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Cluster-Based Routing Protocols for Flying Ad Hoc Networks (FANETs)

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ABSTRACT Flying Ad-Hoc Network (FANET) is a set of Unmanned Aerial Vehicles (UAVs) interconnected wirelessly. FANETs self-organize and provide low-cost, adaptable, and simple-to-implement flying nodes, enabling them to complete complicated tasks more quickly and collectively. The high mobility of nodes and the highly dynamic topology pose challenges to communication design, particularly when creating a routing protocol for UAV networks; this has inspired researchers to contribute and develop this technology. Hierarchical routing technique known as clustering is necessary to offer scalability, survivability, and distribute payload among UAVs to maintain the performance. This study has proposed a comprehensive survey of the cluster-based routing protocols (CBRPs) in terms of their strengths, weaknesses, specific applications, method, number of nodes, and future improvements for serving FANETs. Moreover, 21 CBRPs based FANETs were reviewed in terms of their topology, challenges, scalability, characteristics, clustering strategy, outstanding features, cluster head (CH) selection, routing metrics, and performance measures. In addition, open issues that need to be addressed in future studies in the field of routing protocols for UAV networks were also debated.

INDEX TERMS Clustering algorithm, flying ad hoc network, routing protocol, scalability, unmanned aerial vehicle.

I. INTRODUCTION

In the coming years, flying ad hoc network (FANET) is projected to have a significant impact on the future of human existence since it consists of flying unmanned aerial vehicles (UAVs) that are remotely operated and have no pilot on board. Unmanned aerial vehicles (UAVs) have surpassed all other technology sectors in importance for the foreseeable future. They accomplish more complex applications that are beyond the capabilities of regular Mobil ad hoc network (MANETs) or individual UAVs. UAVs equipped with wireless communication modules and simple sensors can be operated as a single connected group. FANETs are becoming increasingly common, and they can provide actuation services while limiting human interaction and potentially life-threatening dangers [1]–[5]. FANETs have been receiving increased attention from researchers [6]. FANETs may be used in various contexts, from civilian to military, because of their robustness, adaptability, low running costs, and ease of construction [7], [8]. Multi-UAV cooperation, which is an essential part of this project, could lead to a wide range of uses, including precise geographic localization [9], search and rescue missions [10], intelligent transportation systems [11], target detection [12], disaster tracking and monitoring [13], volcano monitoring [14], delivering medical supplies to otherwise inaccessible regions [15], border patrol missions [16], prevention and control of forest fires [17], UAV control by the brain [18], acting as relays for Internet distribution [19], among others Drones are also extensively employed in the military [20]; for example, the US Navy's LOCUST project hires a swarm of autonomous drones to carry out coordinated military operations [21]. Numerous additional applications are being developed in academia and industry in addition to these marketed ones [22]. Surveying and mapping are two examples of this type of work [23]. By allowing each UAV to carry a different sensor and operate in the same area simultaneously, the use of swarms can speed up sensing chores inside a target region while also keeping in mind that several UAVs will work together to provide an appropriate and ideal answer [24]. A future in which

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drones are smoothly integrated into daily lives, allowing us to enjoy a better quality of life [25], [26]. However, despite the advantages mentioned earlier, there are still numerous technological hurdles and challenges to overcome, such as rapidly changing network topology, a node's velocity, energy constraint, communication and cooperation between UAV's, a reliable connection between the UAVs and ground station, the impact of different transmission ranges and density in the FANET environment, as well as the security concerns of FANET. There are four main categories of FANET routing protocols which are the topology-aware, position-aware, cluster-based, and beaconless opportunistic routing protocols. Each one is unique in its way.

Recently, several survey and review researches have focused on the four categories of the routing protocols; for example, the authors in [27] have done a survey paper on location-based routing protocols. This survey focuses primarily on position-based routing protocols and details the benefits and drawbacks of the position-based routing protocols. In addition, they developed a new taxonomy to identify the correct class of each novel protocol. Despite this, they did not cover all the routing protocols, including the cluster-based. Furthermore, the research in [28] surveyed the cluster-based routing protocols (CBRPs) and presented an in-depth description of how cluster-assisted routing protocols can be used to address UAV protocol configuration issues. Based on 18 cluster routings, these protocols are classified with their advantages, disadvantages, and application; discussion on the potential improvements for each protocol was also provided. However, they focused only on CBRPs which is just a type of UAV routing, and did not cover all routing cluster-based protocols. Moreover, Khan *et al.* [29] presented a complete analysis of routing strategies in FANETs, including the goals, problems, metrics for routing schemes, and open issues. Nevertheless, the majority of AI-enabled routing methods have not been explored. Furthermore, the research in [30] focused on UAV networks routing protocols such as position-based, cluster-based, topology-based, stochastic, social-network, and deterministic-based routing protocols. The study involved the evaluation of 21 topology-based routing protocols, 22 position-based protocols, 5 CBRPs, 6 data-forwarding-based routing protocols, and 6 field tests on routing protocols in FANETs and UAV networks. Despite that, there were no additional details on UAV routing methods in this work. As a result, the article did not describe the FANET's architectures of communication and applications, the application and use cases, the mobility models, and the relevant routing protocols. In addition, the authors in [31] conducted a review on UAV network routing protocols. They made a comparative study of evolving routing protocols for UAV networks under various circumstances. Nonetheless, they focused only on position-based approaches while excluding the many reactive, proactive, and AI-enabled routing protocols. Additionally, the research in [32] surveyed the UAV networks routing protocols for both configurations; operating height was used to introduce the author's classification system for UAVs. Furthermore, the use of communication structures in future wireless networks was discussed. The routing procedures are then categorized and compared in terms of whether a base station was used or not. Even so, there is no investigation into clustering algorithms in this study. In another study, Agrawal *et al.* [33] surveyed the geographic-based routing protocol and presented an overview of the advantages and disadvantages of each geographic-based routing protocol, as well as a summary of all comparative analyses of character and quality of service (QoS) metrics of geographic-based routing for FANETs. Nevertheless, it only considered geographically-based techniques, leaving out proactive, reactive, positional, and AI-enabled routing protocol implementations in their various flavors.

In summary, several surveys and reviews have been conducted; however, all of them have several limitations as presented in Table (2). Hence, this review is a more comprehensive and in-depth examination of CBRPs, covering a wide range of topics that were surveyed from a completely different perspective, including a comprehensive review and comparison of the CBRPs based on their strengths, weaknesses, specific applications, method, number of nodes, and future improvements. Moreover, this study compared 21 CBRPs based on their topology, challenges, features, salient features, scalability, clustering strategy, CH election, routing metrics, and performance measures. This review will assist researchers and engineers in selecting the most effective and dependable cluster-based routing algorithms for the deployment of FANETs. The comparative analysis in this study may be valuable in installing effective cluster routing protocols and trustworthy swarm routing protocols. In this study, focus on a cluster-based routing protocol to make up for the deficiencies of the articles above. Scholars have conducted numerous studies on cluster-based routing, position-based routing, and topology-based routing for UAV networks, and numerous routing protocols with a variety of technologies have been developed.

The primary contributions of this study are as follows:

- The study of a wide range of new technologies on CBRPs and carrying out a thorough investigation on their characteristics, techniques, specific applications, method, number of nodes as well as competitive strengths and weaknesses. This to the best of our knowledge makes the survey as the first CBRPs oriented survey for FANETs routing.
- The systematic and comprehensive categorization of CBRPs for UAV networks in consideration of the underlying clustering process is also one of the novelties provided in this survey. We point out that the survey includes 21 different CBRPs.
- A comparative analysis of CBRPs in terms of their challenges, topology, scalability, salient features, characteristics, clustering strategy, CH election, routing metrics, and performance measures. This enables deeper understanding of the capabilities of CBPRs in

TABLE 1. Comparison of existing survey papers in FANETs with our paper.

Author	Position-based routing protocols	Cluster-based routing protocols	Topology-based routing protocols	Beaconless opportunistic routing protocols	Range years
[27]	✓		✓		2007-2017
[28]		✓			2008-2018
[29]	✓	✓	✓	✓	2009-2019
[30]	✓	✓	✓		2001-2018
[31]	✓	✓	✓	✓	2010-2019
[32]	✓		✓	✓	2003-2019
[33]	✓				2005-2020
Our review	✓	✓	✓	✓	2016-2021

terms of the practical aspect and their potential in applications.
- Highlighting the important open issues that need to be addressed in future studies on the development of CBRPs for UAV networks. This provides a solid background and guidance for researchers to consider the important challenges in their future research.

The rest of this review is arranged thus: Section II focused on the routing protocols for UAV networks while Section III reviewed the CBRPs for UAV networks in terms of their strengths, weaknesses, method, the number of nodes, suitability to specific applications, salient features, challenges, and characteristics. In Section IV, a comparative review of the CBRPs was presented in terms of their topology, scalability, clustering strategy, CH selection, routing metrics, and performance measures. Section V focused on the significant open issues that needs to be discussed in future studies on the development of UAV networks. The final section (Section VI) presented the conclusion of the review paper.

II. ROUTING PROTOCOLS FOR UAVS

The literature is full of numerous routing protocols that have been proposed and developed for Ad-Hoc networks; these include the position-aware, cluster-based, topology-aware, & beaconless opportunistic routing protocols. Because FANET is a subclass of Mobile Ad-Hoc Network (MANET) and Vehicular Ad-Hoc Network (VANET), researchers initially examined protocols employed in those networks for potential applicability in UAV networks. However, due to the unique properties of FANET nodes, such as speed, energy scarcity, and fast changes in connectivity, most of these protocols cannot be employed directly. As a result, it is critical to alter these protocols to meet FANET standards. In addition, several Ad-Hoc networking protocols have been suggested in the literature. This part provides a classification rather than a complete list of the existing routing protocols for FANET as earlier categorized. Each category will be examined in detail in the following subsections are depicted in Figure (1).

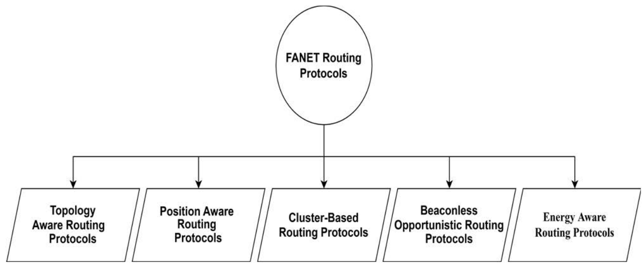

FIGURE 1. Routing classification for Flying Ad Hoc Network (FANET)[31].

A. TOPOLOGY AWARE ROUTING PROTOCOLS (TARPS)

The rapid mobility of FANET nodes results in drastic changes in the topology of the network. Dynamic and asymmetrical changes in topological and structural features can cause network disruption. Hence, numerous knowledge-based routing protocols have been proposed to address this problem. Its goal is to enhance routing by adding more knowledge to the routing such as knowledge extracted from movement patterns. On the other hand, various routing protocols intended for topology adjustment are developed based on the standard functionality of MANET, such as the incorporation of Global Positioning System (GPS) location features and the direct application to FANET. There are still other factors to consider. This section has included some routing protocols that solve topological challenges, particularly in the FANET situation. To adapt to complicated settings, nodes can collect data about changes in the topologies of their surroundings over time. Numerous routing protocols can also be merged based on the task demands. Some protocols rely on topology-based routing protocols, such as the Topology Construction Method (TCM) [34], Distributed Priority Tree-Based Routing Protocol (DPTR) [35], Topology Change Awarding Based Routing Choosing Scheme (TARCS) [36], and Q-learning-based topology-aware routing (QTAR) [37], and Temporally ordered routing algorithm (TORA) [38]. Also, other researchers have incorporated software defined networks (SDN) in topology aware routing for FANETs. In the work of [39], SDN based FANETs (STFANET), a coordination protocol that encapsulates both an efficient SDN-based UAV communication and a set of topology management algorithms, which is a Software-defined networking (SDN) based Topology management for FANETs was proposed. The purpose is to create and maintain a FANET topology that will offer a consistent and stable communication link between independent nodes conducting solo or collaborative tasks via relays.

B. POSITION AWARE ROUTING PROTOCOLS (PARPS)

These routing protocols are based on the user's geographic location information. Each node can establish geographical broadcast about its speed and location to its neighbors using GPS. The node can rely on location service, such as the Reactive Location Service (RLS) or the Grid Location Service (GLS) to determine the destination's position Hierarchical Location Service (HLS). Because nodes make local judgments rather than exploring the status of the entire network, it is appropriate for highly dynamic networks such as FANETs. The benefit is that it eliminates the problem of frequent network node disconnection caused by the unpredictability of node mobility. There are three types of routing protocols: (i) Non Delay Tolerant (non-DTN), (ii) Delay Tolerant (DTN), and (iii) heterogeneous routing protocols. Some protocols rely on position-based routing protocols, such as Robust and Reliable Predictive Routing (RARP) [13], Jamming-Resilient Multipath Routing (JarmRout) [25], and Ground Control System Based Routing (GCS) [40], and extension to AntHocNet [41].

C. CLUSTER-BASED ROUTING PROTOCOLS (CBRPS)

Clustering refers to the partitioning of a network into different clusters and subclusters that are interconnected. The clustering concept is a technique for categorizing nodes that share a familiar geographic neighborhood; such nodes are classified into numerous groups primarily to address the FANET's resource scarcity issue. The role of the cluster head (CH) of each cluster is to work as a coordinator within the subcluster. Hence, each CH is considered a temporary Base Station (BS) for the clusters it is located. Clustering is a technique that relies on arranging network nodes into a series of overlapping clusters. Clustering enables hierarchical routing by recording pathways between clusters rather than between nodes. It improves network scalability, increases route lifetime, improves throughput, reduces routing overhead, and saves UAV energy. In this study, 21 CBRPs were discussed as presented in the extensive review in Section IV [42]–[62].

D. BEACONLESS OPPORTUNISTIC ROUTING PROTOCOL (BORPS)

These are ad hoc networks that require no direct connection between the source nodes and the destination nodes, rather, they rely on node's mobility for their communication. The conventional multi-hop wireless networks, such as wireless mesh networks, MANETs, and wireless sensor networks lack a mechanism for resolving network connection disruptions under adverse conditions. As a result, network performance falls dramatically when a connection is lost, perhaps even to the point of failure. In practice, however, the topological structure is subject to change, and connectedness is usually not guaranteed. As a result, to assure job completion efficiency, it must examine the routing protocol to determine the most efficient data transmission channel. The benefit of beaconless opportunity routing protocols is that they enable and sustain network connectivity even when delays and intermittent links are present. Some protocols rely on Beaconless Opportunistic Routing Protocol, such as Cross-Layer Link Quality and Geographical-Aware Beaconless Opportunistic Routing Protocol (XLinGO) [63] and Adaptive Context-Aware Beaconless Opportunistic Routing Protocol (CABR) [64].

E. ENERGY AWARE ROUTING PROTOCOLS (EARPS)

WBAN can be used in conjunction with aerial vehicles to collect health data and transmit it to a base station. Furthermore, flying things' unbalanced energy usage will lead to earlier mission failure and a rapid decline in network lifespan. Using an ant-based routing system called AntHocNet [65], discusses how to exploit each UAV's residual energy level to assure a high level of safety. The usage of IoT-assisted aerial vehicles in health care would improve operational performance, surveillance, and automation optimization, making flying IoT a smart application. Also, the work of [66], enhances energy efficiency and overall network performance using modified ant colony optimization.

III. CLUSTER-BASED ROUTING FOR UAV NETWORKS

The clustering of ad-hoc UAV networks is a powerful network management approach that can considerably enhance the overall performance of ad-hoc UAV networks. The main characteristics of ad-hoc UAV networks have been thoroughly evaluated for their distinctive features, distinctive characteristics, potential strengths, and weaknesses. Clustering in a UAV network has several advantages, such as scalability, reliability, energy efficiency, data aggregation, fault tolerance, connectivity, coverage, and reduced delay. As the number of nodes increases, CBRPs will become more complex and can be widely adopted. The existing clustering protocols are mostly categorized into two which are probabilistic and deterministic clustering. The difference between them is that the former generates the decision using probabilistic models while the latter has a deterministic decision. The probabilistic cluster algorithm's primary purpose is to discover the optimal routing path while extending the service life of the network. The probabilistic clustering protocols are also subclassified into dynamic, bio-inspired, and hybrid clustering. With the deterministic CBRPs, more confident metrics determine the CH. The deterministic clustering algorithms may be further classified into four types of weight-based clustering, fuzzy-based clustering, heuristic-based clustering, and compound clustering. The classification of CBRPs is shown in Figure (2). The operational behavior, inherent characteristics, method, number of nodes, competitive strengths, weaknesses, and specific applications of the protocols are discussed

A. CBRPS BASED ON PROBABILISTIC CLUSTERING

The main purpose of probabilistic cluster algorithms is to discover the optimal routing path while extending the network's lifetime. The CH is randomly selected in various probabilistic cluster-based routing algorithms. This section examines in detail the probabilistic-based CBRPs.

1) DYNAMIC CLUSTERING

This form of the clustering requires that cluster formation and CH selection are actively managed [42], [43]. Each node participates in a CH selection arrangement, and some CH computation methods are used.

a: MOBILITY AND LOCATION-AWARE STABLE CLUSTERING (MLSC)

In this regard, the study in [42] presented the MLSC protocol for establishing peer-to-peer links between UAV swarms to maintain collaboration and coordination. MLSC aims to reduce the current challenges of dynamic topology and UAV mobility. The MLSC routing protocol is compared to the traditional Ant Colony Optimization (ACO) and Grey Wolf Optimization (GWO) schemes. The study incorporated mobility and coverage probability into the MLSC protocol for randomly deployed UAV networks are depicted in Figure (3). In this regard, the study first showed how many CH UAVs are needed to cover the maximum area while consuming the least amount of power in a specific location. Following that, the study suggested the k-means clustering technique for optimally locating settled CHs. Additionally, a cluster maintenance strategy that takes relative mobility and location into account to increase the cluster network's stability was presented.

The CH sends a proclamation message to the UAVs indicated in the cluster domain, inviting them to combine the given cluster. The proclamation message contains information on the CH's Identification, location, and hop count. Once the backbone tree is complete, each CH can store information about its neighboring CHs. Firstly, it offers the ideal deployment strategy for CH UAVs to optimize the chance of coverage. This model investigates the link between cluster size and the chance of achieving maximum coverage in a network to determine the ideal cluster size with the fewest transmissions. A decreasing normalized mean distance ∂_k between neighboring UAVs implies that the possible CH UAV is closer to the neighboring UAVs. As a result, the mean relative distance ∂_k of an unmanned aerial vehicle is defined as:

$$\partial_k = \frac{\sum_{n=1}^{N_n} \sqrt{\left[\Delta x_{k,n}\right]^2 + \left[\Delta y_{k,n}\right]^2 + \left[\Delta z_{k,n}\right]^2}}{N_n \cdot max\,\{Z_k\}} \tag{1}$$

With the normalizing factor being equivalent to the most important value of the set Z_k that contains all Euclidean distances between UAVs.

Secondly, a distance-based k-means clustering technique and clustering results management technique was introduced using updated relative location information from the UAVs. The distance between the ground station/sink and the inter-cluster UAVs on an average basis can be represented as:

$$\mathcal{D}_k = \frac{\sum_{k=1}^{N_c} \sqrt{\left[\Delta x_{k,0}\right]^2 + \left[\Delta y_{k,0}\right]^2 + \left[\Delta z_{k,0}\right]^2}}{N_c \cdot max\,\{\varphi_k\}} \tag{2}$$

where φ_k represents the set of all Euclidean distances between the sink and inter-cluster UAVs.

As earlier explained, the CH selection index is computed by adding the normalized values of the mean relative speed and distances.

b: UAV ROUTING PROTOCOL (URP)

The study in [43] created a method for monitoring crop health using cutting-edge technologies such as UAVs and wireless sensors. URP is a dynamic cluster-based routing system developed to collect data from sensor nodes via fixed or mobile sinks. They collected data from distributed nodes through a stochastic process or planned path using a mobile sink node coupled with a UAV. A UAV emits to activate all sensor nodes, sends a beacon message within its immediate vicinity, and clusters them according to the path and type of data.

Numerous parameters (including remaining energy, renewable energy sources, the rate of energy consumption, the antenna size, and the distance to the UAV) are considered throughout the URP decision-making process. The proposed system dynamically builds clusters and picks CHs based on the situation and then provides a reliable connection between the UAV and the CH for the collection of important data for subsequent processing & decision making. Figure (4) depicts the described dynamic clustering technique.

Candidate CHs, candidate clusters (CCs), and Cluster members (CMs) are the three types of routing cluster nodes (CCHs). CCHs and UAVs are invited by designating a node to serve as a CH.

2) BIO-INSPIRED CLUSTERING

This technique utilizes information from nature and combines it with other techniques are depicted in Figure (7) to produce a motivating result [44]–[52].

a: BIO-INSPIRED CLUSTERING SCHEME FOR FANETS (BICSF)

The BICSF protocol for UAV networks was presented by [44] to alleviate the current issues associated with topology management and make communication within the FANET more convenient. The BICSF routing protocol is compared to several other bio-inspired algorithms such as Grey Wolf Optimization (GWO) and Ant Colony Optimization (ACO). The three phases of BICSF are depicted in Figure (5). BICSF for FANETs was developed as a hybridization of the Krill herd (KH) mechanism and the Glowworm Swarm Optimization (GSO) mechanism.

The primary motivation for utilizing the GSO method for CH selection is that it enables us to determine the status of each UAV based on its Luciferin level and position.

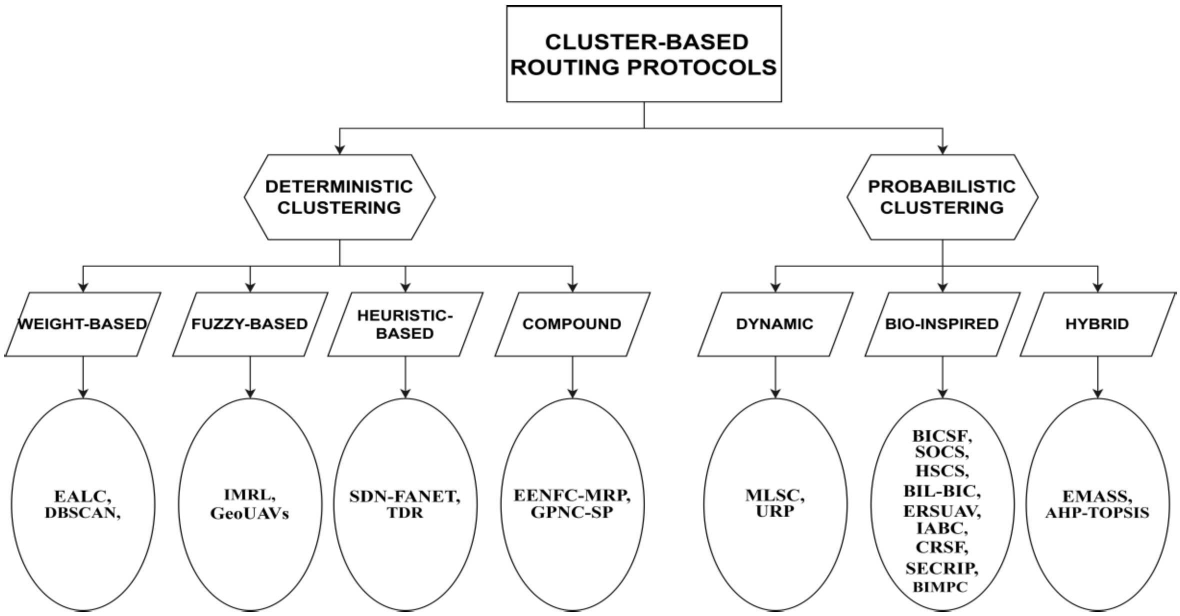

FIGURE 2. Classification of cluster-based routing protocols for UAV network.

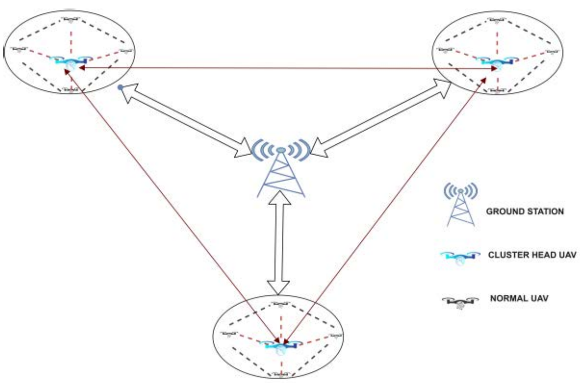

FIGURE 3. Location and mobility aware clustering in UAV networks [42].

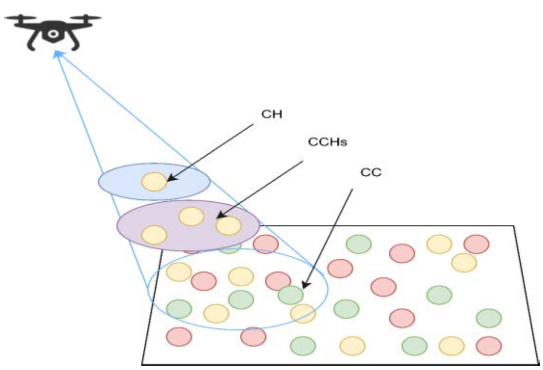

FIGURE 4. Dynamic clustering scheme in URP[43].

A glowworm's present status can be determined by examining its luciferin level, its distance from other glowworms, and neighborhood range. Equation (3) is used to calculate the fitness value. All UAV rankings are based on the fitness value for optimum CH selection. The formula presented in Equation (4) may be used to calculate and update the Luciferin value:

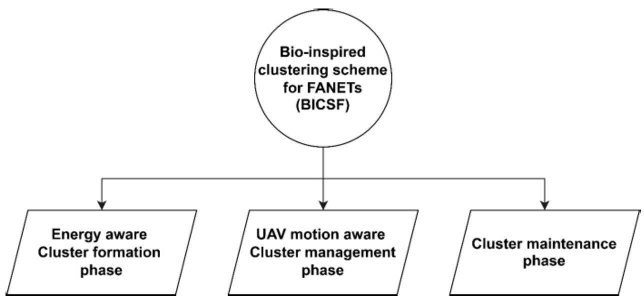

FIGURE 5. Phases of Bio-Inspired Clustering Scheme for FANETs (BICSF) [44].

$$L_i(t+1) = (1-\rho)L_i(t) + \gamma F\left(p_i(t)\right) \tag{3}$$

where:

$L_i\,(t)$ denotes the current luciferin value for glowworm i

$L_i(t-1)$ denotes the current luciferin value for glowworm i

ρ denotes the luciferin decay constant and it belongs to [0, 1]

γ dentes the luciferin enhancement fraction

$F\,(p_i(t))$ is the objective function of glowworm i at its present location (p_i).

The CH, in general, is the node whose fitness value is the highest. It proposed a cluster management system influenced by the KH. It also solved the flying node's optimal position problem using biological genetic approaches such as mutation and crossover operators. In terms of cluster communication, they calculate the path detection function using equation 4:

$$\text{Path detection function} = \frac{\omega_1 \times \text{residual energy}}{(\omega_2 \times N_i)(\omega_3 \times \text{distance})} \quad (4)$$

where ω_1 = weight for residual energy, ω_2 = the weight of number of neighboring UAVs, & ω_3 = weight for intra-UAVs distance; $\omega_1 + \omega_2 + \omega_3 = 1$.

The cluster maintenance phases define a threshold for energy level of every UAV that is used to check the current energy of every cluster member i, and to decide whether the cluster member is dead or not based on reaching a residual energy lower than the defined threshold.

b: SELF-ORGANIZATION BASED CLUSTERING SCHEME (SOCS)

This scheme (SOCS) was presented by [45] for better network management and improved communication across UAVs. SOCS intends to alleviate some of the present issues associated with topology management to improve communication in FANET. The SOCS routing protocol is compared to several other bio-inspired protocols such as ACO and GWO. SOCS for FANET relies on the behavioral pattern of GSO. The GSO algorithm determines a glowworm's luciferin value and neighborhood range. GSO was chosen for FANET because of its capacity to provide an ideal solution in the context of a glowworm's luciferin value shifting. This enables the application of this GSO quality to cluster-based FANETs.

Each glowworm in the GSO algorithm has a unique local decision range and luciferin value, also known as the neighborhood range. A glowworm's luciferin value is dictated by its objective function and location. The luciferin value of the glowworm is updated using Equation (3).

To ensure data transfer and optimal communication, clustering strategy incorporates CH selection based on connectivity to the GCS, and a fitness function dependent on the residual energy value and the luciferin value of the UAV. The cluster formation is depicted in Figure (8). As it is shown in the figure, the existence of base station and ground control station is needed.

Each drone calculates its fitness using the Equation (5) throughout the cluster building mechanism:

$$\text{Fitness} = w_1 \times f_1 + w_2 \times f_2 \quad \text{where } w_1 + w_2 = 1 \quad (5)$$

The UAV's residual energy function in Equation (6):

$$\begin{aligned} f_1 &= RE_i = (IEL_i - CEL_i) \\ f_2 &= L_i(t+1) \end{aligned} \quad (6)$$

Here, RE_i denotes residual energy, IEL_i denotes the ith UAV's beginning energy, and CEL_i denotes the ith UAV's current energy level. The Equation (6) function is used to determine the luciferin value.

After calculating fitness, each UAV broadcasts HM in addition to its fitness. When the UAV gets HM, it evaluates it compared to its fitness level. The UAV populates and updates the NTAB with UAV entries, ranking them in decreasing fitness order for each new HM. When a UAV is linked to GCS, it self-identifies as CH.

c: HYBRID SELF-ORGANIZED CLUSTERING SCHEME (HSCS)-

The HSCS protocol with the Internet of Drones (IoD) was presented by [46]. HSCS intends to improve the administration and maintenance of clusters used for UAV communications. The HSCS routing protocol is used compared with other bio-inspired algorithms, such as the Bio-inspired FANET clustering scheme (BICSF). HSCS is divided into three phases: cluster selection and creation, cluster maintenance, and network maintenance and communication are depicted in Figure (9). HSCS for drone-based cognitive IoT is developed by combining Glowworm Swarm Optimization (GSO) and Dragonfly Algorithm (DA).

The CH selection and cluster creation step utilize the GSO algorithm. Particular instances for CH selection are considered based on physical fitness and connectedness to the BS, which is determined using the drone's position and comprises residual energy and luciferin value. The CH is picked based on its fitness level, while the remaining drones act as its CMs. The energy consumed by data packet transmission can be expressed in Equation (7):

$$E_{TX} = \begin{cases} l * \left(E_{elc} + \epsilon_s * d^2\right) & \text{if } d < d_0 \\ l * \left(E_{elc} + \epsilon_l * d^4\right) & \text{if } d \geq d_0 \end{cases} \quad (7)$$

E_{elc} refers to the amount of energy wasted by electronics for a transmitter or receiver; l is the packet size; d is the metric distance between the transmitter and the receiver, and d_0 is a threshold. ϵ_s and ϵ_l provide the amount of energy used by an amplifier to transmit a single bit across a short or long distance.

The Equation (3) updates the glowworm's Luciferin value.

DA simulates the cluster management phase by utilizing the drones' positions. The CH maintains control of the cluster by periodically updating the drones' positions and informing its members of its topology.

In DA, three primary elements are considered when updating the position of the dragonfly in swarms; these elements are separation, alignment, & cohesion. The separation refers to the avoidance of collision between adjacent ranges; it is determined using Equation (8):

$$S_i = -\sum_{k=1}^{N} X - X_k \quad (8)$$

where X is the current position, X_k denotes the location of the kth nearby person, and N denotes the total number of neighbors.

CH is accountable for data transmission to BS in HSCS. The appropriate route selection is critical for data routing. In HSCS, route selection is efficient when the Route Selection Function (RSF) is determined using Equation (9):

$$RSF = \frac{E_{res}}{(N_i)(D)} \quad (9)$$

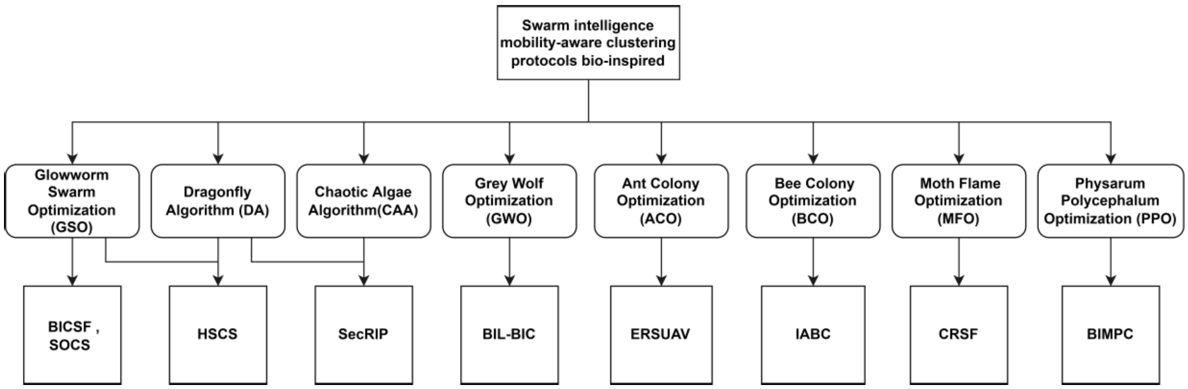

FIGURE 6. Swarm intelligence mobility-aware clustering protocols bio-inspired for UAV networks.

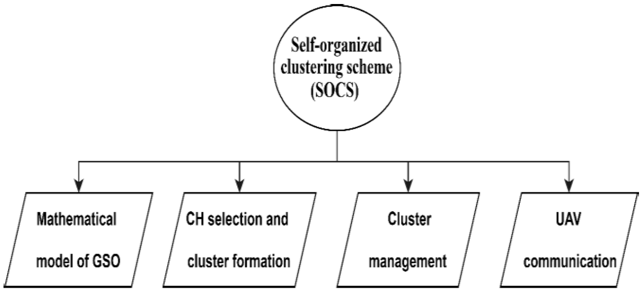

FIGURE 7. Phases of self-organized clustering scheme for FANETs (SOCS) [45].

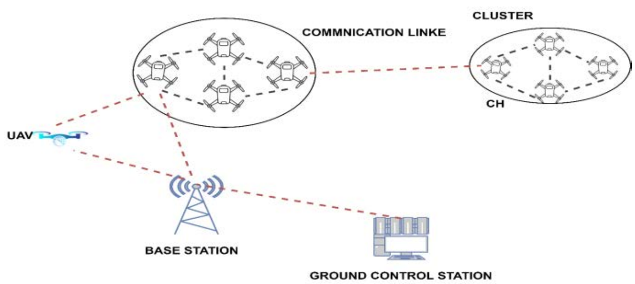

FIGURE 8. Cluster formation depicting different scenarios [45].

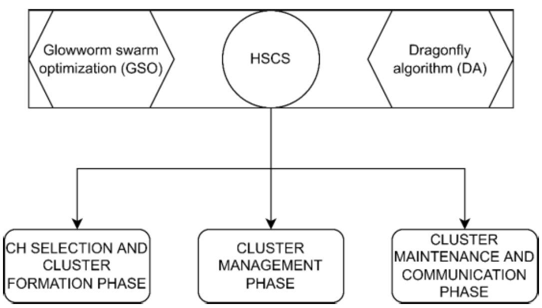

FIGURE 9. Illustration of HSCS concerning phases [46].

As indicated in Equation (9), the *RSF* is dependent on the drone's residual energy (E_{res}), the number of surrounding drones (N_i), and the distance between drones (D).

d: BIO-INSPIRED LOCALIZATION (BIL) AND CLUSTERING (BIC)

The BIL and BIC protocols were developed by [47] for ad hoc UAV networks; they are employed in UAV networks to locate and monitor wildfires in distant areas. The performance of BIL was compared to the Distance Vector Hop (DV-Hop), GWO-based Localization (GWO-LPWSN), Differential Evolution (DE) algorithm with an improved DV-Hop-based localization algorithm (DECHDV-Hop), Three-Dimensional (3D), range-free localization algorithm based on a genetic algorithm (GA) with improved DV-Hop (3D-GAIDV-Hop), & Hybrid-Dimensionality-based PSO (HDPSO) protocols. Then, the analysis of the performance of BIC was done in comparison to that of EALC, BICSF, Cluster-based Location-Aided Dynamic Source Routing (CBLADSR), Mobility Prediction Clustering Algorithm (MPCA), & SOCS. The BIL and BIC for FANETs were also presented as GWO-based compressive sensing (CS-GWO) algorithms for application in the unmanned aerial vehicle (UAV).

A hybrid GWO (HGWO) approach for UAV networks and a distributed localization method based on HGWO that is both energy efficient and range-free was created as well. This technique, dubbed BIL for bounding cube with hop count, minimizes errors during distance estimation. The BIL protocol uses an optimization strategy that relies on the HGWO concept to determine the ideal location of the target unmanned aerial vehicle node. Compared to previous algorithms, the BIL method has a higher precision of localization, a cheaper computational cost, a shorter convergence time, and a lower energy usage.

To extend the network lifetime, it presents the BIC method, a clustering technique based on the HGWO. The size and number of clusters significantly influence the performance during communication in unstable UAV networks; it also minimized the number of required transmissions. The proposed BIC is developed with a special CH selection technique that relies on the fitness value of UAVs. The selection of the CH is based on the node with higher residual energy, shorter distance between clusters, and neighbors. It is responsible for the gathering and transfer of data. As previously stated, U_i's three-dimensional coordinates at a time (t) are as follows: (x_i^{uav}, y_i^{uav}, z_i^{uav}). The distance between two UAVs (U_i and U_j) is calculated using the Equation (10):

$$d^{i,j}\left\{U_i(t), U_j(t)\right\} = \sqrt{\left(x_i^{\text{uav}} - x_j^{\text{uav}}\right)^2 + \left(y_i^{\text{uav}} - y_j^{\text{uav}}\right)^2 + \left(z_i^{\text{uav}} - z_j^{\text{uav}}\right)^2} \quad (10)$$

Additionally, it offer the CS-GWO method, which transmits data in BIC. Within a cluster, cluster members (CMs) communicate with the cluster controller (CH) without using CS-GWO. Following that, the CH transmits data to the BS via CS-GWO routing.

e: EFFICIENT ROUTING STRATEGY FOR UAVS (ERSUAV)

ERSUAV is a helpful way to collect information about farming in distant mountain areas by utilizing UAVs and wireless sensor networks (WSNs) [48]. For the WSN hierarchy, ERSUAV was utilized to design and build the best path for UAVs based on ACO.

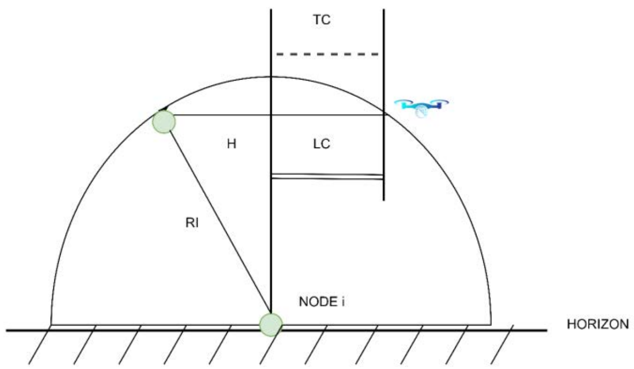

FIGURE 10. Delay calculation method from sensor node i to UAV [48].

ERSUAV combines the clustering capabilities of WSNs with those of UAC. Because all nodes are believed to be stationary, the CHs are GPS-enabled and the UAV has access to the locations of all CHs and the sent data for each node of the same length; hence, the network can be regarded immobile. There are various clusters where the UAV collects data while flying above the CH. Figure (10) illustrates the delay calculation. In ERSUAV, the overall delay of an unmanned aerial vehicle is defined in Equation (11):

$$T_{all} = T_1 + \sum_l^n \left(T_c + T_s + T_{ij}\right) + T_3 \quad \text{and } T_c = \frac{l_d}{V_c} \quad (11)$$

where n is the number of visited nodes, T_1 is the data packet. T_c is the required time delay to establish a connection between I and j, T_s is the required time to transfer data between the UAV and the node, T_{ij} is the required flight time from I to j, T_3 is the required flight time for the UAV to reach the data center from the last node, l_d is the length of the data, and V_c is the bit per second. An unmanned aerial vehicle's energy consumption is defined in Equation (12):

$$P_{all} = P_1 + \sum_l^n \left(P_c + P_s + P_{ij}\right) + P_3 \quad (12)$$

where P_1, P_c, P_3, P_{ij}, and P_s represent the energy used by UAV during flight to the CH from the data centre, the consumed energy by the connection between I and UAV, the utilized energy by the UAV while flying to the data centre from the last node, the utilized energy by UAV while flying from I to j, and the utilized energy by the node and UAV, respectively. The aim of ERSUAV is to reduce delay and improve energy conservation.

The latency and energy consumption between nodes are related to their distance. The authors proposed an optimum path planning algorithm for UAVs based on ACO to minimize delay and energy consumption. At time t, the chance of ant k traveling from I to j is represented thus:

$$P_{ij}^k(t) = \begin{cases} \dfrac{\tau_{ij}^{\alpha}(t) \times \eta_{ij}^{\beta}(t)}{\sum_k \tau_{ij}^{\alpha}(t) \times \eta_{ij}^{\beta}(t)}, & \forall_{j\in N}, \text{and } j \notin M^k, \\ 0, & \text{otherwise} \end{cases} \quad (13)$$

where $\forall_{j\in N}$ denote the angles, and M^k denotes the cluster's active sensor nodes, $\eta_{ij}^{\beta}(t) = 1$ d 2 ij, Ni are the neighbouring nodes of node i, and $\tau_{ij}^{\alpha}(t)$ Pheromones are updated both locally and globally

f: IMPROVED ARTIFICIAL BEE COLONY OPTIMISATION (IABC)

The IABC protocol for ad hoc UAV networks was presented by [49] to mitigate the present issues of high mobility, limited resources, and dispersed nature that have created a new challenge for developing a safe and efficient routing strategy for FANET. The proposed IABC was compared with Artificial Bee Colony Optimization (ABC), GWO, and Particle Swarm Optimization (PSO) algorithms. ABC was enhanced using blockchain technology to develop a secure clustering routing mechanism for FANET. The exploration and exploitation processes were balanced using the IABC algorithm. The AI-Proof of Witness Consensus Method (AI-PoWCA) was also presented. This lightweight consensus algorithm needs not just miners but also a witness to validate blocks before adding them to the blockchain.

A cluster-based routing strategy in which the ideal CH is determined using an IABC-based algorithm (CH) was also presented. CH selection is a critical task for clustering in FANETs because CHs are responsible for routing data from Cluster Members (CM) and transferring it to other CHs. The following collection of objectives was observed when calculating the proposed fitness function: Remaining Energy and Reputation, Total Online Time, Transaction Volume, and Mobility Connectivity.

First, the proposed IABC algorithm was used to pick a CH selection that requires a UAV with considerable residual energy. The fitness function's primary goal is that if a UAV is chosen as a CH, it should have the maximum residual energy $max\ (E_r)$, the maximum reputation ranking $max\ (R_r)$, the maximum online time $max\ (O_t)$, the maximum transactions $max\ (T)$, the minimum UAV mobility 1 $min(M)$, and the maximum UAV connectivity $max(C)$. As an example, consider the Equation (14) suggested fitness function:

$$f = \frac{max\ (E_r) + max\ (R_r) + max\ (O_t)}{min(M)} + \frac{max(T) + max(C)}{min(M)} \tag{14}$$

The observer bee uses Equation (15) to determine the nectar content, or fitness of the newly created solution and then uses greedy selection to select an improved food source.

$$p_i = \frac{f_i}{\sum_{i=1}^{SN} f_i} \tag{15}$$

where f_i denotes the fitness of the ith population-wide solution and I denote one, two, three, or more, and SN is the population size. As a result, fitness is proportional to p_i in the inverse direction.

The second phase is network construction, which requires all UAVs except CHs to send requests to adjacent CHs to join a cluster. The CH maintains an updated routing table. Under the proposed system, each modification to the routing table is treated as a blockchain transaction and communicated to the blockchain module. Each CH is responsible for three tables: the Cluster Member Table, the Two-hop Member Table, and the Edge Member Table.

The next step is to safeguard the route data. Once a predefined number of transactions have occurred, a block is formed. The consensus process is engaged to validate and attach the block to the blockchain. The consensus process requests a witness node to witness to the block by including the witness's digital signature in the block. A successful verification block is attached to the local chain and broadcast to all other CHs in the network.

Finally, to assess conduct a security analysis. The impact of AI-Proof of Witness Consensus Algorithm (AI-PoWCA) on assaults, consumption, and availability of energy for FANET is compared to Proof of Work (PoW), Proof of Stake (PoS), and Proof of Attack (PoA), such as 51% attack, Long-Range Attack, DDoS Attack, and Sybil Attack.

g: INTELLIGENT CLUSTER ROUTING SCHEME FOR FLYING AD HOC NETWORKS (CRSF)

The CRSF protocol for network development and administration was presented by [50] to establish network stability and address collaboration, cooperation, and communication issues among FANET UAVs are depicted in Figure (11). Due to the mobility of UAVs, network formation for data routing becomes more complicated. The CRSF routing protocol was compared with other bioinspired clustering schemes for FANETs (BICSF) and ACO. Cluster routing's primary objective is to develop a self-organized networking method that assures network stability while incurring less complexity and higher throughput, resulting in prolonged cluster service life. A more streamlined approach requires less energy, thereby improving cluster service life and throughput. CH selection, cluster creation, cluster administration, CH re-selection, and the FANET routing mechanism are the major stages of the proposed scheme.

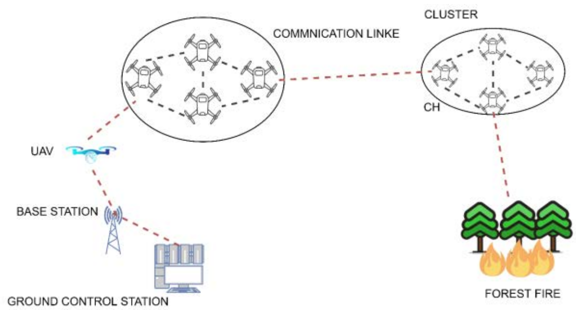

FIGURE 11. System model for UAV networks (CRSF) [50].

It considers solely the energy consumed during communication and calculate energy consumption using the first-order radio model. The energy consumed during the transmission (E_{Tx}) and reception (E_{Rx}) of m-bits is computed using Equation (16):

$$\begin{aligned} E_T(m, d) &= E_{Tx}(m, d) + E_{Rx}(m, d) \\ E_{T_x}(m, d) &= E_{\text{TRC}} \times m + E_A \times m \times d^2 \\ E_{Rx}(m, d) &= E_{\text{TRC}} \times m \end{aligned} \tag{16}$$

It proposes the use of MFO to capitalize on the transverse orientation of moths that enables them to fly long distances in a straight path; hence, MFO is a better method for position calculation; it is a 3-tuple algorithm that uses the approximation function to determine the optimal global solution as given by Equation (17):

$$\text{MFO} = (I, P, T) \tag{17}$$

where I produce a random population of moths and their associated fitness values, P drives them toward the flame. At the same time, T evaluates the termination criteria and returns true or false depending on the value of the criterion.

Equation (5) is used to determine the fitness function for selecting the CH; w1 and w2 are weights assigned to characteristics used to evaluate UAV fitness in CH selection.

The route considers the UAV with the shortest range and the maximum residual energy. The RIF may be calculated using the Equation (18):

$$\text{RIF} = \frac{R_E}{D_{\text{UAV}}} \tag{18}$$

where DUAV is calculated in equation (19):

$$D_{\text{UAV}} = D_{i,j} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \tag{19}$$

The proposed CRSF's overall computational complexity is provided in Equation (20):

$$C(\text{CRSF}) = C(\text{fitness function}) + C(\text{position}) \tag{20}$$

Total complexity is estimated as (O(N) + O(N)) O(N) in the first instance, (O(N) + O(CN)) O(CN) in the second case, and (O(N) + O(CN)) O(CN) in the third case.

h: SECURE AND RELIABLE INTERCLUSTER ROUTING PROTOCOL (SECRIP)

The SecRIP protocol for ad hoc UAV networks was presented by [51] to address the current issues associated with topology management and facilitate communication in FANET. SecRIP is a safe and reliable routing system for data transport in a flying ad hoc network. This SecRIP is focused on enhancing the Quality of Service (QoS) and Quality of Experience (QoE) metrics. Figure (12) implies the network model for the SecRIP protocol. SecRIP is based on the DA and the Chaotic Algae Algorithm (CAA) which are responsible for cluster selection, administration, and data transmission between clusters.

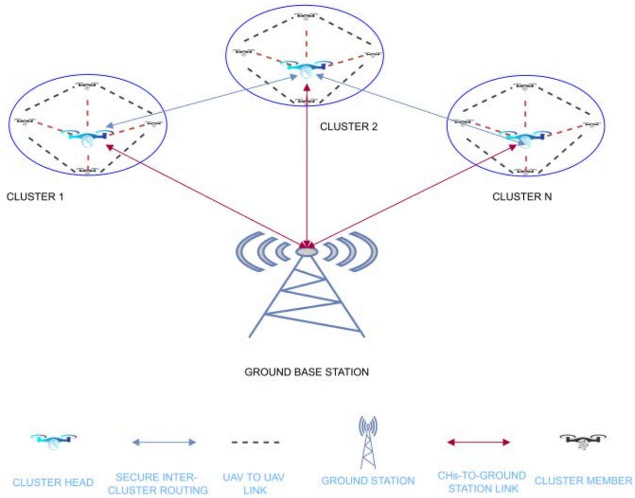

FIGURE 12. **A network model for UAV networks (SECRIP) [51].**

SecRIP is a routing protocol that focuses on clustering so that node energy efficiency is optimized. SecRIP's objective is to detect and select the most efficient CHs for routing. Each CH encrypts data transmission using the NTRU algorithm. Equation (21) illustrates the search agent's operation.

$$\vec{W} = \left| \vec{V} \cdot \vec{X}_p^*(i) - \vec{X}(i) \right| \tag{21}$$

where i is the iteration counter, $\vec{X}_p^*$ is the position of the best node, $X^{\rightarrow}$ is the vector that encodes the location of the node.

Equation (22) denotes the required energy to transmit a packet from node 'j'.

$$E_j^S = lE_{\text{elec}} + l\varepsilon_{\text{amp}} D^2 \tag{22}$$

where E_{elec}—radio energy dissipation of energy required for data propagation and reception, ε_{amp} is the factor for one-bit message amplification before transmission over a long distance.

In an ad hoc network, a high degree of node mobility affects the network's components. Equation depicts the CH and other nodes as having varying degrees of mobility. Despite their mobility, the primary objective is to build stable clusters that can persist in the wild for an extended period.

$$M = \max_{k=1-k} \left\{ \sum\nolimits_{\forall n \varepsilon C_k} \sqrt{V_{nj}^2 + V_{CK}^2 - 2V_{ni}^2 V_{CK}^2 \cos \frac{\theta_{ni} - \theta_{ik}}{2}} \right. \tag{23}$$

This term refers to a network's total number of nodes. Congestion is more likely to occur when a network has a significant number of nodes. This leads to a decrease in network performance. The trust degree is derived by averaging the values of all the parameters as specified in Equation (24):

$$D_t = \sum E_j^s, RSS, M, D_{\text{EE}}, C \tag{24}$$

i: BIO-INSPIRED MOBILITY PREDICTION CLUSTERING (BIMPC)

BIMPC protocol was presented for UAV networks by [52]. It contributes to ad-hoc UAV networks by combining UAV mobility with the foraging model of *Physarum polycephalum*. BIMPC addresses the issue of UAV network mobility and topology modification. BIMPC is in charge of cluster establishment and maintenance. The present UAV is considered capable of calculating the sum of one-hop neighbors' values and the cluster's stability. All UAV nodes must compute the value of their nearby nodes in order to become a CH. It is calculated using equation (25):

$$CHP_i(t) = \sum_{j \in N} \frac{d}{dt} \Delta P_{ij}(t) \tag{25}$$

where I and j are UAVs, P_{ij} represents the current flowing by use of the pitot tube, $CHP_i(t)$ is the likelihood that the existing UAV I will evolve into CH, and N represents the singular set -hop surrounding UAVs of the current UAV node i. All UAVs send Hello packets to their neighbours during cluster formation, compiling a list of neighbours. When the present UAV gets two consecutive Hello messages from its nearby UAVs, it determines the likelihood of the current and adjacent UAVs sustaining their connection and movement.

The prediction of connection failures and cluster alterations is possible with the BIMPC algorithm. When the current cluster head $CHP_i(t)$ value decreases significantly, it is not optimal to become a CH. As a result, rotation of the CH is required, and the CH's rotation formula is given in Equation (26).

$$ACHP_i(t) = \frac{1}{M} \sum\nolimits_{j \in N} \frac{d}{dt} \Delta P_{ij}(t) \tag{26}$$

where I and j denote the UAV nodes, N is a collection of adjacent UAVs capable of making a single hop, and M denotes the cluster's total number of UAV nodes.

When the sum of two is $ACHP_i(t)$ is more significant than, it demonstrates that the present CHi is no longer eligible for progression to the rank of CH. CH is only rotated if the conditions are met in Equation (27):

$$\Delta ACHP_i(nT) = ACHP_i(t - nT) - ACHP_i(t) > \emptyset \tag{27}$$

where n is a positive value and T is the period of the hello packets.

3) HYBRID CLUSTERING

This method combines the advantages of the two protocols. [53], [54].

a: ENERGY AND MOBILITY-AWARE STABLE AND SAFE CLUSTERING (EMASS)

EMASS, a protocol for ad hoc UAV networks, was presented by [53]. The EMASS clustering technique is presented to address UAVs' rapid mobility and ensure safe inter-UAV distance. The EMASS routing protocol is used in conjunction with other protocols to improve and enhance necessary measures in two well-known methods previously described in the literature, namely BICSF and Energy-Aware Link-based Clustering (EALC). The EMASS algorithm is presented for FANETs to enable the balance of loads, energy-aware clustering, data transmission, and routing between UAVs while ensuring network stability and security. The EMASS method is divided into the cluster management and CH election phases.

This function took a variety of parameters into account, including the residual energy of the UAVs, the nodal degree of the UAVs, and the distance between the UAVs. Equation (5) is used to express this path detecting function;

where w1, w2, and w3 are the weights assigned to the various parameters and w1+w2+w3 = 1. According to scientists, energy-efficient path identification decreases cluster energy consumption and increases the life of the FANET.

Each UAV determines the collection of nodes in its transmission vicinity that are its neighbours. As a result, it calculates and sends its fitness value to its neighbours using Equation (28):

$$\text{Fitness} = \frac{w_1 * \text{Energy}_{\text{res}}}{(w_2 * avg_{\text{dis}})\,(w_3 * \text{delta}_{\text{diff}})} \tag{28}$$

where $\text{Energy}_{\text{res}}$ is the remaining energy value of UAVs, avg_{dis} the mean distance between two UAVs and their neighbouring nodes, and $\text{delta}_{\text{diff}}$ is the parameter for the delta difference. W1, w2, and w3 denote the degree of a node; an ideal degree determines whether a node can be a member of the cluster.

$$\text{delta}_{\text{diff}} = \mid \text{Ideal\_tegree} - \text{Node}_{\text{degree}} \mid \tag{29}$$

Equation (30) is used to determine the fitness function β_i :

$$\beta_i = \frac{1}{w_1\lambda_i} * \frac{w_2 E_{R,i}}{w_3\sigma_i} \tag{30}$$

Here, w1, w2, and w3 are weighting factors for the characteristics utilized, such that w1 + w2 + w3 equals 1. The CH will be picked from the node whose fitness function is the lowest.

The CH election method attempts to split the network efficiently into clusters. Each cluster contains an optimal node that is elected as the CH. The EMASS identifies the most suitable CH using the utility function described in the CH selection process. This method involves no UAVs, but only used unmanned aerial aircraft traveling in the same direction.

The UAV with Idi is deemed a CH if it has the smallest fitness function I in Ω_i as seen in Equation (31).

$$CH = \{Id_i \mid \beta\,(Id_i) \leq min\,\{\Omega_i\}\} \tag{31}$$

Following the cluster creation phase, a cluster maintenance procedure manages network configuration changes. As a result, it strives to maintain the network's stability and resilience. When the CH is compelled to quit its job, the backup CH is selected. The technique is used to identify which cluster member is the most qualified to be chosen as a new CH (which will be referred to as backup CH) (BCH_i) based on Equation (32).

$$BCH_i = \{i \mid \beta_i \leq min\,\{\text{remaining}CM_i \in C_i\}\} \tag{32}$$

The maintenance phase accounts for the changes that may occur in the network topology, such as a CH joining or leaving the network, or a CM_i joining or leaving a cluster.

b: ANALYTIC HIERARCHY PROCESS-TECHNIQUE FOR ORDER OF PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (AHP-TOPSIS)

The TOPSIS protocol for ad hoc UAV networks was presented by [54]; for effective clustering in FANETs, a hybrid AHP-TOPSIS method was applied. TOPSIS hybrid algorithm is used to improve the quality of received video streams, which is a primary purpose of a UAV. It overcomes energy consumption, effective bandwidth use, effective clustering of UAVs, and intelligent communication with ground stations. AHP-TOPSIS hybrid algorithm is used to choose CHs, and receives video frames captured by other UAVs via Wi-Fi and sends them via a 5G link to the ground station. The TOPSIS routing protocol was compared with GSO. When two well-known mobility models (Paparazzi and Random Waypoint) were compared to the other methods, there was a significant reduction in the number of CHs and the average energy consumption of the UAV.

The role of the ground controller is to intelligently identify the UAVs that will be the CH at regular intervals using the AHP-TOPSIS algorithm. Consequently, the UAVs' swarm reduction and efficient bandwidth use, traffic, and delay associated with sending live video frames are reduced, resulting in superior video quality at the ground station and reduced UAV energy consumption.

The ground stations provide data to the fixed controller through 5G; the information provided includes the residual energy (RE), number of neighbours (NN), coverage area (CA), & mobility speed (MS) (see Equation 33).

$$RE^* = \frac{RE}{(RE + CA + NN + MS)} \tag{33}$$

Then, the weights (w_i) are calculated using Equation (34):

$$w_i = \frac{\sum \text{Row}}{\text{Number of columns}} \quad \forall_i = 1, 2, 3, \ldots, n \tag{34}$$

This stage will determine the relative weight criteria using various weighing methods. Weighing can be accomplished in various ways, including the row sum technique, column sum technique, arithmetic mean technique, geometric mean technique, extraordinary vector approach, and square sum technique. This work utilized the row summarization method.

TOPSIS decision matrix ($D_{n\times m}$) is an option criterion matrix given as in Equation (35).

$$D_{n\times m} = \begin{pmatrix} RE_{11} & \cdots & MS_{1n} \\ \vdots & \ddots & \vdots \\ RE_{m1} & \cdots & MS_{mn} \end{pmatrix} \tag{35}$$

Finally, the calculation of the relative proximity of an option to the optimal solution was done by multiplying the distance of the option from the ideal negative option by the total of the distances between the negative and positive ideal options. Equation (36) can be used to get the alternate C_{i} for each UAV:

$$C_{\mathrm{i}} = \frac{s_i^-}{s_{\mathrm{i}}^+ + s_{\mathrm{i}}^-} \, (0 < \mathrm{C_i} < 1) \tag{36}$$

The system generates a ranking of UAVs capable of executing CH functions and imaging. The closer this value is to 1 for each UAV, the closer to the optimal response; so, it has a greater chance of being picked as the network's CH than other UAVs.

Discussion and Analysis: To conclude on cluster-based probabilistic clustering, Table (2) compares the performance indices used to evaluate the methods in terms of the number of nodes, competitive strengths, weaknesses, potential application, and possible future improvements.

B. CBRPs BASED ON DETERMINISTIC CLUSTERING

To determine the CH in the deterministic CBRPs, more certain measurements are used; energy, closeness, centrality, and node degree are the most often used metrics. By overhearing and exchanging messages, nodes gain information from surrounding nodes.

1) WEIGHT BASED

This clustering technique uses a variety of parameters, such as transmission power, remaining energy, and several neighbour's nodes [55], [56].

a: ENERGY-AWARE LINK-BASED CLUSTERING (EALC)

The EALC protocol for ad hoc UAV networks was presented by [55] to resolve its two primary issues: insufficient flight time and poor communication routing in FANET. The EALC routing protocol is compared with ACO and GWO. EALC attempts to overcome both of these issues through efficient clustering. Firstly, the transmission power of UAVs was modified based on predicted operational requirements. The transmission distance is optimized, which reduces packet loss rate (PLR), improves network quality, and reduces communication energy consumption. Transmission power is inextricably linked to transmission range as in Equation (37):

$$P_T = P_R + 20\log\left(\frac{4\pi R}{\lambda}\right) - G_T - G_R \tag{37}$$

where G_T is the transmitting side's antenna gain, and G_R is the receiving side's antenna gain; λ is the transmitting frequency's wavelength, while P_R is the receiver's sensitivity.

Secondly, the CHs were selected using the k-means density clustering technique. K-means sorting takes each node's fitness value as input, and the CHs and their related members are output as in Equation (28).

While most past works have been focused on statically weighting fitness factors, static weighting might be biased in favour of the fitness function, hence, incapable of delivering accurate findings. If all nodes fall within the same range of transmission, a CH must be selected based on its fitness value. The nodes' energy level is regarded as a fitness parameter in EALC. Suppose node A has a 90 percent energy level while the remaining nodes have a state of energy of around 50%; in that case, this discrepancy qualifies node A as a CH. Additionally, suppose node F has a 30% energy level; in contrast, the others have a high degree of energy, 50%, but shorter than the others. In that case, node F might be elected as a CH.

b: DENSITY-BASED SPATIAL CLUSTERING OF APPLICATION WITH NOISE (DBSCAN)

The DBSCAN was proposed as a distributed clustering approach for UAVs networks by [56]. The distributive system described by DBSCAN includes a clustering algorithm, an optimal path planner, and an optimal sensor manager. DBSCAN uses extended Kalman filters (EKFs) to estimate the location of mobile targets. DBSCAN aims to provide an efficient route planner and sensor administrator for tracking a large number of mobile agents. Clustering is a powerful technique for solving communication and computational problems. The clustering method's initial step aims to make it easier for UAVs to sense and communicate by utilising a separate creating set of objectives. The DBSCAN routing algorithm seeks to ensure the accuracy of target geolocation. The authors developed a distributed strategy in their study that leverages the benefits of a model predictive control and dynamic weight graph based on the target information density.

EKFs are used to rate an object's location and speed during geolocation. According to reports, each UAV is equipped with an inertial measurement unit (IMU) and a loud GPS. The kth target is determined using Equation (39):

$$p_k^i = p_u^i + L\left(R_b^i R_g^b R_c^g l_k^c\right) \tag{38}$$

where i is the inertial framework, g is the body framework, c is the gimbal framework, and u is the camera framework of the UAV. Here, p_u^i denotes the inertial coordinate frame

TABLE 2. Comparison of cluster-based probabilistic clustering.

Protocol	Ref	Year	Method	Strength	Weakness	Potential application	Number of UAVs	Possible future improvements
Dynamic clustering								
MLSC	[42]	2020	Increase the network's stability and accuracy by minimising needless overheads and latency by using numerous design features with minimal resource limitations.	Establish a relationship between the maximum likelihood of CH coverage and cluster size to calculate the optimal cluster size with the least network overhead.	Centralised clustering has a short network lifetime and is not the ideal technique for electing the CH.	To enhance coordination and collaboration, links are built among UAV swarms.	20 to 140 UAVs	A future enhancement to MLSC is the inclusion of high-speed UAV nodes.
URP	[43]	2018	It is developed and validated a dynamic data collecting system that allows for data collection from selected nodes within a defined area.	URP can be used to rapidly deploy a UAV network in the absence of pre-existing infrastructure.	URP is designed for usage with Wireless Sensor Networks (WSNs) that are helped by UAVs and employ a single-hop transmission approach that cannot be stretched to a multi-hop transmission scheme.	URP can be utilised to develop Internet of things (IoT) agriculture technologies based on UAVs for crop health monitoring.	1 to 91 Dead Nodes	Numerous enhancements to URP may be conceivable in the future. Rather than relying on a single UAV, numerous UAVs can be utilised.
Bio-inspired clustering								
BICSF	[44]	2019	minimise battery resource and mobility of UAVs	Low energy consumption and an increase in the lifetime of the cluster.	The algorithm's clustering procedure is based on selecting CHs using the passive distance metric. This distance does not consider the safety degree required between nodes to lessen the likelihood of a collision and increase network stability.	suitable for highly dynamic UAVs communica tion	15 to 35 UAVs	In the future, the BICSF routing may improve the distance between multi-UAV-based systems.
SOCS	[45]	2019	Improved the frequency of link failures caused by mobile UAVs	decreased energy consumption in the network, increasing the cluster's lifetime	The distance between UAVs is just five metres, whereas the distance between UAVs and CH is expected to remain flexible.	Can be used to communicate among UAVs.	15 to 35 UAVs	It will concentrate our efforts on this domain of study to improve congestion control in resource-constrained UAV networks.
HSCS	[46]	2019	It may alleviate networking-related challenges by delivering a self-organizing cluster-based networking solution for IoT applications using drones.	Reduced energy consumption as a result of energy-conscious CH selection and cluster management.	Reduces energy consumption without sacrificing latency or route connection	Optimised for multi-swarm drone network topology management scheme implemented for fire detection	15 to 35 UAVs	By adding position from DA rules into the cluster management algorithm, they can ensure swarm behaviour inside the cluster and the CMs' alignment with regard to the CH.
BIL&BIC	[47]	2021	Applications for detecting and monitoring wildfires in remote locations	Develop energy-efficient UAV network localisation and clustering techniques and decrease the number of transmissions in (UAV) networks.	Due to the nature of multi-hop communication, the proposed technique may increase the number of hops necessary to transmit data from the CM to the BS.	It is approved for usage in urban areas as UAV networks for wildfire detection and post-fire monitoring.	20 to 140 UAVs	It will examine the possibility of employing several antennas.
ERSUAV	[48]	2016	Aiming at the implementation of UAVs in WSNs to monitor agriculture information	Higher scalability, less latency, and enhanced efficiency	Because centralised clustering has a finite network lifespan, it is not optimal for electing the CH.	It is ideally suited for data gathering in farmland-based WSNs, including temperature and humidity monitoring.	25 to 200 UAVS	ERSUAV has the potential to be expanded to embedded platforms.
IABC	[49]	2020	It aims to resolve FANET's routing and data security issues.	Reduce the fitness function associated with choosing a CH based on reputation, residual energy,	The UAV may fly freely inside the communication zone and make randomly chosen decisions—the probability distribution changes with each iteration.	Especially well-suited for highly dynamic UAV networks and security.	10 to 80 UAVs	IABC routing may be enhanced in the future by utilising witnesses for block verification, hence making this system a highly resilient

TABLE 2. ***(Continued.)*** **Comparison of cluster-based probabilistic clustering.**

				online time, connectivity, mobility, and transactions.				notion.
CRSF	[50]	2021	resolve UAV communication issues	Increase communication efficiency and cost savings For FANET's route selection and load balancing to be efficient.	Because UAVs are movable, the relative mobility of CM and CH UAVs varies over time. This will result in a cluster's CH being re-selected.	It is used to describe the number of UAVs deployed to transmit data to a remote-control centre, which can be connected to any disaster or even.	15 to 35 UAVs	In the future, Router efficiency may be improved by using mobile nodes.
SECRIP	[51]	2020	assists in significantly streamlining the routing procedure within the network	When connections are added, there is minimal delay, and packets are secured by identifying suitable nodes along the path from various clusters.	If the distance between the sender node and the CH exceeds this amount, the message was not received by the CH, and the node will broadcast an emergency message to the CH. However, this strategy is only successful with low-mobility UAVs.	secure wireless communication routing between UAVs.	100 to200 UAVs	In anticipation of future development, they propose to expand the proposed SECRIP to incorporate robust security mechanisms to preserve transmitted data.
BIMPC	[52]	2016	seeks to address the issue of network topology changes and mobility in UAV networks.	Improved cluster creation and maintenance in large-scale UAV networks for highly dynamic clustering	Considers only UAV nodes with a moderate degree of mobility	It May be used to create highly dynamic large-scale ad hoc unmanned aerial vehicle networks	50 to 250 UAVs	BIMPC aims to take into account UAV nodes traveling at fast speeds.
Hybrid clustering								
EMASS	[53]	2021	Address UAVs' rapid mobility and establish safe inter-UAV distances	ensure network stability and security by assuring load balancing, data forwarding, energy-aware clustering, and routing among UAVs.	There is a possibility that the number of single CH will increase. Increased routing overhead as a result of frequent cluster topology updates and centralised clustering has a finite network lifespan.	utilised to create effective remote monitoring in a variety of UAV applications	20 to 140 UAVs	They believe it can make substantial progress by providing a new SDN-based architecture for managing the generated FANET clusters using the recommended EMASS algorithm.
AHP-TOPSIS	[54]	2021	As a primary mission of a UAV, it is to improve the quality of the received video stream.	decreases the computation rate and reduce by at least half the number of comparisons	Utilise a logically restricted number of UAVs to provide live video to base stations.	Transfer of high-definition live video between UAVs and information-gathering sites	80 to 256 UAVs	It will attempt to find a more efficient method of selecting values from the AHP matrix.

of the UAV, L is the distance from the UAV to the target, l_k^c denotes the target's normal vector k, R_b^idenotes the vehicle body framework, R_g^b denotes the gimbal framework, and R_c^g denotes the camera framework.

DBSCAN automatically generates clusters of varied sizes and shapes without the need for any fundamental data about the data. Clusters are formed in which the data is analysed and need a certain minimum of points, denoted by the term minPts. The most significant distance circumferential to a point x is used to organise data. The DBSCAN algorithm identifies clusters based on the local density of the data. The distance between x and its -neighbourhood is expressed in Equation (40):

$$N_\varepsilon = \{\text{y} \mid \delta(\text{x,y}) \leq \varepsilon \tag{39}$$

where δ(x, y) denotes the Euclidean distance between two nodes.

2) FUZZY BASED

Clustering is the process of allocating data points to clusters so that objects within each cluster remain similar while things in other clusters vary [57], [58].

a: LOCALISATION MULTI-HOP HIERARCHICAL ROUTING (IMRL)

The IMRL is a cluster routing protocol based on fuzzy logic that outperforms current algorithms in terms of energy efficiency, data transmission, and localisation accuracy [57]. It is based on a weighted centroid localisation mechanism that relies on a fuzzy logic inference to determine the coordinates of UAV nodes based on their RSSI values. The suggested data routing strategy is based on node weighted centroid localisation. The distance between the anchor and the UAV is determined by comparing their RSSI values and monitoring the flow across a wireless channel. The creators of

IMRL routing chose the next-hop CH primarily based on the node's location. When an efficient data transmission method is utilised, the network's lifetime is enhanced while energy consumption is reduced. The authors proposed a fuzzy interface-based approach for range-free UAV localisation as a first step toward building a fuzzy-based localisation algorithm. RSSI values are utilised to locate unidentified UAV nodes. Following cluster formation, UAVs undertake area scans and interact with other UAVs via pre-established channels. The range is computed using a signal propagation model and the RSSI data after collecting all the RSSI signals. However, the exact location of the UAV cannot be easily determined due to the noise caused by RSSI.

The authors recommended that to increase location accuracy, the position of the UAV is calculated using edge weight estimation. Following the determination of the node's position through the localisation technique, the subsequent stage is to choose an efficient next-hop CH for data transfer. The CH election considers the state with the most excess energy. The essential target is to ensure uniform distribution of energy among all CMs. The CH is accountable for multi-hop data transfer from the CMs to the BS. The rotation of the CH is weighted.

b: GEOCAST ROUTING PROTOCOL FOR FLEET OF UAVS (GEOUAVS)

The GeoUAVs is a protocol for ad hoc UAV networks presented by [58]. Geocast routing protocol for FANET's fleet routing challenge tries to transmit data to a specified group of mobility drones recognised geographically. GeoUAVs combine with other bio-inspired routing protocols such as AntHocNet and BeeAdHoc. GeoUAVs routing protocol is used for a group of UAVs that collectively cover the wildfire zone, considering the dynamic topology of UAVs with 3D mobility and guaranteed transmission accuracy. The location of each UAV is calculated using a GPS in three coordinates (X, Y, and Z). Due to the square nature of the Transmission Zone (TZ), the information must be guaranteed to be sent to all UAVs within the TZ in addition to the application as shown in Figure (13). At first, the source UAV transmits the first geocast packet PUAVS.

Dissemination of packets in *TZ* : When a UAV_j gets a packet PUAVS from a UAV_j, the UAV_jverifies the packet's relevancy. A packet PUAVS is deemed significant if and only if the three requirements of Equation (41) are met:

$$\begin{cases} UAV_j \text{ in } TZ(t) \\ UAV_j \text{ receives } P_{UAV_S} \text{ for the first time} \\ t \in [S\ \text{Start}_t,\ End_t] \end{cases} \quad (40)$$

where UAVs denotes the source UAV; T ZS M in(t): $TZ(t)$ minimum coordinate at the current local time t; T ZS Max(t): $TZ(t)$ maximum coordinate at the current local time t; Start t: The application's start time; End t: The application's end time; UAVS Info: UAVS Information content

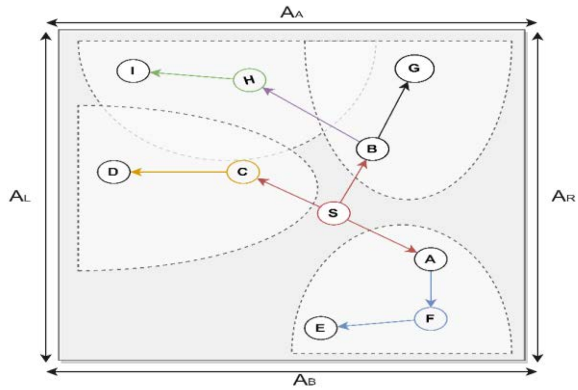

FIGURE 13. Packet dissemination in GeoUAVs [58].

3) HEURISTIC BASED

Clustering is a technique that is based on the centroid estimate approach used in centroid learning. A continuous search is undertaken in the centroid of the local region until a good result is obtained [59], [60].

a: SOFTWARE-DEFINED NETWORKING FANET (SDN-FANET)

The SDN-FANET was developed as a combination of several UAVs to achieve a FANET [59]. SDN-FANET decouples the data and control planes and enables the programming of the network via using a central controller to control all the control operations of FANET using global UAV context data such as movement trajectories, UAV locations, and residual energy. CAPONE is another cluster-based control plane message management solution for SDN-FANET that is based on contextual information of the UAV; the UAV information can be predicted by the controller without delivering control signals.

Additionally, CAPONE organises the FANET by using a Gap statistics technique to estimate the number of clusters that will be later used to determine the leader and members of a group using a Fuzzy C-means method. Thus, CAPONE minimises bandwidth usage and signalling cost while ensuring the delivery of control messages in FANET settings. From a control plane perspective, the CH acts as a local controller in each group, doing more sophisticated tasks, whereas group members provide UAV contextual information to the CH.

Fuzzy clustering is made up of k clusters, c1, c2, and ck, and a split matrix M = mi,j [0, 1], where I = 1...n and j = 1...k, and each entry mi,j reflects the degree of belongingness of an item I to a cluster cj. The objective function is minimized using the fuzzy C-means algorithm in Equation (42):

$$J = \sum_{i=1}^{N} \sum_{c=1}^{C} \mu_{ic}^{m} D_{ic}^{2} \quad (41)$$

The Gap statistics Gap (c) compares the goal functions of sets B and their initial locations, which are calculated using equation (43). It offers information on the organisation of the positions in each cluster c compared to a set of disorderly positions. As a result, the clustered index used to optimise this function's value should offer a decent estimate of the cluster number to use:

$$\text{Gap}\,(c) = \left(\frac{1}{B}\right) \sum_{b} \log\left(J^{*}_{c,b}\right) - \log\left(J_{c}\right) \tag{42}$$

Due to the imprecision of the approach, the Gap (c) function normally produces an average gap value. The accurate representation of the value given by Equation (43) is achieved by determining the standard deviation $sd(c)$ for each cluster number c using Equation (44):

$$sd(c) = \sqrt{\frac{\sum_{b}\left(\log\left(J_{c,b}\right) - \frac{1}{B}\sum_{b}\log\left(J^{*}_{c,b}\right)\right)^{2}}{B}} \tag{43}$$

The intersection of the simulation error $s(c)$, given in Equation (45), and the maximum Gap (c) values is calculated. The most negligible c value is considered the ideal estimated number of clusters.

$$s(c) = sd_{c}\sqrt{1 + B^{-1}} \tag{44}$$

b: TRAFFIC-DIFFERENTIATED ROUTING (TDR)

The TDR is a centralised traffic-diverse cluster routing system developed by [60] to fulfil the needs of services that are time-sensitive and demand high dependability. TDR presents a novel model for predicting transmission reliability that considers both nodes forwarding capabilities and network availability. The TDR protocol separates all UAVs into clusters, each commanded by a stationary top UAV. Each UAV node should have an inbuilt GPS that keeps its position and speed. The controller may connect with all UAVs in the cluster through Hello and ECHO messages and collect information about their position and speed. To forecast connection availability, it is supposed that the total range of transmission of all UAV nodes and the GPS position of each node has been calculated previously.

Each UAV node, ni and nj, has an identical radio transmission range, dmax. The symbols (x_i, y_i, z_i) and (x_j, y_j, z_j) denote the t0 locations of ni and nj, respectively. The velocities of ni and nj are (vx_i, vy_i, vz_i) and (vx_j, vy_j, vz_j), respectively. The Equation (46) formula may be used to determine the distance:

$$d_{ij}\,(t_0) = \left[\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2 + \left(z_j - z_i\right)^2\right] \tag{45}$$

After a particular interval t, the distance between ni and nj is defined as:

$$\begin{aligned} d_{ij}\,(t_0 + t) = \Big\{ &\left[\left(x_j + v_{xj}\mathrm{t}\right) - \left(x_i + v_{xi}\mathrm{t}\right)\right]^2 \\ &+ \left[\left(y_j + v_{yj}\mathrm{t}\right) - \left(y_i + v_{yi}\mathrm{t}\right)\right]^2 \\ &+ \left[\left(z_j + v_{zj}\mathrm{t}\right) - \left(z_i + v_{zi}\mathrm{t}\right)\right]^2 \Big\}^{\frac{1}{2}} \end{aligned} \tag{46}$$

4) COMPOUND

Cluster head (CH) selection is based on the mobility and connectivity of nodes in a network [61], [62].

a: ENERGY-EFFICIENT NEURO-FUZZY CBRP CONSTRUCTION WITH METAHEURISTIC ROUTE PLANNING (EENFC-MRP)

The EENFC-MRP attempts to mitigate current issues such as limited battery ability of UAVs, quick mobility, and the highly dynamic nature of FANET connection [61]. The given model is energy efficient due to the clustering and routing methods based on EENFC and MRP. The EENFC-MRP routing protocol is compared with the model's KHOA, GWOA, ACOA, and PSOA. Figure (14) illustrates the process of proposed EENFC-MRF model.

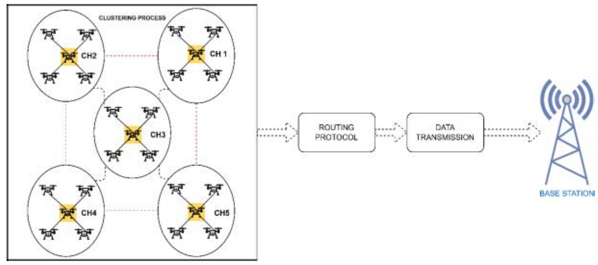

FIGURE 14. **Process in EENFC-MRP Model for UAV networks [61].**

The EENFC model employs three input factors (average distance to nearby UAVs, residual energy (RE) in the UAV, and UAV degree) to determine CHs and build the topology.

The methods of supervised learning and single-layer perceptron learning were used to train a system to select CHs as in Equation (48):

$$W_i(t-1) = W_i(t) + \mu \times \left(\mathrm{O}_T - \mathrm{O}_A\right) \times L \tag{47}$$

where W_i signifies the weight factor of the ith cell, ith means the number of inputs cells, denotes the learning rate, L denotes a cell's input, O_A denotes the system's output, and O_T denotes the needed output.

The *RE* of the UAV (x) while sending *k* bits to the receiving UAV (y) over a distance can be defined as in Equation (49):

$$RE = E - \left(E_T(k, d) + E_{R(k)}\right) \tag{48}$$

where E signifies the UAV's existing energy and E_T denotes the energy consumed for data sensing.

The average distance (AvgD) to neighbouring UAVs is one of the three characteristics used to select the CH. The AvgD number represents the average of the distances between UAVs and their single-hob adjacent UAVs, which can be represented by:

$$\text{AvgNBDist}_i = \frac{\sum_{j=1}^{NB_i} \text{dist}\left(i, nb_j\right)}{NB_i} \tag{49}$$

where dist $\left(i, nb_j\right)$ denotes the distance between the UAV and its jth neighbour.

The ideal path for inter-cluster UAV communication is selected using the Quantum Ant Lion Optimization (QALO)-based MRP algorithm.

The MRP algorithm's purpose is to minimise both latency and power consumption. The frequency of UAV visits determines the delay or power usage. As a result, it can be characterised using Equation (51):

$$minf\ (L) = \sum_{l=1}^{n1} d_{L_i L_{i+1}} \tag{50}$$

where L signifies a node-based network, it is an NP-hard issue that the QALO algorithm can solve.

b: GRID POSITION NO CENTER SHORTEST PATH ROUTING (GPNC-SP)

The GPNC-SP aims to mitigate the nodes moving quickly with high sensitivity [62]. GPNC-SP substitutes the logical network distance for the exact ED. This protocol computes & maintains adjacency connections and topological structure automatically by utilising a sensing and updating method. It determines the shortest routing route using the Dijkstra approach.

- Additionally, the routing route is dynamically optimized by constructing a regional reconstruction strategy (RSS). Two metrics are simultaneously used to explain the range of the optional logical grid width; these are the elective communication zone percentage and the sensitivity to the size of the logical grid (Sg). The GPNC-SP routing protocol attempts to improve calculation speed, connection stability, computational complexity, and network overhead considerably.

GPNC-SP is a 2-D logical network-based partitioning algorithm. Each network is defined by the coordinates of a GwGw square (x, y). The protocol has two nodes, I and j, that are positioned in grids A (a,b) and B, respectively (c, d). Grids A and B have coordinates marked by (a,b) and (c,d), respectively. The network distance between I and j is calculated using Equation (52):

$$D_{ij}^{G} = |AB|^{G} = \left[\sqrt{(|a-c|+1)^2 + (|b-d|+1)^2}\right] \tag{51}$$

GPNC-SP routing obtains the location of each node using a neighbour database. Nodes move after a predetermined period of an interval; each node acquires updated location information by using a GPS tracking device and thus accurately updates the grid location. The partition and grid size are determined using Equation (53):

$$W^{G} = \left|\frac{W}{G_w}\right| \quad \text{and } H^{G} = \left|\frac{H}{H_w}\right| \tag{52}$$

In the logical network space, W^G and H^G denote the length (H) and width (W) of S, respectively. The UAV j's logical grid at time t is defined as in Equation (54):

$$x_j^G(t) = \left[\frac{x_j(t)}{Gw}\right] \epsilon \left[0, W^G\right]$$
$$y_j^G(t) = \left[\frac{y_j(t)}{Gw}\right] \epsilon \left[0, H^G\right] \tag{53}$$

where $x_j^G(t)$ and $y_j^G(t)$ denote the UAV j's grid locations at time t. The suggested methodology is distinct from the standard grid technique. It necessitates a more compact logical grid to split the UAV node's mission and substitute the relative grid location for the geographical position when a link is updated owing to the UAV node's rapid mobility.

Discussion and Analysis: To end consideration of the deterministic clustering based CBRPs, Table (3) compares the performance indices used to evaluate their methods, number of nodes, competitive strengths, weaknesses, potential application, and possible future improvements. The table is divided into weight-based methods, fuzzy-based methods, heuristic-based methods, and compound. The weakness of the methods in general are related to the safe-distance to avoid collision, scalability, capability to modify the altitude, and overhead.

IV. COMPARISON OF CLUSTER-BASED ROUTING

This section describes the unique aspects of current CBRPs in Table (4). For each of the 21 studied protocols, the different innovative features for UAV networks are stated. According to findings, the CBRPs such as HSCS, BIL&BIC, CRSF, EMASS, TOPSIS, and GEOUAV have better performances as compared to BICSF, SOCS, EALC, URP, BIMPC, IMRL, ANTHOCNET, and BEEADHOC in terms of highly dynamic, energy-restricted and communication and cooperation for UAV networks. Moreover, bio-inspired routing protocols and hybrid routing protocols outperformed the other routing protocols.

This review includes two critical comparative investigations. In Table (5), all the FANET CBRPs covered thus far are evaluated against one another using a variety of criteria in order to distinguish them and get a sense of which routing protocol should be used in a particular context. Table (6) examines and statistically discusses the various simulation tools utilised as a verification approach. From our study, UAV networks are prone to fast mobility and topological change. A weight-based clustering strategy is critical for cluster-based routing. Cluster formation, including CH selection, requires consideration of several variables, including the UAV's energy state, buffer size, location, and velocity. By electing a suitable CH, the packet delivery ratio and the network's lifetime can be increased while lowering delay.

V. OPEN RESEARCH ISSUES AND FUTURE CHALLENGES

This review discusses a range of CBRPs for FANET that fall under various routing mechanisms, each of which employs a unique technique for routing data among flying nodes. The most recent studies were summarized; the characteristics of each protocol group were described. Numerous shortcomings have been identified during an in-depth examination of these routing algorithms that degrade the protocols' performance as their communication context varies. Routing protocols for UAVs are still in development. The following are the main problems for UAV networks: frequent connection failures, cluster building time, cluster lifetime, packet losses, throughput limitations, height routing overhead, limited bandwidth, & triggered modifications of the routing tables; these issues must be resolved to construct a CBRP for

TABLE 3. Comparison of cluster-based deterministic clustering.

Protocol	Ref	Year	Method	Strength	Weakness	Potential application	Number of nodes	Possible future improvements
				Weight Based				
EALC	[55]	2018	It aims to solve wasteful flight times and to route	Increases the lifetime and latency of UAVs	The algorithm's clustering approach is based on the passive distance assessment to pick CHs. This distance does not account for the needed safety grade between nodes to reduce the chance of a collision and maintain network stability.	maybe used to communicate amongst UAVs in a peer-to-peer manner	20 to 60 UAVs	It may be feasible to do effective routing with very high mobility nodes in the future.
DBSCAN	[56]	2017	Multiple target tracking methods for cooperative UAVs that is scalable.	The UAV identifies the cluster and retrieves the CM's location and velocity.	UAVs maintain a constant height of around 100 metres above the ground.	It can be used to detect rapidly moving targets in vehicular networks and objects in UAV-assisted target tracking systems.	number of UAVs is small	To solve communication capacity constraints and concerns about sporadic communication in the future.
				Fuzzy Based				
IMRL	[57]	2018	Used to route data based on location in places where GPS is unavailable or challenging to get.	Extends the lifetime of the network and improves the localisation accuracy	Considers only UAVs with limited mobility; control packet loss results in low localisation accuracy.	ideal for dynamic communications in space and on the ground	50 UAVs	IMRL routing is intended for use exclusively in an outside environment. In the future, the IMRL can be used in interior environments with numerous reflections and multipath padding.
GEOUAVs	[58]	2019	Managing wildfires, particularly in difficult-to-reach areas	Providing data to a specific group of mobile UAVs based on their geographical position in order to control an active fire	are harmed by the lack of dependability and scalability	intended to transmit time-sensitive short packets that may be used to manage an active fire while considering the dynamic nature of the fire. changing topology and reliability	10 to 100 UAVs	It intend to enhance GeoUAVs by incorporating more parameters to increase reliability and scalability and by implementing a recovery technique.
				Heuristic Based				
SDN-FANET	[59]	2019	ensures the delivery of UAV management and control signals while minimising network overhead.	Enhances control message transfer by utilising less network capacity.	Centralised clustering constraints the network's longevity, stability, and security.	Collaboration between several UAVs in order to construct a FANET	34 UAVs	It intend to investigate more dynamic and diverse situations, including various data source nodes, including cars, ground users, and others.
TDR	[60]	2017	seeks to meet the unique quality of service needs of delay-sensitive and reliability-critical services.	Considers various quality of service needs and enhances THR, PDR, and delay	High overhead and inefficient energy use	can be employed in time-critical applications.	40 UAVs	In the future, it may be strengthened by lowering the cost of traffic flow to minimise overhead and energy consumption and restricting the selfishness of malicious nodes to prevent node forwarding failures.

TABLE 3. *(Continued.)* **Comparison of cluster-based deterministic clustering.**

				Compound				
EENFC-MRP	[61]	2021	Develops a Low-Energy Neuro-Fuzzy Cluster-based Topology Construction Method	network lifetime, throughput, energy efficiency, and average latency were all improved.	Routing overhead grew as node density increased, assisting in avoiding collisions and contentions and therefore boosting node density.	Select the most efficient clustering procedure to transmit data with the least amount of energy dissipation possible for UAVs.	10 to 100 UAVs	Data aggregation and network slicing methods may optimise network resource management.
GPNC-SP	[62]	2017	replaces the original Euclidean distance with the logical grid distance in order to lessen the sensitivity of fast-moving nodes	Network overhead is reduced by enabling nodes to broadcast only their location information.	Grids with a greater width necessitated more great route updates, and the protocol found paths with a greater communication distance.	Ideal for highly fast-moving and dynamic unmanned aerial vehicle (UAV) applications.	35 UAVs	The fundamental mission of UAVs is in three-dimensional space.

TABLE 4. **Innovative features of existing CBRPs.**

Protocol	Reference	Innovative features
MLSC	[42]	Mobility and Location-aware Stable Clustering
URP	[43]	Dynamic clustering approach
BICSF	[44]	A bio-inspired combination of glowworm swarm optimisation (GSO) and krill herd (KH)
SOCS	[45]	Self-organisation-based clustering approach
HSCS	[46]	A bio-inspired combination of glowworm swarm optimisation (GSO) and dragonfly algorithm (DA).
BIL, BIC	[47]	A bio-inspired localisation and clustering approach
ERSUAV	[48]	A bio-inspired routing based on an ant-colony algorithm
IABC	[49]	Improved Artificial Bee Colony Optimization approach
CRSF	[50]	An intelligent cluster routing approach
SECRIP	[51]	A secure and reliable routing protocol approach
BIMPC	[52]	A bio-inspired mobility prediction clustering approach
EMASS	[53]	An Energy and Mobility-aware Stable and Safe Clustering approach
AHP-TOPSIS	[54]	Analytic hierarchy process-technique for order of preference by similarity to an ideal solution
EALC	[55]	A bio-inspired combination of ant colony optimisation and grey wolf optimisation-based clustering approach
DBSCAN	[56]	Distributed and density-based clustering approach; a location-aided cluster-based routing.
IMRL	[57]	Fuzzy logic-based centralised clustering approach
GEOUAVS	[58]	Geocast routing protocol approach
SDN-FANET	[59]	Software-Defined Networking approach
TDR	[60]	A centralised traffic-differentiated cluster-based routing
EENFC-MRP	[61]	An Energy-Efficient Neuro-Fuzzy Cluster-based Topology Construction with Metaheuristic Route Planning approach
GPNC-SP	[62]	Logical grid position-based routing approach

UAV networks. The clustering routing strategies provided in this study aim to improve cluster formation by utilising either energy information or estimated node locations. According to our findings, we found that CBRPs such as HSCS, BIL&BIC, CRSF, EMASS, TOPSIS, and GEOUAV have better performance compared to BICSF, SOCS, EALC, URP, BIMPC, IMRL, ANTHOCNET, and BEEADHOC in terms of highly dynamic, energy-restricted and communication and cooperation for UAV networks. Moreover, bio-inspired routing protocols and hybrid routing protocols outperformed the other routing protocols. While the protocols have shown considerable success in data delivery in clustered FANETs, they have also demonstrated some shortcomings. These issues and challenges are focused on routing scalability, cluster-based routing complexity reduction, energy-efficient routing, routing latency minimisation, load distribution between nodes, and routing security enhancement. As a result, there is a need to create a more appropriate mobility model for UAV nodes to avoid these concerns. Table (7) described the eight promising future study directions that deserve attention in this regard.

A. **Dynamic Topology Control:** Mobility that is dynamic and constantly changing link quality owing to changes in UAV scheduling and node distances in FANET, resulting in link interruption and topology changes. Node density is the number of available nodes in a given geographical unit. The UAVs are designed to fly

TABLE 5. Comparison of CBRPs.

Protocol	Year	Clustering Strategy	Intra-cluster comm	Inter-cluster comm	CH mobility	CH type	CH role	CH election	Protocol Complexity	Scalability	Topology
MLSC	2020	Distributed	k-hop	k-hop	Stationary	Heterogeneous	Aggregation	Dynamic	High	Yes	hierarchical
URP	2018	Dynamic	1-hop	k-hop	Stationary	Heterogeneous	Relay	Dynamic	Moderate	___	hierarchical
BICSF	2019	Dynamic	K-hop	K-hop	Movable	Heterogeneous	Relay	Weighted Metrics-based	High	Yes	Grid
SOCS	2019	Dynamic	K-hop	K-hop	Stationary	Heterogeneous	Relay	Weighted Metrics-based	Moderate	Yes	Grid
HSCS	2019	Dynamic	1-hop	K-hop	Stationary	Heterogeneous	Relay	Weighted Metrics-based	High	___	Grid
BIL,BIC	2021	Distributed	1-hop	k-hop	Stationary	Heterogeneous	Relay	Weighted Metrics-based	High	Yes	Ad hoc
ERSUAV	2016	Centralised	k-hop	k-hop	Stationary	Heterogeneous	Aggregation	Deterministic	Moderate	___	hierarchical
IABC	2020	Distributed	1-hop	k-hop	Movable	Heterogeneous	Aggregation	probabilistic	Moderate	Yes	hierarchical
CRSF	2021	Dynamic	k-hop	1-hop	Movable	Heterogeneous	Relay	Weighted Metrics-based	High	Yes	Grid
SECRIP	2020	Dynamic	1-hop	k-hop	Stationary	Heterogeneous	Aggregation	probabilistic	Moderate	___	Ad hoc
BIMPC	2016	Distributed	1-hop	k-hop	Movable	Heterogeneous	Aggregation	Hybrid	High	Yes	Ad hoc
EMASS	2021	Centralised	K-hop	K-hop	Movable	Heterogeneous	Relay	Weighted Metrics-based	High	Yes	hierarchical
AHP-TOPSIS	2021	Distributed	1-hop	1-hop	Stationary	Heterogeneous	Relay	probabilistic	High	Yes	hierarchical
EALC	2018	K-means	K-hop	K-hop	Movable	Heterogeneous	Relay	Weighted Metrics-based	Moderate	___	Grid
DBSCAN	2017	Distributed	1-hop	K-hop	Movable	Heterogeneous	Aggregation	Weighted Metrics-based	High	Yes	hierarchical
IMRL	2018	Centralised	1-hop	K-hop	Movable	Heterogeneous	Relay	Weighted Metrics-based	Moderate	Yes	hierarchical
GEOUAVS	2019	Dynamic	1-hop	K-hop	Movable	Heterogeneous	Aggregation	Dynamic	Moderate	Yes	hierarchical
SDN-FANET	2019	Centralised	1-hop	K-hop	Stationary	Heterogeneous	Aggregation	Weighted Metrics-based	Moderate	Yes	hierarchical
TDR	2017	Centralised	K-hop	1-hop	Movable	Heterogeneous	Relay	Weighted Metrics-based	High	Yes	hierarchical
EENFC-MRP	2021	Dynamic	K-hop	K-hop	Movable	Heterogeneous	Aggregation	Compound	Moderate	Yes	Ad hoc
GPNC-SP	2017	Centralised	K-hop	K-hop	Movable	Heterogeneous	Aggregation	Compound	High	Yes	Grid

at a high speed and for the fact that the sky is far from the ground, the distance between nodes is very lengthy, resulting in a relatively sparse node density.

B. **Energy constraint:** Energy-efficient routing is a critical component of network lifetime. Generally, UAVs use batteries to power their operations and flight time. Increases in battery capacity may affect the performance of UAVs beyond a certain point due to the energy-to-weight ratio. The UAVs create an unwanted neighbourhood by exchanging numerous greeting messages inside the group, resulting in energy waste. As a result, one of the primary issues facing FANETs is effective battery and charge management.

C. **Multimedia Communication Routing:** UAVs are frequently employed in various industries, including aerial photography, agriculture, and expedited delivery. However, as people's needs grow, visual information will no longer suffice. Real-time video and audio data transfer has developed as a prominent application trend.

TABLE 6. (Continued.) Comparison of CBRPs.

Protocol	Packet delivery ratio	Cluster building time	Cluster lifetime	Energy efficiency	End-to-end delay	Overhead	Throughput	Density	Simulation tool
MLSC	✓				✓	✓			MATLAB
URP				✓			✓		OMNET++
BICSF	✓	✓	✓	✓					MATLAB
SOCS	✓	✓	✓	✓					MATLAB
HSCS	✓	✓	✓	✓				✓	MATLAB
BIL,BIC		✓	✓	✓	✓				MATLAB
ERSUAV				✓	✓				C++
IABC	✓			✓	✓		✓		NS-3
CRSF	✓	✓	✓	✓			✓		MATLAB
SECRIP	✓				✓	✓		✓	NS2
BIMPC	✓	✓			✓	✓			MATLAB
EMASS	✓	✓	✓	✓	✓			✓	MATLAB
AHP-TOPSIS				✓	✓				OMNET++
EALC		✓	✓	✓					MATLAB
DBSCAN		✓							MATLAB
IMRL			✓	✓					MATLAB
GEOUAVS	✓				✓		✓		NS-3
SDN-FANET	✓			✓	✓	✓			OMNET++
TDR	✓				✓		✓		___
EENFC-MRP			✓	✓	✓		✓		MATLAB
GPNC-SP			✓			✓		✓	MATLAB

TABLE 7. Research issues and directions for FANET.

Issues	Research problem	Research direction
Dynamic Topology Control	A change in topology can result in the formation of an asymmetric link.	Appropriate handling technique for such a highly dynamic topology.
Energy constraint	The constrained energy level will affect the cruising duration and range of UAVs.	Protocols that drain less energy and a shift toward a green energy concept.
Multimedia (video dissemination) routing	FANET requires the transmission of several video streams.	Developing a routing system with a higher percentage of leading transmissions, a smaller lag, and less distortion.
Efficient path planning	UAVs' high altitude and rapid flight speed may cause them to divert from the path and collide with obstacles.	Trajectory optimisation method.
UAVs Communication	The distance between nodes is more significant than in other ad-hoc networks.	Protocols require time to discover routes; as a result, communication latency increases.
Security	UAVs may be hijacked, their privacy compromised, or an adversary may damage them.	Node's privacy protection; Anti-interference routing protocol.
Ensuring QoS	Ensuring low latency, determining the trajectory path to provide service, synchronisation among UAVs.	The chain mobility model combines the Manhattan Grid and Random waypoint models.
Position	Data delivery to a specific set of mobility drones based on their geographic position.	Predicting the position of a UAV in the future for route selection and maintenance.

To guarantee that multimedia video information is sent efficiently, with a low frame loss rate, and with short latency, we must pay particular attention to the routing protocol's architecture to meet the user's expectation of service quality.

D. **Efficient path planning:** Although various research ideas on UAV path planning have been published, numerous difficulties and issues persist. As a result, air-to-ground UAV network communication requires efficient path design.

E. **UAVs Communication:** UAVs can travel at a high speed, which complicates communication with other UAVs. Additionally, in contrast to other ad-hoc networks, the distance between nodes is more significant in this network. Different transmission ranges and densities have different effects on the FANET environment.

F. **Security Issues:** Due to FANET's unique characteristics, it has been challenging to upgrade its defences against evolving security threats. On the other hand, FANET must be addressed. The malicious nodes might seize control of the UAV and collect sensitive data from it.

G. **Ensuring QoS:** There are also certain quality of service (QoS) issues to handle, such as maintaining low latency, calculating the optimal trajectory path for service delivery, synchronisation among UAVs, and protection against jammer assaults.

H. **Node location:** FANET demands more accurate and real-time location data due to the nodes' rapid speed and the multi-UAV network's dynamic topology. FANET, in comparison to other forms of ad hoc networks, has very dynamic attributes due to some basic functional differences. Due to these features, FANET is considered a highly independent ad hoc network and has attracted much research interest.

VI. CONCLUSION

In this paper, we presented an overview of clustering-based routing protocols. Routing in FANETs seeks to improve route stability, survivability, distribute payload among UAVs, network coverage, cooperation, and collaboration to maintain the ability of the system in handling a higher number of UAVs while tackling high dynamism, cost-prohibitive, and residual energy. When it comes to FANETs, routing is accomplished by a collaborative effort amongst network operators. Several routing protocols have been proposed for UAV networks over the last decades. A comparative study of 21 CBRPs for UAV networks was presented in this work. Additionally, this review has compared 21 CBRPs based on their challenges, characteristics, outstanding features, topology, scalability, clustering strategy, CH selection, routing metrics, and performance measures. Overall, this study will assist researchers and engineers in selecting the most effective and dependable cluster-based routing algorithms for FANET deployment.

According to the findings of the study, each routing protocol seems to have its own set of strengths and weaknesses and their applicability for specific applications, methods, number of nodes, salient features, and characteristics. There are eight promising directions: dynamic topology, control energy constraint, multimedia communication routing, efficient path planning, UAVs communication, security issues, ensuring QoS, and node location.

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