An Energy and Mobility-Aware Routing Protocol for FANET using Clustering-Based Intelligence

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***Abstract*—** Flying Adhoc Networks (FANETs), otherwise called as Unmanned Aerial Vehicles (UAVs) have arisen in different practices as of late. The quick development of UAVs causes unfortunate connection unwavering quality and information transmission effectiveness. To handel this issue, many clustering protocols have been developed. Among them, an Energy and Mobility-Aware Stable and Safe clustering (EMASS) protocol guarantees robustness and reliability in FANETs by allowing dynamic data transmission. But, it broadcasts hello messages regularly to maintain the routing path, resulting in high bandwidth and energy utilization. In this context, it is crucial to adjust the hello message interval and avoid redundant hello messages in high- mobility FANETs so that an Intelligent-based Energy and Mobility-aware Clustering (IEMC) protocol is proposed in this article. First, a novel bio-inspired process named Battle Royale Optimization (BRO) is introduced for cluster creation and Cluster Head (CH) selection processes. Then, a Deep Q- Learning (DQL)-based fast dynamic hello interval algorithm is developed to fine-tune the hello message interval and provide an energy-efficient solution for path maintenance. The DQL algorithm determines the hello interval by using data about allowed flying zones, the number of UAVs, communication, and speed range to adapt to rapid topological alterations. Using this protocol, both bandwidth and energy utilization are minimized. Finally, the simulation results illustrated that the IEMC protocol achieves greater network performance in contrast withthe existing clustering protocols for FANETs.

***Keywords*—** *FANET, Clustering, EMASS protocol, BRO algorithm, Hello messages, DQL, Reliability, Stability*

Introduction

UAVs, commonly known as drones, are widely used in a variety of industries and activities today [1-3]. FANET is a particular sort of network that consists of numerous UAVs flying in a coordinated and cooperative way [4]. They have many distinctive aspects that distinguish them from Mobile Adhoc Networks (MANETs) and Vehicular Adhoc Networks (VANETs), including greater mobility, squad-based implementation, and quick and regular topological modifications [5-6]. As a result, these aspects have an impact on UAV robustness and make designing routing protocols difficult.

UAVs have the disadvantage of inadequate energy resources owing to functional constraints, which restricts their processing capability. Such problems affect the longevity and dependability of the network [7]. These drawbacks need to be properly explored for energy-efficient deployment that permits constant and consistent communication links. The process of coordination and data transmission gets increasingly difficult as more UAVs form swarms. But, individual UAVs in swarms cannot coordinate across a vast region due to their restricted transmission range. Also, because UAVs move quickly in these systems, transmission between UAVs is often sporadic. Therefore, it is a necessity to explore such problems for UAV topologies to make them acceptable for a variety of applications and activities [8].

To overcome the aforementioned problems and reduce the workload associated with inter-UAV coordination and data transfer, UAV clustering protocols have been developed [9]. This can achieve higher scalability, effective network supervision, and enhanced network efficacy regarding greater throughput, less delay, balanced load, and lower power usage. All clusters consist of a single selected CH and many Cluster Members (CMs). The CH alone takes responsibility for transmission with its CMs and other CHs [10]. One of these CHs can be responsible for transmitting data to the Ground Base Station (GBS). The high mobility and dynamic topology of UAVs require complex routing protocols to ensure reliable and stable connectivity. Using typical clustering techniques for dynamic, high-mobility UAVs may lead to an increase in link failures. Also, constant changes to the cluster's configuration can have a severe impact on the stability of the routing protocols [11]. Recent FANET clustering protocols focus on standard factors such as mean distance between nodes and node degree for CH selection and data transmission between CMs. The CH selection is performed using the sequential search, which enables all nodes to discover their closest adjacent nodes. Regrettably, this strategy might raise the failure probability, particularly when using a dynamic network.

To combat this issue, an EMASS protocol [12] were designed for FANETs based on the extension of the Energy- Aware Link-based Clustering (EALC) method [13] and Bio- Inspired Clustering Scheme for FANETs (BICSF) [14]. The mean absolute distance between nodes was determined by the safe distance computed during the clustering procedure to alleviate collisions. As well, it must have a robust topology to calculate an accurate number of clusters. For this reason, only the stable UAVs located in a similar communication range in the safe region were considered as robust adjacent nodes and engaged in the CH selection process. On the other hand, routing protocols in FANETs often broadcast Hello messages to maintain paths for data transfer. It may increase bandwidth utilization and energy dissipation in high-mobility UAV scenarios. Only a few earlier routing protocols addressed this issue by setting the hello period to an unrealistically lengthy or limited duration, causing the discovery of adjacent nodes to be delayed. According to this context, a new protocol is needed to determine the accurate number of Hello messages to alleviate both bandwidth and energy utilization.

Therefore, this manuscript designs an IEMC protocol to minimize excessive Hello message broadcasting in a highly dynamic UAV scenario. In this protocol, the BRO algorithm is initially proposed for the cluster formation and CH selection processes, which determines the most suitable CH according to the utility function of each UAV. After that, the DQL algorithm is introduced to adjust the Hello message interval according to the network density during path maintenance. It determines the hello interval by using data about allowed flying zones, the quantity of UAVs, communication, and velocity. Also, the learning parameters are automatically fine- tuned according to the UAVs' environments to adapt to rapid topological modifications. According to this algorithm, the adjacent route between the source and destination nodes can be discovered by broadcasting a limited quantity of hello messages. This results in less bandwidth utilization and energy dissipation in the network by alleviating excessive overhead. Thus, this IEMC protocol preserves network reliability and robustness during data transfer.

The remaining manuscript is prepared as follows: Section II presents earlier optimized clustering protocols in FANETs. Section III explains the IEMC protocol, and its efficiency is shown in Section IV. Section V summarizes the article and suggests future work.

Literature Survey

Khan et al. [14] presented a BICSF by utilizing the hybrid Glowworm Swarm Optimization (GSO) and Krill Herd (KH). The GSO generated a power-aware group and selected a CH. Also, an efficient cluster control scheme was adopted based on the KH. The ideal location of the UAV was found by genetic processes. Moreover, a path identification process was applied to select paths based on the weighted remaining power, quantity of nearby nodes, and distance among the UAVs. But, the cluster lifespan was degraded while increasing the quantity of

UAVs because more nodes in a group led to frequent topology changes.

Ganesan et al. [15] designed a Bio-inspired Optimized Leader selection for several Drones (BOLD). The Spider Monkey Optimization (SMO) was used to create the clusters according to the drone's vicinity to all others, their connectivity to others, and the remaining power. Then, the Particle Swarm Optimization (PSO) method was used to choose CH adaptively according to its present location, remaining power, and velocity. But, it did not consider the communication range, which was essential to choose CHs because it tends to have poor network interaction when the communication range was extremely low or extremely high.

Khanna et al. [16] presented a leader-based scheme to resolve the local mutual exclusion issue for FANETs. Also, a fuzzy logic method was applied to choose the leader according to the node speed, direction, link quality, and distance from the resource, which enhances the total competence and waiting period. But, it didn't control data loss, which impacts the throughput. Salam et al. [17] developed a bio-inspired mobility-aware clustering optimization method for FANET routing based on bees' intelligent foraging behavior. Initially, the clustering issue was modeled as an adaptive optimization dilemma. The best CH and balanced cluster were then selected using an intelligence-based method based on relative mobility, remaining power, and transmission load. But, it needs additional factors to improve network efficiency.Shahraki et al. [18] presented a new routing protocol for FANET using modified Ant Colony Optimizer (ACO). The energy stabilizing variable was adopted to enhance energy efficiency. But, the mean end-to-end delay was still higher than the TORA and DSR protocols. You et al. [19] designed a Coverage-Efficient Clustering Algorithm (CECA) for FANET that adjusts the coverage regions under latency and energy restraints to improve the coverage efficiency of the UAV network. However, it was not effective to account for how the clusters and entire network respond to the regular topology alterations due to node mobility.

Asaamoning et al. [20] presented a novel Dynamic Clustering Mechanism with Load Balancing (DCM-LB) for effective data transmission in FANETs. The efficient data transmission was achieved by grouping UAVs adaptively using a political optimizer, which considers the mobility of UAVs, and balancing load among clusters using a Shannon entropy function, which considers transmission queues and network load. But, the mean energy utilization was still high when increasing the number of UAVs since it did not consider energy factors for optimization.

Arafat & Moh [21] designed Bio-Inspired Localization (BIL) and Clustering (BIC) methods in FANETs. Initially, a Hybrid Gray Wolf Optimization (HGWO) scheme was adopted to design an energy-efficient 3D BIL method. Then, an energy-efficient BIC method was developed that uses the GW leadership hierarchy to enhance clustering efficacy. A logical framework was also used to determine the best clusters with the fewest transfers. Further, a GWO-based Compressive Sensing (CS-GWO) method was employed to create a path between CHs and BS for data exchange. But, because of multi-hop transmission, the hop count was increased to send the information between CM and BS.

Bharany et al. [22] designed an Energy-Efficient Clustering Protocol using the Moth Flame Optimization (EECP-MFO) for network construction and node implementation. A variant of K-means clustering was used to select the CH. By selecting the proper CHs, the cluster's lifetime was improved, and the routing traffic was minimized. This process was followed by image-based compression to minimize the quantity of data that should be sent. Moreover, the reference point cluster mobility framework was utilized to transmit information via the best route. But, the UAVs may send similar packets, which drain the UAV's constrained resources and degrade the network's efficiency.

Yan et al. [23] presented a clustering method for FANET using the Binary Whale Optimization Algorithm (BWOA). Initially, the ideal quantity of groups was computed by the network bandwidth and node coverage criteria. After that, the CHs were chosen by the BWOA, and the clusters were segregated according to distance. Also, the cluster maintenance scheme was used to maintain the clusters. But, it needs advanced optimizers to achieve local optimality for CH selection with greater network efficiency.

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Proposed Methodology

This section explains the IEMC protocol for FANETs. First, the UAV network model and the fitness function considered for clustering are discussed. Second, the BRO- based clustering algorithm in FANETs is described. Third, the DQL framework is explained for determining and fine- tuning the hello message intervals according to the network topology during routing path maintenance.

A. Network Model

The UAV network is constructed as portrayed in Fig. 1. In this study, the UAV net is considered as an undirected Euclidean graph $G = (V,)$, where V denotes the group of UAVs, and E denotes the group of connections of G. Consider

r is the communication range between 2 UAVs i and j. To simplify, consider that r is equal for each UAV in the network. Also, E is described by the delineation of UAV neighborhood, i.e., 2 UAVs are called adjacent when the distance between them is lower than r.

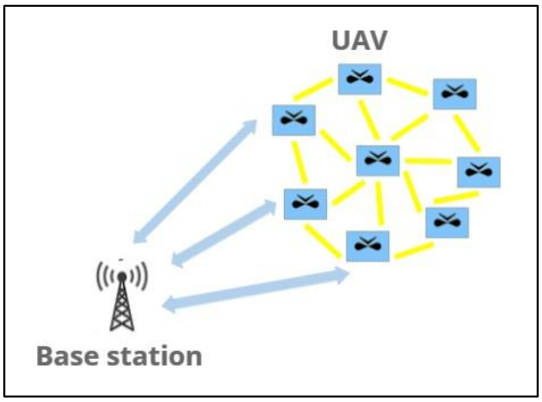

Fig. 1. UAV Network Model

B. Determination of Fitness Function

The fitness function for the proposed clustering protocol is determined by considering the residual energy (ER,i), mean safety degree (λi), and mean mobility-awareness factor (σi) for UAV i in the given communication range [12]. The fitness function (βi) is determined byCH, the BRO is introduced, which determines the fitness function defined in Eq. (3).

The BRO algorithm is encouraged by a kind of digital game called "Battle Royale (BR)". The BRO is an inhabitant- based procedure where all individuals are defined as fighters that would want to travel toward the non-dangerous (ideal) location and eventually live. A few kinds of BR tournaments initiate as fighters hurdle from a surface and fall onto the map. First, the BRO initiates by an arbitrary population that can be evenly disseminated in the solution area. After that, all fighters attempt to injure the closest fighter by killing a missile. So, fighters in better locations inflict destruction on their closest neighbors. If particular fighter is injured by the other, then its destruction level upsurges by 1. Such relationships are computed as $xi.dest = xi.dest + 1$, where

$xi.dest$ is the destruction level of i^{th} fighter among the population, and i denotes the sum of possible solutions in the population ($i = 1\ldots N$).

Also, fighters need to modify their location instantly after undergoing destruction and attack enemies from the other end. Thus, to emphasize exploitation, the injured fighter travels toward a spot somewhere between the past location and the best location discovered so far (the elite fighter). Such relations are computed as:

$x_{inj,} = x_{inj,d} + r(x_{best,d} - x_{inj,d})$ (4) In Eq. (4), d is the dimension of the problem space, $xinj,d$

indicates the location of the injured fighter in d, $xbest,d$ defines the best solution obtained so far, and r denotes an arbitrarily created number that is uniformly distributed in the range [0,1]. Besides, when injured fighters can cause harm to their enemies in subsequent iterations, $xi.dest$ can be

1

$\beta i =$ (1)

$w_1\lambda_i$

$\times$ $w2E_R$,

$w3\sigma i$

reassigned to 0. As well, to emphasize exploration, when the destruction level of a fighter exceeds the predefined threshold, the fighter passes away, reappearing arbitrarily in

In Eq. (1), $w1$,2, and $w3$ denote the weight values of the

respected factors such that $w1 + w2 + w3 = 1$. The UAV having the minimum fitness value is selected as a CH.

In the broadcast of hello messages among the UAVs, all

the feasible problem space, and $xi.dest$ can be reassigned to

0. This activity prevents earlier convergence and promotes better exploration. After being destroyed, the fighter returns to problem space as follows:

UAVs i will maintain the record of β associated with the node $x = r(ub - lb\ ) + lb$

degree (i.e., the total amount of neighbors of every (ndi)) of its nearby UAVs.

$\Omega_i = \{k \mid \forall k \in ndi\}$ (2)

The UAV with IDi can be considered as a CH only if its

βi is the least one in Ωi as:

$\boldsymbol{CH} = \{\boldsymbol{IDi} \mid (\boldsymbol{IDi}) \leq \mathbf{min}(\boldsymbol{\Omega i})\}$ (3)

Based on this fitness function, the BRO-based clustering and CH selection process is executed, which is described below.

C. Battle Royale Optimization (BRO)-based UAV Clustering for CH Selection

The CH selection using the BRO algorithm presented in Algorithm 1 intends to effectively split the UAV system into various groups. Every group consists of an ideal UAV, chosen as the CH, and other CMs. To choose the best suitableinj,d d d d

In Eq. (5), lbd and ubd define the minimum and maximum limits of d in problem space, correspondingly. Additionally, in all Δ iterations, the achievable search space of the problem initiates to cut down toward the optimal result.

$MaxC$

The primary value is $\Delta = \log\ (MaxC)$, but then

10

$\Delta = \Delta + round$ $\left(\frac{\Delta}{2}\right)$, where $MaxC$ denotes the maximum number of iterations. This relationship adds to both exploration and exploitation. As a result, the minimum and maximum limits can be modified by

$$lbd = xbest,d - SD(xd)$$

$$ubd = xbest, + SD(xd) \quad (6)$$

In Eq. (6), $S(xd)$ denotes the standard variance of the entire population in $\bar{d}$. Accordingly, when lbd or ubd surpasses the actual minimum or maximum limit, it assigns

to the actual lbd or ubd. Additionally, to emphasize elitism, the best fighters discovered in all iterations are preserved and called elite (best CH).

Once the clustering process is completed, cluster maintenance is applied, as in [12], to handle the probable modifications in the network structure. This process is applied to find the most suitable CM to be chosen as a new CH without initiating the CH selection again. It ensures the network's reliability and robustness. On the other hand, when a new UAV is inserted to the system, the CH selection algorithm (Algorithm 1) must be performed again.

Algorithm 1 Pseudocode of BRO-based UAV Clustering

Input: N number of UAVs

Output: Optimal number of clusters and their CHs

In the primary step (iteration $t = 0$, i.e. no cluster is created), all UAVs begin with a primary mode, then broadcast a hello packet to each of their neighboring UAVs;

//(Hello message interval is determined by the DQL framework as in Algorithm 2)

Begin $\boldsymbol{if}(\boldsymbol{xinj.dest < threshold})$

$\boldsymbol{fo}(d = 1{:}Dimension)$

Modify the location of injured fighter as follows:

$xinj,d = r\left(\max(x_{inj,d}, x_{best,d}) - \min(x_{inj,d}, x_{best,d})\right) + \max(x_{inj,d}, x_{best,d});$

$\boldsymbol{end\ for}$

$xinj.dest = xinj.dest + 1;$

$xwin.dest = 0;$

$\boldsymbol{else}$

$\boldsymbol{fo}(d = 1{:}Dimension)$

$xinj,d = r(ubd - lbd) + lbd;$

$\boldsymbol{end\ for}$

Modify $(xinj)$;

$xinj.dest = 0;$

$\boldsymbol{fo}(each\ UAVk\ in\ the\ network)$ // $0 \leq k \leq (N - 1)$

//Discover the adjacent nodes of $UAVk$

$\boldsymbol{for}\ (i^{th}\ UAV\ (i \neq k))$ // $0 \leq k \leq (N - 2)$

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//Neighborhood creation

$\boldsymbol{if}(dis_{k,i} \leq$ r && $dis_{k,i} \leq \delta)$

$adjacent[UAV_k] \leftarrow UAV_i$;

$\boldsymbol{end\ for}$

$\boldsymbol{if}(t \geq \Delta)$

$\boldsymbol{end\ if end\ if}$

Modify $(ubd - lbd)$ using Eq. (6);

$\Delta = \Delta + round\left(\frac{\Delta}{2}\right)$;

$\boldsymbol{end\ if}$

$\boldsymbol{end\ for}$

$\boldsymbol{fo}(every\ UAV_i \in adjacent[UAV_k])//0 \leq i \leq$

$(nd_i - 1)$

Initialize a population (i UAVs) in a

random manner;

Initialize each parameter such as the highest iteration

$(MaxC)$, and population dimension;

$shrink = cei(\log 10(MaxC))$;

$\Delta = round\left(MaxC / shrink\right)$;

$\boldsymbol{whil}(t \leq MaxC)$ //t: current iteration

$\boldsymbol{fo}(i = 1{:}population\_size)$

//evaluate i^{th} fighter with closest one (j)

$inj = i$; //inj: injuried fighter

$win = j$; //vic: winning fighter

$\boldsymbol{if}\left(f(xi) < f(xj)\right)$

$inj = i$;

$win = j$;

$\boldsymbol{end\ if}$

If lbd or or ubd surpasses the actual minimum or maximum limit, it assigns to the actual lbd or ubd;

$\boldsymbol{end\ while}$

Choose the best fighter (CH) as the solution;

CH transmits a request message to its direct adjacent nodes which turn into its CMs;

Each adjacent node of the selected CH is no longer permitted to contribute in the selection process and can be omitted from the set of available UAVs;

end for

Repeat the process for every remaining node;

Apply the cluster maintenance algorithm to handle network topology alterations;

End

Alternatively, the UAVs pursue certain movement forms during their traveling at equal altitudes. This causes frequent broadcasting of hello messages among UAVs, which leads to more bandwidth and energy wastage in the network. To resolve this problem, an applicable quantity of hello messages should be broadcasted within an optimal interval to guarantee a bandwidth and power-efficient routing among UAV nodes, providing the highest coverage of the target region and the longest lifespan.

The goal is to develop the DQL-based fast dynamic hello interval learning algorithm to avoid excessive hello message broadcasting between the UAVs, which guarantees a balance

between the mobility, energy, bandwidth, reliability, and stability demands of the FANET.

D. Deep Q-Learning (DQL)-based Fast Dynamic Hello Interval Algorithm

The DQL is adopted (referred to as "enhanced actor-critic network learning"), which uses the Deep Neural Network (DNN) with Q-learning to create the hello messages by selecting the optimal value of the rule function rather than discovering the action according to the particular distribution. This framework adaptively fine-tunes the hello period and the rest interval relating to each UAV in the network. So, in high- mobility FANETs, this framework creates low values for the hello period that defines the modification of the system structure so that link alterations appear often in an adequately dense network. In low-mobility FANETs, a greater value of the hello interval is created so that the link alterations are occasional in low-density networks, resulting in a minimum hello interval.

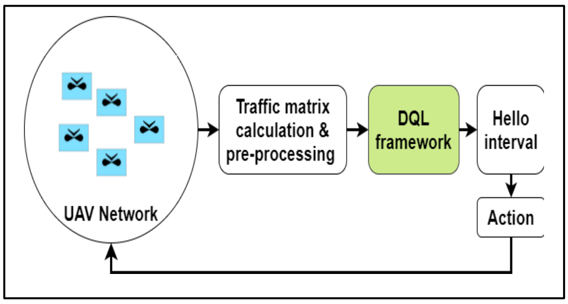

Fig. 2. Novel Framework for Hello Interval Fine-tuning in FANETs

A novel framework for fine-tuning the hello interval is illustrated in Fig. 2. First, the network topology and new traffic matrix is created. If the traffic demand between UAVs

i and j is denoted as fij, then the traffic demand between N

UAVs is defined by traffic matrix T.

$0\ f_{12} \cdots f_{1m}$

$$\begin{bmatrix} \\ \\ \end{bmatrix}$$

discrepancy in the Q-factor. This procedure runs with 3 hyperparameters: (i) learning samples (G), (ii) epochs (P), and (iii) the different indices (Q) utilized by Q-table.

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The amount of epochs is essential to operate and learn the DQL mediators, whereas the action is associated with G. The network environment is include n parameters such as the communication range (r), the acceptable airspace (AS), the quantity of UAVs (N), and the velocities (v) of the UAVs.

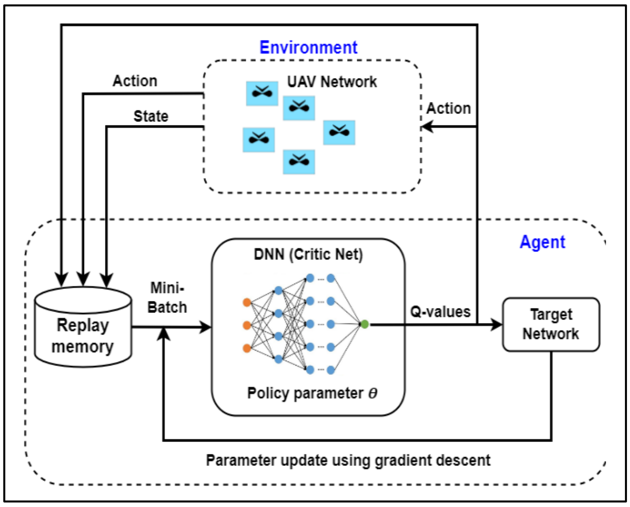


Fig. 3. Overview of DQL Framework

In Algorithm 2, initialize the Q-table defined by the parameter θ, the buffer B with an action at, incentive rt, net state st, and the new state st+1, replay memory $\mathscr{F} \leftarrow \mathscr{F} \cup$

$\{(st,t,rt,st+1)\}$, and the mini-batch M. Finally, the hello message period is determined based on the rule's updating gradient $\nabla\theta$.

Algorithm 2 Pseudocode of DQL-based Fast Dynamic Hello Interval Determination Algorithm

Input: Communication range r, acceptable airspace AS,

$T =$ 0 0 ⋯ $f2m$ (7) N UAVs, and velocity v

⋯ ⋯ 0 ⋯

0 0 ⋯ 0

After that, a pre-processing step is applied that lessens the amount of network variables. Also, the information is analyzed via the neural layer, and the DQL mediator creates a novel framework. So, a result about the hello period is obtained, and an action about the hello period is conducted.**Result:** Hello message period $THello$

Begin

Initialize θ, ϕi, $i = 1,\ldots,$ B with $\mathscr{F} \leftarrow \mathscr{F} \cup$

$\{(st,t,rt,st+1)\}$, and $\phi target,i \leftarrow \phi i$;

$\boldsymbol{fo}(i = 1,\ldots,P)$

Regularly, the traffic information is given to the DQL to discover connection weights and reduce the latency according to the state vector (output vector to create the hello s_{t+1};Initialize $a_t \sim \pi_\theta(\cdot|s_t)$ reward r_t, and new state

message interval).

The DQL in the network defines the fast data transmission using the hello packets to enhance the system efficiency. The DQL mediator gets the net condition to calculate the hello period. So, a group of connection weights $[l1,\ldots,n]$ is computed for the state vector that depends on the hello packets. The routes are determined, and the routing protocol creates different routes. The best hello period finds the route, and the FANET efficacy is also updated.

An overview of the DQL framework applied for FANET is shown in Fig. 3, and the pseudocode for the DQL is presented in Algorithm 2, where an ensemble of P Q-factors is utilized arbitrarily and separately to minimize the***end for***

for(G)

Utilize $M = \{(s,,r,s')\}$ from $\mathscr{F}$;

end for

Initialize n with system environments $\frac{AS \times v_{max}}{\pi \times N \times r^2 \times v_{min}}$;

Utilize Q of Q different indices from $\{1,\ldots,\}$; Initialize the Q-factor y as:

$$= r + \gamma\left(\min_{i \in Q} Q\phi_{target,}\left(s',a'\right) - \alpha \log \pi\theta\left(a' \mid s'\right)\right), \quad a' \sim \pi\theta\left(\cdot \mid s'\right) \tag{8}$$

UAV velocity	20 m/s – 60 m/s
Mobility model	Reference point mobility model
Propagation model	Free space
Message size	250 bytes
Transmission rate	2.4 GHz
MAC protocol	IEEE 802.11a
UAV communication range	100-350 m

//γ: discount factor

fo$(i = 1,\ldots,P)$

Modify ϕi with gradient descent as:

$$\phi_i \leftarrow \nabla_{\phi} \frac{1}{|Q|} \sum_{(s,a,r,s') \in \mathscr{F}} \left(Q_{\phi_i}(s,a) - y\right)^2 \tag{9}$$

end for

Initialize the desired network with parameters $\phi target$,

$\leftarrow \rho\phi_{target,} + (1 - \rho)\phi_i$;

A. PDR

It measures the quantity of packets properly sent from the source UAVs to the target UAV. It is calculated as:

1

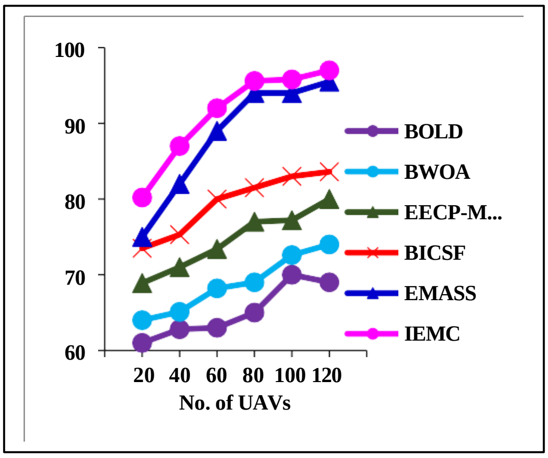
Initialize θ, $\left(\frac{1}{P}\right.$ ~ $(\tilde{a}$ $))$ — $\nabla\theta_{|\mathscr{F}|}$

$\sum received\ data\ packets\ at\ the\ destination$

$PDR =$

$\sum transmitted\ data\ packets\ from\ the\ source$(11)

$Q\ (s,a\ (s)) - \alpha \log \pi$



$(s) | s$;

$s \in \mathscr{F}i=1$ ϕ θ θ

Adjust the hello interval as:

$T_{Hello} = n \times \nabla$

End1

$\theta mean$

0)

In the learning task of the DQL, the variables of the critic net to reach the Q-table and related variables of the actor net to learn the policy are modified constantly. Thus, this DQL framework automatically fine-tunes the hello message period depending on the topological modifications to circumvent broadcasting more hello messages during routing.

Moreover, the DQL framework's training rate and incentive variables are adapted according to the system environments. Thus, this IEMC protocol can alleviate both energy and bandwidth utilization during path maintenance in the FANETs.

I. SIMULATION RESULTS

The effectiveness of the IEMC protocol is assessed and judged with the existing protocols: EMASS [12], BICSF [14], BOLD [15], EECP-MFO [22], and BWOA [23]

utilizing MATLAB simulations. Table 1 lists the simulation parameters, where 50 simulations are utilized. Additionally, for the DQL, the learning sample number is denoted by 180, the number of learning epochs is 1800, B's size is 40000, and

M is 60. The training rate of both actor and critic networks is 0.0001. The discount factor is 0.9 in the Q-table.

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The Packet

Delivery Ratio (PDR), End-to-End Delay (E2D), energy consumption, routing overhead, and cluster lifespan are

Fig. 4. PDR vs. No. of UAVs

In Fig. 4, the PDR values of various clustering protocols vs. different quantities of UAVs are shown. It is observed that the IEMC protocol achieves a maximum PDR compared to the other protocols (reaching up to 97%) because of the new CH selection algorithm, which results in high robustness and enables efficacious data transfer among UAVs. Overall, the IEMC protocol increases the PDR by 40.12%, 32.62%, 22.37%, 14.82%, and 3.42% compared to the BOLD, BWOA, EECP-MFO, BICSF, and EMASS, correspondingly.

B. End-to-end Delay

It measures the mean interval taken by the packets to reach their destinations. It is determined by

$$\sum p \in L \; T\;(p\;)\;\; T\;\;(p\;)$$

assessed under a different quantity of UAVs. $E2D =$ $i \quad A \quad i \;\; D \quad i$ (12)

$Total\ number\ of\ data\ packets\ (L)$

Table 1. Simulation SettingsIn Eq. (12), pi is the received packet, $T(pi)$ is the receiving period of pi, and $TD(pi)$ is the sending period of pi.

Parameters	Values
Network area	1500*1500 m^2
Simulation interval	200 seconds
Number of UAVs	200
UAV energy at beginning	85 W/h
Constant bit rate	100 kbps

In Fig. 5, the average E2D values of various clustering protocols vs. different quantities of UAVs are highlighted. It is addressed that the average E2D of the IEMC protocol is lower than the other protocols due to the selection of more robust CH, which contributes to the fewer packet collisions and E2D. Overall, the IEMC protocol lessens the average

E2D by 35.66%, 32.41%, 29.09%, 24.46%, and 11.77% compared to the BOLD, BWOA, EECP-MFO, BICSF, and EMASS, correspondingly.

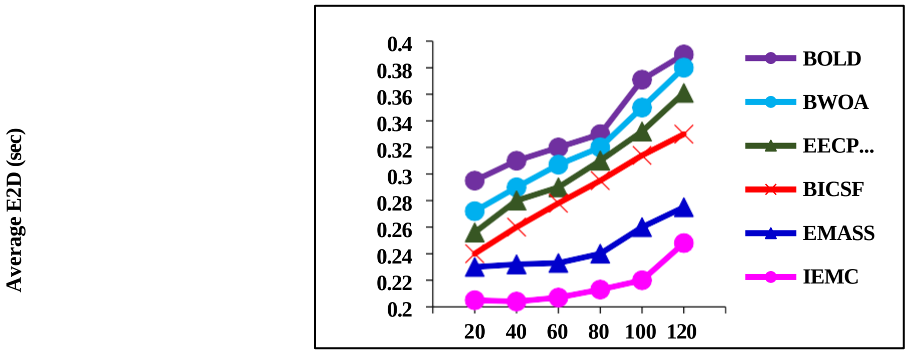

Fig. 5. Mean E2D vs. No. of UAVs

C. Energy Consumption

It computes the overall energy used by each UAV per second as follows:

$$Etotal = Ez \times Tz \qquad (13)$$

In Eq. (13), pz is the energy dissipated in mode z, and Tz is the time spent in z. The mode z can be data transmission, data reception, idle and data sensing.

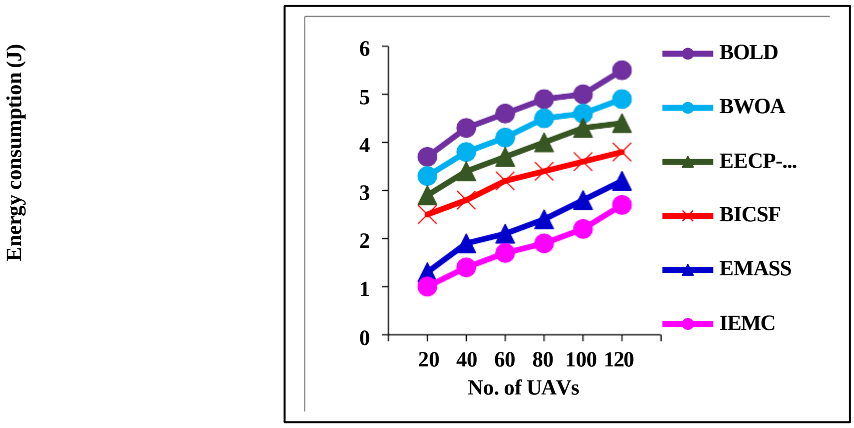

Fig. 6. Energy Consumption vs. No. of UAVs

In Fig. 6, the energy consumption values of various clustering protocols vs. different quantities of UAVs are demonstrated. It is observed that the IEMC protocol consumes less power compared to the other protocols due to the execution of the BRO algorithm for clustering and selecting the optimal CHs; so preserving cluster robustness and conserving energy for new CH selections. The IEMC protocol decreases energy consumption by 61.07%, 56.75%, 51.98%, 43.52%, and 20.44% compared to the BOLD, BWOA, EECP-MFO, BICSF, and EMASS, correspondingly.

D. Routing Overhead

It is the fraction of each message created in the packet forwarding task to messages received at the target node.

In Fig. 7, the routing overhead results of various clustering protocols vs. different quantities of UAVs are highlighted. It is noticed that the routing overhead of the IEMC protocol is less than the other protocols because of

adjusting the hello interval dynamically, which contributes to less bandwidth usage and smaller overhead. Overall, the IEMC protocol minimizes the routing overhead by 30.49%, 26.98%, 24.21%, 18.55%, and 12.42% compared to the BOLD, BWOA, EECP-MFO, BICSF, and EMASS,

correspondingly.

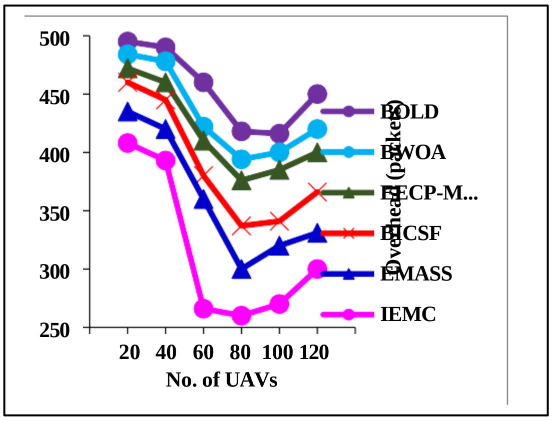

Fig. 7. Routing Overhead vs. No. of UAVs

E. Cluster Lifespan

It defines the interval that intervenes from the CH selection and cluster creation till the interval a novel CH is reselected. It is sign of cluster robustness.

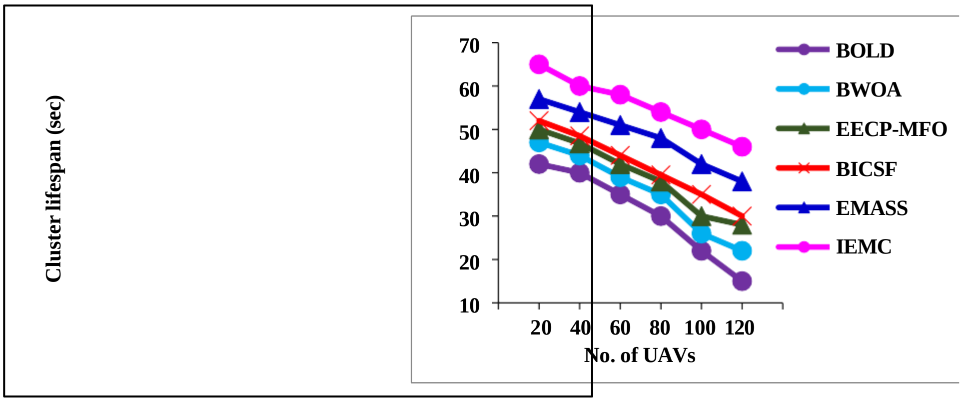

Fig. 8. Cluster Lifespan vs. No. of UAVs

In Fig. 8, the cluster lifespan of various clustering protocols vs. different quantities of UAVs is portrayed. It is observed that the average cluster lifespan of the IEMC protocol is increased by improving the stability of CHs based on the BRO algorithm compared to the other protocols. Overall, the IEMC protocol improves the cluster lifespan by 80.98%, 56.34%, 41.82%, 33.73%, and 14.83% compared to the BOLD, BWOA, EECP-MFO, BICSF, and EMASS,

correspondingly.

Conclusion

In this article, the IEMC protocol was proposed for FANETs to deal with the bandwidth and energy utilization due to broadcasting unnecessary hello messages during CH selection and routing. First, the hello message interval was automatically adjusted by the DQL framework to broadcast an optimal quantity of hello messages according to the network density. Next, the BRO algorithm was adopted for clustering and CH selection, depending on the fitness function of each UAV in the FANET. It is significant to observe that this IEMC protocol can decrease the bandwidth

and energy utilization in the network while reducing the routing overhead, resulting in maximum network longevity and PDR. The simulation outcomes revealed that the IEMC protocol outperformed the existing clustering protocols for FANETs in terms of lower overhead, E2D, greater energy and bandwidth savings, packet deliverability, and cluster stability. Overall, the results proved that the IEMC protocol has a PDR of 97%, an average E2D of 0.248s, an energy consumption of 2.7J, a routing overhead of 300 packets, and a cluster lifespan of 46s compared to the other clustering protocols.

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