Cluster selection for load balancing in flying *ad hoc* networks using an optimal low-energy adaptive clustering hierarchy based on optimization approach

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Abstract

Purpose – Flying *ad hoc* networks (FANETs) have a major effect in various areas such as civil projects and smart cities. The facilities of installation and low cost of unmanned aerial vehicles (UAVs) have created a new challenge for researchers. Cluster head (CH) selection and load balancing between the CH are the most critical issues in the FANETs. For CH selection and load balancing in FANETs, this study used efficient clustering to address both problems and overcome these challenges. This paper aims to propose a novel CH selection and load balancing scheme to solve the low energy consumption and low latency in the FANET system.

Design/methodology/approach – This paper tried to select the CH and load balancing with the help of low-energy adaptive clustering hierarchy (LEACH) algorithm and bat algorithm (BA). Load balancing and CH selection are NP-hard problems, so the metaheuristic algorithms can be the best answer for these issues. In the LEACH algorithm, UAVs randomly generate numerical, and these numbers are sorted according to those values. To use the load balancing, the threshold of CH has to be considered; if the threshold is less than 0.7, the BA starts working and begins to find new CH according to the emitted pulses.

Findings – The proposed method compares with three algorithms, called bio-inspired clustering scheme FANETs, Grey wolf optimization and ant colony optimization in the NS3 simulator. The proposed algorithm has a good efficiency with respect to the network lifetime, energy consumption and cluster building time.

Originality/value – This study aims to extend the UAV group control concepts to include CH selection and load balancing to improve UAV energy consumption and low latency.

Keywords *Ad hoc* network, FANET, Cluster head selection, Load balancing, Optimization algorithm, Fly *ad hoc* network

Paper type Research paper

1. Introduction

Fly *ad hoc* networks (FANETs) can be described as a new form of mobile *ad hoc* network (MANET) in which the nodes are defined as unmanned aerial vehicles (UAVs) (Campanile *et al.*, 2013). The UAVs' communication must rely on the *ad hoc* network between the UAVs system (Mukherjee *et al.*, 2018). Several benefits of FANETs can be mentioned, like searching in high-risk areas, destruction operations, border surveillance, fire management, surveillance, accident measurement, remote sensing and traffic monitoring (Sang *et al.*, 2020). Single UAVs have been used for many years, but, nevertheless, there are many benefits in using a small UAV group instead of expanding and launching one single large one (Cevik *et al.*, 2013). One of the most prominent problems is their communication in small groups. Compared with UAVs size, the small size is proven to be particularly beneficial in civilian applications due to various advantages: the purchase price and maintenance and repair expenses are lower (Siebert and Teizer, 2014). Furthermore, they are simpler to construct and run.

Multicluster FANETs can communicate across a broader region, while single cluster networks cover only a small area (Wheeb *et al.*, 2022). This type of topology can bring lower costs and optimize the overall network performance (Nor and Mohamed, 2019). The limited energy of UAVs in large networks is an important issue for the researchers, so transmitting the data directly to base station (BS) leads to

network inefficiency (Brik *et al.*, 2020). In such scenarios, the whole network is divided into several clusters, each cluster having a cluster head (CH) (Sefati and Tabrizi, 2021a, 2021b). These CHs are selected from the members of the UAVs, and other remaining members are associated with it. The UAV sends their data to a local CH in each cluster, then this CH processes and aggregates the data from all the other UAVs and sends it to the BS (Okcu and Soyturk, 2014). Clustering in FANET involves efficient grouping of UAVs into separate clusters; each UAV belongs to only one group and communicates only with its own CH (Wheeb *et al.*, 2022). The CH can communicate directly with the BS or multistage through other intermediate CH-UAVs with the BS.

In multicluster FANET context, this paper offers a unique technique that uses the IEEE 802.15.4 MAC layer protocol in both beacons enabled and beaconless modes for UAV-to-UAV communication (Molisch *et al.*, 2004). Single- and multicluster configurations have both been examined. Even though IEEE 802.15.4 has a low data rate protocol (Sefati *et al.*, 2021) (up to 250 kbps at 2.4 GHz), we propose the use of 802.15.4 MAC protocol for inter- and intracluster communication in multicluster FANETs. 802.15.4 may be used inside the cluster to produce better outcomes and decrease complexity and bandwidth occupancy in both single- and multicluster situations. The proposed method in this paper use the low-energy adaptive clustering hierarchy (LEACH) algorithm and bat algorithm (BA). In our approach, the CH is selected first, according to the LEACH algorithm, and then the most suitable CH concerning load balancing is found, according to the BA. To choose a CH, all UAVs randomly generated a number based on the LEACH algorithm; therefore, to select the first CH, the LEACH algorithm uses the lowest number generated between all nodes. But, in time, the CH energy and performances decrease, therefore we must determine a new CH according to threshold. If the threshold is lower than 0.7, the BA starts to work and finds a new CH according to the transmitted pulses. In summary, the main contributions of our work in this article are:

- achieving the best deployment in FANET by optimization of the BA and LEACH algorithm criteria;
- increasing the network lifetime, reducing the latency and decrease the duration of CH selection using by LEACH; and
- establishing a load balancing among the UAVs present in a FANET and reducing energy consumption using BA.

The remainder of the paper is laid out as follows: Section 2 is the literature review; Section 3 introduces and elaborates the proposed algorithm; Section 4 reports and discusses the experimental data sets and simulation results. Finally, Section 5 concludes the study and gives directions for further research.

2. Literature review

CH selection will be defined as a method of sending data between two UAVs that are not within the transmission range of each other. This will include defining the rules necessary to create the route, sending the data packets, maintaining the path, retrieving the routes when necessary and choosing the best CH. Load balancing and CH selection will be considered an essential part of FANET communication. CH selection and load balancing protocols in FANET generally assume that the UAVs can be achieved using satellite access technologies through the global positioning system (GPS) (Basan *et al.*, 2022). Depending on the type of topology, as well as on the scenario considered, different criteria have been established to find the appropriate path to be used in mobile networks (Rodríguez-Sanz *et al.*, 2021). This section briefly reviews several papers that have dealt with the CH selection and load balancing in the FANET.

Khan *et al.* (2019a, 2019b) to ensure optimum energy utilization and reliable routing, presented a bioinspired clustering approach based on swarm optimization and a krill herd strategy to partition network nodes into multiple clusters. The choice of CHs in this concept is based on the residual energy levels of nodes. Further they propose efficient cluster management algorithm using motion of UAVs to align themselves with the CH in a cluster. The dynamics networks are taken into account by aligning the cluster nodes in a consistent manner based on insect social behavior, such as mobility and changing. They also use the genetic algorithm (GA) for operations like mutation and crossover to find the UAV's best location. They offer a path discovery function for efficient communication based on the weighted residual energy, number of neighbors and distance between the UAVs. The proposed method achieves better results in cluster building time, energy consumption, cluster lifetime and probability of successful delivery. However, this proposed method does not consider load balancing and is not tested in the real environment.

Bhandari *et al.* (2020) proposed a mobile and location-aware clustering system that calculates transmission efficiency by taking into account coverage probability and cluster size. In this algorithm, the number of CHs is determined using a K-mean clustering technique, with cluster maintenance based on the relative speed and distance of the UAVs. However, this strategy causes buffer overflows and significant energy and bandwidth costs, making the protocol unsuitable for time-critical application situations that demand continuous task execution. In this proposed method a self-organizing-based clustering has been developed for MANET to adapt the network topological changes, with the goal of aggregating node mobility based on zones to improve network growth. However, this method has a low complexity and low cluster building time.

Zang and Zang (2011) suggested the mobility prediction clustering algorithm depend on the characteristics of the UAVs. The prediction clustering algorithm and link expiration time are applied in the clustering process for solving the difficulty of the high mobility of UAVs. In this proposed method, each normal node sends the own data to CH, such as unique ID, status of the state, node's weight, location, speed and neighbor number nodes. Furthermore, the authors use the GPS that offers location and mobility information of the UAVs to compute the link expiration time among two nodes. The authors used the NS2 environment to simulate the network. The resulting outcomes indicated that this method could decrease the encoding time and increase duration of CHs; nevertheless, the mentioned technique has a low reliability and availability.

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Gankhuyag *et al.* (2017) proposed the optimized link-state routing (OLSR) algorithm. The main idea is to use the GPS information to aid in the routing process and CH selection in highly dynamic conditions. Then, they minimize the amount of control traffic through selected nodes. Using this strategy, each node maintains the configuration information by intermittently exchanging link-by-mode messages. The OLSR algorithm reduces control messages and updates the CH using a multipoint response (MPR) strategy for updating and configuring each node in the network and selecting a set of neighboring nodes to resend packets. To select CH by MPR, each node alternately publishes a list of neighbors using the HELLO message. Each node can select a header from a list of suitable nodes and close neighbors. This method has a lower energy consumption in terms of network life than the other compared algorithms, but it suffers from low accuracy.

Wang and Bao (2007) proposed a technique that combines the weighted clustering algorithm (WCA) algorithm and the GA. In their approach, the authors attempt to consider criteria such as the spatial position of the nodes to select a CH. The selected CH has the highest energy and the largest capacity to exchange information over large areas. The selection of a CH is spatially responsible for the GA, and the load balancing of the appropriate node for CH is the responsibility of the WCA algorithm. GAs can find the best spatial location due to their simplicity, comprehensiveness, stability and parallel search. Due to the inherent characteristics of mobile networks, the issue of obtaining an energy-aware routing is essential. On the other hand, optimization algorithms, especially GA, have a high quality in estimating costs; therefore, in a repetitive process, it tries to achieve better choices and lower costs than in the previous steps. This method offers good results with respect to position in terms of cluster construction.

Qingwen *et al.* (2015) proposed a method for load balancing and CH selection using OLSR and ad-hoc on-demand distance vector (AODV) methods. In this research, small UAVs are used to monitor traffic, energy consumption of UAVs and for routing other nodes. This paradigm addresses the deployment of numerous mini-UAVs. When compared to other forms of *ad hoc* networks, FANETs have several distinguishing characteristics. Furthermore, the authors present several interesting problems addressed by the scientific community. The protocol must be able to create an effective route between UAVs in real time as the topology changes. The simulated results based on NS2 proved that this algorithm has a good performance in low latency and packet delivery rate (PDR); however, the authors did not tackle the issues related to energy consumption.

De Rango *et al.* (2019) proposed a method for the agriculture industry, in which they used the flight of a multirotor UAVs, which is a type of unmanned robot. This paper proposes a bio-coordination protocol inspired for the management of UAV in agriculture. In this scenario, the farmers need to be cautious about parasites and sudden climate change that may destroy crops or reduce crop quality. The authors used the link state advertisement (LSA) protocol for routing among neighbors' packet data and sharing information in this research. Each router creates a database for an area that contains the latest received LSA. An essential part is, indeed, the sufficient management and coordination of these new devices to plan particular approaches capable to

support adequately to the agriculture operators. In this paper, the authors simulated the proposed system based on NS3, and the results show that this algorithm has a good performance concerning low lost packets and low energy consumption; however, the authors did not handle issues related to load balancing.

Soundararajan and Bhuvaneswaran (2012) introduced a new technique for avoiding congestion in network communication flows, called multipath load balancing and rate based congestion control, which is based on a rate control mechanism. In *ad hoc* networks, multipath routing may balance the load better than single-path ones, decreasing congestion by splitting the traffic into many pathways. They developed a system based on adaptive rate control. The destination node replicates the estimated rate from the intermediate nodes and forwards the feedback to the sender through an acknowledgment packet. This approach is superior to traditional congestion control as the transmitting rate changes based on the expected rate. This method obtained good performances with respect to low latency and low cost; however, this algorithm suffers from high energy consumption. Table 1 shows the advantages and disadvantages of the proposed methods in related work section.

3. Problem statement

The FANET system combines identification, communication, networking and cloud computing technologies in large-scale monitoring and review environment (Sharma *et al.*, 2022). The UAVs form a network where each one can communicate with the others. Energy consumption is one of the essential features for FANET to extend the life of the network systems. Energy storage strategies should be proposed to achieve acceptable energy consumption and improve network lifetime for UAV systems (Sefati and Tabrizi, 2021a, 2021b). FANET systems require a strong network infrastructure and a proper routing protocol. The battery power in an UAV is limited, thus draining the UAV battery may disrupt the entire network or the entire mission. Cluster-based techniques are one of the approaches to reduce energy consumption in the network. In a FANET network, the CH is responsible for collecting UAVs data, then processes it and sends it to the BS. The non-CH UAVs cannot send data directly to the BS. One of the essential problems of this clustering method is related to the load balancing (Sefati *et al.*, 2022). In this model, more energy consumption may cause network drop, so a load balancing in the CH-UAV is necessary. In Figure 1, each cluster member sends their own data toward its own CH, then the CH prepare the information and send it to CH of region 3. Then region 3 CH, sends the data to BS. Figure 1 shows the FANET system.

3.1 Difference between ad hoc network model and challenge of these methods

Ad hoc wireless networks are classified according to their usage, on deployment, communication and mission objectives. In addition, FANET can be classified as a subset of VANET, and VANET is a subset of MANET, as shown in Figure 2. The typical features of FANET with *ad hoc* networks and the existence of several unique design challenges have become an emerging research area. This section describes in detail the difference between a FANET and an *ad hoc* wireless network.

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Table 1 Advantages and disadvantages of the proposed methods

Author name	Proposed method	Advantages		Disadvantages	
Khan *et al.* (2019a, 2019b)	Swarm optimization and a krill herd	1	Low cluster building time	1	Load balancing is not considered
		2	Probability of delivery success	2	Not tested in real environment
Bhandari *et al.* (2020)	K-mean clustering formation	1	Low complexity	1	Increase in energy consumption
		2	Low cluster building time	2	High bandwidth costs
Zang and Zang (2011)	Mobility prediction clustering algorithm (MPCA)	1	Decrease the encoding time	1	Low reliability
		2	Increase duration of cluster heads	2	Low availability
Gankhuyag *et al.* (2017)	Optimized link-state routing (OLSR)	1	Lower energy consumption	1	Low accuracy
		2	High network life time		
Wang and Bao (2007)	Weighted clustering algorithm	1	High cluster construction	1	High cost
Qingwen *et al.* (2015)	AODV	1	Low delay	1	High energy consumption
		2	Low packet delivery rate	2	Test in simulator
De Rango *et al.* (2019)	Link state advertisement (LSA)	1	Low lost packets	1	High cost
		2	Low energy consumption	2	Low load balancing
Soundararajan and Bhuvaneswaran (2012)	Multipath load balancing and rate based congestion control (MLBRBCC)	1	Low latency	1	High energy consumption
		2	Low cost		

**Figure 1** Process of FANET network
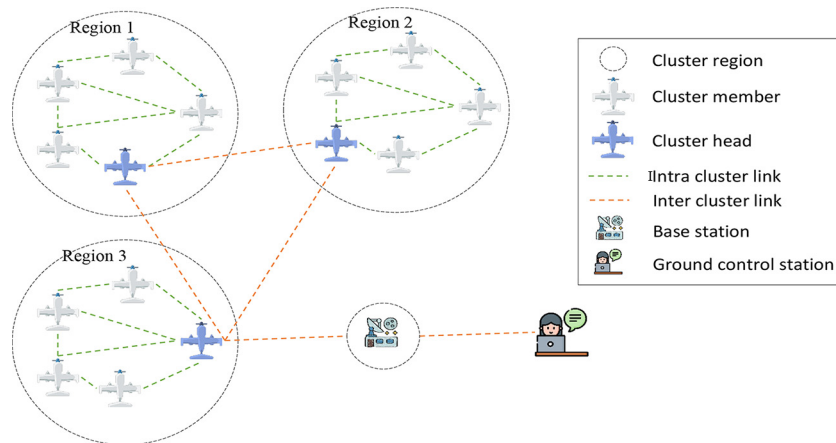
Source: Mowla *et al.* (2019)

The most notable distinction between FANET and other *ad hoc* networks is the problem of node mobility. MANET node mobility and node speed are relatively low in comparison to FANET. The degree of mobility of FANET nodes is much higher than the ones of MANET and VANET. The speed of the UAVs is between 360 and 460 km/h, which results in several communication challenges in the design (Faid *et al.*, 2022). Depending on the degree of mobility, changes in FANET topology are often more significant than the ones that occur in MANET and VANET (Nor, 2021). The failure of application platforms is unaffected by network topology in addition to the mobility of FANET nodes. When a UAV crashes, the connections in which the UAV was involved in fail, and, for that the topology must be updated. Table 2 shows the comparison of networks.

The main challenge in the FANET network is the limitation of UAVs energy resources. It is not possible to recharge the UAVs' batteries or replace them after they have entirely discharged their energy because, in many scenarios, the UAVs are used in unique and extended operations. Therefore, the goal of traditional networks is to achieve a high level of quality of service. FANET protocols should primarily focus on energy conservation to maximize the network life. Clustering is one of the critical solutions to achieve energy efficiency in the FANET.

Figure 2 Differences in *ad hoc* networks
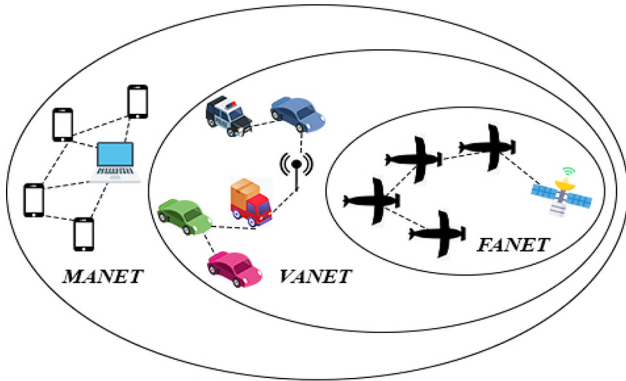
Source: Hong and Zhang (2019)

3.2 Service quality parameters

There are several service parameters that enable the evaluation of the network service quality, as follows:

PDR: This ratio between the total number of packets received at a destination and the total number of packets generated in the whole network, which shows the percentage of total packages successfully delivered. Equation (1) shows the PDR of network (Hussain *et al.*, 2020):

$$\text{Packet delivery rate} = \frac{\sum \text{No.of packets recived}}{\sum \text{No.of packets sent}} * 100\% \tag{1}$$

Network lifetime: It shows how long the network can operate successfully, meaning the time until the first node runs out of energy. Efforts should be made to extend the life of the network to extend the period of time in which data packets are transmitted to the BS. Equation (2) shows the network lifetime. In other words, break of the time in which from the beginning of the network until the death of the first node. It expresses that for how long the existing network is/was stable (Hussain *et al.*, 2021):

$$N_{Lifetime} = \begin{cases} \dfrac{1}{\sum_{i=1}^{n} w_i} (If\ n \geq 1) \\ 1\ (If\ n = 0) \end{cases} \tag{2}$$

where w_i shows the weight of every weak module, and n shows the number of weak modules.

Consumed energy: For using the UAVs in a large area, the energy can bring limitations. In UAVs, the essential parameters can be energy consumption. The following equations (3)–(6) give the total energy consumed:

$$E_t = E_C + E_F + E_S \tag{3}$$

where E_C is the energy dissipated during communication, E_F represents the energy required for flying and E_S is the energy consumed by different sensors on the UAV. The energy consumed during communication is given by Khan *et al.* (2019a, 2019b):

$$E_C = E_{TX} + E_{RX} \tag{4}$$

$$E_{TX} = E_{TRC} * K + E_A * K * D^2 \tag{5}$$

$$E_{RX} = E_{TRC} * K \tag{6}$$

where E_{TRC} is the energy dissipated while running transmitter and receiver. E_A is the energy for amplifier. K represents the bits transmitted between UAVs and D represents distance between transmitting and receiving UAVs.

Delay: Means the total time a signal needs to get from the source UAV to the target UAV across a given network. The delay is a critical element for assessing the performance of a communication network. End-to-end delays comprise processing, queuing and transmission delay of the link in a network. Equation (7) may be used to illustrate the average delay mathematically:

$$D_{End-to-end} = \sum_{t=1}^{N} (T_t + R_t + B_t + P_{rt}) \tag{7}$$

where T_t is transmission time, R_t is retransmission time, B_t is buffer time and P_{rt} is processing time.

3.3 The bat algorithm

The BA is a well-known population meta-heuristic algorithm based on nature and operates like the sound reflection behavior of bats, which inspired the design of this algorithm (Kumar *et al.*, 2016). Bats can find location based on sound and using this mechanism. They emit sound pulses and listen to the reflection that comes from colliding with objects. Therefore, bats calculate their distance from objects, and they can detect the difference between an obstacle and prey, being able to hunt

Table 2 Difference of the *ad hoc* network (Hong and Zhang, 2019)

Parameters	MANET	VANET	FANET
Node mobility	Low	High	Very high
Mobility model	Random	Regular	Regular mobility models are used for preset paths.
Node density	Low	High	Very low
Topology change	Slow	Fast	Fast
Radio propagation model	Close to ground	Close to ground	High above the ground
Power consumption and network lifetime	Energy efficient	Not needed	Energy efficiency for mini-UAVs, but needed for small UAVs
Computational power	Limited	High	High

even in the dark (Kalko and Schnitzler, 1993). The BA is based on the following rules.

A) All bats can estimate the distance and detect the difference between prey and fixed obstacles by using echo tracking.

B) Each bat has a position vector, a velocity vector and a frequency vector, which are updated during the algorithm iterations, modeled in equations (8)–(10). Each bat has a speed of V_i^t and a location of X_i^t with repetition t and frequency F_i. Among all bats, there is only one optimal solution X_*, therefore, the three rules mentioned in the previous section can be calculated using the following formulas:

$$F_i = F_{\min} + (F_{\max} - F_{\min})\beta, \quad \text{where} \quad 0 \le \beta \le 1 \tag{8}$$

$$V_i^t = V_i^{t-1}(X_i^{t-1} - X_*)f_i \tag{9}$$
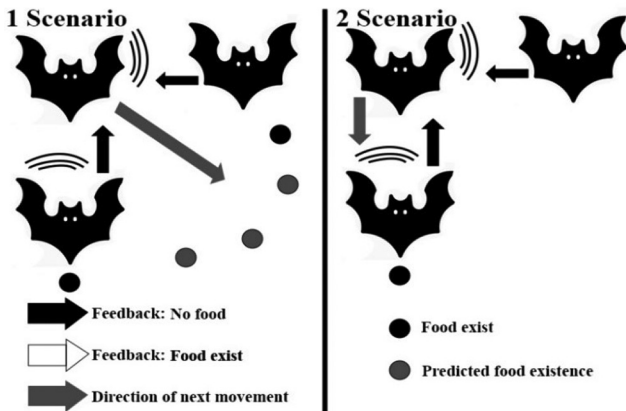
$$X_i^t = X_i^{t-1} + V_i^t \tag{10}$$

where β is a random number in the range of 0 and 1. As mentioned earlier, we can either use wavelengths or frequencies for implementation, we will use $F_{min} = 0$ and $F_{max} = 1$, depending on the domain size of the problem of interest. Initially, each bat is randomly assigned a frequency which is drawn uniformly from $[F_{min}, F_{max}]$. Figure 3 fully suggests how the BA works, illustrating two flight scenarios: the first one is once the food is confirmed to exist around the two selected bats, and the second scenario just, only one food has existed.

3.4 Threshold setting in cluster head

The suggested algorithm aims to extend the life of FANETs by load balancing the CH correctly and promptly using the threshold. The proposed method is using a threshold, various clustering techniques in each round and a multihop approach for data transmission to the BS. The threshold has several general characteristics:

- each CH threshold is reviewed after the LEACH algorithm selects the optimal CH; and
- the size of the clusters is determined based on the distance to the BS.

Figure 3 How the bat algorithm works

Feedback: No food

Feedback: Food exist

Direction of next movement

Food exist

Predicted food existence

Source: Chakri *et al.* (2018)

As a result, the cluster size increase as the node moves away from the BS. The d_0 distance is used to assess whether the transmission model is free space or multipath propagation. If the distance between the sender and recipient nodes is smaller than d_0, the transmission model is free space, while if the distance is larger than d_0 the multipath propagation model is used. If E_{elec} is the amount of energy used to transfer each bit of data from the sender to the receiver, the total energy spent to deliver a L-bit data packet from a sender to a receiver who are within d distance of each other (Mazinani *et al.*, 2019):

$$E_{tx}(L,d) = \begin{cases} L * E_{elec} + L * \varepsilon_{fs} * d^2 & if \quad d < d_0 \\ L * E_{elec} + L * \varepsilon_{fmp} * d^4 & if \quad d > d_0 \end{cases} \tag{11}$$

where ε_{fs}, measured in Joules/(bit m^2), is the amount of energy used to transmit the data packet, while ε_{fmp}, measured in Joules/(bit m^4), is the energy consumed due to multipath propagation:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{fmp}}} \tag{12}$$

As stated above, one of the goals of the proposed method is to reduce the number of delivered messages while also increasing the networks' lifespan by lowering cluster creation time. Several metrics are important for this application, namely:

The residual energy: Because the CH's tasks are so important in each cluster, the node with the most remaining energy has a greater chance of becoming the CH. Equation (13) shows the residual energy of UAVs. Following data transmission, each node in the network expends a certain amount of energy, varying from node to node (Sun *et al.*, 2021):

$$P_h = \sqrt{\frac{(m_u g)^3}{2\pi r^2 n_w p_a}} \tag{13}$$

where m_u is the mass of UAV, g is gravitational acceleration, r_w and n_w are the radius and number of wings, respectively, and p_a represents air density. The UAV flight power p_f can be calculated as follows:

$$P_f = (P_{\max} - P_h)\frac{v_u(t)}{v_{\max}} \tag{14}$$

where v_{max} represents the UAV maximum flight speed, $v_u(t)$ is the UAV flight speed during time slot t and P_{max} is the UAV flight power when the speed is v_{max}. According to equations (13) and (14) the residual energy by the UAV for hovering and flying can be calculated as below:

$$\begin{cases} E_h = P_h t_h \\ E_f = \int_0^{t_f} p_f d_t \end{cases} \tag{15}$$

where E_h and E_f indicate energy consumption for hovering and flight, respectively, t_h and t_f represent the time for hovering and flying, respectively.

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Node stability: The goal of choosing this parameter is to find nodes close to CH. This distance is known as the trust distance D_{trust}. This distance is described in $[d_{min}, d_{max}]$, where $0 \leq d_{min} < d_{max}$, $d_{min} < d_{max} \leq$ R, and R represents the communication radius of the nodes. If the distance among UAV and CH is less than d_{min}, they are extremely near to each other. In contrast, if the distance between UAV and CH is greater than d_{max}, the distance is very high. This process is illustrated in Figure 4. As shown in this figure 4, the first CH is located in center. Whereas, $node_1$ and $node_3$ are outside this range. As a result, $node_2$ is the best node that can be selected as the CH. The node stability is calculated based on equation (16) (Sefati and Navimipour, 2021):

$$Stability = \begin{cases} 1 - \frac{|d_{Min} - D_{ij}|}{d_{Min}}, & 0 \leq D_{ij} < d_{Min} \\ 1, & d_{Min} \leq D_{ij} \leq d_{max} \\ 1 - \frac{|D_{ij} - d_{Max}|}{R - d_{Max}}, & d_{Max} < D_{ij} \leq R \end{cases} \quad (16)$$

where D_{ij} is Euclidean distance between UAV and CH at the moment when the RREQ message is received.

The node's distance to the previous round's CH: Due to the significance of node position in each cluster, this metric is regarded as one of the key factors in the CH selection process. As a result, the CH with the shortest distance to the BS in previous rounds has a more substantial chance of being picked. If the energy of the UAVs and the number of their neighbors did not undergo a drastic change at the end of the first clustering, it is very probable that in the next round the current CHs are reelected. Therefore, in the second clustering no elections are held. We used the threshold of CH based on residual energy, number of neighbors and distance between UAVs to calculate the threshold.

$$Threshold = \frac{W_1 \cdot residual \ energy}{(W_2 \cdot N_i)(W_3 \cdot d)} \quad (17)$$

where N_i neighboring UAVs which are within the cycle of the communication radius. W_1, W_2 and W_3 are the residual energy

Figure 4 Describing D_{trust} between nodes in space
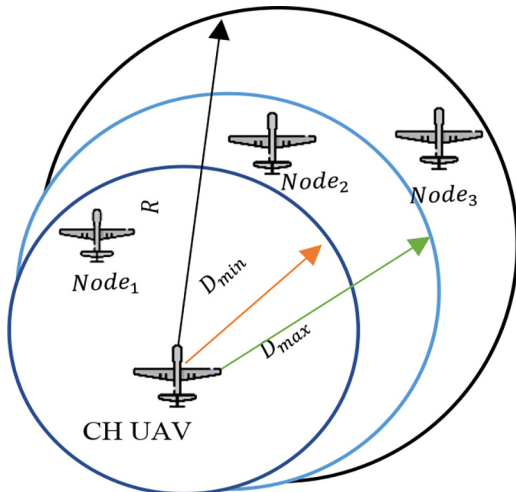
Source: Lee *et al.* (2021)

weight, N the number of neighboring UAVs and d is the distance between the UAVs, respectively. In a normal condition, the total of these three parameters should equal 1. Choosing a proper threshold value between "0.5" and "0.9" the "0.7" yielded far better results (Mazinani *et al.*, 2019). If the threshold is higher than 0.7, the CH continues to function normally; however, its parameters will naturally drop with time. If the threshold goes below 0.7, the BA begins searching for a new CH.

3.5 The proposed method

LEACH is a MAC technology based on time division multiple access that includes clustering and a primary routing mechanism. LEACH aims to reduce the amount of energy to establish and maintain clusters. In LEACH, it is assumed that each node has a transmitter capable of reaching the BS or the closest CH directly, but that using all of the time would waste enormous energy. To select a CH, first all UAVs randomly generated the numerical. The UAV with the lowest number is selected as a CH. Then the position of the UAV is measured; if the selected UAV is in an ideal location, then it will be chosen as CH; otherwise, the numbers will be generated again. After choosing the optimal CH, the threshold is evaluated in each round. If the threshold is less than 0.7, the BA algorithm is run and it finds a new CH according to the emitted pulse rate, sound or intensity, depending on the situation. The UAV with lowest sound intensity and highest pulse emission rate should be determined as the new CH. The proposed method is described in more detail below.

Step 1: First, all UAVs provide their information to the BS such as number identification and location.

Step 2: Generate random number among the UAVs, and several UAVs are randomly selected as temporary CH. The process of selecting a CH is that each UAV generates a random number, and then the UAV is selected as a CH whose random number is less than a threshold. Equation (18) shows threshold calculation:

$$T(n) = \begin{cases} \dfrac{p}{1 - p * \left(r * \bmod \dfrac{1}{p}\right)} & \text{If } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (18)$$

where, p is the required number of clusters, r is the current period number, G is the set of UAVs that were not selected as the header in the previous $\frac{1}{p}$ cycle.

Step 3: Classification of generated numbers and sort random numbers

Step 4: Calculate the distance of UAVs from the BS, where $D_{N_i}^{BS}(max)$ shows the maximum distance between the N_i th UAVs and the BS, which according to equation (19):

$$D_{N_i}^{BS}(max) = Max(dis(n_i * S_{N+1}) \forall n_i \in S_n \quad (19)$$

Step 5: Calculate the distance of the CH to the BS, where $D_{N_i}^{CH}(max)$. Calculate the randomly selected CH distance with the BS according to equation (20):

$$D_{CH}^{BS}(max) = Max(CH_j * n_{N+1}) \forall j \in CH \quad (20)$$

Step 6: As the energy of the nodes and the number of their neighbors did not undergo a drastic change at the end of the

first clustering, the current CHs are probably reelected in the next round. Therefore, in the second clustering, no elections are held. After CH is determined in the first clustering, some of their energy is saved in variables. In this step, after analyzing the CH threshold, If the threshold is less than (0.7), the BA algorithm starts to find the new CH; if it is higher than this amount, the current CH is worked. Section 3.4 describes the threshold and calculating and finding the amount.

Start the BAT algorithm

Step 7: The bats transmit loud sound pulses and listen to the echo of the surrounding objects. Although each pulse lasts only a few thousandths of a second, it is still a constant frequency, usually 25 to 150 kHz. As the velocity of sound in air is typically V = 340 m/s, the ultrasonic sound wavelength is, for a constant frequency F:

$$\lambda = \frac{V}{F} \qquad (21)$$

Step 8: To select the new CH and load balancing between the CH, the BATs search to hunt the suitable CH according to equations (8)–(10)

Step 9: To find the best UAV and determine the new CH, the pulse emission rate (r_i^0) and sound intensity (a) must be calculated as well as the position of the best UAV to be selected as the CH, which is calculated according to equations (22) and (24). Then the UAV with lowest sound amplitude and highest pulse rate should be instated as the new CH:

$$A_i^t = \frac{1}{v_i^t} \qquad (22)$$

$$A_i^{t+1} = \alpha = A_i^t \qquad (23)$$

$$r_i^{t+1} = r_i^0[1 + \exp(y_t^\alpha)] \qquad (24)$$

where r_i^0 is the initial velocity and A_i^0 is the initial loudness, α which are selected randomly, and y_t are constants ($0 < \alpha < 1$; $y_t > 0$). A_i^{t+1} is the average loudness of all the bats at time t. r_i^{t+1} the pulse emission rate at time t, while v_i^t are randomly move to hunt at a speed of V_i at t time.

Step 10: When one of the current best solutions is selected for the local search section, new solution is generated locally for each of the bats using a random walk:

$$X_{new} = X_{old} + \varepsilon A^t \qquad (25)$$

where X_{old} is a randomly selected solution from the current optimal solution, where ε is a random number obeying the uniform distribution in $[-1,1]$, while A^t is the average amplitude of the sounds from all the bats at the tth iteration. X_{new} new location for each bat is generated locally.

Step 11: The bat with the highest pulse emission rate has the lowest movement speed; when the bat gets closer to the prey, its speed decreases, and, also, the sound decreases, whereas the pulse emission rate increases. In this step select the temporary CH for sending the connection message.

Step 12: After selecting the temporary CH, the location of CH should be calculated, according to the above

equations (19) and (20). If this was the correct position, the algorithms will continue, otherwise, it will start searching again.

Step 13: After selecting the temporary CH based on the pulse intensity and emission rate and location of CH, the energy consumption should be considered according to equations (3)–(6). If the energy consumption of the temporary CH is lower than the average of the rest of the other UAVs in region. In that case, the pulse will be propagated transmitted again, but if the energy consumption of the CH is higher than the average, the UAVs will be notified. Figure 5 shows the flowchart of proposed methods.

4. Obtained results and discussion

We examined the performances of the proposed method based on three algorithms, bioinspired clustering scheme FANETs (BICSF) (Khan *et al.*, 2019a, 2019b), grey wolf optimization (GWO) (Aadil *et al.*, 2018) and ant colony optimization (ACO) (Maistrenko *et al.*, 2016) in the same data set. The parameters of the simulation scenarios and the results obtained are also discussed.

### 4.1 Simulation environment and data set
NS3 is one of the most powerful software for simulating and analyzing computer and telecommunication networks. NS3 allows the user to link different aspects of the network from the physical layer to affect the application layer. This software allows designers and researchers to simulate the performance of the protocols, equipment and network architectures with great accuracy. The predictions of this software are close to the ones obtained via measurement in a real environment. The hardware used was an Intel Core i7 3.2 GHz processor with 16 GB of RAM. Table 3 shows the simulation parameters.

4.2 Obtained result
In this section, we analyze and discuss the results of the simulations. The graphs obtained for all three scenarios are examined depending on the number of UAVs and compared with the ones obtained using ACO, the GWO and the BICF algorithms. We also compared the results obtained when the simulation has been performed on two different simulation areas sizes in terms of energy consumption, network lifetime, latency, cluster building time and PDR. It should also be noted that in comparing performance, the workload is the same for all cases. The BA is a population-based metaheuristic method that examines the response region according to the location of UAVs in the domains and obtains better responses than other methods. In the first scenario, the four algorithms are compared with each other, with respect to energy consumption versus the number of UAVs present in the UAVs network. Based on the results presented in Figure 6, we observe that the proposed method shown superior performance compared to all the other methods. BICSF also has a good performance when compared with GWO and ACO algorithms.

Figure 7 presents the results obtained with respect to the total network lifetime versus the number of UAVs present in the network. All the UAVs are conventional setup to send the acquired data to the sink based on a multihop communication. When all of a network's nodes consumes their energy, the network is shut off. The proposed strategy outperforms all the

Figure 5 Flowchart of proposed method
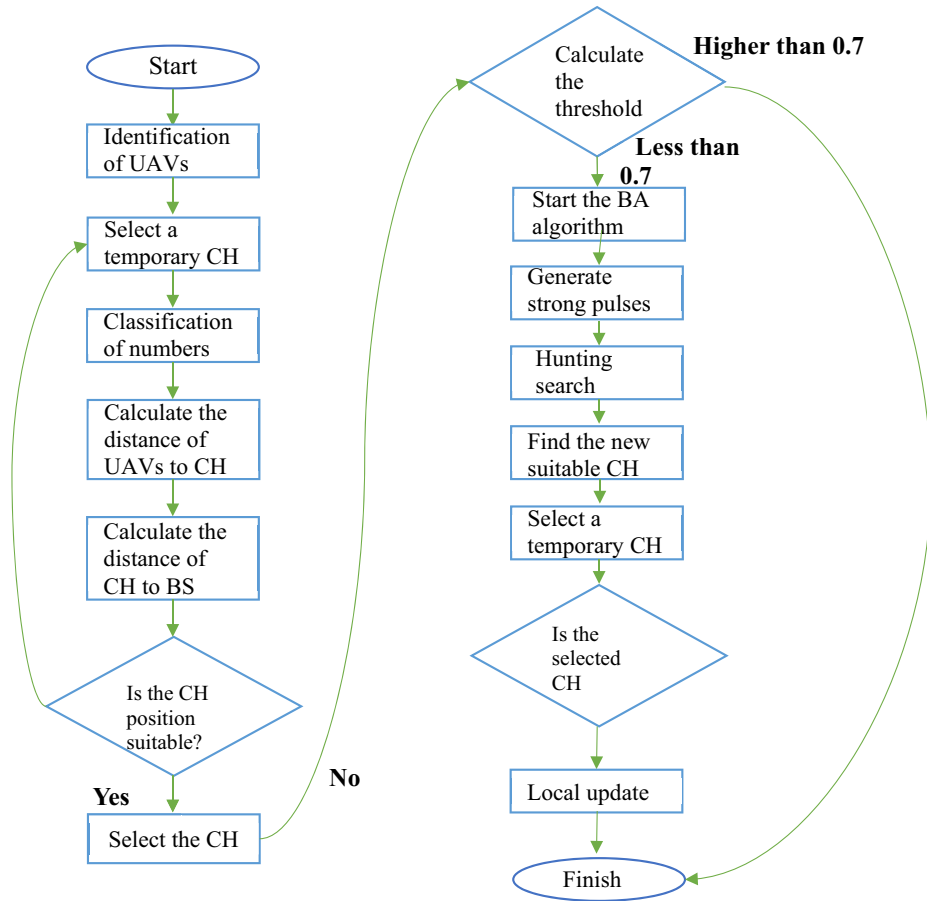
other methods, with respect to this metrics, and has also achieved the best network lifespan performance.

Another essential method in evaluating FANETs is the network latency. The lower the latency in the network the better the connection to the BS will be achieved. Figure 8 shows the results obtained in terms of the transmission delay

Table 3 List of simulation parameters (Khan *et al.*, 2019a, 2019b)

Parameter	Value
Simulated area	$1500 \times 1500\,\text{m}^2$ and $2500 \times 2500\,\text{m}^2$
Mobility model	Random waypoint
UAV number	10, 20, 30, 40, 50
No. of simulation runs	50
Simulation duration	120 s
Node's velocity	20–50 m/s
Traffic type	CBR
MAC layer protocol	802.11
Signal propagation model	Friis
Data links antenna	Omnidirectional
Antenna coverage range	150, 200, 250, 300, 350
Transport protocol	UDP
Packet size	512 kbytes

versus the number of UAVs. It can be easily observed that the proposed method presents the best result, although results obtained using other algorithms are very close, the next one being the BICF one.

The time consumed by the algorithm from receiving inputs to generating outputs is known as cluster construction time, which shows the algorithm's computational complexity. Because UAVs have low computing power and memory, cluster build time affects UAV performance. Figure 9 shows the results obtained in terms of clustering building time versus the number of UAVs, and, based on the results obtained, the

Figure 6 UAV energy consumption at the scale of $1500 \times 1500\,\text{m}^2$ scale
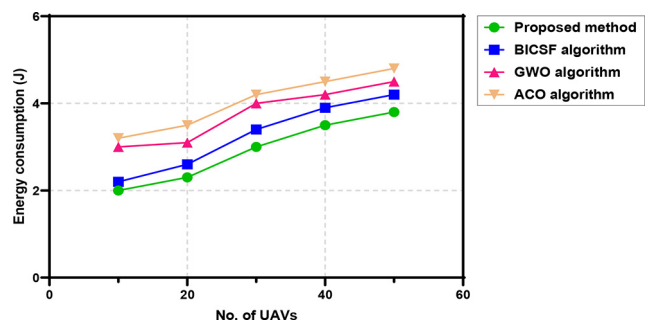
Figure 7 Network life at the 1500 × 1500 m^2 scale
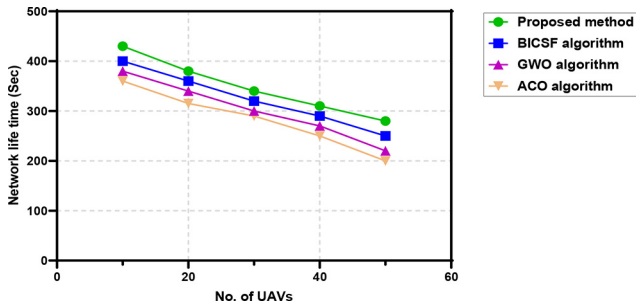
Figure 8 Delay at 1500 × 1500 m^2 scale
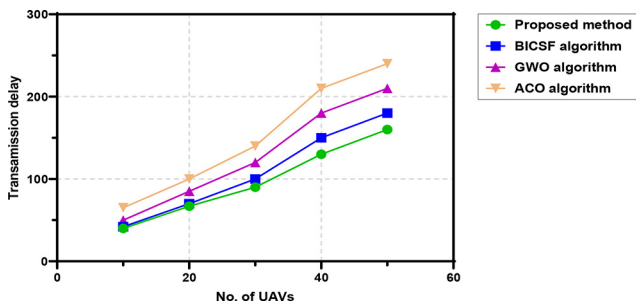
Figure 9 Cluster building time at 1500 × 1500 m^2 scale

Figure 10 PDR at 1500 × 1500 m^2 scale
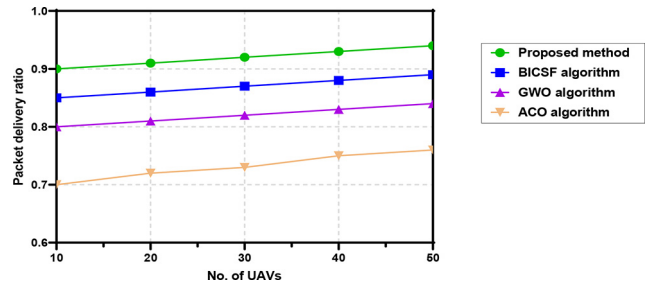
Figure 11 Energy consumption at the 2500 × 2500 m^2 scale

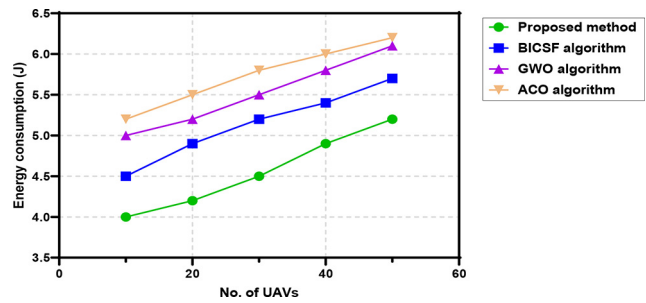**Figure 12** Network lifetime at the 2500 × 2500 m^2 scale

proposed method takes less time to complete a cluster then all the other ones.

The total number of packets received by the sink in various UAVs scenarios was examined, as shown in Figure 10, that shows the packet delivery ratio as a function of the number of UAVs. The proposed approach achieves the best results, followed closely by the BICF one, while the ACO algorithm does not provide satisfactory results.

In Figure 11, the energy consumption versus the number of UAVs is presented for all approaches at a larger scale, of 2500 × 2500 m^2. The strategy proposed achieves the best performances among its three rivals in terms of node energy, as it can be easily observed from Figure 11.

As predicted, the suggested solution has the best performance in terms of network life in this second case, as shown in Figure 12. When the number of UAV is 20, the BICSF algorithm and the proposed method are approximately the same, as the number of UAVs increase the proposed

method has better performance than all the other candidates. Again, the ACO algorithm does not have a good efficiency in the network lifetime.

Network latency is one of the essential parameters that failure to address can cause a temporary crisis in FANET. Delays in data transmission in FANET are inevitable, but the amount of latency depends on the type of algorithm proposed. Figure 13 shows the transmission of delay versus the number of UAVs for the scale of 2500 × 2500 m^2. In this case, the results show that the BICSF and proposed method achieves better results than the ACO algorithm and GWO algorithm.

Clustering is one of the effective techniques for proper energy management and extending the life of FANETs. One of the critical parameters in the construction of optimal clusters is selecting the appropriate CH. In addition to increasing the network's life and the data received in the BS will reduce the wasted energy. Figure 14 shows the cluster building time as a function of the number of UAVs in the 2500 × 2500 scale, and as expected, the proposed method achieves best results.

Figure 13 Network latency at the 2500 × 2500 m² scale
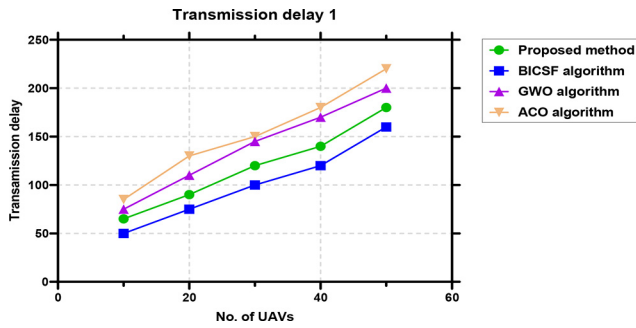
Figure 14 Cluster building time at 2500 × 2500 m² scale
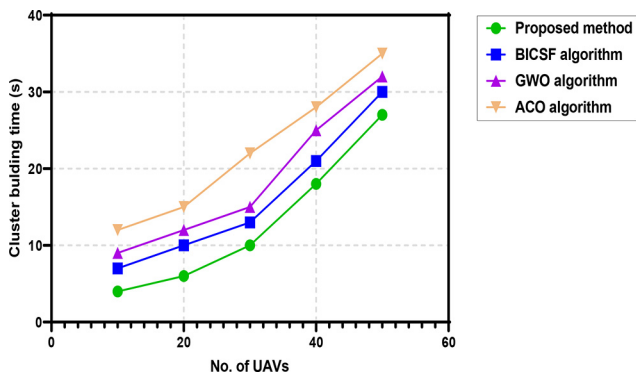
Energy consumption is used to estimate the number of packets received in the base station. The more energy usage is steady; the more packets are received at the base station. This improvement is due to the CH selection, which guarantees that all clusters are balanced. This equilibrium stabilizes CH selection, resulting in consistent energy loss. In addition to the energy problem, the data acquired from the simulation in Figure 15 shows the PDR versus the number of UAVs and that the proposed algorithm is also the best in the second scenario.

5. Conclusions and future work

In the proposed method, a combination of two algorithms, LEACH and BA, is used to reduce the energy consumption and increase network lifetime. One of the main concerns in designing clutter selection protocols and load balancing of

Figure 15 PDR at 2500 × 2500 m² scale
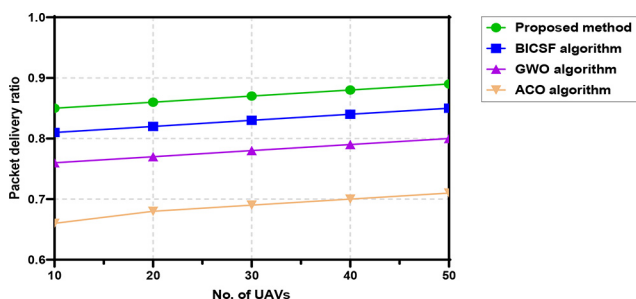
FANET is optimizing UAV's energy consumption. Therefore, the main goal should be to design a method for selecting a suitable and energy-efficient CH to ensure that the energy consumption between the network nodes is distributed fairly. In this paper, to select a CH, first all UAVs are randomly generated by the numerical by LEACH. The UAV with the lowest number is selected as CH. The position of the UAV is then measured; if the selected UAV is in an ideal location, the UAV will be chosen; otherwise, the numbers will be generated again. To use the load balancing, the threshold is first considered. If the threshold is higher than 0.7, the BA algorithm is stared to find new CH according to the emitted pulses. As it is clear from the results obtained in the article, the proposed method achieved better results than other algorithms presented in the literature, namely, BICSF, GWO and ACO, with respect to energy consumption, latency and cluster building time in large-scale networks and packet delivery ratio. In the next research studies, the authors can be focused on performance in small scale and peripheral sizes, and they can use the machine learning and deep learning for routing and then for load balancing they can focus on the metaheuristic algorithms.

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