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A Review Of Routing Protocols For FANET

Shanshan Dong, Zhijun Tang*, Haowei Ma

School Of Information And Electrical Engineering, Hunan University Of Science And Technology, Xiangtan, China

Abstract:
With the continuous development of radio and aviation technology, the research on Flying Ad-hoc Networks (FANET) has become the hotspot. FANET is a distributed network composed of multiple Unmanned Aerial Vehicles (UAVs) in a self-organized form, which has great potential for application in both military and civil fields. Different application scenarios have different requirements for FANET channel resource allocation. To facilitate future in-depth research on FANET, a comprehensive investigation into FANET routing protocols and related knowledge was conducted. Firstly, common mobility models and routing techniques in routing protocols are introduced. Then, FANET routing protocols are reviewed and analyzed based on existing knowledge of routing protocols. Routing protocols are classified into five categories, and each discussed routing algorithm is introduced in detail from the perspectives of principles, strengths and weaknesses, and applicability scenarios. Finally, the problems and current status of optimization of OLSR routing protocols are discussed.
Keywords: *FANET, UAVs, routing protocol, OLSR, distributed network*

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I. Introduction

Unmanned Aerial Vehicle (UAV), a low-altitude vehicle with embedded computing, wireless communication, sensors, and small cameras that can collect information and transmit data to ground stations at any time, has been widely applied in various fields. However, the limited carrying capacity of a single UAV cannot meet higher realistic requirements, and with the development of UAV manufacturing technology and the advancement of wireless communication, The application of drones has expanded to include the collaborative tasking of clusters of drones, i.e., the formation of Flying Ad-hoc Network (FANET) [1]. With the advantages of easy deployment, high flexibility, versatility, and low cost, FANET is widely used in civil and military fields, including public safety and disaster relief [2], intelligence surveillance [3], traffic monitoring [4], and relay networks [5].

The characteristics of a FANET, such as high mobility, high dynamics, and fluctuating traffic patterns, present considerable challenges to adaptive routing and efficient packet delivery [6]. To meet the performance requirements in different scenarios, an in-depth study of the characteristics of FANET and the selection of routing protocols is also needed to provide a highly efficient and resilient network environment.

Many scholars summarized the research related to FANET from several perspectives. Amponis et al [7] performed a detailed comparison and evaluation of traditional cross-layer routing schemes. Oubbati et al [8] compared the differences between geolocation-based routing protocols and gave an overview of the characteristics of routing protocols. Beegum et al [9] presented a systematic and comprehensive review of hybrid and non-hybrid-based BIA routing methods and analyzed the application of bio-inspired strategies in FANET routing. Arafat et al [10] provided a detailed overview of the use of the Medium Access Control (MAC) protocol in FANET in terms of key features, performance factors, and working principles.

II. System Model

Topologies of FANET

The communication network topologies for UAVs can be broadly classified into three categories: star topology, mesh topology, and hierarchical topology [11]. A star topology is a network configuration in which all UAV nodes are directly connected to one or more ground control nodes. In this topology, all communication between the UAVs is centrally controlled through a ground control center. As shown in Figure 1. This topology is relatively simple in terms of connectivity, is readily expandable, and exhibits low network latency and low transmission error. However, it is susceptible to network paralysis in the event of a failure of the central node or an interruption in the communication link between the UAV and the control center.

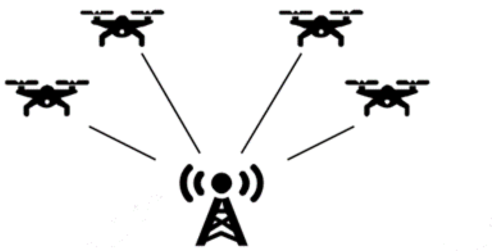

Figure 1. Star Topology

A mesh topology is a self-organizing network consisting of a ground control station and several wirelessly communicating UAV nodes, where each UAV node is connected to at least two other nodes. As shown in Figure 2. Mesh topology is distinguished by its flexibility, reliability, and superior performance in comparison to star networks. In a mesh network, packets are transmitted directly between UAVs via one- or multi-hop forwarding. The ground controllers are primarily responsible for control and management and are not directly involved in data forwarding between UAVs. However, In the event of an emergency or when required by certain applications, the ground controller may also receive and aggregate data information from the UAV.

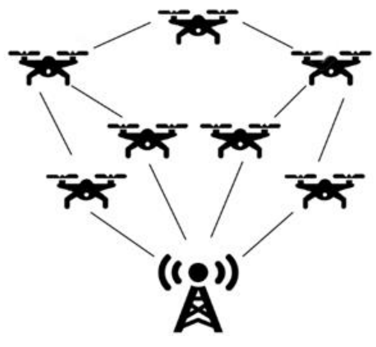

Figure 2. Mesh Topology

In hierarchical topology, the communication system of UAV nodes is divided into three layers. The first layer comprises communication between UAVs within a cluster. The second layer encompasses communication between backbone UAVs, otherwise known as cluster heads. The third layer represents communication between backbone UAVs and the base station. As shown in Figure 3. This network topology is designed to reduce the communication load and computational burden on the ground station, which is responsible for communicating with the backbone UAV and processing a portion of the control information. Nevertheless, this topology is not capable of circumventing the single point of failure issue at the cluster head.

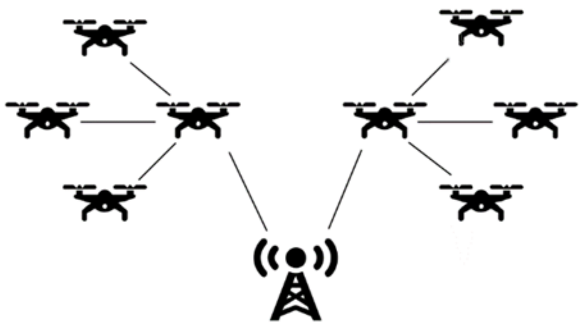

Figure 3. Hierarchical Topology

Applications of FANET

The occurrence of natural disasters, including earthquakes, tsunamis, typhoons, and torrential rains, has a significant impact on human life. With the rapid advancement of drone technology, drones have become an integral component in the provision of emergency relief [12].

The role of UAVs in disaster areas is primarily evident in their capacity for disaster detection, material transportation, communication relay, rescue positioning, and auxiliary rescue operations [13]. The utilization of drone swarms has the potential to enhance the efficacy of rescue operations, thereby reducing the number of casualties and the extent of property damage.

Disaster assessment: The drone can utilize its aerial advantage to capture real-time high-definition photographs and transmit rescue signals to disaster-stricken areas with rugged terrain, providing the disaster relief command with real-time and precise data about the circumstances in the affected area. Furthermore, the drone can be equipped with infrared scanning equipment and GPS positioning equipment, which enables the detection of potential injuries and the swift and precise localization of stranded individuals, thereby enhancing the efficacy of rescue operations.

Assessment of the point of destruction of buildings in the affected area: The main role of drones in natural disasters is disaster reconnaissance, The infrared sensors integrated into drones enable them to conduct infrared imaging of buildings in disaster-stricken areas, providing real-time access to building damage and facilitating the generation of more comprehensive and accurate disaster information for emergency command. Additionally, drones can disseminate timely information to search and rescue personnel, enabling them to make informed decisions and enhance rescue efficiency.

Evacuation and materialization: The drone can rapidly transport materials to the disaster area via the aerial route to help the rescue team equip the materials; at the same time, it can help the rescue team carry out personnel evacuation work to enhance rescue efficiency. Furthermore, the drone can be equipped with a loudspeaker amplification device to remind the personnel to evacuate promptly, to provide robust support for the emergency command.

Communications relay： In the event of a disruption in communication in the disaster area, the drone can realize a temporary communication function by mounting communication equipment to provide necessary communication support for the disaster area. In the literature [14], a self-organizing FANET scheme for economical backup communication was proposed. This scenario considers a post-disaster scenario that provides communication support for disrupted users who are unable to access the network via FANET deployment.

Intelligent agriculture: drones can be used in agriculture for crop scouting and fertilizer spreading, which can greatly improve productivity and avoid wasting resources. In the literature [15], Six scenarios for the application of FANET in agriculture are presented, and a chunked design is proposed to define the different roles and functions of UAVs in different agricultural scenarios.

Military: Deployment of FANET as a means of achieving military advantage [16], Clusters of drones augmented with artificial intelligence are used to locate and track dispersed mobile missile launchers.

Remotely sensed： In the field of remote sensing and earth detection, UAVs are widely used in surveillance and mapping due to their low cost and speed. In the literature [17], FANET is used in a large-scale mapping scenario in a millimeter- accuracy coastline simulation model to analyze the advantages of UAV clusters over traditional techniques using time efficiency, processing efficiency, and labor costs as metrics.

Characteristics of FANET

FANET, as a specific type of mobile ad-hoc network (MANET), exhibits some fundamental attributes of the wireless sensor network (WSN) and vehicular ad-hoc network (VANET), while also displaying unique characteristics. Table 1 illustrates the distinctions between FANET, VANET, and MANET.

Table 1. Differences between FANET, VANET, and MANET

	MANET	**VANET**	**FANET**
Node type	Phone etc.	vehicle	UAV
Node movement speed	low(6km/h)	medium-high (20-100km/h)	low-high (6-460km/h)
Node density	low	high	very low
Topology change	slow	fast	fast
Transmission model	ground	ground	low altitude
Computational capability	weak	strong	strong

Types of Nodes

FANET is a self-organizing network of drones comprising multiple UAVs. UAVs can be classified in several ways, with the most common categorization being fixed-wing UAVs (FW-UAVs) and rotary-wing UAVs (RW-UAVs) based on the type of wing[18]. In comparison to FW-UAVs, RW-UAVs exhibit enhanced flexibility, enabling vertical take-off and landing, and the capacity to maintain a fixed position in the air. The comparative performance of FW-UAVs and RW-UAVs is illustrated in Table 2.

Table 2. Performance comparison of FW-UAVs and RW-UAVs

	speed	**battery life**	**payload**	**Flight level**	**Static Hovering**
FW-UAVs	fast	Long	large	high	incapable
RW-UAVs	slow	short	small	low	capable

Dynamic Topology

UAV nodes are distinguished by high dynamics and rapid topology changes. In a three-dimensional environment, these characteristics give rise to unstable communication links and high packet loss rates.

Consequently, designing efficient and reliable routing protocols has emerged as a prominent area of research in FANET.

Energy Constraint

The energy sources for drones are primarily built-in rechargeable battery blocks or solar panels. However, the power range of these sources is constrained by battery size limitations. Furthermore, the energy consumption of drones during flight is considerable, particularly for smaller drones whose payload capacity is significantly influenced by energy constraints [8].

Quality of Service (QoS) Constraints

Compared to MANET, FANET exhibits superior efficiency, destructibility, cost-effectiveness, and detectability while imposing more rigorous performance standards. The varying mission scenarios necessitate the establishment of specific performance indicators to assess the network's efficacy. QoS metrics include several key performance indicators, such as packet delivery rate, packet loss rate, throughput, delay, delay jitter, and bandwidth. A lower latency value indicates a greater speed of information dissemination. A lower packet loss rate indicates a higher probability of successful data transmission. An increase in throughput indicates an expansion in network capacity. A smaller jitter value (i.e., delay at higher frequencies) indicates a more stable network, as evidenced by a reduction in fluctuations in the transmission of data.

FANET has different constraints on the QoS of the network in different applications. For example, it is necessary to reduce the delay between the drone and the receiver during data transmission to ensure that there is sufficient available bandwidth [19], ensure that the end-to-end delay in transmission is less than 40ms per 1kb packet in a search and rescue mission in a disaster area [20].

Moving Model

Mobility models serve as the foundation for the deployment and simulation analysis of FANET. For the different characteristics, the typical mobility models are as follows.

Random Way Point (RWP) Mobility Model [21]: In this model, the node randomly selects a target location, designated as D, from the region of interest. It then proceeds to move towards the target location at a randomly selected speed, denoted as $v \in [v_{min}, v_{max}]$. Upon reaching the target location, the node remains there for a randomly selected time interval, represented by $t_p \in [0, T]$. As a consequence of the probability distribution in two-dimensional space, the probability of a target point crossing the center of the simulation region is high. This results in an uneven distribution of node densities. As the simulation time increases, the nodes converge more closely to the location of the center of the region when they are in motion.

Random Direction (RD) Mobility Model [22]: In this model, the node is not required to select a target point; instead, it randomly chooses a moving direction d from the interval $[0, 2\pi]$ and moves in direction d with a random velocity $v \in [v_{min}, v_{max}]$ for a while until it reaches the region boundary point E. It then randomly remains for a certain time, using E as a new starting point to re-select the moving direction and velocity. Since nodes do not change direction and speed during movement and stop only upon reaching the boundary, it can lead to too many nodes staying at the boundary. Contrary to the RWP model, the RD model has a small probability density at the center of the region and a large probability density at the edges.

Distributed Pheromone Repel (DPR) Mobility Model [23]: Each UAV in this model maintains its pheromone map, and the UAVs choose the direction of movement based on the number of pheromone odors, which can enhance coverage. However, the pheromone keeps the UAVs away from each other while causing the link to break.

Gauss Markov (GM) Mobility Model [24]: The velocity and direction of a node in the present time interval within this model are contingent upon the velocity and direction of that node in the preceding time interval, in addition to a tuning factor that regulates the extent of randomness in the movement of the node. The equations governing the velocity and direction of the node are as follows:

$$v_n = \alpha v_{n-1} + (1-\alpha)\bar{v} + \sqrt{(1-\alpha^2)}v_{x^{n-1}} \quad (1)$$

$$d_n = \alpha d_{n-1} + (1-\alpha)\bar{d} + \sqrt{(1-\alpha^2)}d_{x^{n-1}} \quad (2)$$

Where v_n and d_n denote the speed and direction of the nth time interval, respectively, α is the tuning factor, $\alpha \in [0,\ 1]$, $\bar{v}$ and $\bar{d}$ denote the mean values of the speed and direction of the node, respectively, and $v_{x^{n-1}}$ and $d_{x^{n-1}}$ are independent Gaussian random variables having a mean of 0 and a variance of 1. The formula for updating the node position is as follows:

$$x_n = x_{n-1} + v_{n-1} \cos\theta_{n-1} \quad (3)$$

$$y_n = y_{n-1} + v_{n-1} \sin\theta_{n-1} \quad (4)$$

Where(x_n, y_n) and(x_{n-1}, y_{n-1}) denote the position coordinates of the node at the nth and n-1st time gaps, respectively, and v_{n-1} and θ_{n-1} denote the velocity and direction of the node at the n-1st time gap, respectively. The GM model has a smoother motion trajectory, and the speed and direction of the nodes do not change abruptly, eliminating unreasonable motion behaviors such as sharp stops and sharp turns, which is suitable for simulating real-world motion.

Semi-Random Circular Movement (SRCM) Mobility Model [25]： The model in which the UAV makes a circular motion around a certain two-dimensional circular region, based on which the approximate distribution function of the node movement probability is derived, the SRCM can produce a uniform node distribution and good movement performance in FANET. Enhanced Gauss-Markov (EGM) Mobility Model [26]: The EGM mobility model is a modification of the Gauss-Markov mobility model that aims to improve the applicability of FANET. The EGM mobility model introduces additional mechanisms for eliminating and limiting sharp stops by including altitude and acceleration as additional parameters for each mobile node. Paparazzi Mobility (PPRZM) Model [27]: The model has five possible walk states, Dwell, Directional Point, Figure of Eight, Scan, and Ellipse, which can be customized to perform more diverse tasks by setting different walk probabilities.

Routing Technology for FANET

To satisfy the specific requirements of FANET and its distinctive flight environment, the following data transfer techniques are commonly employed by FANET [8].

Store-carry and Forward (SF) Technology

This technique is primarily utilized in the domain of data transmission and routing. In the store-and-forward mechanism, a node initially stores the received data in its local memory and subsequently transmits it to the subsequent node. This approach guarantees the integrity and reliability of the data, as there is sufficient time for verification and potential repair of the data before it is forwarded.

Greedy Forward (GF) Technology

GF technology is a data transmission strategy that reduces the transmission distance and energy consumption by selecting the next closest node to the destination node to forward the data. This strategy facilitates the rapid propagation of data within a network; however, it has the potential to result in the formation of routing loops. Literature [28] put forth a novel link metric scheme that is based on a greedy forwarding strategy. This approach addresses the routing null problem by taking into account energy consumption, transmission distance, and the probability of successful reception in the next node selection.

Path Discovery (PD) Technology

PD technology is the process of identifying a valid route from a source node to a destination node. It typically entails the utilization of routing protocols, such as Dijkstra's algorithm or Bellman-Ford algorithm, for the construction and maintenance of routing tables.

Single Path (SP) Technology

SP technology is a data transmission technique that utilizes a single path for the transfer of data. This approach reduces redundant traffic and enhances network bandwidth utilization. However, it may also impact the reliability and real-time performance of data transmission in the event of a failure of the designated path.

Multi-Path (MP) Technology

Multipath technology is a technique that uses multiple paths for data transmission. This technique increases the reliability and fault tolerance of the network because if one path fails, data can be transmitted via other paths. However, it also increases the control and management complexity of the network.

Prediction Technology

Prediction techniques are mainly used to predict the behavior and performance of the network, such as traffic prediction, routing prediction, etc. Through prediction techniques, the state of the network can be known in advance and adjusted accordingly to improve the performance and stability of the network.

III. Classical Routing Protocol Classification

This section focuses on classical routing protocols, and this paper lists five types of FANET routing protocols: table-driven routing protocols, on-demand routing protocols, hierarchical hybrid routing protocols, geographic routing protocols, and power control routing protocols. As shown in Figure 4.

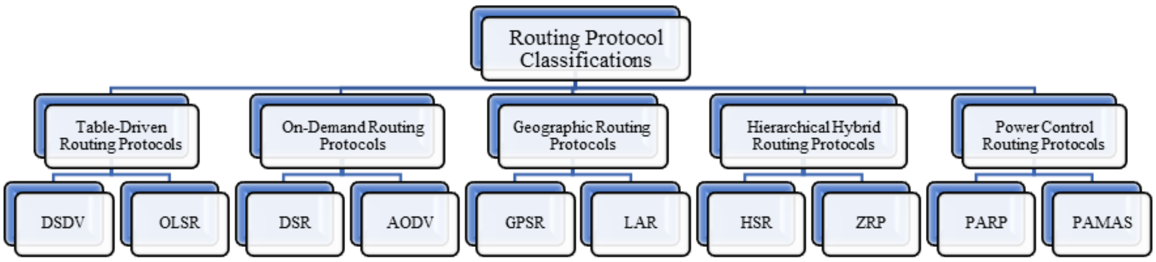

Figure 4. Routing Protocol Classifications

Table-Driven Routing Protocols

Table-driven routing protocols, also known as proactive routing or a priori routing protocols, are based on the principle that each node maintains a routing table that contains routing information about the arriving nodes. Each node in the network periodically broadcasts routing information to the entire network, thereby capturing and maintaining the global topology. When the source node needs to send a message, it can immediately get the route to reach the destination node. In the event of a change in the network topology, the relevant nodes will broadcast the topology change information to the whole network to update the routing table information and spread this update message throughout the whole network.

Because nodes have global topology information, table-driven routing enables fast route selection and optimization. However, this approach necessitates a considerable amount of network overhead to maintain real-time topology information. The main table-driven routing protocols are DSDV [29] and OLSR [30].

Destination-Sequenced Distance-Vector (DSDV)

The DSDV routing protocol represents an enhancement to the traditional Bellman-Ford routing algorithm. To address the problem of routing loops, DSDV incorporates the destination node sequence number into the forwarding table. In the DSDV protocol, each node maintains a routing table that contains information regarding the destination node and the path to it. This information includes the destination node address, the next hop address, the number of hops in the route, the sequence number of the destination node, and the time at which the route was established [31]. DSDV updates routes by periodically exchanging routing table information between neighboring nodes. There are two main types of update methods: a full update, which includes the entire routing table in the topology update message and is suitable for fast network topology changes; and a partial update, which contains only the changed part and is usually suitable for slow topology changes.

The operation process of the DSDV protocol includes: a) creation of the routing table; b) maintenance of the routing table; and c) detection of link outages. DSDV employs a sequence numbering system to avoid routing loops and has a relatively short route establishment delay, which allows for the rapid establishment of routes for nodes and the transmission of data. However, as network topology changes become more frequent, all nodes must disseminate routing information. Consequently, as the number of nodes increases, the routing overhead rises significantly, and unidirectional communication is not supported. Furthermore, the convergence time for routing is prolonged. Accordingly, DSDV is suitable for network environments where the network size is limited and the topology changes slowly.

The Optimized Link State Routing (OLSR)

OLSR is a table-driven link-state routing protocol that has been optimized for the classical link state (LS) protocol. OLSR reduces the sending of packet messages through the Multipoint Relays (MPR) mechanism. The protocol initiates its operations by performing link detection and neighbor discovery functions through the periodic exchange of Hello packets between nodes. Subsequently, the MPR message declaration function is performed through the periodic interaction of topology control (TC) packets. The topology thus established serves as the foundation for MPR-based routing.

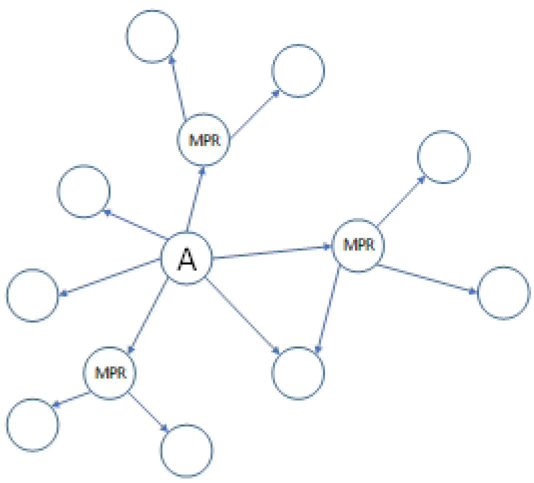

Figure 5. Flooding Mechanisms for OLSR

The OLSR routing protocol utilizes MPR node forwarding to reduce the number of control packets transmitted, and the flooding mechanism in OLSR is shown in Figure 5.The operation process of the OLSR protocol includes a) Interaction of routing information; b) Calculation and selection of routes; and c) Distribution of data. OLSR routing protocol is an a priori link-state routing protocol, nodes in the data transmission already exist to reach the destination node path information, with the advantages of path selection waiting delay is small; The protocol uses a relay node forwarding mechanism to reduce the routing overhead due to flooding of link state information; However, in OLSR, whether the link state changes or not, the topology control information is periodically flooded, which has a high overhead and poor network extensibility, so it does not apply to the network scenario with sparse nodes.

Each UAV node under OLSR can capture the network topology in real time, which is suitable for network scenarios with short concurrent transmissions and low latency.

On-Demand Routing Protocols

On-demand routing protocols, also known as randomized routing protocols or reactive routing protocols, are based on the principle that route discovery is initiated only when there is a demand for communication, and inactive nodes do not store routing information. Unlike table-driven routing protocols, On-demand-driven routing protocols do not need to generate routes in advance, and nodes do not need to broadcast topology information globally periodically, only when the source node needs it, so they can save network resources, but this type of routing has to complete route discovery before sending out the packet, which increases the end-to-end delay of the network. On-demand routing generally consists of two phases, route discovery and route maintenance. The distinctions between the various routing protocols of this type are manifested in the process of discovering routes, the methods of obtaining and maintaining information, and how data is transmitted. DSR [32] and AODV [33] are more typical examples.

Dynamic Source Routing (DSR)

DSR protocol is based on the concept of source routing, the so-called source routing, that is, the header of each data packet contains information about the entire route to the destination node，In the DSR protocol, there is no requirement for nodes to periodically broadcast routing updates throughout the network. When nodes move or communication services change, it is unnecessary to disregard topological changes that do not impact the routes currently in use.

The operation process of the DSR protocol includes a) Routing discovery; and b) Routing maintenance.

DSR supports unidirectional links, and during the relay RREQ phase of route discovery, intermediate nodes are required to append their addresses to the request packet before forwarding it. The DSR protocol provides a rapid reactive service that guarantees the successful transmission of data packets, which is suitable for self-organizing network environments where nodes are moving at high speeds; however, the necessity of embedding complete routing information in each data packet header in protocols inevitably results in additional routing overhead, which in turn reduces the overall network bandwidth utilization. This approach is not well-suited for large-scale networks, and it also exhibits limitations in terms of protocol scalability.

Ad Hoc On-Demand Distance Vector Routing (AODV)

AODV is a routing protocol based on the On-Demand Distance Vector protocol. In contrast to the DSDV protocol, which is based on a table-driven approach, the AODV protocol does not necessitate the real-time maintenance of topology information. Instead, the route request process is only initiated upon the transmission of a message and the subsequent failure to establish a route to the destination node. The AODV protocol employs a broadcast route discovery mechanism analogous to that of the DSR protocol. However, the routing of AODV is dependent on the dynamic routing table constructed and maintained by intermediate nodes. The route discovery process of AODV comprises two stages: the establishment of reverse routes and the establishment of forward routes. In AODV protocol, the efficiency of the protocol is improved as each node in the route maintains a routing table and hence the header of the data message no longer needs to carry the complete routing information. AODV combines the advantages of DSR and DSDV with low processing and storage overhead and the ability to react quickly to changes in link state. Furthermore, the system is capable of rapid response to alterations in the link state.

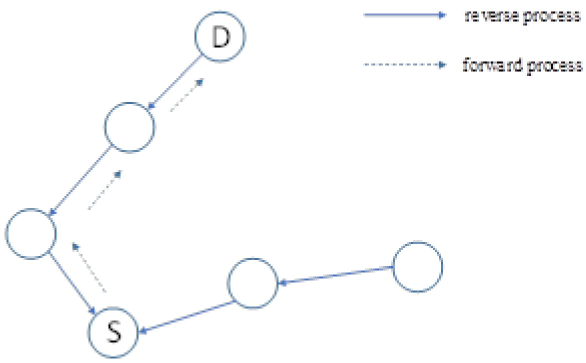

Figure 6. Route Discovery Process for AODV

The operation process of the AODV protocol includes a) Routing discovery; and b) Routing maintenance. The process of route discovery for AODV routing protocol is shown in Figure 6. The AODV protocol represents an enhancement over DSDV in its approach to route establishment. During the routing process, intermediate nodes do not need to maintain routing information or participate in routing table exchange. In the route discovery phase, when a node requires the transmission of a message and there is no valid route to the destination node, a route discovery process is initiated by broadcasting an RREQ packet to the network. AODV permits intermediate nodes to respond to the RREQ. Once the route has been identified, the intermediate node or the destination node transmits an RREP packet to the source node in a unicast fashion. The RREP is transmitted along the reverse path that has just been established. Therefore, AODV does not support unidirectional links. In the route maintenance phase, the route discovery process is restarted when the source node gets a link outage message. A distinctive feature of AODV is that it introduces multicast routing protocol extensions and solves the infinite counting problem using sequence numbers. However, similar to WRP, it needs to send hello messages at regular intervals, which causes some additional overhead.

Geographic Routing Protocols

In a geographic routing protocol, each node is equipped with the location information of all other nodes, which is employed to discover the routes and determine the transmission path. The control of the flooding range of route discovery according to geographic location information has the potential to reduce the network overhead. However, it is very difficult for the nodes to have the geographic location information of their neighbors or global topology, which leads to problems such as low packet arrival rate and difficulty in route establishment. Moreover, the configuration of each node with a GPS device increases energy consumption. The main commonly used geolocation routing protocols are GPSR [34] and LAR [35].

Greedy Perimeter Stateless Routing (GPSR)

GPSR is a stateless routing protocol where nodes keep only the neighbor node table and not the routing table. In the GPSR protocol, each node in the network is aware of its location and that of its neighboring nodes, and can address their locations uniformly. When a node needs to send a packet, if the distance from the current node to the destination node is greater than the distance from the neighboring node to the destination node, the greedy forwarding method is employed; otherwise, boundary relaying is utilized. GPRS addresses the local optimization issue resulting from greedy forwarding by integrating these two forwarding techniques.

GPSR is a location-based routing protocol, the advantages of which are that nodes store almost no routing state information and thus have low routing memory overhead, and there is no need to flood requests throughout the network, so there is little control overhead for routing; GPRS can quickly adapt to topological changes in the network. However, due to the inherent characteristics of node mobility and random distribution, etc., GPRS utilizes boundary forwarding to ensure the continued transmission of packets to the destination node when the greedy strategy fails, if the network topology is static, the generation of numerous packets to the same destination node through the same length of forwarding path may result in the inefficient utilization of energy and an augmented delay. Meanwhile, the data robustness of the GPSR protocol is high, as long as the network connectivity is not destroyed, there must exist a path to reach the destination. However, the GPSR protocol does not consider the residual energy situation of relay nodes, which tends to make some nodes used frequently.

Location-Aided Routing (LAR)

LAR is a routing protocol that uses geographic location information to optimize the performance of the protocol by obtaining geographic information, limiting the route search range, reducing the number of nodes affected in the route discovery process, and reducing the amount of Class II route control packets sent to alleviate network overhead and improve the protocol performance. The LAR routing protocol represents an enhancement to the RREQ packet flooding mechanism present in the DSR protocol. The LAR protocol addresses the issue of elevated routing overhead observed in the DSR protocol, which could potentially result in communication congestion.

Hierarchical Hybrid Routing Protocols

Hierarchical hybrid routing protocols are capable of combining the advantages of both table-driven and on-demand routing protocols by employing a logical hierarchical structure within the network.

Nodes in the network are classified into distinct levels or "clusters" based on their geographical positioning or other relevant criteria. For nodes within a cluster, table-driven routing algorithms are employed, whereas on-demand-driven routing algorithms are utilized for inter-cluster communication. This approach effectively integrates the advantages of both table-driven and on-demand routing protocols while avoiding their respective drawbacks. However, the dynamic topology characteristics in FANET may result in frequent cluster head failures, which can lead to routing disruptions. The most commonly used hierarchical hybrid routing protocols include ZRP [36] and HSR [37].

Zone Routing Protocol (ZRP)

ZRP is a routing protocol that employs a combination of table-driven and on-demand routing policies, based on a multi-hop technique. In this technique, each node has an area centered on itself, and the number of nodes in the area is related to a set radius of the area. In the ZRP protocol, the central node in a zone employs the table-driven routing protocol i.e., Intra-Azone Routing Protocol (IARP) to ensure the maintenance of an up-to-date routing table for the rest of the nodes within the zone, as well as for the nodes outside the zone, the on-demand routing protocol i.e., Interzone Routing Protocol (IERP) is employed to establish provisional routes for route finding and route maintenance between disparate routing domains. Moreover, Border Broadcast Resolution Protocol (BRP) is utilized to curtail redundant forwarding during inter-area route discovery. The performance of ZRP depends on the value of the zone radius parameter, which should be determined based on the network characteristics (e.g., node density, node speed, etc.)

The operation process of the ZRP protocol includes a) division of protocol regions; b) selection of intra-regional protocols; c) selection of inter-regional protocols; and d) query control mechanisms. The process of route discovery for the ZRP routing protocol is shown in Figure 7. ZRP protocol employs a table-driven routing approach within a specified region to circumvent the initialization delay issues commonly observed in on-demand routing protocols. Additionally, the route update overhead is minimal due to the limited scope of the region. Between regions, it utilizes an on-demand approach to mitigate the high interaction overhead commonly associated with table-driven routing protocols. Furthermore, when searching for routes between regions, it sends a request grouping to border nodes to enhance the route lookup speed. However, the ZRP protocol only allows nodes within the destination node area to answer, increasing the time for the source node to establish a route. Additionally, it periodically transmits packets, which increases network overhead.

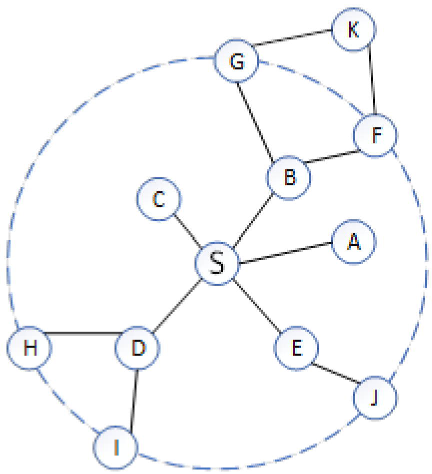

Figure 7. Route Discovery Process for ZRP

Hierarchical State Routing (HSR)

HSR protocol is a hierarchical link-state routing protocol that employs a group mobility model to divide the nodes in a network into distinct groups, which then form a logical subnetwork. HSR protocol employs a distributed clustering idea to generate physical hierarchical addresses of the nodes based on their physical location. This enables the protocol to determine the forwarding paths of data packets. Additionally, the protocol manages the location of nodes based on their logical addresses. Within each logical subnet, there is at least one attribution agent that is responsible for managing the correspondence between the logical addresses and the current physical addresses of the nodes within that subnet, and for forwarding data packets for the managed nodes. Nodes must register with the attribution agent to report the latest physical address.

Power Control Routing Protocols

The power control protocol is a real-time adaptation technology utilized in a network. It is capable of automatically adjusting the transmission power of communication equipment which makes it possible to minimize the power consumption of the network while satisfying the workload of the communication devices.

The principle of power control protocols in wireless networks is to optimize the transmission power of wireless signals, thereby minimizing power consumption while maintaining the desired level of communication speed and reliability. The primary goal is to reduce the overall power consumption of the network without compromising the data transmission rate. This technique is primarily utilized in Wireless Local Area Networks (WLANs) to facilitate optimal transmission of devices at low power consumption. The prominent power-controlled routing protocols are PARO [38] and PAMAS [39].

Power-aware Routing Optimization (PARO)

PARO is an on-demand mechanism for routing that does not require proactive route maintenance. When the source node needs to seek a route, the sending power is reduced by increasing the number of forwarding nodes between the source and destination nodes, PARO selects a route with the lowest total energy consumption over multiple routes between a pair of nodes using the sending power of each hop as a reference criterion to minimize the total energy consumption of the communication process.

The PARO power-controlled routing protocol is comprised of three fundamental algorithms: listening, redirection, and route convergence. These three steps collectively facilitate the identification of a communication route that optimizes the total energy consumption.

In comparison to other routing protocols, PARP demonstrates a reduction in energy consumption during the route discovery process. This protocol employs energy consumption as a metric for route selection, utilizing as many forwarding nodes as possible to minimize the power expenditure at each transmission hop. This approach ultimately results in a reduction in the total energy consumption associated with the communication process.

Power-Aware Multi-Access with Signaling (PAMAS)

PAMAS is an energy-efficient MAC protocol designed for Ad-Hoc networks. The protocol divides the physical channel into separate control channels and data channels, which are used to send control packets and data service packets, respectively. PAMAS is an improvement of the Multiple Access with Collision Avoidance (MACA) protocol; its fundamental service access process is the same as MACA, continuing to employ the RTS-CTS handshake mechanism. However, following a successful handshake interaction between the sender and receiver, data transmission commences. In this scenario, only RTS and CTS are transmitted via the control channel. Additionally, the PAMAS protocol employs a busy signal mechanism. Upon receiving a data packet, the receiving node sends a busy signal on the control channel for a designated period. This signal protects the data packet from interference caused by hidden terminals and is analogous to the BTMA protocol.

PAMAS has been demonstrated to save at least 10% of the energy consumed in sparse networks and up to 70% in fully interconnected networks while maintaining no impact on latency or throughput.

IV. OLSR Improvements In FANET

Directions for improvement

In the OLSR protocol, only the nodes selected as MPRs are capable of forwarding control messages, so the selection of the MPR set has a direct impact on the performance of the network. Additionally, the following problems exist in the OLSR protocol.

The selection of MPR sets is subject to a certain degree of redundancy.

In the OLSR protocol, the MPR set is selected using a greedy algorithm from the one-hop neighbor nodes. Initially, the nodes connecting the two-hop isolated nodes are selected. Subsequently, the nodes are selected by using the coverage of the nodes as a criterion; the nodes that can cover more two-hop nodes are selected, until the elected MPR set covers all the two-hop neighbors. The MPR is selected as the node with the highest coverage of one neighboring node, and the resulting set of MPRs may not necessarily be the smallest. The selection of UAV network nodes for the OLSR is not based on considerations of the QoS of the network.

OLSR employs hop-based routing metrics to provide a visual representation of link length, reduce the number of node packet forwards, and minimize the overhead associated with packet processing and forwarding. However, in FANET, the hop-count-based routing metric is not an accurate reflection of the true quality of the links in the network. Consequently, OLSR may select low-quality links with fewer hops over high-quality links with more hops, which ultimately results in a deterioration of the network quality.

Related Works

OLSR is a classical proactive routing protocol with the potential to reduce data transmission delay. In recent years, numerous improved algorithms on OLSR have been proposed for application in FANET.

To address the issue of excessive route control overhead associated with the OLSR protocol, literature[40] proposed an optimization of the size of the MPR set, which also results in enhanced network performance. However, this approach necessitates a considerable increase in the required transmit power. To reduce the routing overhead and improve the link quality, literature [41] proposed an optimization of the selection mechanism of MPRs, whereby MPR nodes with higher residual energy, higher link survivability time, and more neighborliness are selected based on a fuzzy mechanism. This approach is expected to reduce the delay, increase the packet delivery rate and throughput, and improve the energy overhead in the network. Literature [42] proposed a location-based improved OLSR routing protocol. This new protocol addressed the issues of high mobility, topology transformation, and energy constraints in existing FANET protocols. The authors combined the location information of the nodes, calculated the link expiration time, and considered the residual energy of the UAVs. They also incorporated energy constraints for MPR selection. Additionally, literature [43] proposed a MOLSR routing protocol that selects the optimal MPR based on a combinatorial metric, taking into account both mobility and energy factors, which improves the overall performance of the network.

V. Discussions

In recent years, numerous researchers have devoted their efforts to the field of FANET, proposing numerous enhancements to topology-based routing protocols and introducing a plethora of novel techniques. Such as prediction-based routing protocols, which employ neural network techniques to forecast the mobility patterns of nodes and estimate the probability of successful transmission of UAV nodes under network topology transformations and end-to-end delay.

This article provides an overview of the fundamental concepts and techniques associated with Ad-hoc networks, including mobility models, routing techniques, and application scenarios. It aims to provide readers with a preliminary understanding of Ad-hoc networks. However, in FANET, further research is required into the specific mobility models that are necessary for various application environments. This is because different performance metrics must be considered in different applications. While this paper outlines classical routing protocols in FANET, it is imperative to consider the unique characteristics of a 3D environment and energy constraints associated with FANET. Future research should be devoted to the development of new high-performance routing protocols to effectively address these challenges.

Conflict of Interest

The authors declare no conflict of interest.

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