With the increase in the number of nodes, the average delay of the RE-AODV routing protocol is slightly higher than that of the original AODV routing protocol.

The number of fixed nodes is 100, and the simulation simulated scenarios with initial energy of 10, 15, 20, 25, 30, 35, and 40 respectively. When the remaining energy of the node is high, the improved protocol is no different from the original protocol, so the delay of the lower initial energy and the higher initial energy is basically the same; when the remaining energy is low, the key node dies and rerouting causes the delay to increase ; At other times, the RE-AODV protocol preferentially selects paths with longer hops to protect key nodes, resulting in increased delay, but the increase in delay is still controlled at a relatively low level. As shown in Figure 3.

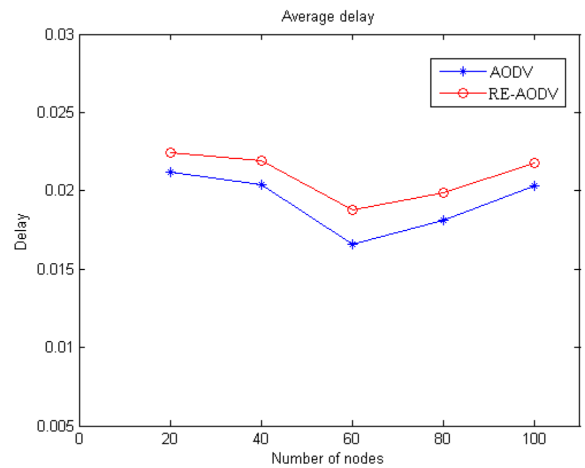

Fig. 2 Effect of number of nodes on average delay

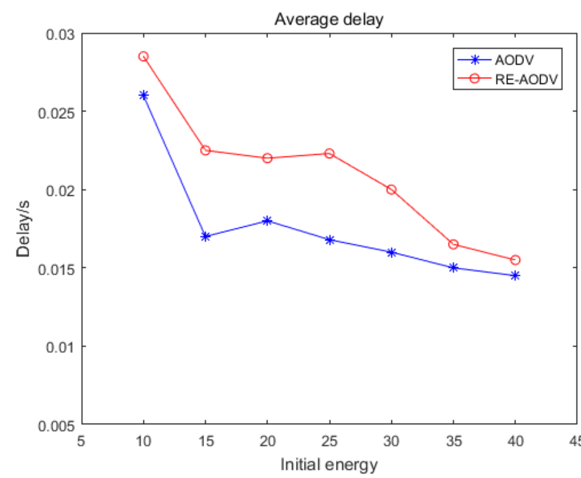

Fig. 3 Effect of number of nodes on average delay

(b) Packet delivery rate

The selection and comparison of the packet delivery rates of the two protocols under different numbers of nodes are selected. As shown in Figure 4. When the number of nodes is 20 and 40, the delivery rates of the two tend to be equal. As the number of nodes increases, the changes in network topology become more obvious. The packet delivery rate of the RE-AODV protocol is gradually higher than that of the original AODV protocol. When the number of nodes is 100, the packet delivery rate of the RE-AODV protocol is compared to the original AODV agreement has increased by 0.66%.

The packet delivery rates of the two protocols under different initial energies are selected and compared. When the initial energy is 10 and 15, because we use the RE-AODV algorithm, the RE-AODV protocol will execute the algorithm to protect the key nodes so that they will not die soon and effectively increase the packet delivery rate. Therefore, the RE-AODV protocol is the delivery rate is significantly higher than the original AODV agreement. With the increase of the initial energy, the delivery rate showed an upward trend before and after the improvement, and finally stabilized at 100% delivery rate. As shown in Figure 5.

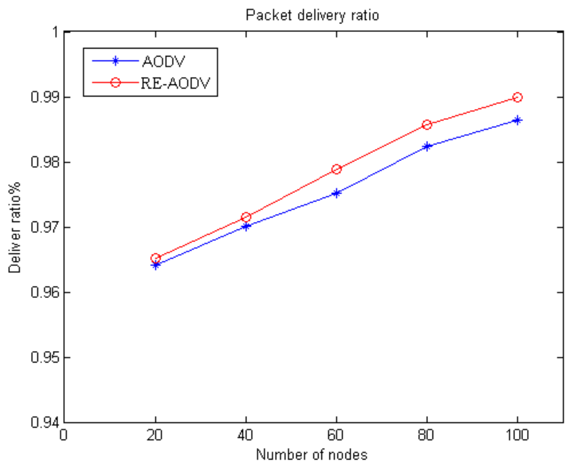

Fig. 4 Effect of number of nodes on packet delivery rate

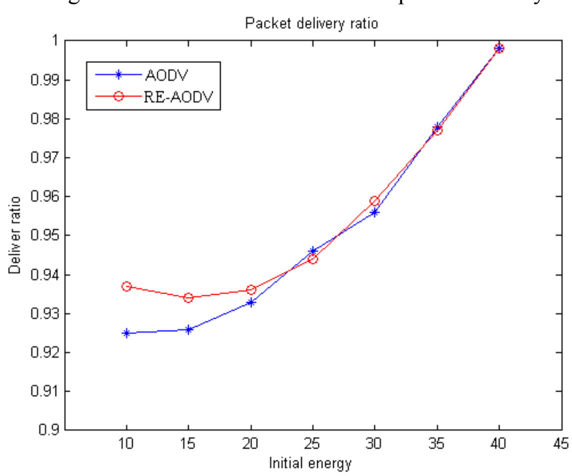

Fig. 5 Effect of initial energy on packet delivery rate

(c) Network lifetime

The experiment selected 5 nodes with different numbers for comparative analysis. The results show that when the number of nodes is 20, 40, 60, 80, 100, the network survival time of the improved protocol using the RE-AODV algorithm is significantly higher than that of the original AODV protocol. At the same time, with the increase in the number of nodes, the difference in network survival time between the RE-AODV protocol and the original AODV protocol becomes more and more obvious. As shown in Figure 6.

The experiment selected nodes with initial energy of 10, 15, 20, 25, 30, 35, and 40 for comparative analysis. The experiment found that the overall life span of the RE-AODV routing protocol is better than that of the original AODV protocol. This is because the RE-AODV algorithm protects key nodes, makes the energy consumption of all nodes in the network as even as possible, and effectively extends the network life cycle. As shown in Figure 7.

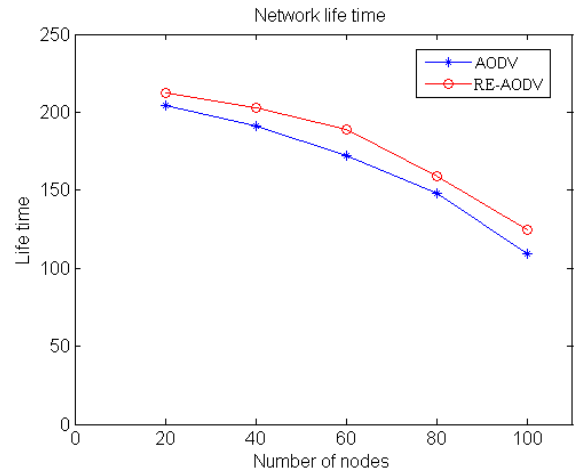

Fig. 6 Effect of number of nodes on network lifetime

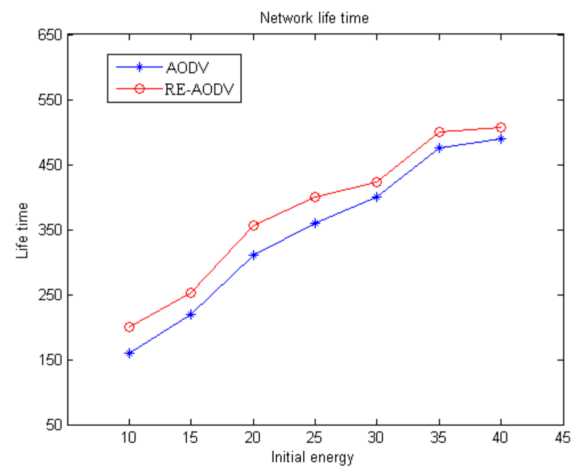

Fig. 7 Effect of initial energy on network lifetime

5.3 Test Conclusion

From the comparison of average delay, packet delivery rate and network survival time, as the number of nodes and initial energy increase, the RE-AODV protocol has achieved energy saving and prolonged network survival despite sacrificing part of the average delay. Purpose. During data transmission, the RE-AODV algorithm adopts an energy-saving strategy. First, the intermediate nodes with lower energy are protected. When the energy is lower, the packet delivery rate can be effectively guaranteed, and the energy of all nodes can be balanced, which fundamentally extends the overall survival of the network. time.

6. Conclusion

In order to protect key nodes from dying quickly, this paper proposes an energy-constrained routing algorithm RE-AODV, which detects the energy consumption of each node in the network at all times, and maintains the life time of the network by protecting low-energy nodes. The simulation experiment results show that compared with the original AODV protocol, the algorithm successfully prolongs the network survival time, reduces the number of dead nodes, and better optimizes the energy consumption problem of wireless Ad Hoc networks. However, this article does not consider the location of key nodes in the topological network. The follow-up work will continue to conduct in-depth research on the topological location and prediction of nodes while ensuring the stability of the network link.

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References

[1] Himanshu Walia, Mandeep Singh, and Rahul Malhotra, A review: mobile Ad Hoc routing protocols, International Journal of Future Generation Communication and Networking, vol. 9, no. 2, pp. 193-198, 2016

[2] Bai X, Zhao D, and Bai S, et al, Minimum connected dominating sets in heterogeneous 3D wireless Ad Hoc networks, Ad Hoc Networks, vol. 97, no. 102023, 2020

[3] Liang Jianwu, Liu Xiujuan, Liu Xiaobo. Energy Aware Routing Protocol based on Direction Prediction in Ad Hoc Network [J]. Application Research of Computers, 2017, 34(07): 2108-2112.

[4] Sorribes, Jose Vicente et al. Collision Avoidance Based Neighbor Discovery in Ad Hoc Wireless Networks[J]. Wireless Personal Communications, 2021: 1-25.

[5] X. J. Du, D. Wu. Adaptive Cell Relay Routing Protocol for Mobile Ad Hoc Networks[J]. IEEE Transactions on Vehicular Technology, 2006, 55: 278-285.

[6] Aqeel Taha, Raed Alsaqour, Mueen Uddinet al. Energy Efficient Multipath Routing Protocol for Mobile Ad-Hoc Network Using the Fitness Function[J]. IEEE Access, 2017, 5: 10369-10381.

[7] Yang Li, ZHAO Wenhong, WANG Wei, et al. Secure Routing Protocol in Ad Hoc Network Based on Reliable Backbone Network. Journal of Sichuan University (Engineering Science Edition), 2016, 48(02): 111-117.

[8] Arush Sharma, Dongsoo Kim. Energy efficient multipath ant colony based routing algorithm for mobile Ad Hoc networks[J]. Ad Hoc Networks, 2021, 113: 102396-102410.

[9] Mohammad Nabati, Mohsen Maadani, Mohammad Ali Pourmina. AGEN-AODV: an Intelligent Energy-Aware Routing Protocol for Heterogeneous Mobile Ad-Hoc Networks[J]. Mobile Networks and Applications, 2021: 1-12.

[10] Li Jiamin, Wang Mengling, Zhu Pengcheng, et al. Highly Reliable Fuzzy-Logic-Assisted AODV Routing Algorithm for Mobile Ad Hoc Networks[J]. Sensors, 2021, 21: 5965-5965.

[11] Mohit Angurala, Manju Bala, Sukhvinder Singh Bamber. Performance Analysis of Modified AODV Routing Protocol With Lifetime Extension of Wireless Sensor Networks[J]. IEEE Access, 2020, 8: 10606-10613.

[12] Liang Jianwu, Ma Xiaoliang, Xu Longlong. Research and Optimization of AODV Routing Protocol in Mobile Ad Hoc Network. Journal of Chongqing University, 2015, 38(04): 152-158.

[13] Guo Pengcheng. Research on AODV On-demand Routing Protocol in Ad Hoc Networks [J]. Science Technology and Engineering, 2013, 13(18).

[14] Chen Shuwang, Song Shuli, Song Tongtong, et al. Improved AODV Routing Protocol Based on Energy Balance and Congestion Degree. Science Technology and Engineering, 2020, 20(12): 4798-4802.

[15] Ghori Muhammad Rizwan et al. Optimization of the AODV-Based Packet Forwarding Mechanism for BLE Mesh Networks[J]. Electronics, 2021, 10: 2274-2274.

[16] Zou Xiuming. High Energy and High Signal Strength Node-Priority AODV Routing Protocol. Computer Engineering and Applications, 2014, 50(17): 86-89.

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