A Low-Overhead Routing Protocol for FANET Based on Ant Colony Algorithm

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Abstract. To address the problems of low network throughput and delivery rate and high communication overhead between nodes due to frequent topology changes of flight self-assembled networks, this paper proposes a SE-AODV routing protocol optimized based on the traditional on-demand distance vector routing protocol. The new protocol takes into account the actual influencing factors such as energy and received signal strength, and combines the pheromone calculation rules of the ant colony algorithm to update the routing table, while optimizing the optimal path selection basis. Simulation results show that compared with traditional on-demand distance vector routing and EE-AODV, the new routing protocol not only shows more obvious advantages in throughput and packet delivery rate, but also reduces routing overhead, and is more suitable for scenarios where nodes are in high-speed motion.

Keywords: UAV · Flying Ad Hoc Network · AODV Routing Protocol · ACO

1 Introduction

With the development of technology, multiple miniature unmanned aerial vehicles (UAVs) coordinating and cooperating with each other can form a multi-UAV system. Compared with a single large UAV, a multi-UAV system composed of multiple small UAVs has the characteristics of low cost, high flexibility, and high reliability [1, 2]. However, there are still many problems that need to be solved in multi-UAV systems, among which, it is very meaningful work to design efficient routing protocols for multi-UAV systems to ensure efficient systems of multi-UAV systems.

Flying Ad hoc network (FANET) is a special kind of Ad hoc networks with UAVs as nodes and are considered by many as a special example of Mobile Ad hoc network (MANET) [1]. Communication between FANET nodes is a challenging task that requires routing protocols that support the effectiveness of such transmissions. Since FANET are special in nature and operate in a specific environment, routing techniques need to be tailored for it.

The routing technology of FANET needs to be adapted to its unique mobility model and operating environment in order to guarantee correct data forwarding. Therefore, its

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requirements are completely different from those of mobile and vehicular self-assembly networks. Establishing communication links with low latency, high throughput, and low routing overhead can greatly improve the communication benefits of flight self-assembled networks [2], so the development of routing for FANET is of great interest. The scheme proposed in this paper is based on the Ad hoc on-demand distance vector (AODV) routing protocol for mobile self-organizing networks, based on the special characteristics of FANET [3, 4], considering the energy factor and the received signal strength factor in practical applications, and referring to the pheromone calculation rules of the ant colony algorithm to select the optimal path, and proposes a new On-demand routing protocol SE-AODV. This scheme aims to improve packet throughput and packet delivery rate in the network and reduce the routing overhead of the whole network during packet transmission.

This article focuses on the classical on-demand vector routing protocol (AODV) for mobile self-organizing networks, and proposes an optimized routing protocol SE-AODV (Signal and Energy-AODV) for in-flight self-organizing networks considering the received signal strength and energy as well as the number of hops.

2 Related Work

In recent years, many routing protocols for FANET have been proposed by domestic and foreign experts and scholars [5–7], aiming at improving packet delivery rates and reducing overhead and packet loss rates. Existing routing protocols can generally be classified into two broad categories [8]: single-hop routing and multi-hop routing. Single-hop routing is mainly used in situations where the topology is fixed, which results in very poor fault tolerance and is unsuitable for dynamic environments. Multi-hop routing can be divided into two categories: topology-based routing and location-based routing. The details are shown in Fig. 1 below.

Single-hop routing uses a fixed static routing table to transmit messages. This routing protocol is lightweight, not suitable for dynamic environments, and is commonly used in situations where the topology is fixed. In multi-hop routing, message information is transmitted between multiple nodes and is not directly transmitted to the destination node. Therefore, how to choose the appropriate data forwarding path is the core of route discovery.

Topology-based routing protocols can be further divided into two categories: active routing and passive routing. In active routing, routing information is pre-recorded and stored in each drone, so that packets can be transmitted in real time without waiting. However, the disadvantage of this routing protocol is that it incurs a high communication overhead because each node needs packets to establish a route. Passive routing, also known as on-demand routing, looks up routing paths on demand only when packets need to be sent. Unlike active routing, passive routes are constructed only when the source node needs to send information and are not pre-built, creating routing tables as needed. The advantage of this is that it is not necessary to collect topological information about the entire network, but it is sufficient to obtain only a portion of it.

Therefore, passive routing is more energy efficient than active routing, can effectively reduce the control message overhead, and is more adaptable to the high dynamics of UAV nodes.

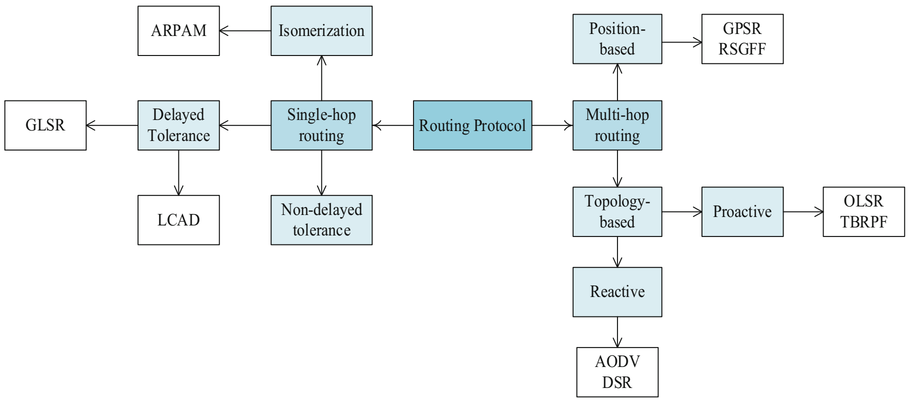

Fig. 1. Classification of Existing Routing Protocol.

In the literature [9], Rao et al. proposed a backup routing protocol AODV nth BR, which provides multiple alternate routes to the source node in case of link failures in the network. It is based on the classical AODV routing protocol and achieves efficient transmission of packets by establishing multiple routes.

In the literature [10], scholar Shubhajeet Chatterjee and his team proposed a new routing protocol E-Ant-DSR based on the existing dynamic source routing protocol (DSR), considering the combination with Ant colony optimization (ACO). The new protocol improves the optimal path selection by considering The new protocol improves the optimal path selection by considering multiple measures of link quality, congestion and hop count, calculates the pheromone of the path, and selects the optimal path for packet transmission based on the pheromone count of multiple paths.

An energy efficient AODV routing protocol EE-AODV is proposed in the literature [11]. The original RREQ packet field of AODV is modified using node residual energy and hop count as cost metric to find the optimal energy efficient routing. The protocol is then simulated using NS-2 to compare the performance output benefits of EE-AODV routing protocol with classical routing protocols in terms of network lifecycle, delivery ratio, routing overhead and energy consumption.

AODV, as a traditional passive routing protocol, was often used in mobile self-assembly networks in the past. Compared with other traditional routing protocols, such as OLSR, it has more advantages in terms of packet delivery rate and throughput. However, if it is used directly in FANET, it still leads to problems such as excessive routing overhead, low throughput and packet delivery rate.

In FANET, the rapid movement of nodes makes the topology of the network prone to great dynamic changes, which leads to easy breakage of links between nodes. This characteristic poses an unprecedented challenge to design a routing protocol with good scalability, robustness and high performance. The ant colony algorithm has strong robustness and is easy to combine with other algorithms. It has good distributed computing capability and all these advantages are compatible with the requirements of Ad hoc networks. Therefore, this article considers a new scheme SE-AODV that integrates energy, received signal strength and hop count calculation based on the traditional AODV protocol with reference to the pheromone calculation rules of the ant colony algorithm, and the optimized new protocol SE-AODV will be introduced next.

3 Metrics and Frame Structure

The traditional AODV includes two processes, route discovery and route maintenance. The scheme proposed in this paper adds energy and inter-node received signal strength metric, combined with hop count comprehensive optimization, which is mainly reflected in the route discovery part. Optimizing the RREQ message transmission process, designing the destination node waiting and optimal path selection, reducing the routing overhead, and improving the packet delivery rate and throughput of routes are the objectives of this scheme.

At the intermediate node, the energy threshold is first set for the node, and if a route request SE_REQ message is received from the source node, the energy of the node itself and the received signal strength between that node and the previous node need to be calculated. If the remaining energy of this node cannot satisfy the threshold, this intermediate node is dropped; if the threshold value is met, the received signal strength between the current node and the previous node is calculated.

For the received signal strength between nodes, if the distance between two nodes is too large, although there will be high broadcasting efficiency, but the link state is unstable; if the distance between two nodes is too small, although the link state is more stable, but the broadcasting efficiency is not high. Considering the above factors, for the received signal strength coefficient between nodes, the following definition is made.

$$S_{ij} = \begin{cases} 3, 0 < D_{ij} \leq 0.3R \\ 7, 0.3 < D_{ij} \leq 0.7R \\ 2, 0.7 < D_{ij} \leq R \end{cases} \tag{1}$$

where D_{ij} denotes the distance between node i and node j; R denotes the communication range of the node, S_{ij}, the link stability coefficient of the node, and D_{ij} is calculated as in Eq. 2.

$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{2}$$

where x_i and y_i are the obtained coordinate values of the current node i, and x_j and y_j are the coordinates of the previous hop node j.

After calculating the received signal strength of a node, its energy parameters need to be processed for subsequent pheromone counting operations, and drawing on the energy calculation in the literature [12], this paper proposes the energy parameters calculation method in the following way.

Each node has an energy value which is set in its initial state. During the route discovery process, the energy of each node decreases after a period of time as the nodes consume a certain amount of energy for both receiving and forwarding packets. Here we define the energy of the node is calculated as Eq. 3.

$$E_i^{res} = E_i^0 - E_{cost} \tag{3}$$

where E_i^{res} denotes the remaining energy of node i at time t, E_i^0 denotes the initial energy of node i, and E_{cost} denotes the total energy consumed by node i from time 0 to t.

$$E_{\cos t} = E_f(i) + E_r(i) \tag{4}$$

$E_f(i)$ denotes the energy consumed by node i for forwarding packets in time t, and $E_r(i)$ denotes the energy consumed by node i for receiving packets in time t.

The ACO algorithm is derived from real ants' foraging behavior. When ants search for food, they start from the nest and move around randomly to find food; in this process, ants secrete a substance called "pheromone" to mark. When ants choose the next path, they compare the concentration of pheromones left by the previous paths and release more pheromones to intensify the marking of the path after they have chosen a suitable path. This foraging process is characterized by a positive feedback.

In this paper, we define pheromones as follows.

After the intermediate node receiving the route request message meets its energy threshold and has calculated the received signal strength, it needs to update its pheromone count value using the above parameters and the information in the SE_REQ message, which is calculated as in Eq. 5.

$$P_{ij} = \frac{S_{ij} \times E_j}{H_{ij}} \tag{5}$$

In the above Eq. 5, H_{ij} denotes the number of hops that a routing request passes through node i from the source node to node j.

Until the route request message is forwarded to the destination node. At the destination node, it first determines whether the current time has exceeded the waiting time, if not, it compares the current pheromone count with the highest recorded historical pheromone value and selects the higher message to update the routing table. Otherwise, when the destination node receives a new SE_REQ message and the current time has exceeded the route waiting time, it sends a SE_REP, i.e., a route reply message, to the source node according to the established reverse routing table until the SE_REP message is forwarded to the source node.

When RREQ is propagated in the network, intermediate nodes update their respective routes to the source node, called reverse routes. The route is considered to be valid.

The original frame structure of AODV contains several modules, such as RREQ ID, destination node address, etc. In this paper, we propose the SE-AODV protocol to add the pheromone count value to the original frame structure, as shown in Fig. 2. The modified frame structure is more convenient for route optimization, as the route request message is transmitted in the path, the pheromone count value is accumulated and recorded until it reaches the destination node.

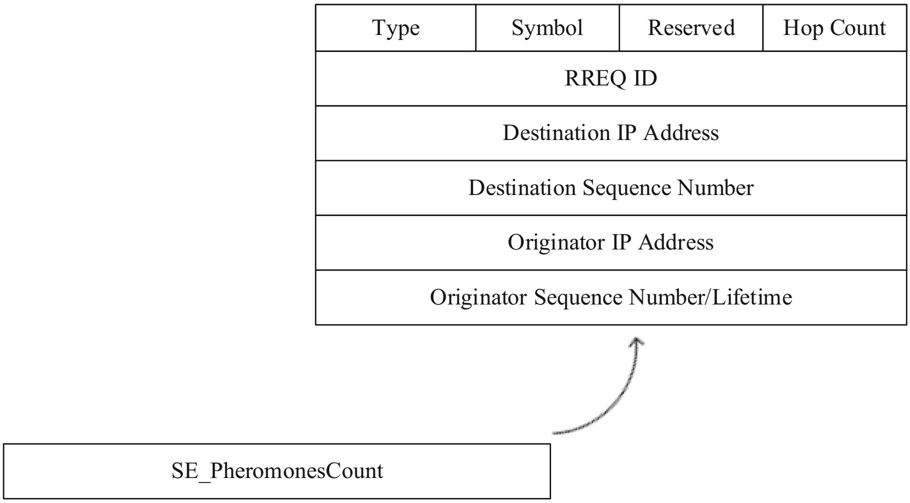

Fig. 2. SE-AODV frame structure.

4 SE-AODV

The whole SE-AODV route discovery process can be summarized as follows.

If a node wishes to deliver some packets to a destination, the packets are sent through the route if it exists; if no available route exists, the route request sending process is initiated.

The source node broadcasts the route request message SE_REQ, and the neighboring nodes receive it and first perform the pre-processing to receive SE_REQ, a process shown in Algorithm 1. After that they perform route request forwarding process and they will create a backlink to the SE_REQ originator. Then they calculate the value of the pheromone and update the routing table of the current node. After that they rebroadcast SE_REQ and add 1 to the hop count metric value.

Algorithm1. Intermediate node preprocessing that receives SE_REQ

```
while received SE_REQ
  if (index == source node of REQ)
    packed free
  end if
  if (index! == destination node of REQ && source node of REQ!= Broadcast id)
    packed free
  end if
  Calculate the energy value
  if (this energy < REM)
    packed free
  else
    Calculate the signal strength
    Calculate the RSSM
  end if
  hopcount++
  Create reverse routing table rt0 and update routing table rt
  Calculate the pheromone count pherCount
  update pheromone in REQ
end while
```

All intermediate nodes follow this process until SE_REQ reaches the destination. When the destination node receives SE_REQ, like the process in Algorithm 2, it starts the wait time function and after waiting for some time, it selects the path with the highest pheromone as the best selected path.

Afterwards, it updates the directional routing table of the destination node using the information in SE_REQ, and then sends a routing answer message (SE_REP) in the direction of the source node until it reaches the SE_REQ initiator.

Algorithm2. The destination node receives SE_REQ processing

while received SE_REQ
  Calculate the signal strength
  Calculate the RSSM
  P_{ij} = pheromone in REQ+pherCount
  Create or update reverse routing table rt0
  if (sequence number in REQ== sequence number in routing table rt)
    if (CURRENT-TIME <= DE-TIME)
      Pheromone in rt = Pheromone in REQ/Hop in REQ
      if (Pheromone in rt > calculated current pheromone value)
        update reverse routing table rt0
        update the pheromone in reverse routing table rt0
      end if
    else
      update sequence number
      send SE_REP
    end if
  end if
end while

When the intermediate node receives the SE_REP message, it will choose whether to update the routing table based on the sequence number and hop count information it carries; after that, it will continue to forward the SE_REP message until it reaches the destination node, which is the source node of SE_REQ. When it reaches the destination node, it will update the source node routing table of SE_REQ based on its information. At this point, the whole route discovery process is completed and a path from the source node to the destination node has been built, and the source node will send packets through this path.

5 Simulation and Analysis

Due to the specificity of FANET, we need to set the scenarios according to their characteristics when selecting them. In this paper, we use the ns-2.35 simulation platform [13, 14] to verify the above proposed innovative method, and we also choose the EE-AODV routing algorithm proposed in the literature [11] and the classical AODV routing algorithm as a comparison.

The selected simulation scenario is in a 1000 m × 1000 m area composed of 50 nodes, the nodes' movement model is RWP movement model, the running speed of each node varies from 20 to 100 m/s, and the node pause time is set to 0 s. The specific parameters are shown in the following Table 1.

Table 1. Simulation parameter.

Parameter	Value/Type
Channel type	Channel/Wireless channel
Simulation area	1000 × 1000 m
Simulation time	100 s
Mobility model	Random WayPoint
Agent type	UDP
Application type	CBR
MAC protocol	IEEE802.11
Initial energy	100 J

Routing overhead is one of the performance metrics that measure the effectiveness of the network and is calculated as follows.

$$\text{Routing overhead} = \frac{P_C}{P_D} \tag{6}$$

In the above equation, P_C is the total number of packets sent in the network and P_D is the total number of packets received.

The routing overhead at different node speeds is shown in Fig. 3. As can be seen from the figure, when the movement rate of the nodes increases, the routing overhead of the network also increases. The reason for this is that as the node speed increases, the energy required by the UAV increases and the network topology also changes more rapidly, resulting in an increase in overhead.

Compared to the classic AODV routing protocol, the routing overhead of EE-AODV has been reduced, but SE-AODV reduces the routing overhead even more significantly. And the increase in routing overhead is smaller when the node speed is higher.

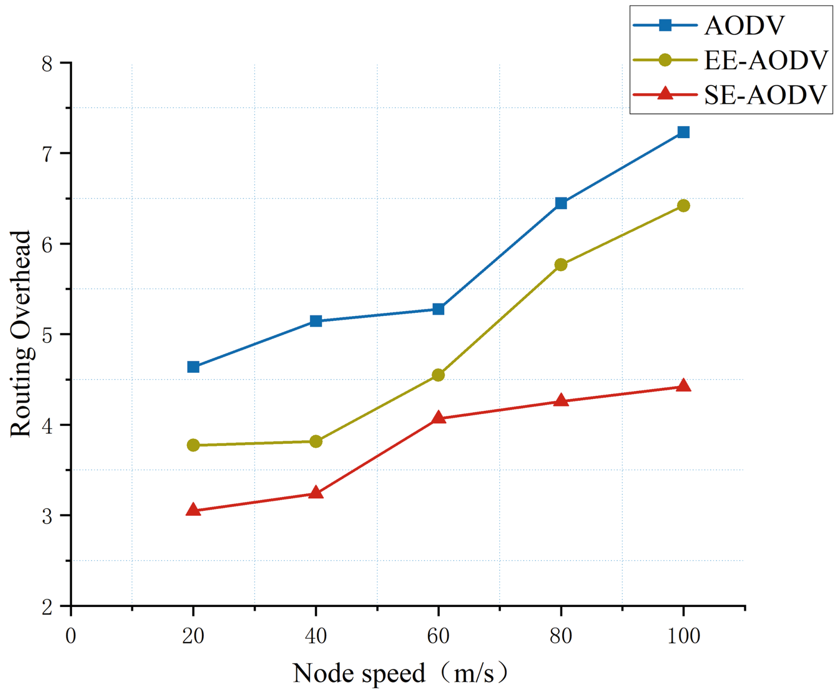

Fig. 3. Routing overhead as a function of node speed.

Throughput, which is the actual amount of data transmitted per unit of time, is an important indicator of routing performance. It is calculated as shown in Eq. 7.

$$\text{Throughput} = \frac{\textit{recevied} \times 8}{\textit{Simulation time} \times 1024} \tag{7}$$

Figure 4 shows the variation of network throughput with the change in node movement speed. Since the maximum number of connections in the simulation parameter is set to 15, the throughput is high because the nodes are well connected and the received signal strength is relatively stable when the node speed is maintained at about 20 m/s. When the node speed increases to 40, the topology in the network starts to change frequently because the maximum number of connections does not change, and it causes a sudden drop in throughput. SE-AODV has a certain improvement in throughput compared to EE-AODV and the classical AODV routing protocol.

This is due to the fact that the optimized SE-AODV routing takes more cases into account, ensuring node energy, received signal strength and hop count. As a result, the number of path breaks is significantly reduced and the packets sent per second are increased. As the node speed increases, the network energy is consumed, the received signal strength decreases, and the throughput of all scenarios decreases accordingly. But overall, the network throughput of SE-AODV is significantly more advantageous.

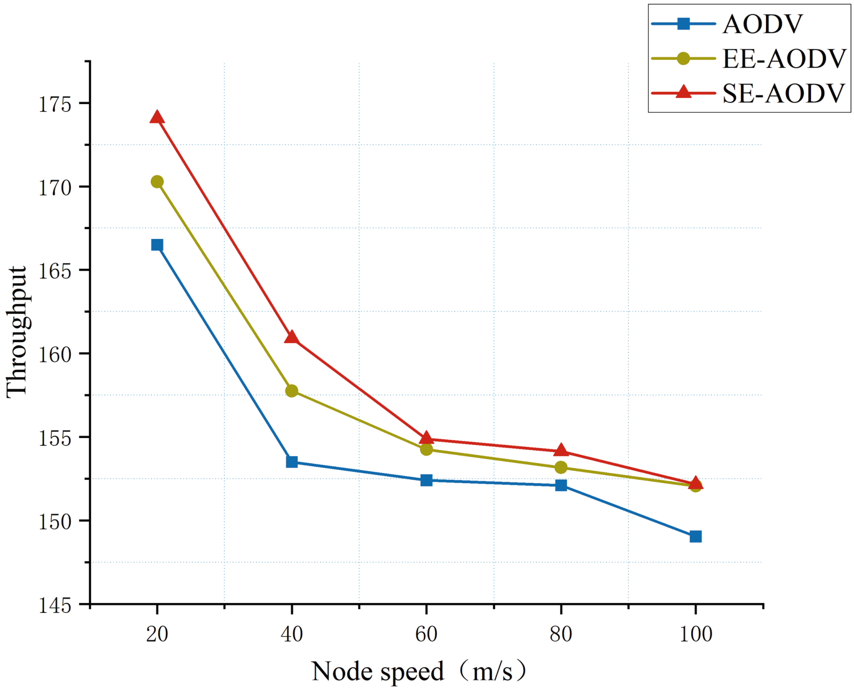

Fig. 4. Thoughtput as a function of node speed.

The grouped delivery rate is calculated as in Eq. 8.

$$\text{Packed Delivery Ratio} = \frac{P_R}{P_S} \times 100\% \tag{8}$$

where P_R is the number of packets arriving at the target node; and P_S is the number of packets that the source node has sent.

Figure 5 shows that SE-AODV exhibits a better performance in terms of packet delivery rate compared to the classic AODV and EE-AODV. At lower node speeds, again due to the maximum number of connections and network topology, it exhibits a sudden drop in the variation from 20 to 40.

After that, as the network node speed increases and the network topology changes faster, the packet transmission rate in the path inevitably decreases. Packets will be cached in the queues of the nodes and when the queues are filled, packets will be dropped, so the packet delivery rate will drop accordingly. With the optimized SE-AODV, the link considers the received signal strength to select the next hop node, so the stability factor of the path is higher and the packet loss is greatly reduced.

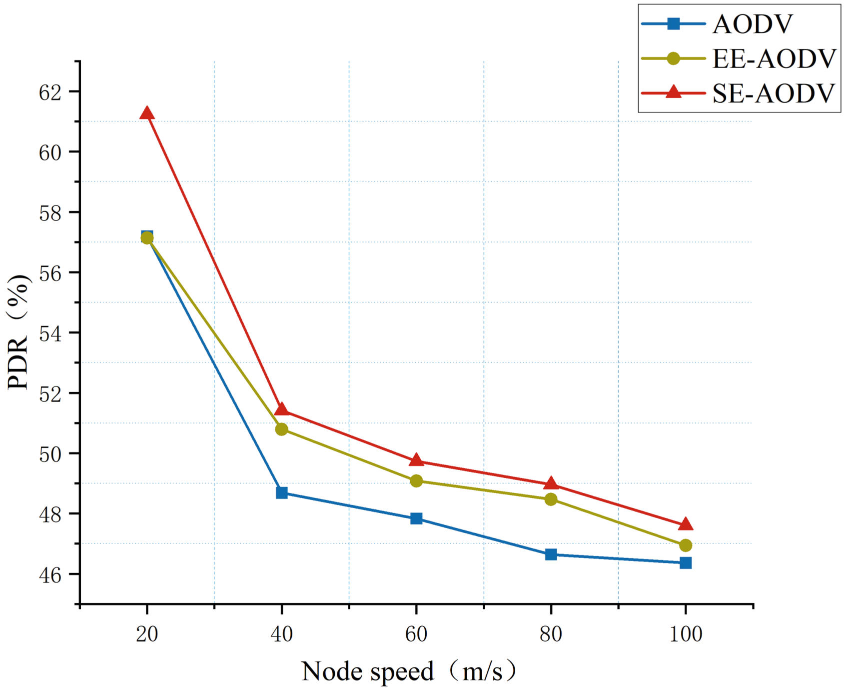

Fig. 5. Packet delivery rate as a function of node speed.

6 Conclusions

In this paper, we propose an optimized AODV routing protocol SE-AODV considering energy and received signal strength to address the problems of high routing overhead, low throughput and packet delivery rate of FANETs routing protocols. The new protocol provides multi-path selection and network energy balancing in terms of energy, received signal strength and hop count. By comparing with the classical AODV and EE-AODV protocols in real simulations, the results show that the SE-AODV protocol has lower routing overhead and has a significant improvement in throughput and packet delivery rate. The effectiveness and superiority of the proposed protocol in this paper are proved.

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