

# A Hybrid Optimization Solution for UAV Network Routing

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**ABSTRACT**

An Unmanned Aerial Vehicle (UAV) network specifies a novel type of Mobile Ad hoc Network (MANET) in which drones serve as nodes and facilitate the retransmission of messages to their final destinations. Aside from its military application, it has recently begun to seep into the civilian sector. Similar to MANET and vehicular ad hoc networks, Flying Ad hoc Networks (FANET) are a subset of ad hoc networks. An FANET is different because it is founded on UAVs. Due to the characteristics of this sort of network, which is defined by a highly changing topology in a 3D environment, we must employ an adjusted configuration method to ensure good routing performance. Therefore, to deal with this problem, a technique that responds to any change in topology by always finding the best route is required. In this work, we propose a new protocol based on the hybrid optimization of the 2-opt heuristic and Honey Badger Algorithm (HBA), called HB-AODV. In order to locate its prey, a badger must move slowly and continuously while using scent markers and mouse-digging skills to catch it. In other words, the most efficient routes in terms of the number of hops are identified. Several simulations were conducted via the 3D version of Network Simulator (NS-2) on different deployment strategies. In comparison to AODV, DSDV, and AntHocNet, the obtained results demonstrated the proposed scheme's good performance in terms of quality of service metrics.

*Keywords-ad hoc networks; UAV network ; honey badger algorithm; heuristic ; optimization ; 3D environment*

## I. INTRODUCTION

At present, wireless technologies offer interesting prospects in the telecommunications area. Ad hoc networks include a set of mobile entities that move arbitrarily, interconnected with each other by wireless technology and organize themselves without a previously defined infrastructure. This type of network has limited bandwidth, energy constraints, limited security, unpredictable topology, and heterogeneous nodes. There are many different ways that ad hoc networks can be put to use. We reference the most well-known example of their application, which is in the realm of military operations, in addition to other tactical applications, such as rescue and research missions. To retransmit messages to their final destinations, UAVs construct a novel type of MANET with drones as nodes [1]. Recent studies have been conducted on the development of collaborative multi-drone systems, where many drones work together to complete a mission with improved performance [2-6].

Many industries, including agriculture, arts (television, cinema, tourism development), cartography (public works, geo-referencing), environment (natural disasters, flora detection, counting and detection of fauna), health- (transportation of emergency materials and medicines), and fire safety, have found use for FANETs. In networks like MANETs, Vehicle Ad hoc Networks (VANETs), or FANETs, each node serves as a terminal or a router. An ad hoc protocol creation must take into account issues such as mobility, unexpected changes in topology, route maintenance, and energy management during packet routing. Routing is a critical problem in ad hoc networks since it ensures that any two nodes in the network are connected at any time, determines valid routes from a source to every precise destination, maintains these routes, and adapts them to topology changes. Proactive, reactive, and hybrid routing methods can be categorized based on how the routes are created and maintained throughout data routing (Figure 1).

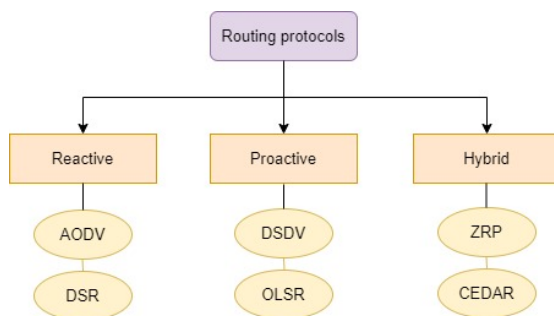


Fig. 1. Routing protocol classification.

Networks using proactive routing techniques ensure that all feasible destinations can be reached at any given time. Even if a route is never utilized, it is preserved. The paths' update messages interchange continuously, ensuring a permanent update of the routing tables. DSDV [7] and OLSR [8] are two examples of proactive routing protocols. In order to provide routing services in wireless networks, reactive protocols, or on-demand routing protocols, have been introduced. Protocols of this category construct and maintain routes when needed.

Routing information can only be obtained by conducting route discovery procedures when the network needs a route. AODV [9] and DSR [10] are two examples. Hybrid protocols, e.g. ZRP [11], try to combine the advantages of the two prior techniques in order to reap the benefits of both.

Observing nature has led researchers to adapt the principles observed in natural phenomena to develop effective algorithms for solving certain difficult problems. A new era is opening with nature-inspired (bio-inspired) algorithms, which are metaheuristics imitating nature to solve optimization problems. Bio-inspired approaches for solving problems have immense potential for research, specifically in the area of routing for all types of ad hoc networks. Ad hoc network routing issues can be resolved using bio-inspired algorithms. In the current article:

- FANET routing protocols are discussed, including traditional proactive, reactive, and hybrid routing methods as well as bio-inspired methods based on various metaheuristics.
- HB-AODV, a routing algorithm for UAVs networks, is described in detail.
- The proposed protocol has been thoroughly analyzed in the field of a FANET. The findings in NS-2.35, in its 3D version, simulations and deployment strategies, all with random waypoint mobility and Free-Space propagation model, are presented along with the analysis's main conclusions.

## II. RELATED WORKS

For their study on traffic monitoring in FANETs, the authors in [12] relied on OSLR routing. From the simulation findings, it is deduced that the OSLR routing protocol is not optimal for low-density, highly dynamic FANETs due to its excessive overhead. However, OSLR allows quick connection and minimal delay. To ensure efficient and secure data transmission in UAV networks, the LTA-OLSR protocol (link-quality and traffic-load aware) was developed in [13]. The Received Signal Strength Indication (RSSI) of packets is analyzed to determine the quality of the link between a node and its neighbors. With channel contention at the MAC layer and the number of packets held in the buffer in mind, the authors devised a traffic load method to ensure light-load routing. Authors in [14] analyzed FANET connectivity using AODV routing. The simulation findings demonstrate that the AODV protocol delivers excellent network connectivity with a high packet delivery ratio while being responsive to a variety of network conditions. A hybrid of on-demand routing and the Reynolds method for keeping routes and connections up and running for data transmission was presented in [15] as BR-AODV in order to keep communication between UAVs stable despite frequent topology changes. The AODV protocol was used because it enables the UAV nodes to obtain routes on demand, making it ideal for real-time message transmission between UAVs. In terms of packet delivery ratio, end-to-end delay, and packet loss, BR-AODV outperforms AODV.

Link state routing is contrasted with a reactive routing strategy proposed in [16]. For the precision agriculture scenario, in which unexpected climate changes pose a serious

threat to crops and cultivation quality, the Reactive Flooding Routing (RFR) was proposed. UAVs are equipped with a specialized sensor that sends data to farmers in real time. UAV deployment was addressed in [17] to set up a wireless network for usage in situations such as disaster relief, search and rescue, and user connectivity in hostile or remote locations. To account for both ground-to-air and air-to-air propagation, the authors suggested a mathematical approach. Both the traditional CPLEX branch-and-cut algorithm and the hybrid metaheuristic Biased Randomized-Iterated Local Search (BR-ILS) were employed to optimize the mixed integer linear programming formulation. The latter was suggested as a means to simultaneously attain optimal or near-optimal answers at a lower computing cost. The experimental results demonstrated that BR-ILS significantly outperformed CPLEX solver for both small and large-sized instances in terms of performance metrics chosen on cases for which CPLEX could find an optimal solution. Due to the need to maximize the minimal data transmission throughput, the authors in [18] proposed a dual sampling bandwidth efficient transmission technique in relation to the UAV flight trajectory. They devised a recursive algorithm that alternatively optimizes bandwidth scheduling and UAV trajectory to get the best solution. Additionally, the algorithm enabling the Dual-Sampling (DS) technique has been iterated with power balance in mind at every step. While the DS approach consumed the second-least energy over extended time periods, it had the highest max-min average data rate. Authors in [25] employed the Genetic Algorithm (GA) to provide the best data operation routes and extend the life of wireless sensor networks by reducing energy consumption. The GA's performance was compared with that of TEEN algorithm.

In [26], the authors presented a self-organization-based clustering technique for cluster formation and management that was inspired by a behavioral study of Glowworm Swarm Optimization (GSO). The choice of the cluster head and the creation of the cluster both depend on the UAVs' connection with the ground control station as well as the value of their luciferin and the amount of energy they have left over. The technique for managing the cluster uses GSO's behavioral research by continually revising the luciferin value in accordance with the location of the UAVs. In addition, they provided a system for route selection for effective communication that depended on the neighbor range, residual energy, and location of the UAV. The harmony search method was modified in [27] to identify the best solution to the cell placement problem. The experimental results demonstrate that this algorithm is effective for resolving the investigated

problem and is characterized by good performance, solution quality, and optimality likelihood. In the same context, the research presented in [28] presents a Red Deer Optimization Algorithm Inspired by Clustering-based Routing Protocol (RDOAICRP) for reducing the problems of instability and mobility that arise during the process of distributing trustworthy data in FANETs. The proposed algorithm included the advantages of the Red Deer Optimization Algorithm for the selection of cluster heads and the generation of energy-aware clusters. In order to ensure effective communication, this system made use of a function for route recognition that was determined by the distance between the UAVs, the number of nearby neighbors, and the weighted residual energy. The feasibility of the proposed RDOAICRP was investigated using the benchmarked clustering-based routing protocols in terms of the cluster lifespan, the likelihood of successful packet delivery, the amount of energy used, and the amount of the time required for cluster building.

The Cluster Based Routing Protocol (CBRP), a single path MANET protocol, was improved in [29] to employ multiple paths. To lessen network traffic congestion and delay, the traffic will be split up across several paths. For both the multipath and single path CBRP routing protocols in MANETs, an analytical model was utilized to calculate the end-to-end delay and queue length. The analytical findings demonstrated the efficiency of the suggested plan. The authors in [30] proposed a bio-inspired clustering technique for FANETs called BICSF. This approach employs a hybrid process that combines GSO with Krill Herding (KH). The GSO method is used for the generation of energy-aware clusters and the selection of cluster heads in the system. In addition, an effective cluster management algorithm was presented that makes use of the behavioral research of KH. This algorithm makes use of genetic operators such as mutation and crossover in order to locate the UAV. The effectiveness of BICSF is measured in terms of the amount of time it takes to build a cluster, the amount of energy it uses, the amount of time it lasts, and the probability that a delivery will be successful using clustering algorithms based on Grey Wolf Optimization (GWO) and Ant Colony Optimization (ACO). Authors in [31] proposed an aware cluster-based route planning scheme, which is an application of Honey Badger Based Clustering with African Vulture Optimization based Routing (HBAC-AVOR) protocol for WSN and validated with comparative simulations in which it performed very well.

The discussed routing protocols are summarized in Table I.

TABLE I. RELATED WORK

Ref.	Algorithm	Year	Advantages	Disadvantages
[12]	OLSR on FANET	2018	Quick connection, minimal delay	Excessive overhead
[13]	LTA-OLSR	2018	Light-load	Introduces delays
[14]	AODV on FANET	2018	Excellent network connectivity, with a high packet delivery ratio	Introduces delays
[15]	BR-AODV	2018	High packet delivery ratio, low end-to-end delay and packet loss	Excessive overhead
[16]	RFR	2019	High packet delivery ratio	Introduces delays
[18]	DS technique	2020	Highest average data rate	Consumes more energy
[26]	GSO on FANET	2019	Good cluster construction time	Introduces routing delays
[27]	HAS	2018	Good performance and optimality likelihood	Excessive overhead
[28]	RDOAICRP	2022	Good packet delivery, delay, and energy used	Excessive overhead
[31]	HBAC-AVOR	2023	HBAC-AVOR outperformed existing techniques with maximum lifetime	Introduces more overhead

### III. THE HONEY BADGER ALGORITHM (HBA)

In the semi-deserts and tropical forests of Africa, southwest Asia, and the Indian subcontinent, a mammal with black and white fluffy fur called honey badger is found [19]. They are recognized for their brave temperament, a body length of 60 to 77cm, and a weight of 7 to 13kg. This adventurous forager eats 60 various kinds of species, including snakes, even though honey is its favorite food. It is an intelligent creature that can use tools. Only when mating with another badger does it venture out in the open. So far, 12 distinct badger species have been identified. Because cubs are born all year round, badgers have no specific breeding season. Even larger predators could not attack them given the courageous nature of the badgers. These animals can also easily climb trees. The badger uses a mouse's sense of smell to track down its prey. Digging begins the process of locating the prey's approximate position, and the animal eventually captures the prey. When searching for food, it can dig up to 50 holes in a 40-kilometer radius in a single day. The badger likes honey, although it is not very skilled at finding hives to investigate. It uses honey guides (birds) to find their hives and extract the honey. Due to this, a partnership is formed between these two animals, in which they work together to get honey from the hives by using badgers' long claws to open them. The mathematical formulation of HBA [19] follows.

1. Updating the density factor. Randomization is controlled by density factor ( $\alpha$ ), which ensures a smooth transition from exploration to exploitation. Equation (1) is used to update the decreasing factor, which decreases with time to reduce randomization.

$$\alpha = C * e^{(-t/t_{max})} \quad (1)$$

The  $t$ -value corresponds to time-varying randomization to ensure smooth transition from exploration to exploitation which is represented by the current iteration of the algorithm. This value is the principal parameter to calculate the decreasing factor  $\alpha$ .  $t_{max} = \max$  iterations possible, while  $C$  is a constant bigger or equal to 1 (default = 2).

2. Updating agent positions. The digging phase and the honey phase are the two phases of the HBA position updating process ( $x_{new}$ ).

• Digging phase: A badger engages in activity resembling the cardioid form when digging. Equation (2) simulates the cardioid motion:

$$x_{new} = x_{prey} + F * \beta * I * x_{prey} + F * r_3 * \alpha * di * |\cos(2\pi r_4) * [1 - \cos(2\pi r_5)]| \quad (2)$$

The best position thus far discovered for the prey is at position  $x_{prey}$ .  $\beta$  is the honey badger's capacity to gather food (bigger or equal to 1, default = 6),  $di$  is the distance between the honey badger and the prey,  $r_3$ ,  $r_4$ , and  $r_5$  are different random numbers between 0 and 1.  $F$  works similar to the flag that changes the direction of the search. It is determined by:

$$F = \begin{cases} 1 & \text{if } r_6 \leq 0.5 \\ -1 & \text{otherwise} \end{cases} \quad (3)$$

where  $r_6$  is a random number between 0 and 1.

The prey's odor intensity  $I$ , the distance between the badger and the prey  $di$ , and the time-varying foraging influence factor  $\alpha$ , all have a significant impact on a badger's behavior during the digging phase. A badger may also experience any disturbance  $F$  while foraging, which helps it locate its prey even more accurately.

• Honey phase: To recreate the scenario where a badger follows a honey guide bird to the hive, do:

$$x_{new} = x_{prey} + F * r_7 * \alpha * d \quad (4)$$

where  $r_7$  is a random number between 0 and 1.  $x_{new}$  denotes the badger's new location and  $x_{prey}$  denotes the prey's location. Equations (3) and (1) are used to calculate  $F$  and  $\alpha$ , respectively. According to (4), a badger explores close to the location where  $x_{prey}$  has so far been discovered based on  $di$ . At this point, the time-varying search behavior ( $\alpha$ ) has an impact on the search. A badger might also discover a disturbance  $F$ .

The HBA flowchart, including population initialization, population evaluation and parameter update is given in Figure 2.

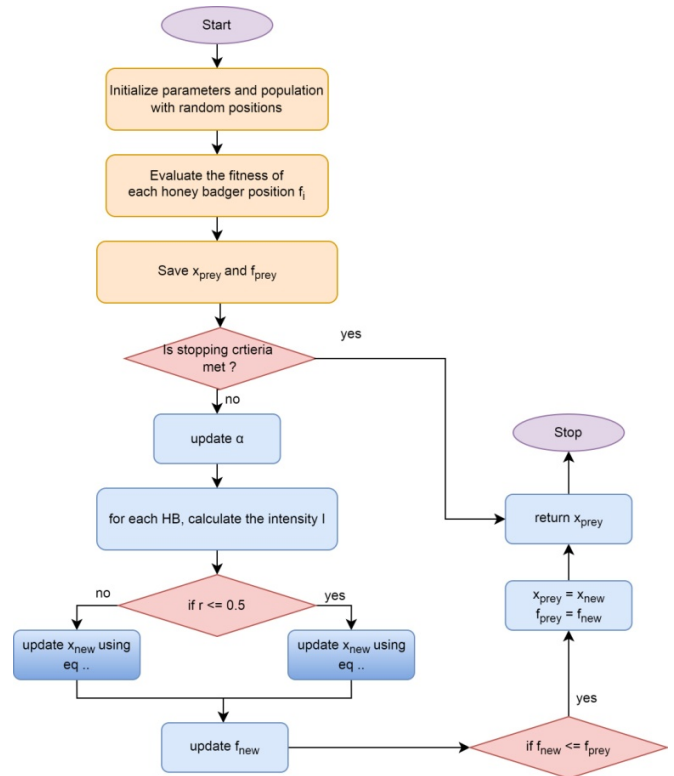


Fig. 2. HBA steps.

### IV. THE PROPOSED HB-AODV APPROACH

The purpose behind using the HBA is that this technique seeks to create a balance amongst the exploration and exploitation stages by traveling the searching space rapidly and avoiding local optimal solutions. In addition, the HBA is

proven effective in resolving empirical problems with difficult searching spaces.

A. Mapping between Communication in HBA and FANET

An analogy between HBA (implemented in HB-AODV) and MANETs is shown in Table II, where the process mapping between them is carried out.

B. Detailed Approach

Our approach begins with the implementation of the HB-AODV protocol step by step and is followed by the creation of simulation scenarios, in order to test how the proposed routing protocol performs. We consider the AODV reactive protocol, the basis of our work is to improve its performance with the HBA metaheuristic. Finding the shortest path from the source node to the destination node is the objective of the HB. The proposed algorithm can be summarized in two phases:

TABLE II. MAPPING BETWEEN HBA AND MANETS

HBA	Ad hoc network
Honey badger	Node
Initial position	Source
Badger food	Destination
Possible path between honey badger and his food	Possible path
Shortest path between honey badger and his food	Shortest path between source and destination

1) 2-opt Heuristic Application for the Construction of the Initial Population

Source-to-destination topology explorations are carried out to identify a population of possible initial solutions as the starting point of the second step. The 2-opt heuristic [20], a powerful local search technique, is then performed. It is typically used to enhance a solution in hybrid techniques. The 2-opt method starts with a predetermined solution and then searches in its neighborhood to optimize the current configuration. The topology is detected following a request triggered by the source node in the event that it requires a route that is unavailable by sending RREQ (route request) reaching the destination d. This occurs when d is not known from before or if the current route to d has expired or is no longer functional. Following a set of requests acquired at the destination level, the population is constructed and processed by the HBA. We modified the format of the RREQ to keep track of the nodes through which it passed [21], by adding a record\_path field (see Figure 3), which is a vector of intermediate nodes, its identifier is added in the record\_path vector each time an intermediate node receives an RREQ to gradually build a solution.



Fig. 3. The modification of the RREQ packet.

The record\_path field is an array containing the identifiers of the nodes starting with the source node (the first box) passing through the intermediate nodes which have received RREQs associated with the source. It ends with the destination

node (the last box) d, where the whole vector represents an initial solution.

In order to generate a population of solutions, the destination saves the RREQ packet header in record\_path with the RREQs from the same source and destination. Its solution is sufficient to represent the network in the format of a graph to apply the graph theory. A graph  $G = (V, E)$  can be used to depict an UAV network of communicating stations, where the vertex set  $V$  represents the stations and the edge set  $E$  the communication links [22]. We use this information to define the links between the nodes of the graph to build an adjacency matrix (see Figure 4), following the construction of a population, where each element is a set of links between nodes, being 1 if there is a link and 0 otherwise [26].

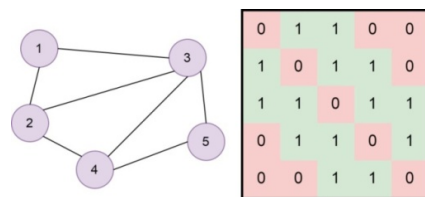


Fig. 4. An example of a graph and its adjacency matrix.

The last thing to do in this step is the application of the 2-opt heuristic. The latter checks each solution (route) in the initial population to see if exchanging two edges results in a shorter path during the improvement process. The algorithm keeps running until no further improvement is possible. The algorithm's flowchart is shown in Figure 5. The result is the initial population to be exploited in the second step.

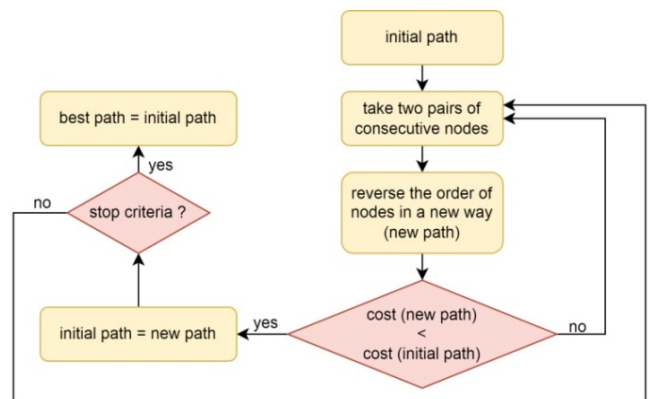


Fig. 5. 2-opt heuristic improvement.

2) Finding the Best Solution by Applying HBA

The HBA metaheuristic is used on the population that was generated in the first step. A method for finding the most efficient path between two nodes is implemented. The number of hops between the source and the destination is the metric to be optimized. The value of the objective function is found in the hop\_count field at the level of the RREQ request, and this value is suitable for the new solution calculated by (2) and (4). We have adapted these equations for our problem whilst always preserving the philosophy of the method. New solutions

are generated by using equations, with only intermediate nodes changing while the source and destination nodes kept unchanged. The process of our contribution is described in the algorithm shown in Figure 6. The result obtained by the equations is real and often invalid when compared with the adjacency matrix. In addition, our protocol provides results of positive integer type to approximate the solutions of integer value, followed by a repair process (repair algorithm) to guarantee, with high probability that valid solutions are obtained.

The result is not always valid. To repair invalid solutions, we have used a repair algorithm based on the adjacency matrix [21]. The steps of the repair algorithm are:

- The first step is to see if two consecutive nodes are connected, and if they are, they are kept. If not, move on to the next step.
- The second step is to see if the first node is connected to any of the following nodes. In this case, we only remove intermediary nodes. Otherwise, we'll move on to the next step.
- The final step is to look for a node that connects to the second node in the neighborhood of the first, and then establish a connection between the two.

An explanatory example is given in Figure 8.

Algorithm 1 HB-AODV

```

Input : Initial population, adjacency matrix AM ;
Output : Best route ;
Begin
Find the best route R in the population
for (each population solution m with random positions) do
  for (every x in m) and (x ≠ source) and (x ≠ destination) do
    Update the decreasing factor  $\alpha$  using Eq. 1
    if rand < 0.50 then then
      Update position xnew using Eq 2
    else
      Update position xnew using Eq 4
    end if
  end for
  Get a new route H
  Repair H using AM
  Update the best route by comparing R and H
end for
Save the best route to send packets
End
    
```

Fig. 6. The HB-AODV algorithm.

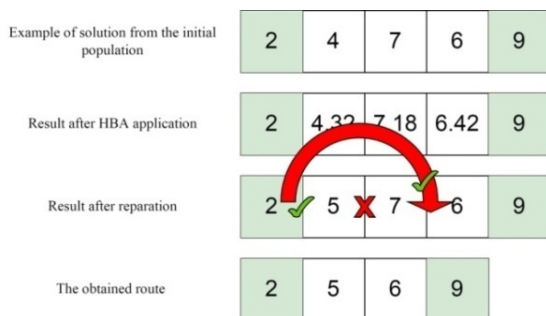


Fig. 7. An example of HBA application.

## V. IMPLEMENTATION AND EXPERIMENTAL RESULTS

### A. Implementation Details

#### 1) Simulation Platform

Using discrete event simulation, NS-2.35 is a freely available network simulator [23]. Using C++ and OTCL (Object Tool Command Language), NS-2.35 can be used on Windows or Unix systems. The development and implementation of low-level operations are done using C++, while code script simulation is conducted with OTCL (Figure 8). For the purpose of obtaining the third dimension Z for UAV movement, we added the 3D environment to NS-2.35 [24].

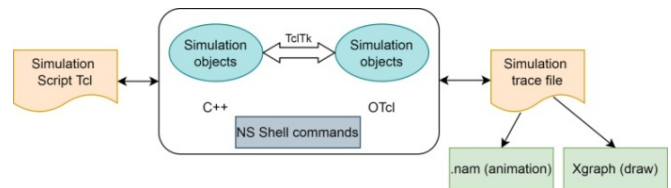


Fig. 8. General structure of NS-2.

#### 2) Simulation Parameters

Table III lists the various simulation parameters.

TABLE III. PHYSICAL CHARACTERISTICS OF MOBILE NODES

Parameter	Value
Simulator version	NS-2.35
Routing protocols	AODV, DSDV, AntHocNet, HB-AODV
Topology	1500 * 1500 * 200
Channel type	Channel/WirelessChannel
Mobility model	Random WayPoint (RWP)
Radio propagation model	Propagation/FreeSpace
Packet length	512
Antenna type	Omni directional
Simulation time	300
Number of nodes	15, 20, 25, 35
Transport agent	UDP
Speed (min/max)	5 - 15 m/sec

#### 3) Radio Propagation Model

Since there is only one direct channel between the transmitter and the receiver in the ideal scenario, we used the Free-Space Propagation Model to simulate this situation (FANET case). The communication range is shown in this form as a circle surrounding the transmitter. The receiver receives all the packets that are inside this circle. In any other case, it gets nothing.

#### 4) Mobility Model

We used the RWP model wherein the mobility of the nodes is typically random, and all the nodes are distributed uniformly within the simulation space. The destination and speed of each mobile node that aims to move are random and limited to a well-determined interval. After moving, the mobile nodes are stopped for a determined time. Then, they move again in the same way as before, until the end of the simulation.

5) Performance Metrics

We opted to compare with other routing to verify the effectiveness of the proposed protocol HB-AODV. We mainly considered the following parameters as determining the routing performance:

- Packet Delivery Ratio (PDR) is calculated by dividing the number of packets received at the destination by the number of packets sent from the source. The maximum network throughput is limited by the packet loss rate, which is specified by PDR. High PDR is an indication of a more reliable network. PDR is calculated by:

$$PDR (\%) = \frac{\sum_1^n CBR_{received}}{\sum_1^n CBR_{sent}} * 100 \tag{5}$$

- A data packet's average End-to-End Delay (E2ED) is the time it takes to move from source to destination. This metric is determined by subtracting the time it took for the source to transmit the first packet from the time it took it to reach its destination. During the latency of route discovery, the interface queues, the MAC layer retransmission delays, propagation time, and transfer are all included in this calculation. This step is critical in determining the amount of time it will take to discover a new route. Low values of E2ED denote the best possible performance for the network. E2ED is calculated by:

$$E2ED (ms) = \frac{\sum_1^n (CBR_{reception Time} - \sum_1^n CBR_{sent Time})}{CBR_{reception Time}} \tag{6}$$

- Throughput (Thr) is the rate of successfully received packets. Thr is calculated by:

$$Thr (kbps) = \frac{Delivery\ Pachets\ Number}{Reception\ Time} \tag{7}$$

VI. RESULTS AND DISCUSSION

A. PDR

Figure 9 shows how the PDR varies amongst the several routing protocols that were examined with a change in speed. PDR is higher in AODV and HB-AODV than DSDV and AntHocNet. As the number and the speed of nodes increase, HB-AODV continues to deliver satisfactory results that reach 96.73%, due to the use of the reactive approach, removes load from the network. On the contrary, in the proactive or hybrid approach, the update of the routing tables is periodic even if no request for connections (useless calculations are performed to reach destinations not requested) is made. The results of HB-AODV are better than those of AODV in terms of PDR in almost all scenarios. The chosen bio-inspired technique (HBA), dropped fewer packets than the other algorithms.

B. E2ED

Figure 10 shows that HB-AODV and AODV provide good performance in terms of the average E2ED with a change in speed. The reactive approach (with high mobility) finds a way to the destination more quickly. HB-AODV is better than AODV in some cases, due to the enhancement of the initial population using the 2-opt heuristic, and the use of a bio-inspired technique that is a fast and gives the optimum route between two nodes in reasonable time.

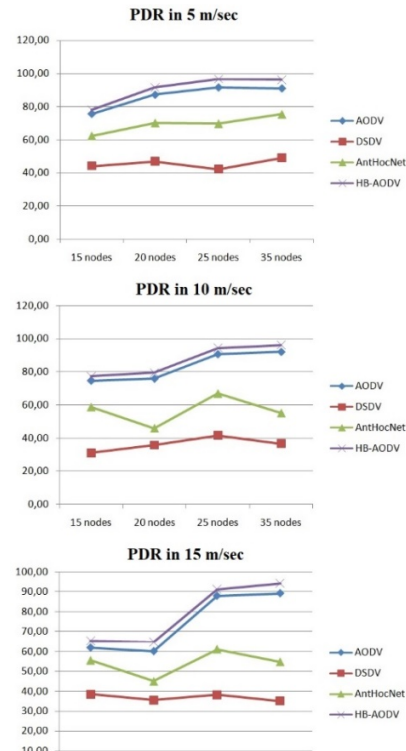


Fig. 9. PDR vs. UAVs density and speed.

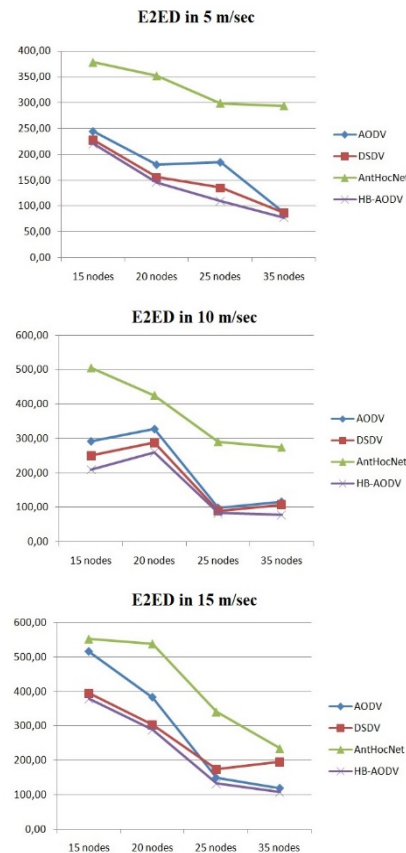


Fig. 10. E2ED vs. UAVs density and speed.

### C. Throughput

Figure 11 shows how the number of nodes affects the throughput with a change in speed of the investigated routing protocols. The AODV and HB-AODV outperform DSDV and AntHocNet in terms of throughput given the behavior of protocols of a reactive and/or bio-inspired nature (combined in the case of HB-AODV), which provides more stable links (large number of received packets) in a short time.

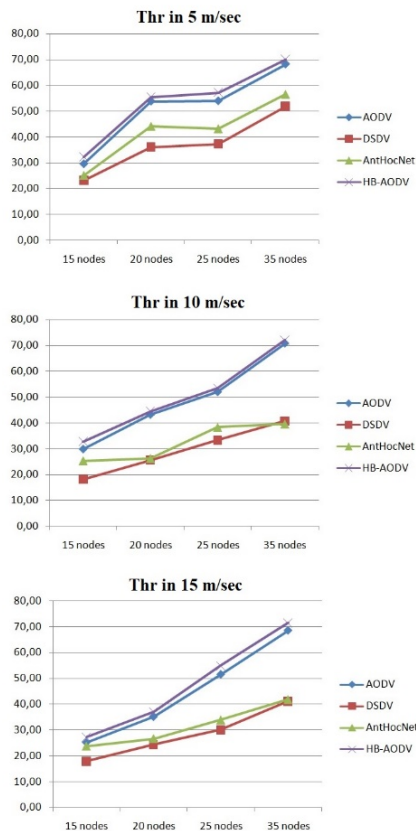


Fig. 11. Thr vs. UAVs density and speed.

By observing the results, we can conclude that when compared to the other routing protocols, HB-AODV provided an excellent compromise between the 3 performance criteria used. We finish by stating that the proposed solution is appropriate for the addressed problem.

HBA is a modern metaheuristic that mimics the foraging behavior of badgers. It shows some efficiency in terms of diversification and intensification whilst exploring the most promising areas using badger scents and by digging or tracking a honey guide bird. The efficiency, which is the goal of our study, was demonstrated by integrating this approach to deal with the routing problem at the UAV networks. We used the 3D version of NS-2 simulator to implement HB-AODV and evaluate its performance so that it could be compared with the existing protocols. Our protocol was compared with the previously mentioned protocols in terms of Quality of Service (QoS) metrics. We found that the proposed protocol performs

efficiently with good results. Its performance is impressive and could still be improved in the future. In addition, it provides packet transmission speed close to AODV's, which is more effective than AntHocNet and DSDV. The monitoring of the results indicates that the HB-AODV is an evolutionary protocol because it presents excellent findings with each extension of the network.

### VII. CONCLUSION

The effectiveness of the reactive approach including the bio-inspired aspect for solving the routing problem in UAVs network has been demonstrated in this paper, especially the HB technique, which when implemented in AODV protocol performed better than other routing protocols of various categories (AODV, DSDV, and AntHocNet), due to the rapid reaction (route discovery) and the strength of metaheuristics, as well as the reactive approach that exploits the network only during a connection request. We proposed a new reactive routing protocol which is an improvement of AODV and is based on the bio-inspired honey badger optimization algorithm and 2-opt heuristic. Simulations were conducted in NS-2.35 with the use of the free-space propagation model, which was adequate for FANET features. In comparison to AODV, DSDV, and AntHocNet, the obtained results demonstrated a very high performance of the proposed strategy in terms of PDR, E2ED, and throughput. Future work will include improvements of this approach to support multiple paths for each transmission.

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