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ROUTING PROTOCOLS IN FANET FOR DISASTER AREA NETWORKS: A REVIEW

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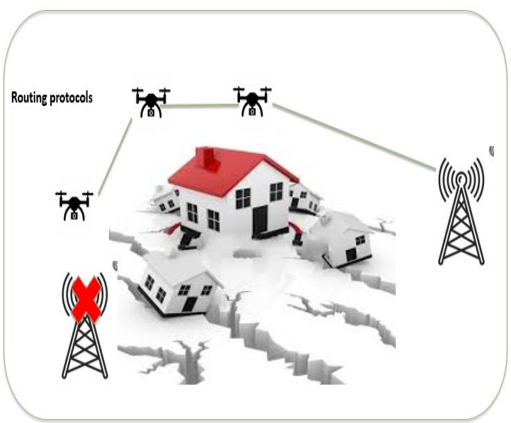
Graphical abstract



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Abstract

A group of small, unmanned aerial vehicles (UAVs) linked together in an ad hoc fashion is called a Flying Ad hoc Network (FANET). The main characteristics of FANETs are the absence of central control, mobility, self-organizing, and flexibility, which makes FANET a suitable solution for disaster relief applications where the typical communication infrastructure is likely to be malfunction. UAVs can be used to scan the afflicted region in search and rescue missions and help set up communication network for survivors of disasters, emergency responders, and the nearest cellular infrastructure. To create a stable and robust connection between numerous flying UAVs in an ad-hoc network, suitable communication routing protocols that could be implemented on highly dynamic networks are required. This paper reviews and investigates current FANET routing protocols to determine which routing protocol is the most appropriate in a particular disaster scenario. In addition, reviewing the mechanism, the performance of existing routing protocols, the simulators utilized, routing metrics, performance metrics, advantages and disadvantages, and the potential application in disaster areas of those protocols. The result of the analysis and investigation of this work indicates that for each disaster situation, there is no particular routing protocol; protocol selection is depending on a number of criteria, including network size, network density, UAV velocity, and disaster application.

Keywords - Unmanned Arial Vehicles (UAVs), Flying Ad hoc Network (FANET), routing protocols, disaster scenarios

1.0 INTRODUCTION

During a natural disaster, the most serious concern is the preservation of human lives, which is why the 72 hours after a disaster are so important. Therefore, fast and efficient search and rescue procedures are required. After an incident, humanitarian operations are typically directed at the evacuation of civil society and search and rescue (SAR) operations [1]. The main problem is the absence of communication. In this sense, the deployment of a smart, mobile, and adaptable network through the usage of Unmanned Arial Vehicles (UAVs) is being considered as one possible alternative for emergencies. The key features of the Flying Ad hoc Network (FANET) are the self-coordinating and ad hoc connection between flying nodes, which could expand the range of communication in the absence of communication networks. UAVs or drone networks have received much attention recently, thanks to new electronic technology like sensors, impeded chips, Global Positioning System (GPS), and low-cost radio interfaces [2]. This leads to open doors for several militaries and civilian applications that use a group of UAVs, such as natural disaster scenarios, SAR operations[3], border supervision, autonomous tracking, good delivery, and agriculture monitoring [4].

Telecommunication infrastructures break down after natural disaster incidents, leading to significant damage and disruption of services. To perform the rescue operations, this needs for a network that can be instantly deployed, including flying vehicles and emergency crews on the ground who will saving a lot of people's lives. Thousands of people suffer during Hurricane Katrina due to the lack of interaction between the relief agencies. The destruction of communication lines in that region remains one of the critical reasons for this [5]. The response time of emergency response workers is the key for helping survivors after a natural disaster. Via aerial assessment UAV networks, optimal situational awareness is attained. Depending on the region, various laws extend to the use of UAVs. However, during a disaster, special permissions are typically issued to flying vehicles to assist emergency team in determining the situation very quickly [6].

FANET, classified as a category of Mobile Ad-hoc Network (MANET) and Vehicular Ad-hoc Network (VANET), according to Figure 1. FANETs are a wireless self-organizing network that links mobile, low cost, and easy to construct aerial nodes like UAVs. Although FANET is a subclass of MANET and VANET, it has different features when compared to different Ad-hoc networks, like mobility, power limitation, and connectivity. The FANET nodes launch into the sky and travel very high in contrast to the MANET nodes. These nodes are small UAV mobile drones flying 3D in the sky. One of the biggest challenges in FANETs is energy usage, and this is because UAVs power embedded batteries with a low energy capacity. Therefore, the construction of communication networks should take into consideration the utility of consumption to maximize the network's lifetime and avoid rapid UAV fail.

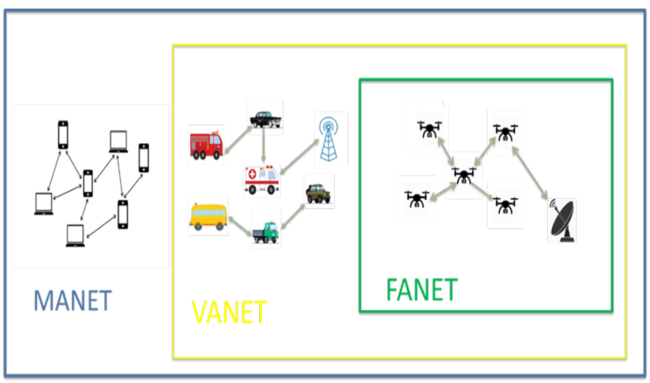

Figure 1 MANET, VANET, and FANET.

Developing a routing protocol for data transference between UAVs is extremely important. However, difficulties associated with developing it, changing topology, high nodes speed, power limitation, and varying UAV allocation, make it challenging to design a routing protocol to ensure efficient communication [7]. Recently, many researchers have optimized the traditional MANET routing protocols to be adapted for FANET characteristics and introduced new protocols for data transmission in FANET.

Table 1 compares the significant differences between the previously reviewed articles in the literature and our review based on the issues and challenges that must be resolved. We identified that the articles were divided into MANET and FANET discussed routing protocol issues and challenges. However, our review focuses on using routing protocols in emergencies and aims to assist researchers and respondents in selecting and designing application-specific routing protocols for various disaster scenarios. We also present a summary of the proposed routing protocols, the network simulator tools and the performance indicators utilized to develop these protocols. This paper reviews the current routing protocols that can be used in different disaster scenarios where two basic categories, topology-based and position-based are comprehensively discussed. The contributions of this work are:

- To review routing protocols in FANET based on routing issues addressed in the literature, besides the mechanism, the performance, the simulators used, routing metrics, and performance metrics.
- To present the limitations of the routing protocols and suggestion of possible application of these protocols in disaster and emergency response scenarios.

The remaining of this paper is categorized as follows: Part 2 presents the use of FANET in disaster scenarios and discusses the applications of UAVs network in disaster management. Part 3 explains the characteristics of FANET and the issues in routing that different researchers are considering to improve the routing protocol in FANET. Part 4 summarizes the routing protocols in FANET, including topology-based and position-based protocols, the simulators used, the advantages and disadvantages, and possible application in disaster scenarios of every protocol. Part 5 discusses issues and challenges associated with designing and simulating routing protocols in FANET. Finally, part 6 concludes the work and discusses possible research directions in the future.

2.0 FANET IN DISASTER SCENARIOS

Natural disasters of several kinds, including earthquakes, tsunamis, landslides, forest fires, and others, have resulted in losses of material goods and human life. This acknowledges the requirement to increase disaster resilience to enhance the capability to anticipate, assess, and react to disasters. Research has demonstrated that UAVs network is a useful tool in natural disaster situations. UAVs can be a promising solution for several emergency responses and disaster relief applications. Thanks to the ability to fly in disaster areas, flexibility, ease of implementation, low operating costs, and self-organization without relay in any infrastructure network. Figure 2 shows the numerous uses of the FANETs in disasters. It shows how UAVs may assist in handling and monitoring any disaster, including floods, earthquakes, tsunamis, forest fire monitoring, hurricanes, and pandemic situations.

The most typical natural disaster is flooding, accounting for thousands of deadly incidents each year throughout the world. Due to their brief duration, these phenomena are regarded as harmful or fatal when they do occur. Most of these casualties may be avoided with early warning, but real-time surveillance is still crucial. FANET can therefore be a valuable tool for monitoring and gathering all pertinent information on floods[7] [8, 9].

One of the costly and deadly natural disasters in the planet is a wildfire or forest fire. Millions of acres of forests have been burned, thousands of people have been evacuated, homes have been destroyed, infrastructure has been wrecked, and most significantly, the threat to human life, are all immediate effects of wildfire.

Table 1 Related survey papers

Ref	year	Ad hoc Network	Application in disaster	Routing protocols	Routing issues	Simulators	Performance Metrics	Description
[10]	2016	FANET	✓	×	×	×	×	The primary UAV applications for disaster management are discussed in this study.
[11]	2017	MANET	×	✓	×	×	×	Communication techniques for SAR operation briefly discussed routing protocols.
[12]	2018	FANET	×	✓	×	×	×	Simulation of OLSR& AODV for disaster monitoring and SAR operation.
[5]	2018	MANET	×	✓	×	✓	×	This survey studies disaster area network architecture and routing protocols in MANET.
[13]	2020	FANET	×	✓	×	×	✓	Strategies and routing techniques for FANET application in Agriculture.
[14]	2021	FANET	✓	×	×	×	×	The study reviewed the FANET mobility model for SAR operations in the disaster area.
[15]	2021	MANET	×	✓	×	×	✓	Reviewed routing protocols in MANET for disaster scenarios
[16]	2021	MANET	×	×	×	✓	×	Reviewed the mobility models in MANET for disaster area scenarios.
[17]	2021	FANET	×	✓	×	×	✓	Simulation of AODV, OLSR, DSR, and ZRP in FANET for different disaster scenarios.
[18]	2022	FANET	✓	✓	×	×	×	Reviewed protocols for various layers in the protocol stack for FANET in the disaster area.
[19]	2022	MANET	×	✓	✓	×	✓	Reviewed MANET routing protocol in disaster management.
Our paper	2024	FANET	✓	✓	✓	✓	✓	Reviewed application of FANET in Disaster management, routing issues, routing protocols, and their mechanism, advantage, disadvantage, and possible application in disaster scenarios.

Human intervention makes monitoring, managing, or assessing forest fires or wildfires exceedingly difficult. Another challenging task is finding and rescuing people from dangerous fire areas. The main advantage of the forest fire monitoring system based on FANET for distant and difficult-to-reach locations are that it employs UAVs rather than the current methods, which rely on satellite imaging and manned aircraft to provide surveillance services on demand [20] [21] [22].

The FANETs network system is essential in any pandemic situation. Compared to conventional ways of operation, UAVs offer several advantages [23]. They dramatically cut reaction times and expenses while lowering physical danger. Additionally, they contribute to enhancing safety in the case of any pandemic scenario. In contrast to traditional airplanes, these UAVs can fly at altitudes as low as above the earth. They have a significant economic advantage when it comes to service and maintenance. UAVs or drones have recently been employed for essential support during the Covid-19 pandemic [24]. The activities and services offered involve locust management, sanitization of contaminated regions, temperature monitoring for detecting fever, distribution of information, and more. UAVs have also been employed to transport life-saving products like food and medicine to inaccessible areas to address supply chain problems.

FANET can provide a wide range of assistance to victims and emergency crews: A-Monitoring, B-SAR, C- Communication system, and D- Damage evaluation, as depicted in Figure 3.

Monitoring: UAVs can function as early warning systems by observing the built environment, collecting data for forecasts, and sending this information to early warning systems such as wildfire monitoring [6].

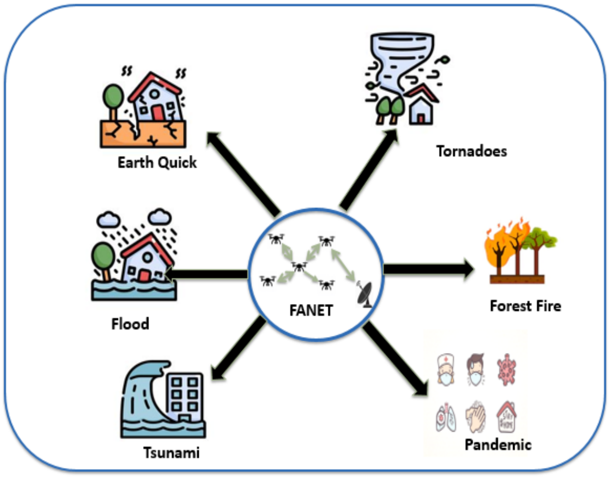

Figure 2 FANET in Natural Disaster

Search And Rescue (SAR): Another possible service is to manage search and rescue processes to collect data about the locations of the victims, the post-disaster situation functionality, and the possible threats that could occur during rescue missions[25-27]. This data is essential for first responders in planning rescue missions and selecting appropriate operational actions.

Communication System: UAVs can also help by establishing communication links connecting rescue teams or expanding the range of communication system. UAVs serve in this scenario as a flexible and fast organized communication system., which is essential when the usual communications infrastructure may be destroyed or damage due to the disaster [28-30].

Damages Evaluation: Evaluation of damages when a disaster occurs is another application of FANET because of the platform's versatility, high spatial resolution, and the resulting 3D pictures [31]. The size of the damage has to be assessed in different ways using UAVs network like UAV video inspection In [32], UAVs are studied as potential tools for gathering information on hurricane-related property damage.

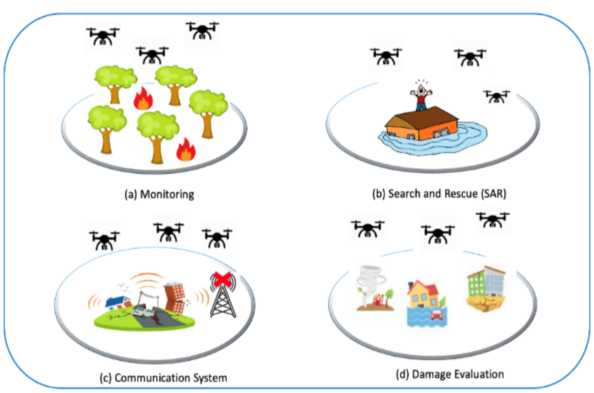

Figure 3 Application of FANET in Disaster Scenarios

3.0 FANET CHARACTERISTICS

FANET differs from MANET and VANET, two other types of ad hoc networks, in that it has a high dynamic network, wide coverage, and restricted energy. The three significant ad hoc network types MANET, VANET, and FANETs, are compared in Table 2. The key features of the FANETs must be met by new routing schemes due to varying ad hoc networks. The following are the difference in parameters and characteristics of the ad hoc networks:

Mobility: The mobility degree is high in FANET, and the UAVs speed is 30–460 Km/h compared with 5–50 Km/h for MANET and 10–120 Km/h for VANET. Moreover, UAVs move in 3D space while MANETs and VANETs move nodes and vehicles in the 2D area. FANET's highly dynamic network topology leads to regular link and network disconnections, which result in poor link quality [33].

Topology change: FANET topology varies more often than MANET and VANET topology, relying on the amount of mobility. Because of the mobility of UAVs is high, failures of the UAV platform often influence network topology. The contacts with the UAV will fail if it is malfunctioning or out of range of communication, resulting in an update of the topology[34].

Energy limitation: Compared to MANETs with the maximum energy limitation and VANETs with the lowest energy limitation, energy restrictions in FANETs are modest. The energy available influences route lifetime. Mini UAVs need to save energy to extended times in the air[35]. While car batteries usually power vehicles with fewer energy restrictions in VANETs.

Density: In opposed to MANET and VANET, the nodes number in given area of FANET is small. This implies that in the sky UAVs are widely separated, and UAVs are split by a large distance from each other. [36].

Coverage: UAVs are an efficient solution when mapping or monitoring big areas. Additionally, UAVs can provide ground users temporary connectivity when terrestrial infrastructures are destroyed.

Propagation model: The line of sight (LOS) available among UAVs is typical in FANETs that leads to a more robust connection, while in the case of MANET and VANET, Non-LOS (NLOS) could occur because of link obstructions.

Connectivity: FANETs have fewer nodes than MANETs and VANETs since the UAVs are typically farther apart (by several kilometers or more), requiring a greater transmission range, resulting in consuming the network resources such as energy.

Frequency bands: The two unlicensed bands frequently used in UAV communication systems are 0.9 GHz and 2.4 GHz, utilizing these bands can lead to congestion. For UAV-to-Ground communications, IEEE 802.11a combined with a 5 GHz frequency yields the greatest results.

3.1 Issues With Routing Protocols

FANET differs from MANET and VANET, two other types of ad hoc networks, in that it has a high dynamic network, wide coverage, and restricted energy. Because of the special characteristics of FANET, like UAVs' high mobility and frequent change in topology, designing routing protocols for such an environment is quite challenging. Several issues decrease the efficiency of the routing protocol, and the researchers designed the routing protocols to overcome one or more of these issues as discussed below:

Energy: UAVs usually launch with a small battery, which means limited energy capabilities. when a node has low remaining energy and is then chosen to forward packets, it will quickly run out of energy, and this causes connection failure and packet loss.

The residual energy of UAVs should be considered in designing routing algorithms for the FANET environment to the long-term stability of the network's operation.

Congestion: Because of its small memory, low node energy, and slow processor, FANET nodes suffer from congestion. This node congestion will cause packet loss and delay, reducing all network efficiency [37]. A congestion-aware algorithm that balance the traffic load should be designed to achieve high reliability and low latency data delivery.

Mobility: UAV nodes move at high speeds, link connection times are short, and nodes can move out of communication range, resulting in frequent link disconnection and route failure. It is crucial to consider the relative speed between deployed UAV nodes[38].

Link quality: The link quality as Received Signal Strength (RSI) or Signal Noise Ratio (SNR) should be considered in designing the routing protocol because a bad link can cause packet loss and decrease the network performance.

Table 1 Comparison between MANET, VANET and FANET

	MANET	VANET	FANET
Node type	Mobile phones, laptops	Cars, trunks, bus	Drones, copters, airplanes, satellite
Node speed	slow	Medium to fast	Medium to fast
Mobility	Low 2D	Medium 2D	High 3D
Topology change	slow	fast	fast
Energy consumption	Energy efficient	Not required	Energy efficient
Density	low	high	low
coverage	low	medium	high
Propagation model	Near to ground NLOS	Near to ground NLOS	High from ground LOS
connectivity	medium	high	low
Frequency band	2.4 GHz	5.9 GHz	2.4/5 GHz

4.0 FANET ROUTING PROTOCOLS:

The FANETs provide various routing protocols aimed in improving packet delivery and maintaining low packet delays and losses. This section reviews recent FANET routing protocols to aid researchers and emergency crews selecting a suitable routing protocol for a variety of disaster situations. This review is based on four routing issues discussed in section 3 thus: energy, congestion, mobility, and link quality. Also, the advantages and weaknesses of every protocol are discussed, besides simulators and possible applications in the disaster area. As shown in Figure 4, in this paper FANET routing protocols divided into two main types: topology-based and position-based. The topology-based protocols were initially designed for MANET and were developed to be adapted to the unique characteristics of FANETs. Topology-based protocols can further be divided into proactive and reactive routing. Position (geographic) routing protocol is another type of FANET routing protocol in which every node can define its location using a GPS. These protocols can be divided into Delay Tolerant Networks (DTN) and Non-Delay Tolerant Networks (NDTN).

4.1 Topology-Based Routing Protocols:

Many routing protocols in this category were originally introduced for MANETs and are modified to be adapted to the particular features of FANETs. Topology based protocols use the IP addresses of UAVs to transmit packets between communication nodes. This class is further subdivided into two categories: proactive routing protocols and reactive routing protocols.

4.1.1 Proactive Routing Protocols:

The proactive routing protocol is often known as table-driven routing. all node periodically keeps routing tables giving the entire topology of the network in this routing protocol. Due to the proactive structure of this routing protocol, routes are instantly accessible when appropriate. However, because of the storage of new routing tables, it suffers from extra overhead costs. While overhead is high, proactive routing minimizes delay as no required for route discovery in initializing data transmission.

Optimized Link State Routing OLSR routing protocol is a link state protocol developed especially for MANET [39]. Routes are maintained and updated continuously in tables. Thus, without any delay, the protocol immediately sets up a connection to all possible destinations, if a route is required. OLSR's main principle is implementing the Multipoint Relay (MPR) principle, and only MPR nodes enable to forward routing and data packets. In OLSR using MPR, UAVs are chosen by OLSR to cover two-hop neighbors, send information about link state, and for packet forwarding to other MPRs, this can reduce overhead. OSLR's key approach, the MPR algorithm, makes it perfect for large, high node density and dynamic networking [40]. OLSR performance was evaluated for the FANET environment in [41], [42], and[43] It achieves suitably well in the FANET network and has maximum throughput and minimum delay over other routing protocols. Although the performance of OLSR is acceptable in FANET, the protocol still suffers from issues. Many packets are exchanged by the proactive protocol, thereby slow to reconnect after disconnection, bandwidth consumption, and network congestion, which cause packet latency and loss. Many researchers have modified the OLSR protocol to make it adaptable for the FANET environment, as in the following discussion, to address these problems.

Energy Awareness Gray Coding EAG-OLSR routing protocol is designed for marine SAR for image transmission [43]. The OLSR was modified by adding improved MPR algorithms to adjust the node's Willingness to choose nodes and its best channel for image transmission.

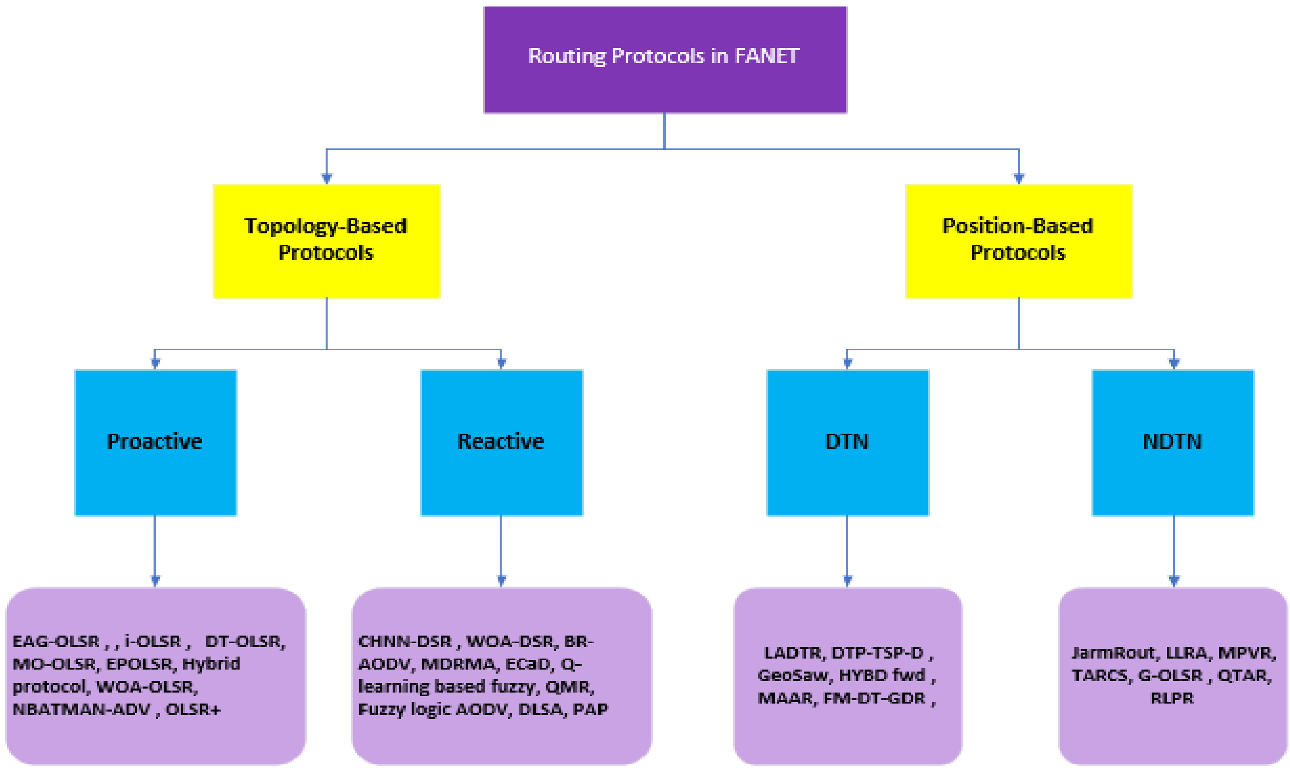

Figure 4 Routing protocols in FANET

By Gray code channel coding, decoding the physical layer results in the cross-layer technique at the network layer and creates a dynamic channel quality measurement threshold for bit error The EAGC-OLSR routing protocol has the advantage of choosing a high-quality link for data transmission, greatly enhancing decoding efficiency. Also, the EAGC-OLSR protocol extends the network lifetime. However, this protocol ignores considering load balancing, energy, and mobility, which are important factors, especially in small UAVs and dense networks. Moreover, predicting and establishing the channel model in ocean FANETs requires several complex environmental factors, such as wind, rain flow, etc. The protocol is more suitable for image transmissions, such as in marine SAR.

An improved Optimized Link State Routing Protocol(i-OLSR) was introduced in [44]. The authors add GPS to the OLSR to reduce the process of route discovery. Because of the rapid movement of UAVs, the topology of networks is change; hence, finding a new UAV location is challenging. In i-OLSR, the link quality and the expected transmission speed-weighted (ETX) are calculated to achieve the mobility model. The proposed work incorporates network mobility, a simple support protocol that enables mobile networks to connect to multiple points on the network using GPS. The node's location is detected using the pursue mobility model concerning acceleration. The 3-D location is used to define the network path. The coordinates from the hello message are used to create the 3-D view. The protocol was simulated by the NS3 simulator. The results demonstrate that the presented work improved latency and packet delivery ratio than the existing protocols. However, the protocol has a complex mobility model. In addition, the energy limitation and load balancing are ignored, which be a problem, especially in small UAVs and dense networks. The i-OLSR protocol can be utilized in applications that's required low delay such as extend the communication range in disaster scenarios in small network with a small number and slow speed of UAVs.

The authors in [45] proposed Dynamic Topology OLSR (DT-OLSR) for the military warfare environment. When nodes leave or enter a network DT-OLSR algorithm Dynamically modifies the transmission cycle of Hello packets depending on the topological changes in the network. The new routing approach adapts the Hello messages broadcast duration according to different dynamic variations in topology. The protocol can decide whether the location and relative speed expected by the Kalman filter algorithm are outside the communications range at the next moment. The GPS is used to determine the node's location. The protocol calls this essential data from the routing protocol function. The authors use the simulation tool Exata to test and compare the DT-OLSR protocol with the OLSR protocol. The outcomes of simulation illustrate that the DT-OLSR protocol improves the throughput and decreases packet loss rate resulting in more reliable network efficiency. However, the end-to-end delay is not considered as a performance metric in the routing protocol evaluation, also the protocol implemented in 2D. DT-OLSR suitable for delay sensitive applications in small network and low drone speed.

Routing protocol for high-density networks that is both latency-aware and energy-efficient, extension of OLSR, is called the Multi-Objective Optimized Link State Routing Protocol MO-OLSR presented in [46]. The routing protocol proposed is topologically awareness and could be utilized in applications with high degree of mobility and need low latency. A new approach for selecting the multifunctional relay nodes, which takes into account the link traffic load, is implemented in the multi-objective optimized link routing protocol algorithm. The suggested approach takes into account the link's stability and energy restrictions. The MPR selection algorithm optimized to take into account the network metrics such as residual energy, traffic load, node load and delay. The MO-OLSR protocol and OLSR versions were simulated and compared. Simulation results show high performance regarding delay, reliability, and power usage. However, the protocol increases routing overhead because of the additional information in hello message The proposed MO-OLSR protocol can be utilized for delay sensitive applications that require low latency with medium network size and medium UAV velocity.

The traditional OLSR routing protocol is modified, and an Efficient Power Optimized Link State Routing (EPOLSR) protocol is proposed in [47]. EPOLSR is a cross-layer design that integrates three layers physical, link, and network to improve power use and routing mechanisms. The enhanced signal is transmitted through the multi-antenna relay to the network layer. The improved network layer signal initiates hello messages that alert the linked neighborhood and change the paths by choosing the right MPR. This cross-layer architecture allows linked access, which improves routing efficiency due to the combined effects of transmitting the best transmission power of clear to send (CTS), request to send (RTS), and acknowledgments on each hop. The connectivity is given, and the possibility of a connection break between the adjacent UAVs is reduced. The process is supported by the RSS obtained at each node, which provides the link's accessibility. The OPNET simulator was used to assess the efficiency of EPOLSR and compare it with the original OLSR. EPOLSR increased the throughput and reduced the delay. However, the high-speed movement and energy restrictions of UAVs should be considered. The protocol is suitable for delay-sensitive applications such as network coverage extension and SAR operation in small network with low speed and small number of UAVs.

A Novel Hybrid Secure Routing for Flying Ad-hoc Networks proposed in [48]. The research study suggested a hybrid optimization model that minimizes connection setup problems and serves as a routing technique appropriate for both static and dynamic scenarios. In order to enhance link discovery, traditional routing algorithms like DSR and OLSR Routing Protocols are combined with nature-inspired bee colony optimization. The shortest path between a source and a destination is found via bee colony optimization. Network Simulator 2 is used to experiment with the suggested hybrid model. The suggested optimized routing works better in terms of the network's decreased latency and communication overhead. Conventional AODV and DSDV models are compared in order to demonstrate the suggested model's superior performance. One drawback of the suggested design is the cost function, which is quite higher than in previous routing models. The protocol is appropriate for applications that cannot tolerate delays, like network extension coverage in disaster scenarios in networks with small numbers and low UAV speed.

A whale optimization algorithm on optimized link state routing (WOA-OLSR) is suggested in [49] to offer the best routing for a secure and energy-efficient FANET. WOA is applied to a multi-objective function that combines a number of characteristics, including drone key utilization: energy, neighbor benefaction, stability time, and more. The WOA is a recently developed optimization method that mimics the manner in which humpback whales hunt and behave. To assess protocol routing performance over FANET in a reasonable manner, the suggested WOA-OLSR is constructed using the MATLAB environment. The outcomes are contrasted with earlier methods, including OLSR, MP-OLSR, P-OLSR, ML-OLSR-FIFO, and ML-OLSR-PMS, based on factors including throughput, packet delivery ratio, end-to-end delay, and power consumption. Based on prior parameters, the computed performance demonstrates WOA-OLSR's higher efficiency. However, load balancing and link quality are ignored, which is a problem. Low-latency applications, such as increasing communication range in emergency situations, could take advantage of this protocol in dense networks with medium UAV speed.

For scenarios involving large-scale small UAV multitasking, an elastic routing approach, the New Better Approach to Mobile Ad-Hoc Network-Advanced (NBATMAN-ADV) is presented in [50]. First, a virtual backbone network based on the connected dominating set is suggested to be built using the New-Unifying Connected Dominating Set (N-UCDS) method. When choosing backbone nodes, the number of nearby nodes, remaining energy, and link time are taken into account as factors influencing the UAV network performance. Second, by installing and operating the NBATMAN-ADV routing protocol the physical layer information signal-to-noise ratio and received signal strength indicator can be utilized by the backbone nodes to evaluate the link's quality. This allows for quick detection of link changes while reducing routing overhead. When compared to other conventional proactive routing methods, the simulation results demonstrate that the suggested routing protocol has a noticeably improved average packet delivery rate, end-to-end delay, and received throughput. Nevertheless, the elected backbone nodes have a certain turnover rate because of the extremely dynamic nature of the UAV nodes. Rebuilding the backbone network takes time and adds some overhead. The protocol can work well when used in dense networks with medium speed UAVs for SAR operations, surveillance, and network coverage extension.

The authors suggest OLSR+, a fuzzy logic-based routing strategy, for FANETs [51]. The goal of this plan is to make the optimized link state routing protocol (OLSR) more useful for FANET applications. There are four primary steps to OLSR+: 1) Identifying nearby nodes. In this stage, they provide an effective method for calculating the lifetime of a link between two UAVs by taking into account the movement direction, relative velocity, distance, and link quality. 2) Choosing MPRs, or multipoint relays. They provide a fuzzy technique in this step for choosing a group of MPR nodes. This method states that a node gets greater fitness to be picked as MPR when it has greater residual energy, a longer link lifetime, and higher neighborhood degree than other nodes. 3) Finding out the topology of the network. Route energy and route lifetime are two new fields added to the topology control (TC) message in this phase, which also involves formatting changes. 4) Routing table calculation. To establish steady routes in OLSR+, two characteristics are taken into account: route lifetime and energy. NS3 is used to simulate OLSR+ and assess how well it performs in comparison to two other approaches: OLSR and greedy OLSR protocol (G-OLSR). Comparing OLSR+ to G-OLSR and OLSR, the simulation results demonstrate that OLSR+ successfully lowers delay and has a better throughput and packet delivery rate. It also enhances the network's energy usage. However, compared to G-OLSR, OLSR+ has greater routing overhead, and the protocol design ignores load balancing in UAV networks. The protocol is more suitable for real-time application in disaster scenarios where the data should be delivered with a low delay, such as network extension and SAR operation in medium-sized networks with medium UAV speeds.

4.1.2 Reactive Routing Protocols

The reactive protocol is the routing-on demand protocol, which discovers or preserves a path upon request. Regular updates are made to the routing table on this type, if such packets are to be sent and no connection exists between two nodes, a path between them should not be calculated Thus, rather of adding new routes, these protocols only keep the ones that are already in use so that the proactive overhead issue is solved. This routing protocol has created two types of messages: Route request and Reply. A route request message is transmitted by the flooding method from the UAV source to all neighboring UAVs, and each UAV follows a similar procedure before reaching the UAV destination. Whereas the destination UAV starts the Route Reply message, it uses unicast mode to reply to the source UAV. There is no requirement to update all network tables in this routing strategy. Bandwidth is efficiently used by reactive routing protocols since frequent updates are not required.

DSR is designed primarily for ad hoc multi-hop mesh mobile node networks[52]. Without any network infrastructure, DSR enables the self-configuration and self-arrangement of a network. Because of the reactive approach of DSR, a discovery procedure is utilized if connection is requested. In DSR, the source node sends the RREQ to the neighbor nodes. In the network, there can be several path request messages; therefore, a request ID is attached to the source node to prevent confusion. The network resorts to route repair when a source node can't use its current route because of topology changes. Also, to reduced overhead, the DSR can respond rapidly to change of network topology and guarantee that data packets reach their destination nodes. The protocol is appropriate for UAV network with rapid mobility and significant topology changes. DSR has been applied to FANETs in many studies, as in [53] and [54], with the majority of them showing its heaviness and inability to cope with multiple disconnections, and there is a high latency due to the finding route process, especially in a highly dynamic network like FANET. Besides a large amount of overhead due to request and response messages.

The authors in [55] improved the DSR routing protocol. They proposed the Continuous Hopfield Neural Network CHNN-DSR routing protocol by using artificial intelligence algorithm, continuous Hopfield neural network, for route improving, which maintains a more stable and secure path, improving FANET stability and network communication efficiency. The work used the node's historical topology knowledge to make the right choice when finding a route next time. This work aims to find the optimal solution for routing problem using neural network's adaptive evolution. As a result, when the network state stabilizes, the CHNN-DSR maps the UAV nodes to the neural network to locate the path. The simulation was carried out using the NS3 simulator. The results illustrated that the packet delivery ratio, end-to-end latency, and throughput are better in the FANETs using CHNN-DSR than those directly using DSR. The main drawback is that the entire evolution process will restart if the route selection process fails because it has low fault tolerance. Besides, if the node's speed is high, the CHNN-DSR delay is also high. In addition, although the algorithm considered the stability of links between FANET nodes, it ignored important factors such as changes in the UAVs' dynamic position and the energy limitation of drones. The protocol is unsuitable for real-time applications due to its reactive feature, which causes high delay. However, it can conduct search and discovery operations to gather information, damage evaluations, and capture images in small size network with small UAV number and low speed.

A Whale Optimization Algorithm (WOA) based DSR protocol (WOA-DSR) suggested in [56] to give FANET an energy-efficient, optimal path. WOA-DSR optimally optimizes the number of neighbor nodes, velocity of movement, energy left, and UAV node stability time, among other influencing elements, and provides FANET with energy-saving routing. Discover WOA, a revolutionary swarm intelligent optimization technique inspired by the natural hunting techniques and habits of humpback whales. The goal of WOA is to optimize feeding strategies by modeling the spiral bubble net of the humpback whale. The WOA-DSR method is simulated in this study using OPNET. When comparing average end-to-end delay, routing overhead, and energy utilization, the simulation illustrates that WOA-DSR outperforms DSR and FA-DSR. The authors haven't calculated the packet delivery ratio, which is a significant factor to reflect protocol performance. The protocol is unsuitable for real-time applications due to its reactive feature, which causes high delays. However, it is capable of performing information gathering, damage assessments, and picture taking during search and rescue activities in medium networks with low-speed UAVs.

Ad hoc On Demand Distance Vector Routing Protocol (AODV) is MANET protocol for hop-by-hop routing[57]. AODV only discovers a path when required and does not maintain destination routes not involved in the communication process. There are three steps in the AODV routing protocol: (i) discover the path, (ii) transfer packets, and (iii) manage routes. Whenever a node is required to transmit a packet, the packet is initially sent through a route discovery operation to find the UAV's location, and then sent along the predetermined route to avoid any loops. AODV has a quick response to topology changes in highly dynamic networks. In addition, AODV does not add additional overhead in routing, and a loop-free protocol can scale to many nodes. The performance of AODV in FANET was evaluated in [41], [42] and [53] and the results illustrate that as the velocity of the UAV rises, the packet delivery ratio of AODV decreases. The latency time of AODV routing increases as the UAV's speed increases due to the route discovery process in networks with a high degree of topological change like FANET. Moreover, it consumes the bandwidth that frequently exchanges control messages in every data transmission. The AODV optimized by researchers to be adapted to FANET environment as follows:

Boids of Reynolds-AODV (BR-AODV) Routing Protocol is a swarm-based routing approach for FANET optimization of the traditional AODV routing protocol [58]. The target is a technique to keep the connection of the links in the route during transfer of data. The protocol benefits from AODV ad hoc routing protocol and a mechanism for maintaining data transmission connectivity and repairing damaged routes using Reynolds biods. The protocol controls the movement of nodes to maintain a reliable connection. In addition, an automated discovery mechanism for ground-based stations was implemented for the reactive association of UAVs and ground station, the FANET is structured as a swarm based on the biological features of swarms, such as node speed, node distance, and network topology self-organization. It was assessed how BR-AODV performed in comparison to the traditional AODV routing protocol. This simulation, show that BR-AODV significantly improves upon AODV in latency, throughput, and packet loss. However, as just five UAVs were involved in the simulation analysis, the protocol efficiency in large FANET needs to be investigated., that might not be indicative of the protocol's actual efficiency. It may be utilized in a well-coordinated UAV movement in monitoring, SAR and damage evaluation in small networks with low UAV speed.

Based on the AODV routing protocol, the authors presented the Multi-Data Rate Mobility Aware Protocol (MDRMA) routing protocol for FANET [59]. The authors considered the distances between the state of the channels and the connected nodes in the routing mechanism. In MDRMA, the establishing of connection routes is a condition upon the achievement of three requirements: intermediate UAV's ability to afford a transmission rate request by the sender, the sender, and receiver nodes are not distancing from one another, and the velocity of the intermediate UAVs not exceeding a specific limit. To ensure that packets are successfully received at the desired UAV at the required informational transmission rate, considering the receiver's sensitivity and the minimum acceptable signal to interference noise ratio. The MDRMA-Power-controlled scheme utilizes adaptations of the 802.11b standard, most especially of the RTS/CTS collision avoidance mechanism. The results of the NS3 simulation demonstrated that MDRMA is effective in providing a justification for network instability by producing quick and stable routes and decreasing the number of link failures. MDRMA has an advantage over the MA-DP-AODV-AHM protocol in term of delay, PDR and routing overhead. However, flooding RREQ and RERR packets generated substantial delays, consume energy, and cause network congestion throughout the route discovery and repairs process, especially in highly dynamic FANETs. Also, the protocol ignores energy and congestion problems in designing the protocol. It is not advised to use the protocol in applications that are affected by delays like real time application because of reactive approach. However, it can capture images in the damage evaluation phase or monitoring and can be used in dense and large networks with high UAV speed.

ECaD, an energy-efficient routing protocol for FANET, is proposed in [60]. In order to ensure an excellent consistency in communicating and forecast a sudden link breakup before it happens, the study supports using the location data and remaining power reserve of every drone. When investigating potential routing options, a robust route discovery process takes into account the paths' connection degree, link breakage prediction, and balanced energy usage. An improved discovery approach modeled based on AODV is used to enhance the established routing paths, and it is improved to make use of control messages in order to obtain a global understanding of the UAVs' energy levels and the degree of connection connectivity. An effective maintenance procedure that offers alternate routes to the destinations and prevents the need to restart the discovery process in the event of an unavoidable disconnect is employed in order to ensure the route is reliable. The scheme's effectiveness is assessed using the NS2 simulator. The results demonstrate the advantages of the suggested strategy in terms of extending the network's lifetime, reducing the amount of path failures, and lowering packet losses. In the other hand, the 2D results of the simulation do not represent the actual FANET environment, and the protocol designers did not consider traffic congestion, which causes connection failure and packet loss. Applications such as SAR and wildfire monitoring, which need precise and instantaneous packet delivery between UAVs in a FANET, can benefit from the use of ECaD in dense networks with medium UAV speed.

An implementation of fuzzy logic for the FANET routing protocol using Q-learning is suggested in [61] . With regard to link and overall path performance, the suggested approach easily chooses the route that need to be processed. The best route to go to the location is identified by every UAV utilizing a fuzzy logic system with parameters at the connection and path levels. The current energy level, transfer rate, and node speed and moving direction between nearby UAVs are examples of link-level parameters; the number of hops and packet delivery time are examples of path-level parameters. When using a reinforcement learning approach, the parameters at the path level are updated in real time. They compared the protocol with original fuzzy logic and Q-value-based AODV, the outcomes demonstrate that the suggested strategy can extend the network lifetime while maintaining a low hop count and energy usage. However, load balancing is ignored, which is an important factor, especially in dense networks. Besides, the simulation implemented in 2D is not reflecting the actual FANET environment. The protocol can be used in forest fire monitoring and post-disaster missions such as SAR in small networks with few UAVs and low UAV speed.

In order to ensure minimum latency and energy efficiency communication, the authors suggest a unique multi-objective optimization routing protocol for FANETs based on Q-learning (QMR) [62]. The suggested protocol allows for adaptive modification of Q-learning parameters to accommodate the high topology changing of FANETs. Furthermore, a novel mechanism for exploration and exploitation is suggested in order to investigate previously unidentified potential optimal routing paths while utilizing the knowledge that has been gained. The suggested approach selects the next hop with the best reliability by re-evaluating neighbor's links during the routing decision-making process, as opposed to relying on previous neighbor links. At regular intervals, every node broadcasts a HELLO packet it includes details about it such its position, power, mobility model, timing for queuing, and discount factor. To construct and update the neighbors' tables, nodes rely on the data included in HELLO packets. The QMR algorithm was simulated with an event-driven wireless network simulator (WSNet) to compare its performance to the current, well-performing QGeo. According to simulation results, the suggested approach can outperform the well-performing Q-learning-based routing system currently in use in terms of packet arrival ratio, delay, and energy usage. However, the protocol does not take into account the link status, such as RSSI or SNR, beside the protocol simulated in 2D, which is not reflecting the actual FANET environment. The approach is appropriate for use in post-disaster scenarios to carry out SAR operations and collect data for assessing damage in a small network with a small UAV number and speed.

The authors introduce a routing strategy for FANET that is based on fuzzy logic in [63]. There are two stages to the suggested routing scheme: the discovery and the maintenance processes. To avoid broadcast congestion and manage the flood of control packets sent out to find a new path in the network, they first provide a method for determining the score of every node in the system. Direction of motion, node residual energy, quality of link, and node stability are the factors that use for determining this score. In order to select path that have high fitness, low latency, and require small hop count for data transfer, they create a fuzzy system as part of the route selection process. In the second stage, there are two parts: first, attempting to avoid route failure by detecting and adjusting routes shortly before failure; and second, recreating failed routes to identify and promptly replace them. The suggested routing algorithm is simulated in NS2 for performance evaluation. Three different routing algorithms: ECaD, LEPR, and AODV have their simulation results compared. From energy consumption, routing stability, packet delivery rate, and end-to-end latency these metrics demonstrate that the suggested routing approach excels over competing approaches. However, the protocol suffers from high routing overhead. Disaster scenarios such as SAR, monitoring, and damage evaluation can utilize the protocol in dense networks with low UAV speeds.

By contrasting the existing routing techniques for FANET's Link Stability Estimation-based Routing and Distributed Priority Tree-based Routing, a hybrid scheme called Delay and Link Stability Aware (DLSA) routing scheme has been presented in [64]. The suggested scheme has the characteristics of cooperative data transmission and connection reliability, in contrast to existing schemes. The link stability metric contains three components that make up this innovative metric: the connection quality, the safety degree, and the mobility prediction factor. A single status sequence links these components. The DLSA routing protocol uses the R-B (Red-Black) priority tree, which creates a network corridor by choosing, among other nodes, the highest priority node for the communication channel, in conjunction with the link stability mechanism to produce significantly better results. By leveraging the advantageous aspects of the current FANETs protocols, LEPR and DPTR, which have the highest number of mathematical terms and equations, it has been demonstrated through MATLAB simulations that the When compared to other protocols, DLSA's routing algorithm provides better end to end delay, packet delivery ratio, transmission loss, and network life time. However, the protocol ignores the energy and congestion control of the UAV network. Applications such as SAR and wildfire monitoring, which require accurate and fast packet delivery between UAVs in a FANET, can benefit from the use of DLSA in a small and dense network with high UAV speed.

By combining a joint decision technique with a machine learning method for ordinary and disaster areas, [65] suggests a FANET routing protocol called Packet Arrival Prediction (PAP) that can adaptively choose the best routing path. They build a PAP module that uses Long Short-Term Memory (LSTM) to expect the data flow of UAV connections. Following this, they take into account the mobility of FANETs and use a Routing Decision Factor (RDF) to jointly assess all links. The optimal transmission path is determined by framing the routing decision-making issue as an optimization challenge and sorting it using a suggested Neighboring UAV Routing choice Factor (NURDF). According to the result of simulation, the PAP protocol has the best performance in terms of latency and packet loss rate (PDR). Although the protocol has considered mobility and data congestion problems it doesn't consider energy and link quality problems, which can improve the protocol performance, especially in FANET. PAP can be applied in small networks with low UAV speed for forest fire monitoring and post-disaster missions such as SAR.

4.1.3 Summary And Discussion of Topology-Based Routing Protocols

In proactive protocols, all nodes keep routing tables and regularly update these tables. This makes proactive protocols able to adjust to changes in the topology with frequent updates and exhibit low route access delays. Nevertheless, mobile UAVs operating in large FANETs, they require a high memory demand for the routing table and extremely high energy and bandwidth consumption owing to the extremely high signaling count for updating and maintaining routing tables. Accordingly, the protocols are more convenient for real-time application in well-connected networks with restricted mobility and few UAVs. The reviewed proactive protocols have an advantage in minimizing the delay that makes this type of protocol appropriate for delay-sensitive applications in disaster recovery, such as network coverage extension and connecting ground nodes in search and rescue team members or transmitting life videos, for example, to search for victims in unreachable areas.

Most protocols consider drone mobility to enhance network performance and extend link life time. Prediction and heuristic methods are used to solve the problems of unstable links, and regular changes in topology cause significant packet loss and delay. This is a result of the high speed of drones and the diversity in distance between drones that is typical of most applications. Mobility prediction aids in the discovery of the most reliable (stable) route, reducing packet transmission ratio and latency.

Furthermore, to expand the lifetime of the network, ensure dependable connections, and prevent unnecessary delays, various routing protocols take into consideration the traffic load status of drones in the network and link quality. Both of them are critical aspects for time-sensitive applications for managing and coordinating in a productive and efficient manner. However, regardless of the number of data packets to send, periodic routing table updates and topology changes involve exchanging many control packets between network nodes. Particularly in highly topologically changed and congested networks, this causes substantial routing overhead and inefficient utilization of resources such as bandwidth and energy.

Reactive routing protocols reduce control overhead by only keeping routing data if a node has a packet to deliver, thereby eliminating the requirement for regular control message exchange. With the goal of satisfying the needs of the FANET routing features, the current MANET routing protocols are enhanced by applying mobility prediction strategies. An accurate mobility prediction technique for selecting the strongest connection and ensuring dependable connections between nodes in a highly topologically changed FANET is required. The major disadvantage of the reactive is that discovering the path takes a long time. Consequently, the network will have high latency during route discovery.

Table 3 State of the art for proactive routing protocols in disaster applications

protocol	year	Energy Aware	Congestion Aware	Mobility Aware	Link Aware	Simulator	Advantages	Weakness	Applications
EAG-OLSR [43]	2017	✓	✖	✖	✓	C++	Improves BER, delay, PDR	Mobility and load balancing are not considered	Designed for Marine search and rescue missions
i-OLSR [44]	2018	✖	✖	✓	✓	NS3	Improves Throughput, PDR, ETED	Complex mobility model	Delay-sensitive applications in small network with a small number and slow speed of UAVs.
DT-OLSR [45]	2019	✖	✖	✓	✖	Exata	Improves the throughput of UAV and decreases PLR	The ETED is not considered, 2D scenario, focus on mobility.	Delay sensitive applications in small network and low drone speed.
MO-OLSR [46]	2019	✓	✓	✓	✖	Unknown	Improves PDR, ETED, no of selected MPR, EC	Increases routing overhead	Delay sensitive applications that require low latency with medium network size and medium UAV velocity
EPOLSR [47]	2020	✖	✖	✖	✓	OPNET	Increases the throughput and reduces the delay	The speed and energy of UAVs should be considered	Delay sensitive applications in small network with low speed and small number of UAVs
Hybrid protocol [48]	2020	✖	✖	✖	✖	NS3	Improve PDR, throughput, ETED	The cost function is quite high, network parameters not considered.	Delay sensitive applications with small number and low speed UAVs
WOA-OLSR [49]	2021	✓	✖	✓	✖	MATLAB	Improved throughput, PDR, ETED, energy consumption	load balancing and link quality are ignored.	Delay sensitive applications in dense network with medium UAVs speed
NBATMAN-ADV [50]	2022	✓	✖	✖	✓	MATLAB &QualNet	improved PDR, ETED, and received throughput.	High overhead	Delay sensitive applications in dense network with medium speed UAV
OLSR+ [51]	2022	✓	✖	✓	✓	NS3	Improved throughput, PDR, delay and energy consumption	High routing overhead and load balancing ignored.	Delay sensitive applications in medium network size with medium UAVs speed

Furthermore, high congestion, power, and bandwidth consumption are the results of flood RREQ and RERR messages during the path discovery and repair stages, which is particularly a problem in fast topology-changing FANETs. Thus, this type of protocol is not appropriate for delay-sensitive applications. Reactive protocols are suitable for applications with a small or medium UAV number, as well as the ability to accommodate communication delays when establishing new routes. Reactive protocols are useful in disaster applications where data delivery is more crucial than delays, like in search and discovery operations for information gathering and damage evaluation.

Most protocols consider one or more but not all four addressed routing issues of congestion, energy limitation, mobility, and link quality, which are essential to achieving reliable communication, as observed in Table 3&4. The consideration of energy limitation in protocol designing is important, that the amount of energy available influences the route lifetime, and Mini-UAVs required to have long-term energy saving in the air. When a node forwards packets with low energy, it quickly runs out, leading to packet loss and connection failure. In order to ensure the long-term stability of the network's functioning, routing algorithms for the FANET environment should take the residual energy of UAVs into account.

In terms of optimization methods, Artificial Intelligence (AI) techniques, such as reinforcement learning, fuzzy logic, artificial neural networks, and particle swarm optimization, have been used in recent years to enhance the functionality and performance of traditional routing protocols to be more adapted to FANET environments. Conventional routing techniques may not be able to keep up with the rapid changes that occur in FANETs. By utilizing AI techniques like machine learning, the routing protocol can gain the ability to learn and adjust to evolving network conditions in real-time, resulting in enhanced performance. Based on a number of variables, including node mobility, network congestion, and link quality, AI can optimize routing decisions. AI-based routing protocols can reduce packet loss, delay, and energy usage by making more effective routing decisions through intelligent analysis of these parameters. A comparison of topology-based routing protocols is illustrated in table 3 and table 4.

4.2 osition-Based Routing Protocols:

Routing protocols that rely on location have recently been introduced, presuming that the geographic location is known for effective routing support of UAVs. They presume that to know the destination node location, and the destination node receives the message without discovering the rout. Each UAV defines its location with a GPS device or any positioning system. This type of protocol is most suited for the high dynamic FANET network. Generally, it can be classified into DTN routing protocols and Non-Delay Tolerant Network Non-DTN routing protocols.

Table 4 State of the art for reactive routing protocols in disaster applications

protocol	year	Energy Aware	Congestion Aware	Mobility Aware	Link Aware	Simulator	Advantages	Weakness	Applications
CHNN-DSR [55]	2016	✖	✖	✖	✓	NS3	Improves PDR, ETED, and throughput	High delay in high-speed	Monitoring, SAR, damage evaluation in small size network with small UAV number and low speed
WOA-DSR [56]	2022	✓	✖	✓	✓	OPNET	Improve ETED, routing overhead, and energy utilization	PDR is not calculated, load balancing ignored.	Monitoring, SAR, damage evaluation in medium network with low-speed UAVs
BR-AODV [58]	2018	✖	✖	✓	✖	NS2	Improves ETED, throughput, PLR	Simulation with only five nodes, focus on mobility.	Monitoring, SAR, damage evaluation in small network with low UAV speed.
MDRMA [59]	2018	✖	✖	✓	✓	NS3	Improves Delay, overhead, PDR	High congestion, energy, and bandwidth consumption	Monitoring, SAR, damage evaluation in dense and large network with high UAV speed
ECaD [60]	2019	✓	✖	✓	✓	NS2	extending network's lifetime, reducing amount of path failures and packet losses.	Network congestion not considered. The simulation in 2D	Monitoring, SAR, damage evaluation in dense network with medium UAVs speed
Q-learning based fuzzy [61]	2020	✓	✖	✓	✓	unknown	Reduce the number of hops and energy used, extending network lifetime	Load balancing is ignored.	Monitoring, SAR, damage evaluation in small network with few UAVs and low UAV speed
QMR[62]	2020	✓	✓	✓	✖	WSNet	Improves PDR, delay and energy consumption	Does not consider link quality and 2D simulation	Monitoring, SAR, damage evaluation in small network with small UAVs number and speed.
Fuzzy logic AODV[63]	2021	✓	✖	✓	✓	NS2	Improved PDR, ETED, route stability, energy consumption.	High overhead	Monitoring, SAR, damage evaluation in dense network with low drone's speed.
DLSA [64]	2021	✖	✖	✓	✓	MATLAB	improve in E2ED, PDR, Transmission Loss, and Network Lifetime.	protocol ignores the energy and congestion control of UAV network.	Monitoring, SAR, damage evaluation in small size and dense network with high UAVs speed.
PAP [65]	2022	✖	✓	✓	✖	unknown	Improve PDR and delay	Energy and link quality problems are not considered.	in small size network with low UAVs speed

PDR = Packet Delivery Ratio, ETED = End-to-End Delay, PLR = Packet Loss Rate, EC = Energy Consumption, BER = Bit Error rate, RSSR = Route setup rate, APLT = Average path lifetime

4.2.1 Delay Tolerant Network Protocols (DTN)

DTN protocols deal with technical problems, such as communication network disconnection. Such protocols utilize the store-carry-and-forward technique once the communication is break down. This way, the data packets are stored until more nodes are met. The approach eliminates overhead as no further control packets are used; however, it causes a large amount of delay, making DTN protocols unsuitable for real-time application.

Location-Aided Delay Tolerant Routing (LADTR) protocol is used in disaster response missions such as search and rescue to capture images and videos and send them back to the ground station [66]. Multiple unmanned aerial vehicles (UAVs) scan for objects and missing persons while a geo-tagged camera tracks the disaster-affected area. Multiple image-collecting UAVs may be dispatched to various locations, using location-assisted communication with store-carry-forward (SCF) technique to enhance the network disconnection. The implementation of ferrying UAVs makes an effective SCF. The forwarding UAV node estimates the UAV node destination location and then determines where to forward. A Guess Markov approach that based on position prediction utilize distance and speed information collected from GPS to approximate the potential position of nodes. Ferrying nodes are often used in UAVs network to enhance link communication between UAVs and the GCS, resulting in a shorter latency and a higher packet transmission ratio. The proposed LADTR outperforms the AODV, GPSR, epidemic, and Spray-and-wait routing protocols in all evaluated scenarios comparing packet delivery ratio, average delay, and normalized overhead routing. However, the protocol considers only 2D UAVs mobility, which does not reflect the real word scenario. Besides, the store-carry-forward technique, which resulted in a considerable delay, caused the protocol to be unsuitable for real-time application. LADTR is suitable for post-disaster scenarios to conduct SAR operations and gather information for damage evaluation in small network with medium number of UAVs and low UAVs speed.

A geographic routing protocol called Deadline Triggered Pigeon with Traveling Salesman Problem with Deadlines (DTP-TSP-D) is presented [67]. The proactive DTN approach introduces dedicated UAVs with the ultimate objective of communicating between original UAVs, eliminating them from consuming power, such as routing and transmission of data. In this protocol, because of their versatility, UAVs can serve as ferries if there are more ground nodes than UAVs. All nodes belong to cluster of ground nodes, and the way it works is to ferry around its home cluster until it is started messages delivery to ground nodes. The UAV buffer message deadlines serve as the foundation for the triggering test., which evaluate the ability of the UAVs to deliver them all in time. A developed Traveling Salesman Problem (TSP) Genetic Algorithm calculates the path with highest number of deliveries. The model was evaluated using MATLAB and compared with Single Route approach and MRT-Grid ferry approach. It gives a higher delivery ratio and lower delay. However, the latency can be increased by constantly discovering new paths. The protocol is suitable for latency tolerance applications such as damage evaluation and monitoring in small network with low UAVs speed.

A routing protocol for airborne networks named Geographic Spray and Wait (GeoSaW) protocol for search and rescue scenarios was proposed in [3]. The protocol uses two sources of information about the nodes concerned: location and the planned mission route as the waypoints. The UAVs follow a previously known schedule and travel along predetermined paths. By using this data estimation of the future position and time of every relay UAV to transmit any data intended for a given destination and enter the path of the relay UAV. Therefore, it's evident that a UAV only transmits the packet to the specified recipients after waiting for them. All UAVs emits a beacon to confirm its existence and location on the network. When a node's neighbors fail to send any beacons within a certain period of time, it is presumed that the node has quit the transmitting range or is non-functional for any cause, and its entry in the neighbor table is removed. Therefore, the authors proposed a partial replication technique, similar to the Spray-and-Wait protocol. The protocols were simulated using The One Simulation Environment and compared with DTN protocols. The presented protocol enhances the packet delivery ratio and routing overhead but still suffers from high delay, that it can apply for non-real-time applications such as capturing images in the case of disasters, search and rescue, and urban surveillance in large network with few numbers of UAV.

The HYBD fwd routing protocol is presented in [68], which is a hybrid packet forwarding technique, to send packets to ground location quickly and reliably. The protocol involves delay-tolerant forwarding and end-to-end routing. When using end-to-end routing, the UAV begins the process of finding a route (route discovery) in order to determine the best route to take in order to transport data to the destination on the ground. When there isn't an end-to-end route, delay-tolerant mechanism is used, and the UAV either carries the data and goes to the ground destination to deliver them, or it forwards the data to the ferry UAV that is travelling there. Extensive simulation experiments using OMNeT++ are used to assess the proposed hybrid packet forwarding approach, and the results show that it can be effective in FANETs when compared to a previous motion-driven packet forwarding approach. However, the protocol only takes into consideration the 2D mobility of UAVs, which is not representative of the real-world situation. Furthermore, a significant delay was produced by the DTN approach, making the protocol inappropriate for real-time applications. The protocol is appropriate for conducting SAR operations and collecting information for damage evaluation in post-disaster scenarios with a medium number of drones and low speed.

Mobility Assisted Adaptive Routing (MAAR),the geographical routing protocol, was presented in [69] and aimed at the intermittently connected FANET. MAAR combines an improved greedy forwarding method and store-carry-and-forward technique with a location to reduce overhead. Unlike classical geographical routing protocols that use alternative locating services to determined location, MAAR integrates location facilities into the routing mechanism, MAAR dynamically update neighboring node information according to node mobility to achieve high accuracy and low delay. It presents a novel metric named IDM to adaptively update other node locations. Furthermore, they used a store-carry-and-forward model to address the technological challenges of networks subject to connection breaks. If the forwarding node is unable to locate a suitable relay node, then store-carry-and-forward algorithm is utilized. The simulated results from the NS3 simulator showed that in term of packet delivery ratio, throughput, and overhead MAAR outperform the GRAA protocol with medium node number and low speed of UAVs. However, the protocol considers the mobility of UAVs, but their energy and load balancing are ignored, which can decrease network life and cause packet loss and congestion.

A novel protocol for transmission of data to GS in sparse FANETs is introduced for use in disaster relief missions, which combines Ferry Mobility-based Direction and Time-aware Greedy Delay-tolerant Routing (FM-DT-GDR). When there are no neighbors, the protocol utilize a store, carry, and forward (SCF) technique to avoid losing of data [70]. According to their relative positions to the ferry and the GS, the search nodes ascertain the closest destination. after receiving the beacon from the ferry node, at which point they relay the appropriate data. The searching UAVs gathered data by the ferry and forwarded to the GS. Between GS and search UAVs, optimized ferry trajectories greatly increase route availability. Additionally, the suggested routing system quickly and effectively chooses the forwarder UAV to transmit the data packets to the designated destination. FM-DT-GDR The NS-3 network simulator is used for the simulation. When compared to conventional DTN routing protocols, FM-DT-GDR offers notable enhancements in end-to-end latency, packet delivery ratio and routing overhead. The protocol is designed for SAR operation in natural disaster scenarios in sparse networks when the number of UAVs is small with low speed.

4.2.2 Non-Delay Tolerant Network (NDTN) Protocols

NDTN protocol operate more efficiently when node density is high since the connectivity problem is not considered. These protocols are primarily intended to transfer the data packets to the recipient with a multi-hop technique as soon as possible through the nodes if the receiver is not within the sender's communication range[2].

Jamming Resistant Multipath Routing Protocol called JarmRout was presented in [71]. The protocol is based on a mixture of three significant approaches: the quality link approach, the traffic load approach, and the spatial distance approach. The link quality approach was presented via the RSSI information of received packets to distinguish the link qualities among UAVs. The protocol includes the channel contention details on the MAC layer in the traffic load approach and the remaining buffer size. The multipath of maximum spatial node-disjunction between the transmitter and receiver nodes is ensured by the use of the spatial distance approach, which computes the spatial distance of multiple routes. JarmRout will defend the network and boost network resilience without wasting resources of network if interference happens unexpectedly, which applies to FANET due to its resource restrictions. The simulation was carried out using an OMNET++ simulator, and performance was compared for OLSR, DSR, and SMR routing protocols. The simulation results showed that the JarmRout enhances the packet delivery ratio, lowers the latency, and lowers the end-to-end communication delay without adding additional overhead communication. Furthermore, JarmRout will preserving the network and increasing its resilience without draining its resources if interference happens unexpectedly, which applies to FANET due to its resource restrictions. The protocol is suitable for real-time application in disaster scenarios. However, the multiple path transmissions of control packets resulted in high energy consumption. JarmRout is suitable for delay sensitive applications such as network extension coverage in small and dense network with medium speed of drones.

The authors proposed the layered UAV swarm network design and the Low Latency Routing Algorithm (LLRA) for forest fire monitoring to improve average delay and connectivity [72]. Various kinds of UAVs are classified according to different tasks into two layers. The LLRA was developed according to the presented layered network design, using part information on UAVs' position and connectivity of the network. Using the appreciation of UAV link stability (SINR), LLRA algorithms can automatically spread additional traffic flows of data through ideal relay nodes to effectively reduce delay. The protocol was simulated and compared with traditional AODV and GPSR protocols. LLRA has a low delay required by real-time application scenarios, such as collecting data from different sensors in the disaster area, real-time video streams, and enabling reliable data sharing among firefighters on the ground in dense network with high UAVs speed. However, the algorithm ignored the energy of UAVs, which can cause problems, especially in mini-UAVs with small batteries.

The Mobility Prediction Based Virtual Routing (MPVR) algorithm is presented to improve communication performance and lifetime routing among cooperative UAVs [73]. In fact, Obtaining the probability density function for a node is carried out with the use of the Gaussian distribution model. For optimal selection of a relay node with least UAV separation, a virtual routing model is further developed. Limiting the bad consequences caused by highly mobile UAVs and dynamic angle adjustment strategy on routing performance, the Gaussian distribution model is applied to compute the probability density function of UAVs. With the goal of increasing reliability and decreasing routing delay between UAVs, a virtual routing based on mobility prediction was developed. The MPVR was simulated and compared with AODV and GPSR. MPVR improved packet delivery ratio, link delay, and the average routing lifetime. However, the protocol considered only the mobility of UAVs; the residual energy, link quality, and network congestion were not considered, which can improve performance and extend the lifetime of a network. MPVR is suitable for extending network coverage in emergency scenarios and connecting ground nodes in real-time, such as search and rescue teams in dens network with medium speed of drones.

For the rapidly changing topology of complex scenarios, a protocol suited for highly dynamic network was proposed in [74] called a Topology Change Aware Routing Protocol Choosing Scheme (TARCS). Periodic Topological Change Perception (PTCP) and Adaptive Routing Choice Scheme (ARCS) are the two key components of this protocol. The first scheme aims to identify topological changes in all UAVs and its neighbors inside the network's one-hop communication range. when node motion changes the relative location of neighboring nodes, the neighboring nodes number can also vary. As a consequence, the network topology can be dynamically modified.

A Topological Change Degree (TCD) was presented to characterize the topological variations that occur in highly dynamic networks based on analyzing the factors that influence change in topology within network nodes. factors such as distance, speed, direction, and the number of neighbors. The author suggested an Adaptive Route Choosing Scheme (ARCS) in the next step. The ideal route can be compute based on identifying the node movement pattern. The UAVs will have connected via the new set protocol before the topology shift is identified after the routing protocol has been chosen. The results indicate that an adequate scheme for routing can adapt and effectively improve network performance to dynamic network topology changes. Simulation implemented using NS-3, and TRAC were compared with AODV, DSDV, and OLSR. Results illustrate that TRAC capable of quickly adjusting to changes in network topology and efficiently enhance network effectiveness. However, the protocol concentrates on topological changes and does not consider the limited power of UAVs or network load balancing. The protocol is suitable for real time applications in dense networks with high speed of drones.

A greedy optimized link state routing (G-OLSR) introduced to facilitate effective communication and cooperation between the unmanned aerial vehicles in a FANET [75]. G-OLSR combines OLSR protocol with greedy perimeter stateless routing (GPSR). This routing technique aims to distribute message of emergencies throughout FANET with the minimum overhead and delay possible, this makes this approach fitting real time applications. Furthermore, this technique can stop routing loops. A greedy method is employed to choose the next hop node during the routing procedure. The routing process shifts to the recovery mode when the greedy procedure doesn't work during the choosing of next-hop node procedure. In this method, a node with the least angle from the transmitter node towards the receiver node is chosen as the next hop node when multiple nearby nodes are equally far from the transmitter node. The Network Simulator NS3 is used to simulate the G-OLSR's performance. According to the simulation results, the suggested mechanism is more effective than the OLSR routing protocol in terms of throughput, packet delivery ratio, message overhead, and delay. However, the protocol ignored network parameters throughout the routing procedure which are necessary to construct stable routes.

To solve the shortcomings of current position-based routing protocols in FANETs, the authors suggest the QTAR protocol, which is based on Q-learning and topology-aware routing [76]. To maintain topological control in QTAR, they use UAV nodes' two-hop neighbor information. The introduced protocol aims to determine the best route from source to destination taking into account the optimal two-hop neighbor connection and taking advantage of the various metrics pertaining to the neighbors' position, delay, velocity, and energy. The authors propose an adaptive Q-learning approach that allows for the dynamic adjustment of Q-learning parameters, such as the learning rate and reward factor, according to the network environment. This enables the algorithm to quickly adapt to changes in network topology. To analyze the performance of the protocol, it was simulated using a MATLAB simulator and compared with GPSR and QGeo, two popular geographic position-based routing protocols currently in use. The simulation findings show that QTAR outperforms the current protocols in terms of energy usage, delay, and packet delivery ratio. QTAR is suitable for delay-sensitive applications such as network extension coverage in dense networks with medium UAV speeds.

RLPR, a reliable link adaptive position-based routing for FANET, is presented in [77]. It utilizes the nodes' relative speed, energy, and signal strength, along with the forwarding angle and geographic distance to the destination, to identify the forwarding zone and find the route, thereby reducing the number of unwanted control messages in the network. RLPR improves network efficiency by selecting relay nodes that are within the forwarding zone and are moving towards the destination. In order to achieve a strong connection, RLPR also considers the intensity and relative speed of the nodes' signals to select the next hop with the best energy level. The Network Simulator (NS2) performance evaluation reveals that RLPR outperforms both AODV and RARP protocols in many scenarios. In comparison to RARP and AODV, the outcomes demonstrate that RLPR improves the network lifetime, control messages overhead, and search success rate. One disadvantage of RLPR is its disregard for node balancing among UAVs. Applications for RLPR include monitoring forest fires, SAR, and other post-disaster operations with a medium number of drones and low speed.

4.2.3 Summary of Position-Based Protocols

In FANETs, position-based DTN routing algorithms are intended to support communication in situations where source and destination nodes have sporadic or nonexistent end-to-end connectivity for a considerable amount of time by integrating store-carry-forward techniques into FANETs to make them more delayed and interruption unaffected. In order to construct routing paths, these protocols rely on the location data of nodes and consider the mobility patterns and connections among nodes. DTN routing protocols, in contrast to typical routing protocols, are capable of overcoming disconnections and delays, which makes them appropriate for networks with irregular connectivity, such as FANETs.

When DTN routing protocols are applied, they are useful for application situations requiring delivery assurance of data and delay tolerance. Moreover, DTN's leniency surpasses the requirements of interconnected applications, particularly when a small number of drones operate at a significant distance from one another. DTN can be used in disaster response operations such as SAR to capture images and videos and send them back to the ground station, in monitoring and predicting disasters, and in damage evaluation by gathering information.

NDTN which are networks that prioritize timely delivery of data packets without tolerating significant delays. Position-based routing protocols are a category of routing algorithms that utilize the location information of network nodes to make routing decisions. General non-delay tolerant position-based routing protocols are Intended for networks that cannot tolerate delays and where node positions are known. Whenever a node requires transmitting data to a specific destination, it chooses the next-hop node by considering its own position and the position of the destination. Various algorithms may be used for route establishment, such as greedy forwarding or perimeter-based routing. Once a route is established, packets are forwarded from node to node along the selected path towards the destination. Forwarding Selections are determined by the positions of nearby nodes relative to the destination.

Nodes in the network must be equipped with some form of positioning system, such as GPS or other localization techniques, to determine their geographic coordinates accurately. This information is crucial for routing decisions based on node positions. That is if the location information is faulty or unavailable, the route cannot be determined. Besides, Non-DTN has a significant hardware requirement due to its reliance on GPS and localization equipment. In addition, the network's connection cannot be guaranteed in highly topology changing and sparse networks, making it impossible to identify the proper next forwarder UAV. Non-DTN is suitable for delay sensitive applications in disaster scenarios with well-connected large scales and dense networks.

Most reviewed position-based routing protocols do not consider the energy resection problem in protocol designing, and also ignored the balance of network load. Choosing suitable forwarder nodes based on different traffic loads might be necessary to improve the packet transmission ratio and latency. During protocol design, load balancing, and energy consumption should be considered, especially in the independent network. To get more precise position information, the mobility prediction method must improve, taking into account the path information of drones in the network. Another important metric is link quality, which most protocols do not consider, as observed in Table 5. A. Bad link quality can cause packet loss and disconnection, especially in intermittent networks. A summary of position-based routing protocols is illustrated in table 5.

6.0 ISSUES AND CHALLENGES:

Compared to conventional ad-hoc networks like MANETs and VANETs, FANETs have Low node numbers, restricted resources, great mobility, rapid topological changes, and regular network splitting are just a few of the unique features of FANETs that make it difficult to create a dependable communication architecture solution, especially in terms of routing.

Route discovery, route maintenance, and packet retransmission can all be increased by frequent link disconnections and network splits. Network performance suffers as a result, which can be unacceptable in urgent situations like disaster relief and rescue operations. The two main challenges to increasing network connectivity are a) the high network topology change degree and b) the high cost resulting from increased computational energy, and routing overhead. By addressing this open issue, there will be better quality of service (QoS) performance, lessening energy consumption, and a higher route setup success rate. More research might be conducted to decrease link disconnections and network partitions and increase QoS.

In terms of applications, the QoS requirements of FANETs vary depending on the specific use case. Applications like SAR and extending network coverage require real-time traffic, while others like information collection in damage can be delayed tolerant. As a result, when designing a routing protocol for FANET it is important to consider the types of data it will carry, and the QoS guarantees that traffic must meet those requirements. Low latency, low bandwidth, and medium jitter are necessary for real-time applications in disaster scenarios like network coverage extension and live video transmitting. Delay-tolerant routing protocols have high latency, tolerance of jitter, and high bandwidth needs for applications like capturing photos in search and rescue operations and damage evaluation. The routing complexity in FANETs grows as a direct result of shifting QoS needs and the adaptability of applications.

In term of delay, simulations show that UAV's high speed causes extra latency, and this delay is viewed as an issue. In reactive routing protocols, the network will experience high latency since pathfinding is time-consuming, and this delay increases in high topology change networks such as FANET. Also, DTN suffers a high amount of delay since it uses the store forward and carries technique. Designing routing protocols while adhering to a constrained delay restriction is seen as an issue.

Other key challenges include minimizing packet loss caused by network obstructions and minimizing overheads, especially for topology-based protocols. Reactive routing techniques suffer additional overhead since they use an additional flooding procedure. In addition, proactive protocols periodically update routing tables, and topology changes involve exchanging many control packets between UAVs in the network, particularly in high topology changes and congested networks, resulting in considerable routing overhead. It is seen as a challenging issue to minimize overhead or packet loss.

The routing protocols of FANETs and UAV networks are simulated using various simulation tools. Most of them do not display outcomes that are logical or realistic. NS-2, NS-3, OPNET, and OMNET++ are the most commonly utilized tools for quantifying and evaluating the efficiency of UAV routing protocols. These, do not imitate any particular routes for communication between UAVs and do not provide 3D communication. These simulators allow random mobility models; and they don't support control-based simulation. Therefore, a new simulator tool is required to enable more realistic mobility models and generate more reasonable outputs. In general, when discussing the disaster area scenarios, the following characteristics affect the choice of routing protocol: UAV mobility patterns, UAV speed, number of participating UAVs, disaster area size, obstacles that impact the transmission signal, such as mountains and tall buildings, and weather conditions. Therefore, a protocol that appears to function perfectly in one situation may not be the best option in another.

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Table 5 State of the art for DTN and non-DTN routing protocols of position-based protocols in disaster application.

protocol	year	Energy Aware	Congestion Aware	Mobility Aware	Link Aware	Simulator	Advantages	Weakness	Applications
DTN Routing Protocols									
LADTR [66]	2018	✘	✘	✓	✘	NS3	Improved PDR, ETED, Overhead	2D UAVs mobility Focus on mobility	Delay tolerant application in small network with medium number of UAVs and low speed
DTP-TSP-D [79]	2018	✘	✘	✘	✘	MATLAB	Improves PDR, ETED	Finding a new path can increase the delay, ignore network parameters	Delay tolerant application in small network with low UAVs speed.
GeoSaw [3]	2018	✘	✘	✘	✘	One Simulation	Improves PDR, delay, Overhead	suffers from high delay, ignore network parameters	Delay tolerant application in large network with few numbers of UAV.
HYBD fwd [68]	2019	✘	✘	✘	✘	OMNeT++	Improved PDR and ETED	Doesn't consider network parameters.	Delay tolerant application with medium number of UAVs and low speed.
MAAR [69]		✘	✘	✓	✘	NS3	Improves PDR, throughput, overhead	Focus on mobility	Delay tolerant application with medium number of UAVs and low speed
FM-DT-GDR [70]	2022	✘	✘	✓	✘	NS3	Improves PDR, ETED, routing overhead	Focus on mobility	Delay tolerant application when number of UAV is small with low speed
NDTN Routing Protocols									
protocol	**year**	**Energy Aware**	**Congestion Aware**	**Mobility Aware**	**Link Aware**	**Simulator**	**Advantages**	**Weakness**	**Applications**
JarmRout [71]	2018	✘	✓	✓	✓	OMNET++	Improved PDR, ETED, Overhead	Energy efficiency problem	Delay sensitive application in small and dense network with medium speed of drones.
LLRA [72]	2019	✘	✘	✘	✓	unknown	Improves PDR, ETED	Considers only link quality	Designed for real time application in disaster scenarios with high UAV speed.
MPVR [73]	2019	✘	✘	✓	✘	unknown	Improves ARL, delay, PDR	considers only the mobility of UAVs	Delay sensitive application in dens network with medium speed of drones
TARCS [74]	2019	✘	✘	✓	✘	NS3	Improves Throughput, PDR, ETED, Jitter	concentrates on topological changes only	Delay sensitive application in dense network with high speed of drones
G-OLSR [75]	2021	✘	✘	✘	✘	NS3	Improves Throughput, PDR, ETED, overhead	Network parameters doesn't consider	Designed for emergency message distribution for disaster in real time
QTAR [76]	2021	✓	✘	✓	✓	MATLAB	Improved energy usage, delay, and PDR	Data load balancing ignored	Delay sensitive application in dense network with medium UAVs speed
RLPR [77]	2021	✓	✘	✓	✓	Ns2	improves the network lifetime, control messages overhead, search success rate	Load balancing doesn't consider	Delay sensitive application with medium number of drones and low speed.

PDR = Packet Delivery Ratio, ETED = End-to-End Delay, ARL = Average routing lifetime

7.0 CONCLUSION

FANET, an ad-hoc network connected to numerous UAVs, has become an effective solution for several applications, such as disaster relief. Taking into account the special characteristics of FANETs, recently Several routing protocols have been introduced to adapt to the FANET environment. In this paper, we comprehensively review the recent FANET routing protocols and the possibility of using these protocols in disaster response scenarios. FANET routing protocols are classified as topology-based and position-based routing protocols and then analyzed in terms of methodology, simulator, routing metrics, advantages, and shortcomings to evaluate the current routing protocols relative to performance metrics. Finally, a summary of open issues and research challenges in FANET routing was argued. More research is needed to design more accurate and efficient routing protocols although current methods for the FANET routing protocol have yielded positive results. Future studies need to take into account the special features of FANETs to fully exploit the potential of UAVs in future wireless network applications, including disaster scenarios and emergency response applications. The paper concluded that no particular routing protocol for each disaster scenario. The choice of protocol is based upon various factors, including network size, network density, UAV velocity, and the specific disaster application, etc. In the future we will test different routing protocols in specific disaster scenarios to evaluate their performance and results considering conditions and applications.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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