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Article

Coati Optimization-Based Energy Efficient Routing Protocol for Unmanned Aerial Vehicle Communication

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Abstract: With the flexible deployment and high mobility of Unmanned Aerial Vehicles (UAVs) in an open environment, they have generated considerable attention in military and civil applications intending to enable ubiquitous connectivity and foster agile communications. The difficulty stems from features other than mobile ad-hoc network (MANET), namely aerial mobility in three-dimensional space and often changing topology. In the UAV network, a single node serves as a forwarding, transmitting, and receiving node at the same time. Typically, the communication path is multi-hop, and routing significantly affects the network's performance. A lot of effort should be invested in performance analysis for selecting the optimum routing system. With this motivation, this study modelled a new Coati Optimization Algorithm-based Energy-Efficient Routing Process for Unmanned Aerial Vehicle Communication (COAER-UAVC) technique. The presented COAER-UAVC technique establishes effective routes for communication between the UAVs. It is primarily based on the coati characteristics in nature: if attacking and hunting iguanas and escaping from predators. Besides, the presented COAER-UAVC technique concentrates on the design of fitness functions to minimize energy utilization and communication delay. A varied group of simulations was performed to depict the optimum performance of the COAER-UAVC system. The experimental results verified that the COAER-UAVC technique had assured improved performance over other approaches.

Keywords: Artificial intelligence; unmanned aerial vehicle; data communication; routing protocol; energy efficiency

1 Introduction

Unmanned aerial vehicles (UAVs) have grabbed a lot of research interest over the past few decades because of several inherent features like their ability to establish a line of sight (LOS) links with the users, mobility, and their easy deployment [1]. Generally, UAVs, otherwise known as drones, are of two types: rotary-wing and fixed-wing. Each type of UAV can be adapted to a particular type of application. For instance, fixed-wing drones were very suitable for the type of mission stationarity was not required, e.g., Military applications like surveillance and attack [2]. But rotary-wing drones have complicated aerodynamics. It even can remain immobile at a specified location. However, it could not able to execute long-range missions [3]. The rotary-wing drones were better suited to offer impermanent wireless coverage to ground users. The participation of several industrial units in UAV production has facilitated minimizing their cost on markets; using a UAV network is no longer a futuristic idea or dream [4]. They were employed in several cases offering wireless connectivity, surveillance, weather forecasting, farming, disaster management, traffic control, and delivery.

A UAV-based transmission system is found to be better in between air and terrestrial medium [5]. But the existing routing path up-gradation of UAVs needs to be improved for completing the data transmission. The ideal path up-gradation was to govern the target area of a sink of network or UAV so that the drone may carry the sensing data to reach them out [6]. The drone sensing data relay transmission would encounter path selection problems, interruption, and distortion. The examination of relay network transmission influenced the transmission time delay and data quality [7]. The data is broadcasted through radio propagation in the routing path up-gradation. Depending on the topological data of the drone self-assembling network routing protocol model, drone self-assembling network transmission data peripheral forwarding, and greedy forwarding as per the communication among UAV swarm and UAV [8], the transmission data forwarding mode is modelled as per the situation, integrated with the spatial features of UAVs in the operation process; 2 forwarding modes were modeled from dual aspects like peripheral forwarding and greedy forwarding [9]. The greedy forwarding: in the UAVs self-organizing network, an adjacent communication node has a small spatial linear distance among the transmission target node, and a local neighbour table can be chosen from the communication node since the next data-delivering nodes, and nodes were considered as the main node in routing protocol [10].

This study introduces a new Coati Optimization Algorithm-based Energy-Efficient Routing Protocol for Unmanned Aerial Vehicle Communication (COAER-UAVC) technique. The presented COAER-UAVC technique establishes effective routes for communication between the UAVs. Besides, the presented COAER-UAVC technique concentrates on the design of fitness functions to minimize energy utilization and communication delay. A varied group of simulations was performed to depict the superior performance of the COAER-UAVC system. The experimental results verified that the COAER-UAVC model had assured better performance over other approaches.

The rest of the paper is organized as follows. Section 2 offers the related works, and Section 3 introduces the proposed model. Next, Section 4 provides experimental validation, and Section 5 concludes the work.

2 Literature Review

Francelin et al. [11] modelled a new method to initiate secured transmission in UAV networks. Initially, the UAV simulation is carried out. Then, using a routing path, the data communication can be executed among nodes; therefore, the best routing path can be constituted by utilizing the Tunicate Swarm Political Optimization (TSPO) technique. This modelled TSPO technique compiles the Political Optimizer and Tunicate Swarm Algorithm. Moreover, the data transmission can be performed through a monitoring agent and evaluation. Also, by utilizing the deep residual networks (DRNs), malicious recognition can be performed by a decision-making agent. Namdev et al. [12] devised a whale optimization algorithm (WOA)-related optimized link state routing (WOA-OLSR) on flying ad-hoc network (FANET) for offering the best routing for energy-efficient and secure FANET. Using WOA, the potentiality of OLSR can be improvised, and assessing results exhibits the superior performance of the WOA-OLSR technique. In [13], the authors developed the joint optimization of relay paths and drone locations in UAV-relayed Internet of Things (IoT) networks as graph issues and proposed a graph neural network (GNNs)-oriented method to solve it efficiently. The authors devised a reinforcement learning-based relay GNN (RGNN) in the training procedure for choosing an optimum relay path for users. Afterwards, the authors jointly use RGNN and location GNN (LGNN) to optimize every UAV's places.

Khan et al. [14] devise a self-organization-oriented clustering scheme stimulated by the behavioural study of glowworm swarm optimization (GSO) for cluster management and formation. The cluster formation and cluster head (CH) selection were carried out based on connectivity with the ground control station and the drones' residual energy (RE) and luciferin values. The cluster management system employs behavioural analysis of GSO by upgrading luciferin values depending on the place of the UAV. Also, the authors devised a system for route selection related to the position, neighbour range, and RE of drones for effective transmission. In [15], modelled a Trust Based Clustering Scheme (TBCS) for FANETs. TBCS leverages a multi-criteria fuzzy technique for classifications relevant to the behavior of nodes in the complex and fuzzy environment. The devised method uses Takagi–Sugeno–Kang fuzzy inference approach. Moreover, a secure CH was chosen depending on computed trust values accountable for transmission with inter-cluster communication and a ground control station.

In [16], blockchain (BC) can be used for investigating the secure transmission among drones to Wireless UAV base stations. Drones were more susceptible to security assaults. The devised BC-related architecture supported secure data transmission in the drone's uncertain surroundings. This study develops a modified PSO technique for superior path selection to enhance network security. Zhen et al. [17] devise an intelligent self-organized algorithm (ISOA) to resolve a cooperative search-attack mission planning issue for multi-UAVs. In the initial stage, an enhanced distributed ant colony optimization (ACO) method was presented to execute the mission planning and produce waypoints. In the next stage, to smoothly join waypoints produced by ACO, the Dubins curve was used.

3 The Proposed Model

In this study, we have introduced a novel COAER-UAVC technique for effective UAV communication. The presented COAER-UAVC technique concentrated on identifying optimal routes for communication between the UAVs.

3.1 System Model

In this work, the UAV deployed are separated into two categories. A primary one is a drone with monitor and communication purposes, but another is a Radio Repeater drone. They utilize similar UAVs but have distinct functions and equipment [18]. Considering the requirement of communication and observation tasks, the coverage region of UAV must be maximized. Fig. 1 illustrates the UAV system model. UAV adopts the U-shaped route to monitor and patrol the fire, which could maximize the patrol region. UAV turns beside a semicircle with a radius of $\frac{d}{2}$. Next, the unit patrol region of the UAV is attained is represented as S_0:

$$S_0 = (v \cdot t) \cdot d + \frac{\pi d^2}{8} \tag{1}$$

whereas v denotes the navigating speed of the UAV, t indicates the time routing in A to B, and d shows the patrol diameter of the UAV. The influence of the curvature of the earth can be evaluated by:

$$d_0 = 2R_0 \cdot \arcsin \sqrt{P_1 + P_2} \tag{2}$$

whereas R_0 indicates the radius of earth, and P_1 and P_2 are shown below:

$$P_1 = \sin^2\left(\frac{\phi_2 - \phi_1}{2}\right) \tag{3}$$

$$P_2 = \cos(\phi_1) \cdot \cos(\phi_2) \cdot s\dot{i}n\left(\frac{\lambda_2 - \lambda_1}{2}\right) \tag{4}$$

whereas P_1 and P_2 represent the intermediate process. ϕ_1 and ϕ_2 show the latitude of the two places, and λ_1 and λ_2 denote their longitude of them.

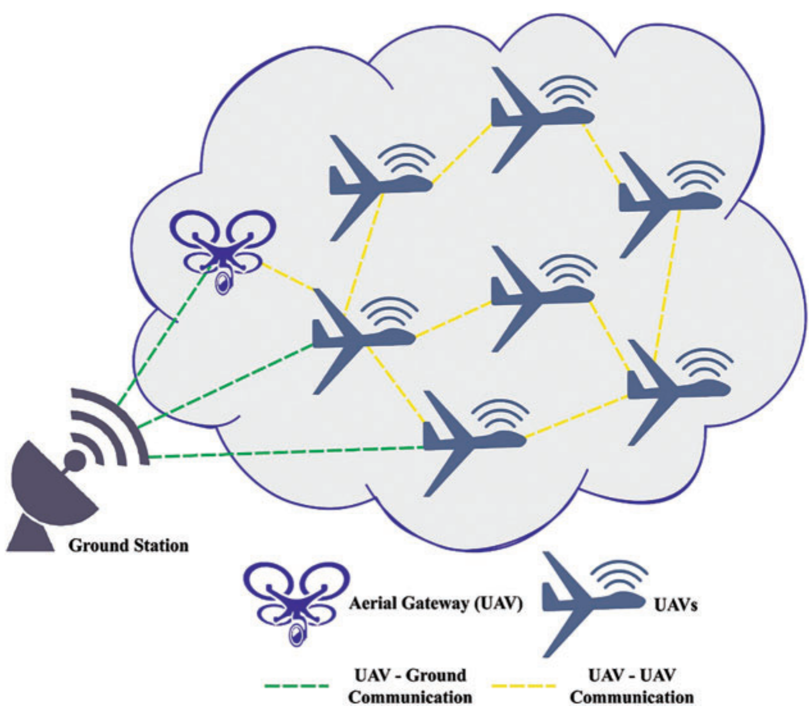

Figure 1: System model

3.2 Algorithmic Design of COA

The COA is a population-based meta-heuristic approach where the coatis are population members of these algorithms. The location of every coati in the searching space defines the value for decision parameters [19]. Therefore, the location of the coatis characterizes a candidate's solution to problems. At first, the location of coatis in the search space is initialized at random based on the following expression:

$$X_i:\ \chi_{i,j} = lb_j + r \cdot (ub_j - lb_j), i = 1, 2, \ldots N, j = 1, 2, \ldots m, \tag{5}$$

In Eq. (5), X_i represents the location of i[th] coatis in search space, $x_{i,j}$ indicates the value of a j[th] dimension, N denotes the number of coatis, m indicates the number of decision parameters, r denotes the random real number within [0, 1], lb_j and ub_j denote the lower and upper boundaries of the j[th] parameter, correspondingly. The mathematical formula for the population of coatis in COA has been given in the following expression,

$$X = \begin{matrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ \lfloor X_N \rfloor_{N\times m} \end{matrix} = \begin{matrix} x_{1,1} & \ldots & x_{1,j} & \ldots & x_{1,m} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ x_{i,1} & \ldots & x_{i,j} & \ldots & x_{i,m} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ \lfloor x_{N,1} & \ldots & x_{N,j} & \ldots & x_{N,m} \rfloor_{N\times m} \end{matrix} \tag{6}$$

The location of the candidate solution in the decision variable results in the assessment of distinct values for the objective function (OF).

$$F = \begin{matrix} F_1 \\ \vdots \\ F_i \\ \vdots \\ \lfloor F_N \rfloor_{N\times 1} \end{matrix} = \begin{matrix} F(X_1) \\ \vdots \\ F(X_i) \\ \vdots \\ \lfloor F(X_N) \rfloor_{N\times 1} \end{matrix} \tag{7}$$

F represents the vector of attained OF, and F_i shows the OF values attained according to the i[th] coatis. In this work, the measure of candidate quality solution is the value of OF. Thus, the population member results in the evaluation of optimum values for the OF is called the optimum population members. Meanwhile, the candidate solution is upgraded, and the optimal population member is upgraded in all the iterations. The procedure of upgrading the location of coatis (candidate solution) from the COA depends on modeling 2 strategies of coatis in nature.

The initial stage of upgrading the coati's population from the searching space can be modeled according to the simulation of the strategy while attacking iguanas. In the presented method, the location of the best members of the population has considered the location of the iguana. Consequently, the location of coatis increasing in the tree can be simulated mathematically as follows.

$$X_i^{P1}: x_{i,j}^{P1} = \chi_{i,j} + r \cdot (Iguana_j - I \cdot x_{i,j}), for\ i = 1, 2, , \left\lfloor \frac{N}{2} \right\rfloor\ and\ j = 1, 2, \ldots, m. \tag{8}$$

Afterwards, the iguana falls to the ground; it can be positioned in an arbitrary location from the searching space. With that regard, coatis on the ground move from the searching space that is formulated by the subsequent expression.

$$Iguana^G: Iguana_j^G = lb_j + r \cdot (ub_j - lb_j), j = 1, 2, \ldots, m \tag{9}$$

$$X_i^{P1}: x_{i,j}^{P1} = \begin{cases} x_{i,j} + r \cdot (Iguana_j^G - I \cdot x_{i,j}), & F_{Iguana^G} < F_i, \\ x_{i,j} + r \cdot (x_{i,j} - Iguana_j^G), & else, \end{cases} \tag{10}$$

For $i = \left\lfloor \frac{N}{2} \right\rfloor + 1, \left\lfloor \frac{N}{2} \right\rfloor + 2, \ldots, N$ and $j = 1, 2, \ldots, m$. Fig. 2 illustrates the steps involved in COA.

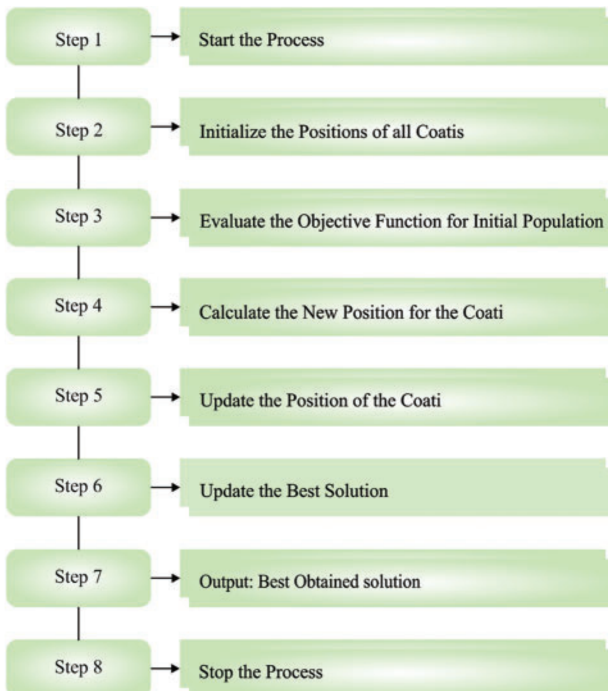

Figure 2: Steps involved in COA

The novel location evaluated for every coati has satisfactory for the updating procedure if it enhances the value of OF, or else, the coati remains in the preceding location. This can be expressed by:

$$X_i = \begin{cases} X_i^{P1}, & F_i^{P1} < F_i, \\ X_i, & else. \end{cases} \tag{11}$$

Now, X_i^{P1} denotes the novel location evaluated for ith coatis, $\chi_{i,j}^{P1}$ is its jth dimension, F_i^{P1} represent the OF values, r indicates a random integer ranging from zero to one, *Iguana* denotes the iguana's location in the search space that describes the location of the best member, $I.quana_j$ represent the jth dimensions, I indicate the integer that is chosen at random within $\{1, 2\}$, $I.quana^G$ indicates the location of an iguana on the ground that is produced at random, $Iguana^G$ denotes its jth decision parameter, F_{Iguana^G} implies the value of OF, and the floor function (greatest integer function).

In the exploitation phase, the location updating of coatis from the searching space can be modeled mathematically according to the behaviors of coatis naturally while encountering predators and escaping from the predators. Coati's move in these strategies results in it being in a safer location closer to the present location that, represents the exploitation capability of COA in local search. For stimulating these behaviors, a random location is produced nearby the location where every coati is positioned according to the following expression:

$$lb_j^{local} = \frac{lb_j}{r}, ub_j^{local} = \frac{ub_j}{t}, whereas\ t = 1, 2, \ldots T. \tag{12}$$

$$X_i^{P2}: \chi_{i,j}^{P2} = \chi_{i,j} + (1 - 2r) \cdot \left(lb_j^{local} + r \cdot \left(ub_j^{local} - lb_j^{local}\right)\right), \tag{13}$$

$$i = 1, 2, \ldots, N, j = 1, 2, \ldots, m,$$

The recently estimated location is satisfactory when it increases the value of OFs that these conditions simulate as follows:

$$X_i = \begin{cases} X_i^{P2}, & F_i^{P2} < F_{i'} \\ X_i, & else, \end{cases} \tag{14}$$

In Eq. (14), X_i^{P2} represent the novel location evaluated for ith coatis, $\chi_{i,j}^{P2}$ indicates the jth decision variable, F_i^{P2} shows the value of OF, r denotes the random integer within [0, 1], t represents the iteration counter, lb_j^{local} and ub_j^{local} represent the local lower, as well as upper boundaries of jth dimensional correspondingly, lb_j and ub_j, denote the lower as well as upper bounds of the jth parameter, correspondingly. Afterwards, the location of every coati from the searching space was upgraded according to the initial and second stages, thus, the iteration of COA can be accomplished. The method of upgrading the population, by using Eqs. (8) to (14) is iterated still the final iteration of this technique. When the run of COA finishes, an optimal solution attained in each technique iteration is returned as the outcome.

Algorithm 1: Pseudocode of COA

Begin COA

Input the optimization problem information.

Set the number of iterations T and the amount of coatis N.

Initialize the position of each coati based on Eq. (5) and assessment of the OF for these initial populations.

For $r = 1: T$

Upgrade the position of the iguana by using the position of the optimum member of the population.

Phase1: Hunting and attacking strategies on the iguana (Exploration Stage)

For $i = 1: \lfloor N/2 \rfloor$

Evaluate novel location for *i-th* coati based on Eq. (8).

Upgrade location of *i-th* coati based on Eq. (11).

End for

For $= 1 + \lfloor N/2 \rfloor: N$

Evaluate the random location for the iguana based on Eq. (9).

Evaluate new position for *i-th* coati dependent upon Eq. (10).

Update position of *i-th* coati based on Eq. (11).

End for

Phase2: The procedure of escaping in predator (Exploitation Stage)

Evaluate the local bounds for parameters through Eq. (12).

For $i = 1: N$

(Continued)

Algorithm 1: Continued

Evaluate the new location for *i-th* coati based on Eq. (13).
Upgrade the location of *i-th* coati based on Eq. (14).
End for
Save the better candidate solution.
End for
The output of optimal solution by COA.
End COA

3.3 Process Involved in Routing Technique

The presented COAER-UAVC technique concentrates on the design of fitness functions to minimize energy utilization and communication delay. The latency and energy consumption of the method was determined in the subsequent. The potential of UAVs has included 3 portions.

$$T_{\mathrm{all}} = T_1 + T_2 + T_3 \tag{15}$$

whereas T_1 implies the latency of flights of UAV in CH to the data center. T_3 simulates the delay of flights of UAVs in the data center to the last node. The T_2 has been collected in 2 portions.

$$T_2 = T_{21} + T_{\mathrm{ij}} \tag{16}$$

In which T_{21} refers to the latency of residence times for UAV (reception time and data broadcast, and developing time of the transmission link between UAV and node), T_{ij} represents the latency of flights in node *i* to node j. At this point, H defines the height of the UAV aboveground. R_{i} stands for the broadcast range of nodes *i*. T_{c} denotes the latency of increasing transmission link in node i to UAV. L_{c} illustrates the flight connection for creating transmission between *i* and UAV. Because of the data transferred length (f_{d}) and bit per second (V_{c}), the kind of transmission chip remains similar and T_{c} has been determined as:

$$\tau_{\mathrm{c}} = l_{\mathrm{d}} l V_{\mathrm{c}} \tag{17}$$

Also, the speed (V_{U}) of UAV is for meeting the provided situation in the subsequent:

$$V_{\mathrm{U}} <= L_{\mathrm{C}}/T_{\mathrm{C}} \tag{18}$$

$$T_{21} = T_{\mathrm{C}} + T_S \tag{19}$$

whereas T_{s} stands for the data forwarded latency between node as well as UAV. Once the visited nodes are n that dependent on the Eqs. (15) to (19), T_{all} is expressed as:

$$T_{all}, = T_1 + \sum\nolimits_1^n \left(T_C + T_S + T_{ij}\right) + T_3 \tag{20}$$

In which T_{ij} determines the flight time in node *i* and node j. The energy consumption of UAVs has contained 3 portions.

$$P_{\mathrm{all}} = P_1 + P_2 + P_3 \tag{21}$$

whereas P_1 depicts the energy consumption of flights of UAV in CH to the data center. T_3 signifies the energy use of flights of UAV in the resultant node to the data center. The P_2 has 2 portions.

$$P_2 = P_{21} + P_{\mathrm{ij}} \tag{22}$$

whereas P_{21} represents the energy consumption of UAVs, P_{ij} denotes the energy utilization of flights from node i to node j.

$$P_{oll} = P_1 + \sum_{1}^{n} \left(P_C + P_S + P_{ij}\right) + P_3 \tag{23}$$

where T_1, T_3, P_1 and P_3 are also significant. Because the data length of data maximum then, T_C, T_S, P_C and P_S are also maximum.

The main function of the MRP technique is for reducing delay and energy consumption. The delay or energy utilization has been chosen by frequent visits of UAVs. Thus, it could be determined as:

$$\min f(L) = \sum_{l=1}^{n-1} d_{L_i L_{i+1}} \tag{24}$$

whereas L stands for the node series.

4 Results and Discussion

In this section, the routing performance of the COAER-UAVC approach was examined in detail. The proposed model is simulated using the MATLAB tool.

Table 1 and Fig. 3 provide a comparative analysis of the COAER-UAVC model with other approaches concerning throughput (THRO). The simulation values inferred that the COAER-UAVC model has gotten higher THRO values. For instance, on 10 UAVs, the COAER-UAVC model has provided an improved THRO of 0.9765 Mbps while the energy efficient neuro fuzzy based clustering with multi-hop routing protocol (EENFNC-MRP), krill herd optimization algorithm (KHOA), grey wolf optimizer (GWO), ACO algorithm (ACOA), and particle swarm optimization algorithm (PSOA) models have reached lower THRO values of 0.9513, 0.9380, 0.9262, 0.9143, and 0.8877 Mbps respectively. In addition, on 60 UAVs, the COAER-UAVC approach has provided enhanced THRO of 0.8581 Mbps while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA models have attained lesser THRO values of 0.7783, 0.6762, 0.5845, 0.5313, and 0.4455 Mbps correspondingly.

Table 1: Throughput analysis of COAER-UAVC approach with other approaches under varying UAVs

Throughput (Mbps)						
No. of UAVs	COAER-UAVC	EENFNC-MRP protocol	KHOA protocol	GWOA protocol	ACOA protocol	PSOA protocol
10	0.9765	0.9513	0.9380	0.9262	0.9143	0.8877
20	0.9750	0.9277	0.8581	0.8226	0.7738	0.7221
30	0.9543	0.8922	0.7975	0.7221	0.6570	0.6378
40	0.9424	0.8596	0.7516	0.6659	0.6111	0.5372
50	0.8996	0.8079	0.6954	0.6023	0.5727	0.4810
60	0.8581	0.7783	0.6762	0.5845	0.5313	0.4455
70	0.8300	0.7590	0.6511	0.5520	0.5224	0.4337
80	0.8197	0.7443	0.6511	0.5446	0.5165	0.4159
90	0.8093	0.7502	0.6289	0.5180	0.5017	0.4189
100	0.7975	0.7309	0.6171	0.5194	0.4928	0.4130

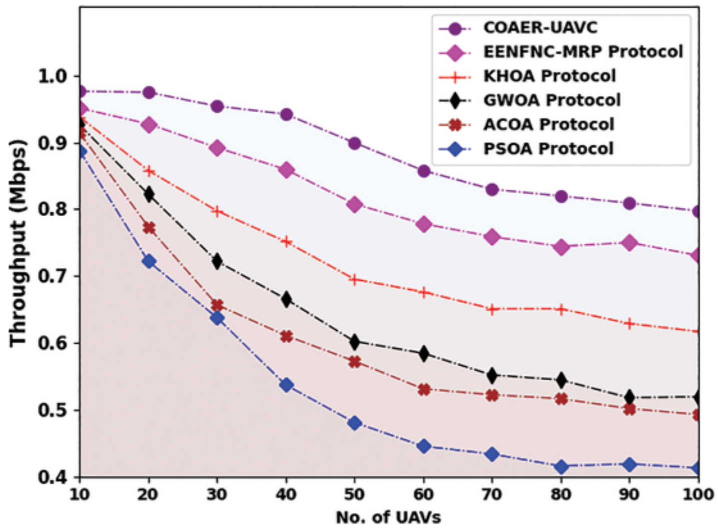

Figure 3: Throughput analysis of COAER-UAVC approach under varying UAVs

A comparative energy consumption (ECON) inspection of the COAER-UAVC model is made under various UAVs in Table 2 and Fig. 4. The outcomes revealed that the COAER-UAVC algorithm has attained the least values of ECON. For sample, on 10 UAVs, the COAER-UAVC model has resulted in a minimum ECON of 31 mJ while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA models have provided a maximum ECON of 32, 38, 39, 48, and 60 mJ respectively. Meanwhile, on 60 UAVs, the COAER-UAVC approach has resulted in a lesser ECON of 110 mJ while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA methodologies have provided a maximum ECON of 123, 147, 159, 173, 188 mJ correspondingly.

Table 2: ECON analysis of COAER-UAVC approach with other approaches under varying UAVs

Energy consumption (mJ)						
No. of UAVs	COAER-UAVC	EENFNC-MRP protocol	KHOA protocol	GWOA protocol	ACOA protocol	PSOA protocol
10	31	32	38	39	43	60
20	51	54	60	66	72	87
30	67	74	85	91	99	121
40	81	92	100	112	126	146
50	99	108	126	142	156	169
60	110	123	147	159	173	188
70	114	134	161	169	188	202
80	124	147	169	191	198	214
90	132	158	177	195	205	222
100	143	174	184	199	215	225

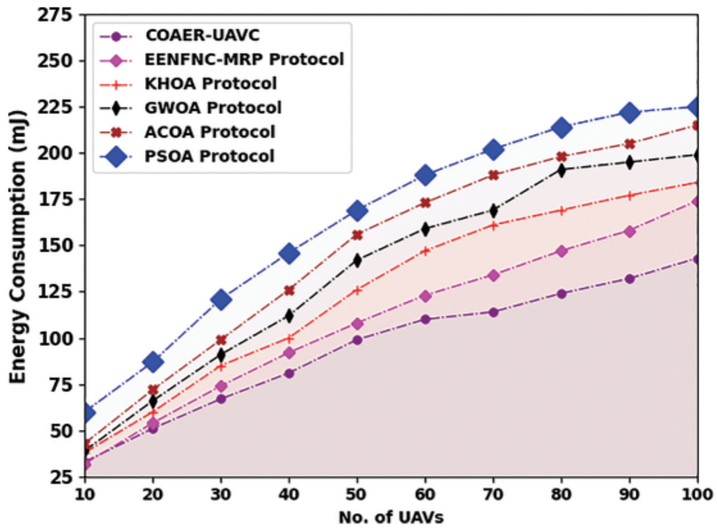

Figure 4: ECON analysis of COAER-UAVC approach under varying UAVs

In Table 3 and Fig. 5, a comparative analysis of the COAER-UAVC methodology with other methods concerning network lifetime (NLT) is provided. The simulation values stated that the COAER-UAVC model has gotten superior NLT values. For instance, on 10 UAVs, the COAER-UAVC algorithm has provided an improved NLT of 5760 rounds while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA approaches have reached lower NLT of 5638, 5270, 5169, 4881 and 4419 rounds correspondingly. Besides, on 60 UAVs, the COAER-UAVC approach has provided a greater NLT of 4974 rounds, while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA methodologies have achieved lower NLT of 4599, 4477, 4160, 3871 and 3641 rounds correspondingly.

Table 3: NL analysis of COAER-UAVC approach with other approaches under varying UAVs

Network lifetime (Rounds)						
No. of UAVs	COAER-UAVC	EENFNC-MRP protocol	KHOA protocol	GWOA protocol	ACOA protocol	PSOA protocol
10	5760	5638	5270	5169	4881	4419
20	5731	5551	5277	5082	4729	4419
30	5573	5385	5090	4816	4607	4282
40	5400	5183	4982	4715	4390	4080
50	5169	4945	4837	4491	4037	3821
60	4974	4599	4477	4160	3871	3641
70	4722	4369	4189	3893	3727	3381
80	4535	4203	3821	3547	3446	3215
90	4405	3850	3634	3338	3201	3057
100	4095	3857	3554	3316	3151	3035

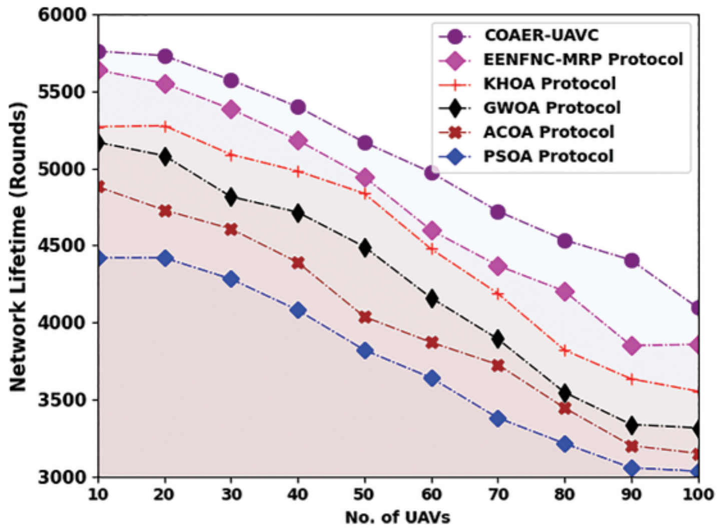

Figure 5: NLT analysis of COAER-UAVC approach under varying UAVs

In Table 4 and Fig. 6, a comparative investigation of the COAER-UAVC algorithm with existing systems in terms of packet delivery ratio (PDR) is provided. The resultant values pointed out that the COAER-UAVC approach has gotten superior PDR values. For sample, on 10 UAVs, the COAER-UAVC model has provided an improved PDR value of 97.78%, while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA methodologies have obtained lesser PDR values of 89.95%, 85.91%, 82.63%, 91.97%, and 72.78% respectively. Followed by 60 UAVs, the COAER-UAVC approach has provided an enhanced PDR of 82.88%, while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA models have gained minimum PDR values of 64.45%, 52.33%, 46.27%, 37.94% and 31.12 correspondingly.

Table 4: PDR analysis of COAER-UAVC approach with other approaches under varying UAVs

Packet delivery ratio (%)						
No. of UAVs	COAER-UAVC	EENFNC-MRP protocol	KHOA protocol	GWOA protocol	ACOA protocol	PSOA protocol
10	97.78	89.95	85.91	82.63	91.97	72.78
20	97.52	89.70	80.10	67.48	71.52	55.11
30	96.01	83.38	69.25	56.88	51.83	39.46
40	92.47	78.84	64.70	52.33	44.76	33.14
50	88.69	71.27	58.64	50.56	39.46	31.12
60	82.88	64.45	52.33	46.27	37.94	31.12
70	74.80	57.89	48.54	44.76	35.42	31.88
80	71.52	50.06	47.03	44.76	35.92	29.86
90	67.98	48.80	46.78	44.76	36.17	28.85
100	66.22	51.07	46.52	44.00	35.16	28.60

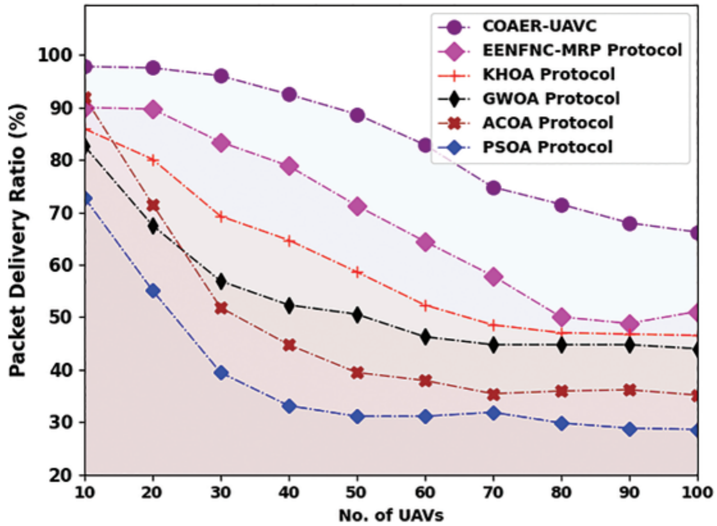

Figure 6: PDR analysis of COAER-UAVC approach under varying UAVs

A comparative packet loss rate (PLR) examination of the COAER-UAVC algorithm is made under various UAVs in Table 5 and Fig. 7. The outcome exposed that the COAER-UAVC system has reached the least values of PLR. For the sample, on 10 UAVs, the COAER-UAVC approach has resulted in lesser PLR of 2.22% while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA methodologies have provided superior PLR of 10.05%, 14.09%, 17.37%, 8.03% and 27.22% correspondingly. In the meantime, on 60 UAVs, the COAER-UAVC approach has resulted in a minimum PLR of 17.12% while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA algorithms have provided higher PLR of 35.55%, 47.67%, 53.73%, 62.06% and 68.88% correspondingly.

Table 5: PLR analysis of COAER-UAVC approach with other approaches under varying UAVs

Packet loss rate (%)						
No. of UAVs	COAER-UAVC	EENFNC-MRP protocol	KHOA protocol	GWOA protocol	ACOA protocol	PSOA protocol
10	2.22	10.05	14.09	17.37	8.03	27.22
20	2.48	10.30	19.90	32.52	28.48	44.89
30	3.99	16.62	30.75	43.12	48.17	60.54
40	7.53	21.16	35.30	47.67	55.24	66.86
50	11.31	28.73	41.36	49.44	60.54	68.88
60	17.12	35.55	47.67	53.73	62.06	68.88
70	25.20	42.11	51.46	55.24	64.58	68.12
80	28.48	49.94	52.97	55.24	64.08	70.14
90	32.02	51.20	53.22	55.24	63.83	71.15
100	33.78	48.93	53.48	56.00	64.84	71.40

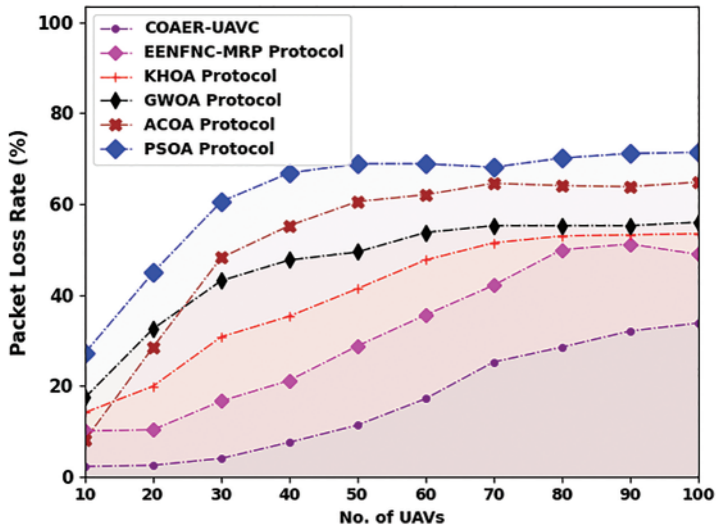

Figure 7: PLR analysis of COAER-UAVC approach under varying UAVs

A comparative average delay (AD) study of the COAER-UAVC technique is made under various UAVs in Table 6 and Fig. 8. The outcomes pointed out that the COAER-UAVC approach has gained the least values of AD. For the sample, on 10 UAVs, the COAER-UAVC algorithm has resulted in minimum AD of 0.15 s while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA systems have provided maximum AD of 0.11, 0.27, 0.30, 0.84 and 1.90 s correspondingly. Moreover, on 60 UAVs, the COAER-UAVC system has resulted in minimum AD of 3.16 s while the EENFNC-MRP, KHOA, GWO, ACOA, and PSOA approaches have provided maximum AD of 5.37, 6.70, 7.46, 9.33 and 10.66 s correspondingly.

Table 6: AD analysis of COAER-UAVC approach with other approaches under varying UAVs

Average delay (s)						
No. of UAVs	COAER-UAVC	EENFNC-MRP protocol	KHOA protocol	GWOA protocol	ACOA protocol	PSOA protocol
10	0.15	0.11	0.27	0.30	0.84	1.90
20	0.38	0.72	1.22	2.13	3.08	4.20
30	0.88	1.75	2.25	3.66	5.41	6.43
40	1.83	3.39	4.57	5.33	7.01	8.30
50	2.55	4.72	5.37	6.21	7.96	9.54
60	3.16	5.37	6.70	7.46	9.33	10.66
70	4.27	6.06	7.46	8.19	10.51	11.89
80	4.91	7.08	8.15	9.22	11.27	12.45
90	5.60	7.62	8.80	10.06	12.45	13.73
100	6.47	7.88	9.33	10.59	13.71	15.19

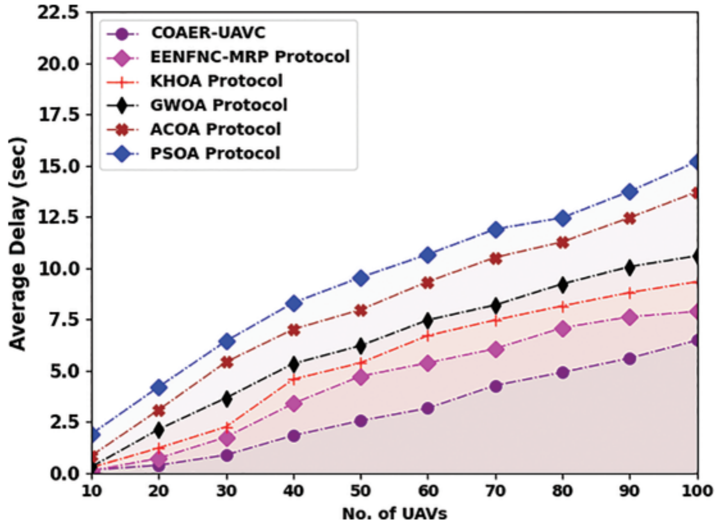

Figure 8: AD analysis of COAER-UAVC approach under varying UAVs

These extensive result analyses showcased the enhanced performance of the COAER-UAVC model on UAV communication.

5 Conclusion

In this study, we have introduced a new COAER-UAVC technique for effective UAV communication. The presented COAER-UAVC technique concentrated on the identification of optimal routes for communication between the UAVs. It is primarily based on the coati characteristics in nature: if attack and hunt iguanas and escaping from the predators. Besides, the presented COAER-UAVC technique concentrates on the design of fitness functions to minimize energy utilization and communication delay. To depict the optimum performance of the COAER-UAVC system, a varied group of simulations was performed. The experimental outcomes verified that the COAER-UAVC model has assured enhanced performance over other approaches. In the future, data aggregation techniques can be applied to improve UAV communication results.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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