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An Energy Based Dynamic AODV Routing Protocol in Wireless Ad Hoc Networks

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Abstract: In recent years, with the rapid development of the Internet and wireless communication technology, wireless Ad hoc networks have received more attention. Due to the limited transmission range and energy of nodes in Ad hoc networks, it is important to establish a reliable and energy-balanced transmission path in Ad hoc networks. This paper proposes an energy-based dynamic routing protocol based on the existing AODV routing protocol, which has the following two aspects of improvement: (1) In the route discovery process, a node selects a suitable route from the minimum energy consumption route and the energy-balanced route designed in this paper according to a "Mark" bit that representing remaining energy of a node. (2) Based on (1), a route interruption update strategy was proposed to restart the route discovery process when node energy was used excessively. Simulation results demonstrate that compared with AODV and other existing routing protocols, proposed algorithm can reduce network energy consumption and balance node energy, thus extending the network lifetime.

Keywords: Ad hoc networks, routing protocol, energy, network lifetime.

1 Introduction

With the rapid development of Internet, wireless network technology has been one of the most popular research areas. Conventional wireless communications are generally centralized or decentralized, requiring the infrastructure of the network to operate normally [Perkins and Royer (1999); Wang, Gu and Yan (2018)]. However, in some special application scenarios such as environmental monitoring and disaster relief, there are always no pre-deployed infrastructures that require the network to quickly establish and transmit data as soon as possible. So as this, wireless Ad hoc network is widely concerned. Wireless Ad hoc network is divided into high mobility network and low mobility network according to whether or not the node moves. In low mobility (or static) Ad hoc network, the frequency of movement of nodes is low and network topology changes rarely. In addition, the communication range of nodes in Ad hoc network is limited. When a node wishes to communicate with a long-distance node, it needs to establish a routing path. Some intermediate nodes act as relay nodes and undertake more

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data forwarding tasks. Hence the energy consumption among nodes is unfair. Therefore, it is important to study routing protocols that consider the fairness of energy consumption among nodes.

In recent years, researchers have made a great many of researches and improvements on the routing protocols applicable to Ad hoc networks. AODV is a typical Ad hoc network routing protocol that is formed by the broadcast route discovery mechanism of the DSR routing protocol [Utkarsh, Mishra and Chinara (2012)]. AODV routing protocol has become a hot-spot in the research of Ad hoc network routing protocol due to its own characteristics and better adaptability. An Energy Saving Ad hoc Routing (ESAR) is proposed in Shivashankar et al. [Shivashankar, Varaprasad and Narayanagowda (2014)]. In ESAR data are transmitted via the selected path until the node in the path reaches a given energy threshold and another alternative path is used for transmission. ESAR increases the network lifetime by applying the concept of thresholds. However, ESAR requires the establishment of many alternative paths, so that the energy consumption of the network is high. Another energy-efficient algorithm is proposed in Cao et al. [Cao, Sharif, Wang et al. (2008)], which uses node lifetime as a cost measure. Literature Tie et al. [Tie, Tan and Lau (2010); Khanna and Naik (2016)] proposed routing algorithm where they took the residual energy as a cost metric. In Tie et al. [Tie, Tan and Lau (2010)], an MMBCR (Min-Max Battery Cost Routing) algorithm is proposed and in which it focuses on the remaining energy of the bottleneck node on the path, then selects the bottleneck node that has the largest remaining energy value as the next hop node. Although it delays the occurrence of the first death node in the network, but the overall network lifetime has not been significantly improved. The ALMEL-AODV (Alternate Link Maximum Energy Level) algorithm proposed in Khanna et al. [Khanna and Naik (2016)] takes residual energy of a node as a cost metric and focuses on the remaining energy of nodes on the path. The standard for selecting routes is that if the sum of the remaining energy of the nodes on the path is the largest, then select it as the route and transmit data through the path. Although ALMEL-AODV has improved the node energy consumption to a certain extent, it pays attention to the residual energy in the entire path and does not consider the residual energy of a single node.

The work presented in Chen et al. [Chen, Chen and Li (2007); Murthy and Garcia-Luna-Aceves (1996)] combines the energy consumption and residual energy in the transmission process as a cost measure for routing. Chen et al. [Chen, Chen and Li (2007)] proposed an EEPR (Energy Efficient Path Routing) algorithm to realize the fairness of energy consumption, thus improve the network lifetime. In Murthy et al. [Murthy and Garcia-Luna-Aceves (1996)], the AODV routing protocol was improved for low-speed Ad hoc networks. Based on the ratio of energy consumption and residual energy to battery capacity, a new path cost measurement function is proposed. It has a good performance in low-speed Ad hoc networks. However, this algorithm only considers the path selection at the source node and lacks real-time performance. By analyzing the research status of Ad hoc networks and combining with the shortcomings of AODV routing protocols and other routing protocols [Shivashankar, Varaprasad and Narayanagowda (2014); Cao, Sharif, Wang et al. (2008); Tie, Tan and Lau (2010)], this paper proposes a new energy-based dynamic routing protocol to deeply study how to better integrate the path energy consumption and node residual energy. These cost metrics need to be improved on the basis of AODV routing protocols to achieve fairness in the energy consumption of nodes in the network, thus improving network lifetime and other network performances.

The paper is organized as follows: The second Section gives the network model, energy model and problem definition. In the third Section, we introduce the design of Energy based on dynamic AODV routing protocol. In the fourth Section, the simulation setting and results are given. Finally, we complete this work in the fifth section.

2 Network model, energy model and problem definition

2.1 Network model

In the network model, the nodes are deployed in monitoring area. This work assumes that the network model is as follows:

(1) The location information of each node in the network is known. The node IDs are incremental in order from 0 and are globally unique IDs.

(2) The initial energy of all nodes is limited, and the greater the amount of data transmitted, the faster the energy consumption.

(3) All nodes receive the same sensitivity and run the same routing protocol.

(4) All nodes have the same data processing capabilities and radio communication capabilities.

2.2 Energy model

In our work, each node has an initial energy. During the operation of the experiment, when the energy of the node turns to zero, it stops working. The equation of energy consumption is as follows:

$$\text{Energy}(\text{J}) = \text{Power}_\text{i}(\text{W}) \times \text{Time}(\text{s}) \tag{1}$$

"Energy" is the total energy consumption of the i-th node, "Power" is the energy consuming power of the i-th node, and "Time" is the energy consumption time of the i-th node. When a node sends a packet, energy is reduced by the node's core power consumption and transmission power consumption. The length of time depends on the size of the packet as follows:

$$\text{Time}(\text{s}) = \frac{8 \times \text{Packetsize}_\text{i}(\text{bit})}{\text{Bandwidth}_\text{i}(\text{Byte})} \tag{2}$$

"Time" is the time that takes for sending the packet at node i, "Packetsize_i" is the size of the packet, and "Bandwidth" is the bandwidth of the node i when the data are sent.

Therefore, when the node sends data, the energy consumption of the data transmission is:

$$E_{s,i}(\text{J}) = \frac{P_{s,i}(\text{W}) \times 8 \times \text{Packetsize}_\text{i}(\text{bit})}{\text{Bandwidth}_\text{i}(\text{Byte})} \tag{3}$$

$E_{s,i}$ is the energy consumed when node i sends a packet, $P_{s,i}$ is the transmit power of node i at the time.

When the network begins to generate and calculate data, each node consumes certain energy to sense and generate data, and the energy is calculated as follows:

$$E_{k,i}(J) = P_{k,i}(W) \times T(s) \tag{4}$$

$E_{k,i}$ is the total energy consumed by node i to sense and generate data, $P_{k,i}$ is the power consumed by the node i of per data, T is the working time of node i. Therefore, when node i sends a packet, the energy consumption of the node includes the energy consumed by the sending data and the energy consumed by the sensing and generating as follows:

$$E_{full,i} = E_{s,i} + E_{k,i} \tag{5}$$

Path loss function

The design of routing algorithm has a great relationship with the channel energy loss. As the transmission distance between nodes gradually increases, the signal loss in space will also increase. In the matlab simulation platform, the wireless network simulation path loss function is as follows:

$$\text{distance}(m) = \text{sqrt}\left(\left(x1(m) - x2(m)\right)^2 + \left(y1(m) - y2(m)\right)^2\right) \tag{6}$$

$$P_{receive}(W) = \frac{1}{d(m)^a} P_{sender}(W) \tag{7}$$

The path loss function takes into account the transmission power of the node, the power consumed by the power amplifier, and the acceptance sensitivity of the node, where P is the power, d is the distance, and α is the parameter. According to the different simulation environment, when the transmission distance between nodes is short, the value of α is set to 2. When the output distance is relatively long, the value of α is set as 4, and the default value of the parameter is 3.5. X and Y represent the coordinates of the nodes.

2.3 Problem definition

AODV routing protocol is one of the most important routing protocols in Ad hoc networks. Compared with the DSR, AODV routing protocol does not store the routing information recorded in all the routing packets, and uses a hop-by-hop forwarding strategy. Compared with the DSDV routing protocol, AODV routing protocol does not broadcast the information of all nodes in the network, but only when the node has data to transmit, the route request is initiated. AODV routing protocol is built on demand, and it does not need to maintain the topology of the entire network, thus reducing the amount of routing broadcast and reducing energy consumption.

There are 3 kinds of control messages in AODV routing protocols: route request (RREQ), route response (RREP) and route error (RERR). The AODV is bi-directional routing protocol. The source node sends RREQ message to initiate route discovery and then establishes the reverse path. The RREP messages are sent back to the source node through the reverse path to establish the forward path.

The AODV routing protocol is used to establish routes on an as-needed basis. It does not need to maintain the topology of the entire network, thereby reducing the amount of routing broadcast and reducing energy consumption.

In our work, we propose an Energy-based dynamic AODV routing protocol called EAODV. Considering the unbalanced energy consumption of nodes we have made four improvements to the AODV protocol:

(1) In some Ad hoc networks, the transmitting power of each node is consistent for node deployment and management. Hence, when the two nodes are relatively close to each other, but still transmit data packets with fixed maximum transmit power, which results a certain degree of energy waste. Moreover, the energy of nodes in most Ad hoc networks is limited, and the waste of energy will not only make them die prematurely, but also shorten the lifetime of the entire network. Therefore, first we propose a node position-based dynamic power control method to reduce energy consumption of nodes.

(2) In AODV, when routing is established, the fairness of the energy consumption between nodes is ignored, resulting in some nodes are often selected, so that their energy is exhausted prematurely; therefore, we propose a dynamic route selection algorithm to realize the fairness of energy consumption among nodes.

(3) Reducing Broadcast Storms: The classic AODV routing protocol establishes routes by broadcasting RREQ messages and RREP messages. In order to establish the shortest path, each intermediate node discards all non-first arrived RREQ messages from the same source node. Hence there is no broadcast storm. However, in EAODV, in order to achieve balanced energy consumption among nodes in the network, more routing information were obtained for selecting an appropriate next hop node and establishing a reverse path. The EAODV routing protocol modifies the policy of accepting only the first arrived RREQ message in AODV. Instead, the node will accept all transmitted RREQ messages. The EAODV routing protocol updates the reverse path if the RREQ message arriving later meets the routing update condition. However, this change will increase the number of RREQs in the network and spread out new problem as “broadcast storms”. Therefore, the following section describes how EAODV routing protocol reduces broadcast storms.

(4) Routing interrupt update policy adopted by the original AODV protocol enables the interrupt update policy only when the node moves out of the communication range or the node dies. The EAODV routing protocol proposes a passive interrupt update strategy, which uses the residual energy of a node and the remaining energy of its neighbor nodes to trigger the routing interruption update algorithm. Some nodes consume too much energy when there are too many data transmitted on the path. With the passive interrupt update strategy, it can switch to more energy path in time. Hence with this routing interruption update policy, the energy consumption between nodes in the network can be more equitable, thus prolonging the network lifetime.

3 Design of energy based AODV routing protocol

3.1 The structure of energy based AODV routing protocol

The proposed EAODV consists of four parts. At first, in order save energy, we proposed a node position-based dynamic power control method that adjusts nodes’ transmission power according to the node location. Secondly, we propose a dynamic route selection algorithm to establish data transmission path according to an energy threshold. Thirdly, for solving the new emerging problem of broadcast storm, we have given a solution. At last, based on the remaining energy of the node, this paper proposed a passive interruption update policy to improve the original AODV route update policy. The details are presented in the following subsections.

(1) Node position-based dynamic power control method

The proposed EAODV in this paper controls the transmit power according to the location of the node. The principles are as follows:

Any two nodes in the network, i is the transmitting node, j is the receiving node, the sensors in the network are the same, the receiving sensitivity of the nodes is the same, and the receiving threshold is P_{Thr}, the unit is dbm. When the power Pr (j) of received signal of the node is equivalent to or greater than P_{Thr}, the data can be successfully accepted.

$$P_r(j) \geq P_{Thr}(j) \tag{8}$$

During the route establishment process, node j receives the RREQ or RREP message sent by node i, which obtains the positional information of node i. According to distance formula, the distance between two nodes D_{is} is obtained and the unit is m. According to the path loss formula, when node j accepts the sensitivity P_{Thr}, in order to successfully accept the data from node i, the appropriate transmit power (dbm) of node i should be:

$$P_s(i) = 10 \times \log 10\left(\left((\mathrm{Dis}+2)^{3.5}\right) \times \left(0.001 \times 10^{(P_{Thr}/10)}\right) \times 1000\right) \tag{9}$$

We can calculate the appropriate transmit power Ps (i) between node i and node j through the formula, and save it in the corresponding routing table of node i. When node i wants to send data to node j, it first queries the routing table. Then, the node transmission power is set to the power value read out from the routing table entry, thereby realizing the dynamic adjustment of the node transmission power according to the distance between nodes. According to the above mentioned principle, the specific implementation is as follows. The two fields "Location X" and "Location Y" are added to the RREQ and RREP frame formats to store the node location information. Through the power control mechanism, we dynamically set a reasonable transmission power according to the distance between two nodes, so as to achieve the purpose of saving node energy and extending the network lifetime.

(2) Dynamic route selection algorithm

The EAODV routing protocol proposed in this paper consists of two route selection algorithms, namely, the Minimum Energy consumption Route selecting algorithm (MER) and the Energy Balanced Route selecting algorithm (EBR). When a node is required to send data, each node in the path dynamically selects one of the routes selecting algorithms to establish a path.

The design of MER

The MER selects the path with the smallest total energy consumption among the numerous available paths from the source node to the destination node. MER uses the path selection algorithm of the AODV routing protocol. When the path is established, the source node broadcasts the RREQ firstly, and the intermediate node only accepts and processes the same first arrival RREQ message of the source node. Thus, creating a route. This is the "shortest path", which is the main idea of the AODV routing protocol. However, the improved routing protocol in this paper will calculate a reasonable transmitting energy based on the distance between two points in the path. If the established route is the "shortest path" in the network, then the total transmitting energy of this path is the smallest. Since the amount of data transmitted by the source node is certain, the sensor models of the nodes in the network are the same, that is, the bandwidth of each node is the same, then, the transmission time of each data for nodes will be the same.

The design of EBR

The EBR, that is, when establishing forward and reverse routes, among the numerous available routes, select the route with node's smallest residual energy is the biggest among the routes.

$$R = \max\{\min\{E_{left}^{i,t}\}\} \tag{10}$$

Here i is the node that passes through the path from the source node to the destination node. $E^{i,t}_{left}$ is the residual energy of node i at time t.

In the network, if the above-mentioned minimum energy consumption routing is always used, it may cause some nodes on the path to run out prematurely. For this reason, energy balanced routing is proposed. During the establishment of the route, the node selects a minimum energy route or energy balance route based on the "Mark bit value" in the RREP message and in the RREQ message to establish a reverse path and a forward route.

(3) Principle of reducing broadcast storms

For the "broadcast storm" generated by the EAODV routing protocol, the solution is as follows:

When the destination address of a RREQ message accepted by a node is not the node, all these RREQ messages are normally broadcast. Therefore, in order to reduce the broadcast storm and select a reasonable transmission path, this paper proposes a hop-based judgment and filtering mechanism, which is to judge and filter these RREQ messages to be broadcast, and reduce the number of RREQ messages that need to be broadcast. The judgment mechanism for reducing broadcast storms is as follows:

First of all, in the routing table node queries the reverse path routing information src_entry, the code is as follows: src_entry=findEntry (msg.src, myID).

When a node receives a RREQ message (msg), the hop value (hopCnt) in the message is incremented by one. This is the number of hops from the node to the source node. When the number of hops from the node to the source node is less than or equal to the hop value in the corresponding routing information plus one, the condition for judging and filtering is met as follows: if (msg.hopCnt+1<=src_entry.hops+1).

By adding such a judging mechanism, a large number of RREQ messages that are not established by using reasonable routes will be filtered out, and the number of RREQ messages broadcast by the node will be greatly reduced, so as to achieve the purpose of reducing broadcast storms.

(4) Passive interrupt update strategy

Based on the remaining energy of the node, this paper proposes a passive interrupt update policy based on the original update strategy of AODV. It is divided into two methods to trigger the routing interrupt update strategy: at first, with the node sending and receiving data packet, node energy is continuously consumed. When the ratio of the real-time residual energy and the battery capacity of the node is less than a threshold α (0.4 in this paper), the interrupt update strategy starts. Secondly, while nodes in the network transmit data according to the established route, it will initiate an interrupt update policy as long as the node satisfies the overuse rule.

The overuse rule of node is as follows:

$$E_{left}^{j,t} * \frac{1}{\beta} < E_{neig\_aver}^{j,t} \tag{11}$$

That is, if the residual energy of node j is multiplied by the parameter 1/β (4 in this paper) is less than the average value of the remaining energy of the neighbor node, it is determined that the node is overused.

When a node initiates an interrupt update policy, the node queries the routing table, then sends RERR packets to its upstream node whose next hop node is this node, and sets the state field of all routing entries of this node to "invalid". After receiving the RERR data packet, the upstream node finds this RERR route and sets the state field of the route entry to "invalid" and continues to send the RERR data packet to its own upstream node.

3.2 Framework design of EAODV routing protocol

This section composed of two parts: the frameworks of RREQ, RREP and routing table and the working process of RREQ and RREP.

3.2.1 The framework design of RREQ, RREP and routing table

According to the main idea of EAODV, the main changes of RREQ, RREP and route table are as follows:

By first adding a "Mark" bit, value is 0 or 1. As there are two route selection algorithms, one of the routes establishing algorithm is selected based on the value of the "Mark" bit in the RREQ or RREP transmitted from the previous hop. If the value is 0, the MER algorithm is used to establish the route. If the value is 1, the EBR is used to establish the route.

The "Minimum remaining energy" represents the minimum remaining energy of all nodes that have passed during the routing establishment.

The current position values of the node are stored in the blanks of "Location X" and "Location Y" in the tables of RREQ, RREP and routing table.

The transmit power to the next hop node is getting from the node sensitivity and path loss function, and records it in the routing table so that the node can query it and use it when transmitting data.

The tables of RREQ, RREP and Routing are shown as follows:

Table 1: The format of RREQ

Format		
Type	Reserved	Hop Count
RREQ ID		
Destination IP Address		
Destination Sequence Number		
Originator IP Address		
Originator Sequence Number		
Mark		
Minimum remaining energy		
Location X	**Location Y**	

Table 2: The format of RREP

Format			
Type	Reserved	Prefix Sz	Hop
Destination IP Address			
Destination Sequence Number			
Originator IP Address			
Lifetime			
Mark			
Minimum remaining energy			
Location X	**Location Y**		

Table 3: Items of routing table

Item	
Device	
Destination Sequence Number	
Sequence Number Mark of Destination	
Other routing Marks	
Interface	
Hops	
Next Hop Address IP	
Lifetime	
Mark	
Minimum remaining energy	
Transmission Power	
Location X	**Location Y**

3.2.2 Data processing of RREQ and RREP

RREQ processing steps

In our work, after a node receives a message, it will call a different acceptance function to process the information based on the header information in the data packet. The working flow of the RREQ message sent by a source node proposed in this paper is as follows:

(1) The node adds the location information to the "location X" and "location Y" field in the RREQ message.

(2) Adding its own remaining energy to the "Minimum remaining energy" field in the RREQ message to be sent by this node.

(3) According to the node energy over-use rule, if the node energy is overused, the value of the newly added "Mark" field in the RREQ message is set to 1, otherwise the value of the "Mark" field is set to 0.

Based on this, the source node broadcasts this RREQ packet. After a node in the network successfully receives the RREQ message, it will immediately query its own routing table entry. If the node is the destination node or has the available "Route" to a destination node in its routing table; it will send RREP messages immediately. If not, the node selects an RREQ with a larger sequence number to create a new route path. If the sequence numbers of RREQs are the same, selects one of them according to the value of the "Mark" field. If the "Mark" field value is 0, only the first arrived RREQ message will be selected to establish the route. If the value is 1, the RREQ message with a large "Minimum remaining energy" is selected to establish a route or update the route, and then generate a new RREQ message, the generating process is as follows:

(1) The node will add the node's location information to the "Location X" and "Location Y" fields in the RREQ message.

(2) The node will compare its own remaining energy to the value of the "Minimum remaining energy" field of the received RREQ message, and add the small value to the "Minimum remaining energy" of the RREQ message to be sent. The value of this field is always the minimum value of the remaining energy of each node in the path.

(3) According to the node overuse rule, if the node is over used, set the value of the newly added "Mark" field in the RREQ message to 1, otherwise, the "Mark" field value is set to be 0.

The node will continue to broadcast the newly generated RREQ message until it reaches the destination node or the node with the routing information to the destination node.

RREP processing algorithm

After receiving the RREQ message, a node in the network obtains the address of the destination node through the "Destination IP Address" field. If the node is the destination node in the RREQ message or has a route entry to the destination node, it will immediately generate a RREP message. The four newly added fields are filled with corresponding values, and are unique among the previously established reverse path to the source node. When a source node or an intermediate node receives a RREP message from multiple paths, it will select the route with a larger sequence number. If the sequence numbers are the same, if the value of the "Mark" field in the message is 0, it selects the first RREP message that arrives to establish a route. If the value is 1, a RREP message with a large “Minimum remaining energy” field is selected to establish a route or update a route.

4 Simulations

We use the Simulink/Truetime toolbox in Matlab to evaluate the performance of the proposed algorithm. The proposed EAODV routing protocol is verified with a typical AODV routing protocol, and compared with the ALMEL-AODV routing protocol proposed in Cao et al. [Cao, Sharif, Wang et al. (2008)] and the LMAODV routing protocol proposed in Khanna et al. [Khanna and Naik (2016)].

4.1 Simulation setting

Simulation parameters are shown in Tab. 4.

Table 4: Simulation parameters

Parameter Type	Parameter value
MAC layer protocol type	802.15.4 (ZigBee)
Node communication range	250 m
Packet transmission rate	2 packet/s
Data packet size	4 bytes
Bandwidth	0.125 Mb/s
Node position	static
Initial energy of node	0.05 J
Initial transmit power	37 dBm
Receiver signal threshold	-48 dBm

The results in this paper are to compare the average of the 50 times of experiments, 36 nodes are randomly distributed in a region of 800×800 square meters.

4.2 Simulation results

For examining the impact of α and β on network lifetime, we set the range of α as 0.1, 0.2, ..., 0.9, and β as 1, 2, ..., 9. Within 800 seconds of the simulation time, the result of Fig. 1 shows that network lifetime is generally longer when the α value is 0.3 to 0.5 and the β value is 4 to 6. Therefore, in the following experiment we set α as 0.4, β as 4.

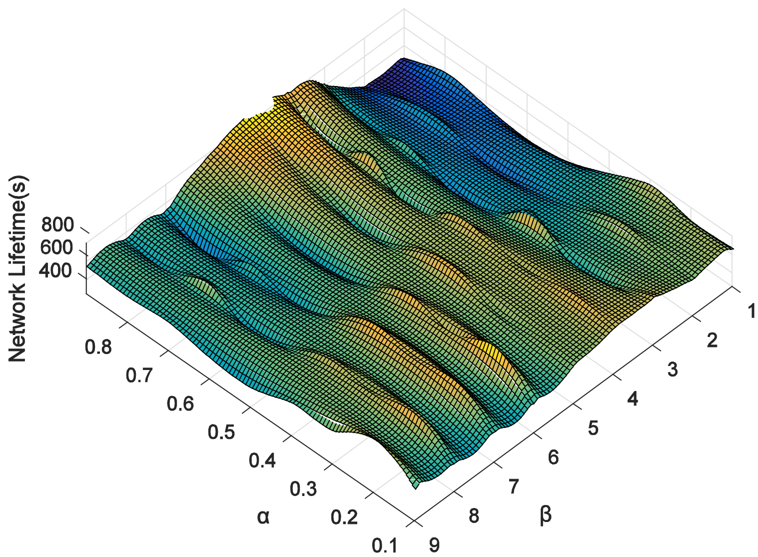

Figure 1: The relationship between α, β and network lifetime

Fig. 2 shows the time when nodes in the network died. We notice that the first node of the AODV and the ALMEL-AODV dies at about 135 seconds, while the dead time of LMAODV is 428 seconds, which is shorter than 272 seconds compared to EAODV. The network lifetimes of the first four nodes in AODV and ALMEL-AODV are close to each other, but both are significantly earlier than the LMAODV and EAODV routing protocol. Similarly, until the eighth node, compared with the other routing protocols, the EAODV has a long network lifetime. Therefore, in terms of network lifetime, the EAODV routing protocol is much better than the ALMEL-AODV and AODV routing protocols.

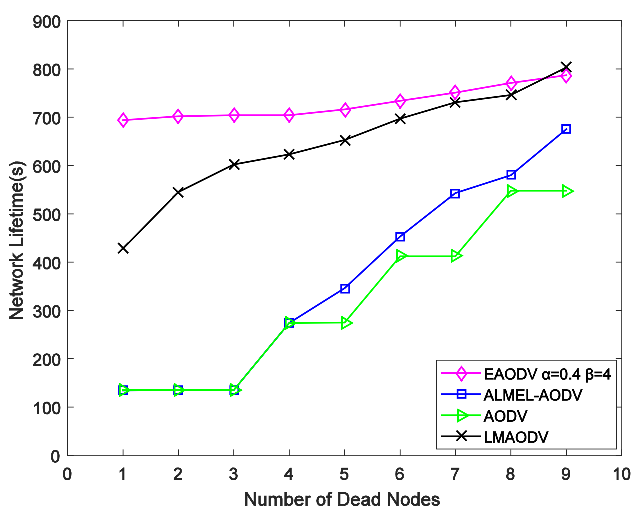

Figure 2: The relationship between the number of dead nodes and time

Fig. 3 shows a three-dimensional view of the residual energy of nodes in a network with a fixed number of nodes.

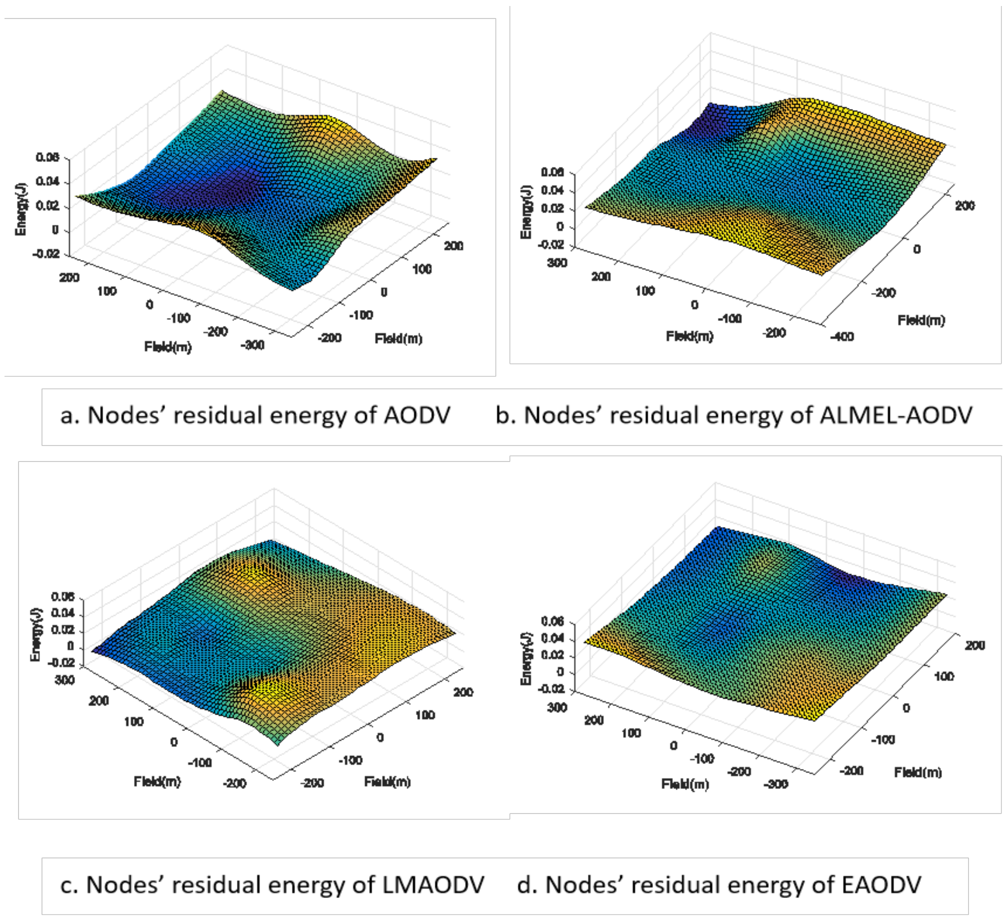

Figure 3: The remaining energy of the nodes in different algorithm

Fig. 3 shows the remaining energy of the nodes participating in the data transmission after 400 seconds of simulation time using four routing protocols in 800×800 simulation areas. In order to achieve the goal of extending the lifetime of the entire network, the energy difference among all nodes in the network should be kept as low as possible. Through the comparison of the four figures, Fig. 3(a) is convex and concave, and the bumps in Figs. 3(b) and 3(c) are slightly better. The residual energy of each node has a certain difference. Fig. 3(d) is more even, because data can be transmitted to avoid nodes with low energy, and when a node is consumed multiple times, route discovery can be re-initiated, so node energy consumption is fairer when using the EAODV routing protocol. Therefore, the central nodes in the network can maintain the network connection if possible, and the network cannot be split quickly.

Fig. 4 shows the packet delivery rates of the four routing protocols under different node numbers. We find from the figure that with the increase of the number of nodes, the

AODV and the LMAODV routing protocol have decreased the packet delivery rate slightly. As the number of nodes increases, the packet delivery rate of EAODV routing protocol increases slightly, and better than the ALMEL-AODV. As the number of nodes increases, the number of selectable paths increases, so that the EAODV routing protocol can select the optimal path.

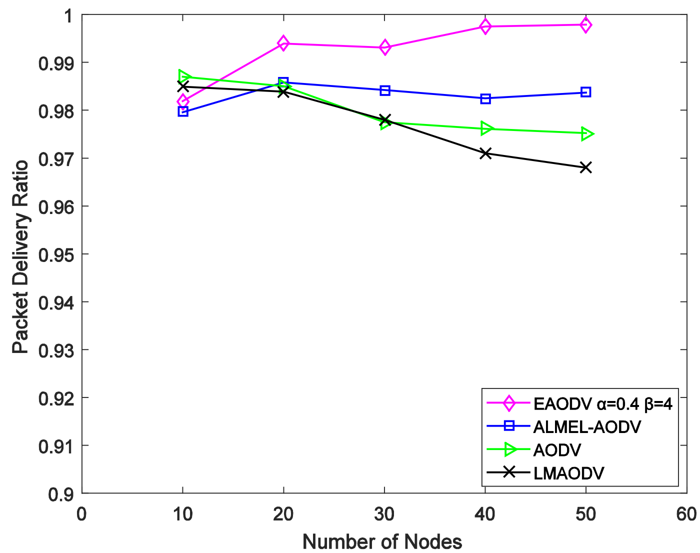

Figure 4: Packet delivery rate of nodes

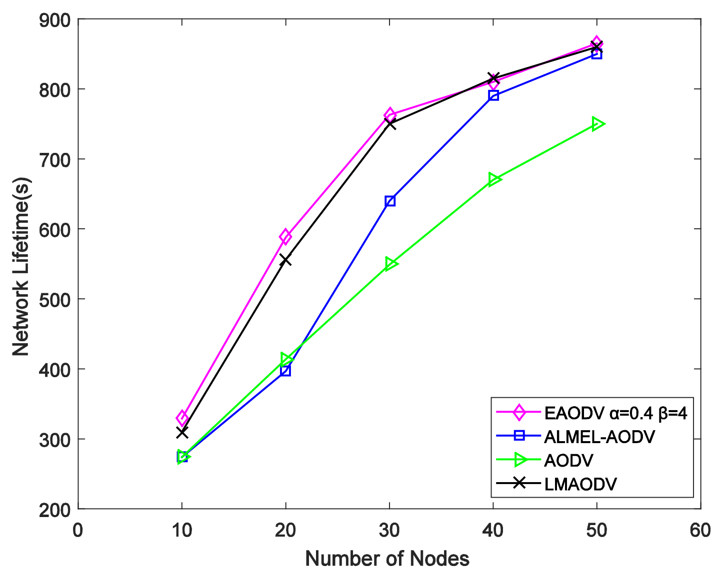

Figure 5: Network lifetime of nodes

In Fig. 5, it can be clearly seen that the EAODV routing protocol and the LMAODV routing protocol are superior to the ALMEL-AODV and the AODV routing protocol. This is because the AODV routing protocol does not consider the node energy and only considers the establishment of the "shortest path". Therefore, the relay node in the path often runs out of energy, which leads to no available path in the entire network in a period of time, resulting in the lowest network lifetime. Although ALMEL-AODV considers the total energy of the path as a whole, it does not consider the fairness of the node's energy consumption in the network.

5 Conclusion

This paper proposes an energy-based routing protocol EAODV based on traditional AODV for low-speed Ad hoc networks. Through the comparison and analysis of the experiment results, the design of EAODV routing protocol is proved to be fairer on nodes' energy consumption, so that achieves longer network lifetime. Besides, EAODV improves the packet delivery rate and throughput, reduces the total energy consumption of the network and the energy consumption per unit packet, so that improves network performance.

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References

Cao, L. J.; Sharif, K.; Wang, Y.; Dahlberg, T. (2008): Adaptive multiple metrics routing protocols for heterogeneous multi-hop wireless networks. *Consumer Communications and Networking Conference*, pp. 13-17.

Chen, J.; Chen, J. P.; Li, Z. B. (2007): Energy-efficient AODV for low mobility ad hoc networks. *International Conference on Wireless Communications*, pp. 1512-1515.

Khanna, N.; Naik, K. K. (2016): Design and implementation of an energy efficient routing approach based on existing AODV protocol in mobile Ad-hoc networks for military. *International Conference on Emerging Trends in Electrical Electronics & Sustainable Energy Systems*, pp. 216-222.

Liu, Z. L.; Li, T.; Li, P.; Jia, C. F.; Li, J. (2018): Verifiable searchable encryption with aggregate keys for data sharing system. *Future Generation Computer Systems*, vol. 78, no. 2, pp. 778-788.

Liu, Z. L.; Luo, D. J.; Li, J.; Chen, X. F.; Jia, C. F. (2013): N-Mobishare: new privacy-preserving location-sharing system for mobile online social networks. *International Journal of Computer Mathematics*, vol. 93, no. 2, pp. 384-400.

Murthy, S.; Garcia-Luna-Aceves, J. J. (1996): An efficient routing protocol for wireless networks. *Mobile Networks & Applications*, vol. 1, no. 2, pp. 183-197.

Perkins, C. E.; Bhagwat, P. (1994): Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. *ACM SIGCOMM Computer Communication Review*, vol. 24, no. 4, pp. 234-244.

Perkins, C. E.; Royer, E. M. (1999): Ad-hoc on-demand distance vector routing. *2nd IEEE Workshop on Mobile Computing Systems and Applications*, pp. 90-100.

Perkins, C. E.; Royer, E. M. (2002): Ad-hoc on-demand distance vector routing. *Workshop on Mobile Computing Systems & Applications*, pp. 94-95.

Shivashankar; Varaprasad, G.; Narayanagowda, S. H. (2014): Implementing a new power aware routing algorithm based on existing dynamic source routing protocol for mobile ad hoc networks. *IET Networks*, vol. 3, no. 2, pp. 137-142.

Tie, T. H.; Tan, C. E.; Lau, S. P. (2010): Alternate link maximum energy level ad hoc distance vector scheme for energy efficient ad hoc networks routing. *International Conference on Computer and Communication Engineering*, pp. 423-428.

Utkarsh; Mishra, M.; Chinara, S. (2012): ESAR: an energy saving ad hoc routing algorithm for MANET. *IEEE Fourth International Conference on Advanced Computing*, pp. 13-15.

Wang, B. W.; Gu, X. D.; Yan, S. S. (2018): STCS: a practical solar radiation based temperature correction scheme in meteorological WSN. *International Journal of Sensor Networks*, vol. 28, no. 1, pp. 22-33.

Wang, B. W.; Gu, X. D.; Zhou, A. (2017): E2S2: a code dissemination approach to energy efficiency and status surveillance for wireless sensor networks. *Journal of Internet of Technology*, vol. 8, no. 4, pp. 877-885.

Wang, J.; Ju, C. W.; Gao, Y.; Sangaiah, A. K.; Kim, G. J. (2018): A PSO based energy efficient coverage control algorithm for wireless sensor networks. *Computers, Materials & Continua*, vol. 56, no. 3, pp. 433-446.