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Elephant Herding Optimization Ad Hoc On-Demand Multipath Distance Vector Routing Protocol for MANET

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ABSTRACT Energy consumption always represents a challenge in the ad hoc networks which spurred the researchers to benefit from the bio-inspired algorithms and their fitness functions to evaluate nodes energy through the path discovery stage. In this paper we propose energy efficient routing protocol based on the well-known Ad Hoc On-Demand Multipath Distance Vector (AOMDV) routing protocol and a bio-inspired algorithm called Elephant Herding Optimization (EHO). In the proposed EHO-AOMDV the overall consumed energy of nodes is optimized by classifying nodes into two classes, while paths are discovered from the class of the fittest nodes with sufficient energy for transmission to reduce the probability of path failure and the increasing number of dead nodes through higher data loads. The EHO updating operator updates classes based on separating operator that evaluates nodes based on residual energy after each transmission round. Experiments were conducted using Ns-3 with five evaluation metrics routing overhead, packet delivery ratio, average energy consumption, end-to-end delay and number of dead nodes and four implemented protocols the proposed protocol, AOMDV and two bio-inspired protocols ACO-FDRPSO and FF-AOMDV. Results indicated that the proposed EHO-AOMDV attained higher packet delivery ratio with less routing overhead, average energy consumption and number of dead nodes over the state of art while in the end-to-end delay AOMDV has outperformed the proposed protocol.

INDEX TERMS AOMDV, elephant herding optimization, MANET, routing protocol.

I. INTRODUCTION

Mobile Ad-Hoc Networks are multi hop, self-organizing networks with highly dynamic and random topology where each node could be a sender, a receiver or a router. In MANET, peer-level communications between nodes are enabled without relying on centralized resources or fixed infrastructure. Mobile nodes mainly rely on batteries for energy, so energy efficient routing protocols have been widely investigated in MANET.

Routing in MANET is one of the major research areas with huge number of studies introducing routing protocols which we can mainly classify based on path discovery into reactive, proactive and hybrid routing protocols. In reactive routing protocols, routes are only discovered when it is needed so they could be also called on-demand routing. Different reactive routing protocols have been investigated as Dynamic Source Routing (DSR) [1]–[4], Ad-Hoc On Demand Vector Routing protocol (AODV) [5]–[9], Global State Routing (GSR) [10], [11], and Associativity-Based Routing (ABR) [12]–[14].

On the other hand, nodes in proactive routing protocols maintain a single or multiple routing tables that are regularly updated by sending broadcasting message to all other nodes to detect updates in network topology. Proactive routing protocols are also known as table-driven protocols. Destination Sequence Distance Vector (DSDV) [15]–[18], Optimized Link State Routing (OLSR) [19]–[21] and Wireless Routing Protocol (WRP) [22], [23] are some of the most investigated proactive routing protocols. Finally hybrid routing protocols combines the advantages of proactive and reactive routing protocols as the Zone Routing Protocol (ZRP)) [24]–[26] and Zone-based Hierarchical Link State Routing Protocol (ZHLS) [27], [28].

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Each type of these routing protocols could be further classified into single path as AODV, DSR and ZRP and multipath routing protocols as Ad hoc on-demand multipath distance vector routing (AOMDV) [29]–[33], Multipath Dynamic Source Routing (MP-DSR) [34], [35] and Routing On-demand Acyclic Multipath (ROAM) [36], [37].

Bio-inspired algorithms (BIAs) emulate principles of the nature and how different organisms react to different situation in life as a group or individually. BIAs proved to be more efficient and autonomous than other Artificial intelligence algorithms in unknown and changing environments as MANET. BIAs as routing protocols in MANET was investigated in many proposed studies as in [38]–[43]. While other researchers believe that the main objective of using BIAs in MANET is to optimize nodes energy as it is one of the main factors that affect the Quality of Service (QoS) Metrics. So many studies have proposed energy efficient routing protocols relying BIAs, emulating the living organisms as ants, bees or even bats in finding the shortest path with less consumed energy as Ant Colony [44]–[47], Particle Swarm Optimization [48]–[52], Bee Colony [53]–[57], Immune System [58], Fish swarm [59] and Bat algorithm [60].

Most of the BIAs proposed as routing protocols for MANET, have been proposed as a hybrid with one of the known multipath routing protocols as AOMDV and MP-DSR for balancing between discovering the best and shortest paths, balancing data load among these paths and conserving nodes energy to reduce the number of the dead nodes and saving network from portioning. So in this study we present an energy efficient hybrid routing protocol of the on-demand multipath routing protocol AOMDV which had proved very promising results in different previous studies and one of the powerful BIAs, the Elephant Herding Optimization (EHO) algorithm. EHO is one of the most investigated bio inspired optimization algorithms in the last decade in different fields as solving benchmark problems [61], Energy-Based Localization [62], image thresholding [63], proportional integral derivative controller tuning [64] and Scheduling in Smart Grid identification [65]. As far as we know EHO hasn't been investigated before as a routing protocol in MANET.

EHO is inspired by elephant social behavior through living in clans containing only the fittest elephants where the weak elephant are excluded. So in this paper we tried to simulate the elephants' behavior by classifying nodes into two clans or classes where the fittest nodes for transmission with enough nodal residual energy will be classified in class one while the rest will be in class two. The shortest paths discovery will be proceeded using AOMDV where incase of any path failure nodes will be reevaluated using EHO updating operator. All discovered paths will be sorted discerningly before data transmission as the data load will be balanced among the discovered paths based on the path energy with respect to all paths energy.

This paper is organized as following. Section 2 covers the related work. While section 3 introduces both the Elephant herding optimization algorithm and the proposed Elephant herding optimization- Ad hoc on-demand multipath distance vector routing protocol (EHO-AOMDV) in details. Section 4 presents the experimental setup and performance analysis. Section Finally Section 5 outlines main conclusions and presents some future work.

II. RELATED WORK

As we mentioned in the previous section that BIAs played an important role in the research field of MANET routing protocols and optimizing energy, so through this section we will present some of the recent studies that discuss BIAs in MANET. Sathiamoorthy & Ramakrishnan in [66] introduced an improved version of ACO based on two strategies for reducing overhead through expecting nodes movements through the network. The proposed algorithm dynamically determines network heuristic parameters for selecting the suitable node for each cluster to allow faster formation of clusters and selection of head. Also in [67] Alleema and Kumar tried to reduced overhead and delay in Peer to Peer MANETs through introducing Volunteer Nodes of Ant Colony Optimization Routing (VNACO). In the proposed protocol the peer node can volunteer to transmit data between source and destination nodes based on her aptitude that is calculated by iterating node connectivity, transmission processing time, node energy and available bandwidth. Results indicated that the proposed protocol reduces 22% out of the network delay and 14% out of the lost packets compared to the state of art. In [68] ACO was used to introduce a routing protocol called A-EEBLR based ACO for selecting the next hop using some metrics including delay, energy drain rate, congestion, link quality through which the optimal path is formed. The results indicated that the A-EEBLR outperformed the state of art. Malar *et al.*, in [69] presented an energy efficient routing protocol based ACO called multi-objective constraints applied energy efficient routing-Ant Colony Optimization (MCER-ACO). The proposed protocol picks the next hop based on node energy, topology dynamic movement and number of packet in path. Results indicated that the proposed protocol outperformed the state of art.

In [70] Chaudhry *et al.*, proposed a hybrid routing protocol based PSO to maximize the network life time called Forwarding Zone Adaptive Particle Swarm Optimization (FZ-APSO). Through the proposed technique the forwarding zone is selected between source and destination using forwarding search space heuristic technique which improves PSO computational time and performance and overcomes its convergence. Results indicated that the FZ-APSO outperformed the state of art in reducing energy consumption, end to end delay and PSO computational time while increasing the network lifetime. In [71] a hybrid algorithm based PSO, clustering algorithm and differential algorithm is proposed for selecting cluster head nodes considering the energy of these nodes. Results indicated that the proposed hybrid outperformed the state of art in maximizing network life time and packet delivery ratio while minimizing the average number of re-clustering required and consumed energy.

Bee Colony was investigated in [72] to modify DSR for ameliorating the optimal path discovery process through eliminating misbehaving nodes causing black hole attacks. The proposed Bee-Mimetic Dynamic Source Routing (BM-DSR) performance was compared with DSR and AODV, achieving superiority in increasing packet delivery ratio but only to some extent. In [73] Babu and Balasubramanie discussed the selection of optimal route through merging fuzzy logic with hybrid optimization approach based on 2-Opt algorithm and the Artificial Bee Colony. Fuzzy rules were used to classify nodes based on end-to-end delay when node intends to leave network which may cause more packets to be lost. Results indicated that using fuzzy rules enhances the hybrid optimization approach performance over Artificial Bee Colony.

In [59] Artificial fish swarm optimization ability to select the best cluster head in MANET based on mobility and remaining energy and degree of connectivity was discussed. Where a hybrid of low energy adaptive clustering hierarchy protocol and artificial fish swarm optimization was proposed to maximize network life time and minimize energy consumption. Results indicated that the proposed hybrid outperformed the state of art. Finally in [60] the bat algorithm was used to enhance the performance of OLSR through introducing Bat Optimized Link State Routing (BOLSR) protocol. The BOLSR selects the optimal path based on the nodes energy dynamics achieving superiority over the state of art in reducing the consumed energy while maximizing the network life time. Finally in [74] the artificial spider silk was used through building the spider web to match the network topology to choose the available paths to the destination where the transmission-latency model was applied to select the best of these available routes to forward packets. Experiments were conducted using Ns2 where results indicate that the spider silk algorithm outperforms the state of art in packet delivery ratio with moderate transmission delay. More studies could be found in [75]–[79].

III. ELEPHANT HERDING OPTIMIZATION- AD HOC ON-DEMAND MULTIPATH DISTANCE VECTOR ROUTING PROTOCOL (EHO-AOMDV)

A. ELEPHANT HERDING OPTIMIZATION

Elephant herding optimization (EHO) is one of the BIAs, emulating herding behavior of elephant group. Different clans of female elephants and young males live together under the leadership of a matriarch, where the grown up male elephants tend to be isolated while still contacting elephants in their family with low-frequency vibrations. Two operators identify the behavior of the elephants in clans, the Clan updating operator for tracking and updating the elephants position in clan and the separating operator for modeling the movement of grown up males elephants out of clans and enhancing the population diversity at the later search phase as shown in figure 1.

We can simply summarize the EHO into four steps

1) The division of elephants population into clans
2) Matriarch is the oldest cow and the fittest elephant in each clan
3) The herding behavior of elephant is customized based on two operators Clan updating operator for updating the position of each elephant in the clan influenced by the matriarch (the fittest elephant in the clan) while the matriarch position is updated based on information obtained by all clan elephants.
4) The adult males (the worst performing male in each generation) leave the clan based on separating operator calculated using the upper and lower bound of the position of elephant. The leaving adults can still contacting elephants in their family with low-frequency vibrations.

From the previous, the researchers believe that EHO as an optimizer can handle the nodes energy consumption problem the MANET faces. All nodes in the MANET could be considered as the elephant population, which will be classified into two clans. The separating operator based on nodal energy will determine which class each node will belong to while the updating operator representing nodes residual energy that will be updated after each transmission which will be described in details in next section.

B. EHO-AOMDV ROUTING PROTOCOL

EHO-AOMDV is an energy efficient multipath load balancing routing protocol based EHO and AOMDV. EHO is mainly used for optimizing nodes energy by classifying nodes population into two clans based nodal energy which could be considered as the separating operator. Nodes with higher energy than the needed to transmit the total number of packets through the node will be set into the first clan, while the others will be set into the second.

The AOMDV protocol is used for discovering T multilink disjoint paths through propagating RREQ messages from source node S to destination D, establishing multiple reverse paths both at intermediate nodes as well as the destination. Duplicated RREQs from the same Source Address and ID will replace RREQs with less nodal residual energy and higher hop counts. The discovered paths from S to D will be sorted descending based maximal nodal residual energy of each path.

The data load is balanced on the T discovered paths according to the path energy percentage with respect to all discovered paths energies. In case of all paths failure or an update in any node energy from the first clan (calculated using updating operator) all nodes in first and second clans will be checked and the clans will be updated by switching nodes. For details we can discuss the EHO-AOMDV in four main phases: Nodes Classification, Paths Discovery, Data load balancing and Paths Maintenance.

a. Nodes Classification: As mentioned before the EHO is trying to optimize nodes energy consumption through

Variables:

$x_{ci,j}$: is the position for elephant *j* in clan *ci*

$x_{new,ci,j}$: is the position for elephant *j* in clan *ci*

$\propto \epsilon[0,1]$ is a scale factor

$x_{best,ci}$: is the fittest elephant in clan *ci*

$r \epsilon[0,1]$

$\beta \epsilon[0,1]$

$x_{center,ci}$: is the centre of clan *ci*

$x_{worst,ci}$: is the worst elephant in clan *ci*

x_{max} : Upper bound of the position of elephant

x_{min} : Lower bound of the position of elephant

randϵ [0, 1] is a stochastic distribution

Step 1: Initialization. Set generation counter *t*=1; initialize the population; the maximum generation *MaxGen*.

Step 2: While *t*<*MaxGen* **do**

Sort all the elephants according to their fitness.

For *ci*=1 to *nClan* (for all clans in elephant population) **do** //clan updating operator

For *j*=1 to n_{ci} (for all elephants in clan *ci*) **do**

Update $x_{ci,j}$ and generate $x_{new,ci,j}$ by

$$x_{new,ci,j} = x_{ci,j} + \propto (x_{best,ci} - x_{ci,j}) \times r$$

If $x_{ci,j}$=$x_{best,ci}$ **then** update $x_{ci,j}$ and generate $x_{new,ci,j}$ by

$$x_{new,ci,j} = \beta \times x_{center,ci}$$

End if

End for *j*

End for *ci* // end of clan updating operator

For *ci*=1 to *nClan* (all the clans in elephant population) **do** // separating operator

Replace the worst elephant in clan *ci* by

$$x_{worst,ci} = x_{min} + (x_{max} - x_{min} + 1) \times rand$$

End for *ci* // end of separating operator

Evaluate population by the newly updated positions.

t=*t*+1.

Step 3: End While

FIGURE 1. EHO Pseudo code [80].

For i=1 to M (for all nodes on the network) do

PTE_{n_i} = TP * β (n_i ,n_{i+1}) // separating operator

If $E_{n_i} > PTE_{n_i}$ **Then** $n_i \epsilon C_1$ **Else** C_2

End If

End For

FIGURE 2. Node Classification phase pseudo code.

classifying the nodes on the network based nodal residual energy which is used as the updating operator (update node residual energy after each transmission), where the nodes with residual energy E_{n_i} exceeding the energy needed for transmitting all packets PTE_{n_i} (the separating operator) through the node n_i will be classified into the first clan else it will be classified into the second clan.

Figure 2 clarifies the pseudo code of the nodes classification into C1 and C2 clans, where TP is total number of packets; β is the energy consumed in transmitting and receiving a packet over one hop and PTE_{n_i} is the energy needed for transmitting all packets over one hop. This phase is important for reducing the number of the dead nodes by assuring that only the nodes with sufficient energy for transmitting will be involved in transmission.

b. Paths Discovery: After classifying the nodes, the disjoint paths discovery process (as in figure 3) starts based AOMDV protocol where a flood of RREQs propagates from the source Node S to the destination D (supposing that the source and the deamination are in C1 to be able to proceed with the transmission). Redundant RREQs with the same source and ID will be evaluated to keep the RREQ with the maximal nodal

6: **For** j=1 to R (for all nodes in Clan C_1) do
7: Flood RREQs from source S to destination D
8: Establishing multiple reverse paths both at intermediate nodes as well as destination
9: Traverse the reverse paths back by multiple RREPs to form multiple forward paths to the destination at the source and intermediate nodes
10: Keep RREQs with the maximal nodal residual energy and less hop count
11: **End For** j

FIGURE 3. Pseudo code of path discovery process.

12: **For** t=1 to T (for all discovered T paths) do
13: **For** x=1 to X (for all nodes on path t) do
14: $Pe_t = min_{x\epsilon t} E_{tx}$
15: **End For x**
16: Sort T paths based energy descending
17: $NP_t = \frac{Pe_t \times TP}{\sum_{t=1}^{T} Pe_t}$
18: **IF** No of failed paths ≠T && $E_{tx} > PTE_{tx}$
19: Forward NP data packets on path t
20: **Else** goto line 1
21: **End IF**
22: **End For t**

FIGURE 4. Paths Maintenance and load balancing phases.

residual energy and less hop count, so we can guarantee discovering the shortest paths with sufficient energy for transmitting the whole data load.

c. Paths Maintenance: In case of all paths failure (as in figure 4), or a loss in any of the discovered paths nodes energy, nodes classification phase should start over again. Through this phase the updating operator re-evaluates all nodes energy in the two clans to update the position of the dead nodes, the nodes lost energy and turned out to have insufficient energy for transmission and finally the nodes gained energy and turned out to have sufficient energy for transmission from the first clan to the second and vice versa before restarting the paths discovery process.

d. Data load balancing: the T discovered paths, are sorted in a descending order where the maximal nodal residual energy Pe_t of each path t is calculated using the minimal nodal residual energy of all the X nodes on the path. Where data load TP is then balanced on the T discovered paths (NP_t: number of packets to be transmitted on path t) according to the path energy percentage in respect to all discovered paths energies as clarified in figure 4 line 17.

Figure 5 provides a graphical description of the nodes classification and paths discovery phases over a simple MANET, where the green nodes are the nodes that were classified into C1 as their residual energy is higher than the energy needed to transmit all packets over one hop while the others were classified into C2. As clarified in part (c) RREQs are only forwarded among all nodes in clan C1 except node J as it did not have any predecessors in C1. In part (d) we have only two discovered paths marked with red links t1=[S-A-B-G-D] and t2=[S-C-F-H-D] that will be sorted in a descending order based their nodal residual energy. Finally the data load of each path will be calculated as clarified based on the energy percentage of each path related to the total energy of all paths so if we have 100 packets for example 60 of them will be forwarded on t1 and 40 packets on t2.

IV. EXPERIMENTAL SETUP AND PERFORMANCE ANALYSIS

A. PERFORMANCE METRICS

For evaluation; five performance metrics were used

- Routing overhead (in Pkts): indicates the number of routing packets transmitted over the network
  Routing overhead
- Packet delivery ratio (PDR in %): indicates ratio between the number of successfully delivered packets to the destination to the total number of sent packets.

$$PDR = \frac{number\ of\ successfully\ delivered\ packets}{total\ number\ of\ sentpackets} * 100$$

- Average energy consumption (in Joule): indicates the average of the consumed energy by all nodes

$$\text{Average energy consumption for n nodes} = \frac{\sum_{i=1}^{n} Intiial\ energy_i - Residual\ energy_i}{n}$$

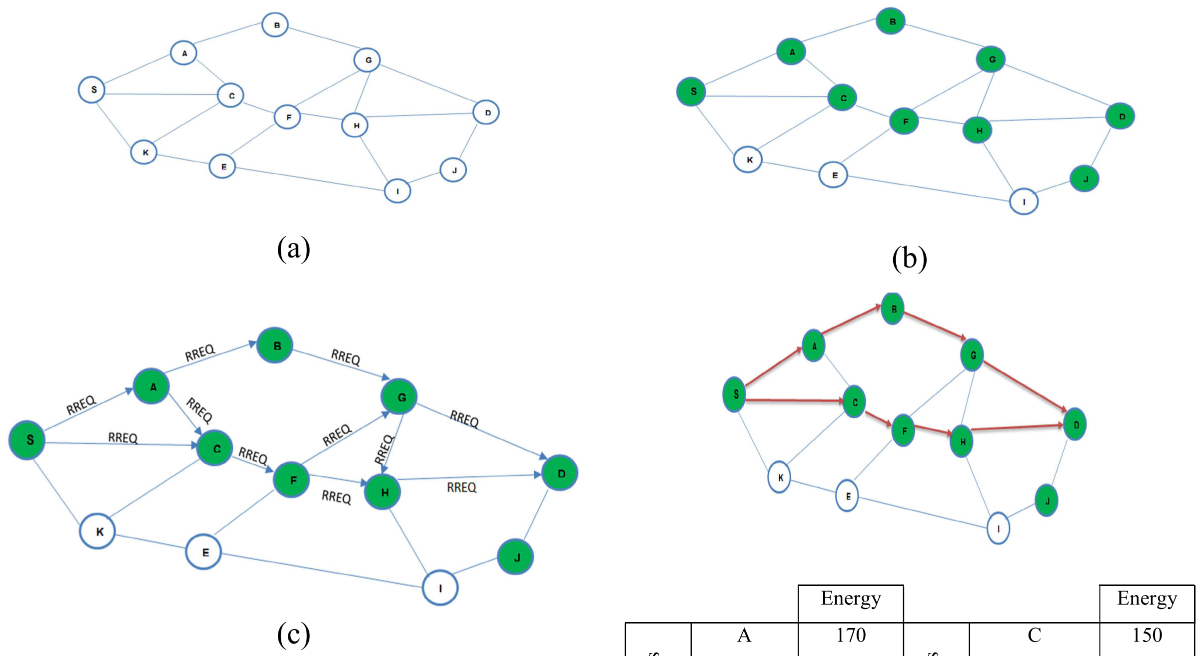
- End-to-end delay (EED in seconds): indicates the time spent for a packet to be transmitted from source to destination.

$$\text{EED for M packets} = \sum_{i=1}^{M} EED_i$$

EED_i = Received time of $packet_i$ - Sent time of $packet_i$

- Number of dead nodes (in nodes): indicates the number of dropped nodes in each transmission round.

Number of dead nodes = Total numbers of nodes-Number of residual nodes



		Energy			Energy
Nodes	A	170	Nodes	C	150
	B	120		F	145
	G	135		H	80
t_1=[S-A-B-G-D]		Min=120	t_2= [S-C-F-H-D]		Min=80
$NP_{t_1}=\frac{120\times100}{200}$=60 packets			$NP_{t_2}=\frac{80\times100}{200}$=40 packets		

(d)

FIGURE 5. Example on Nodes classification and Path discovery phases.

TABLE 1. Simulation parameter.

Simulator	Ns-3
Routing Protocols	AOMDV, FF-AOMDV, ACO-FDRPSO and, EHO-AOMDV
Simulation Time (s)	50,100, 150, 200 Secs
Simulation Area	1500 m × 1500 m
MAC layer protocol	IEEE 802.11
Number of Nodes	50,100,150, 200
Transmission Range (m)	250
Mobility Model	Random way point
Maximum node Speed	5 m/s
Data Packet Size	512, 1024 bytes
Traffic Type	CBR
Initial Node Energy (J)	50

B. EXPERIMENTAL SETUP

In addition to the proposed EHO-AOMDV three protocols were implemented; two BIAs including AOMDV with the Fitness Function (FF-AOMDV) [33] and hybrid Ant Colony Optimization Combined With Fitness Distance Ratio Particle Swarm Optimization (ACO-FDRPSO) [52] and the original AOMDV for evaluation purposes. The evaluation were performed using NS-3 [81] which is a discrete-event network simulator for developing free and open source simulation environment suitable for scientific networking research. The simulation parameters were set during the experiment are clarified in Table 1.

C. EXPERIMENTALRESULTS AND DISCUSSION

Routing Overhead: is one of the evaluation metrics that we expected to be reduced due to the reduction of the number of the control packets transmitted among nodes as they were only transmitted among fitted nodes. The routing overhead was evaluated with respect to the number of nodes. Figure 6 clarifies that the proposed EHO-AOMDV routing

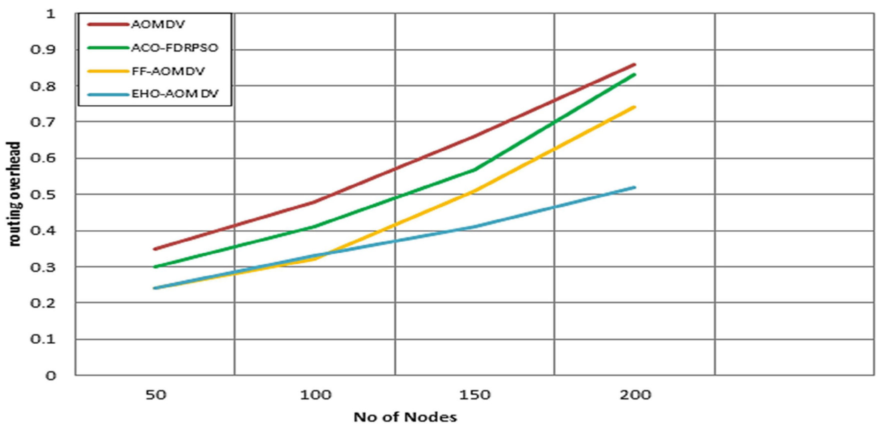
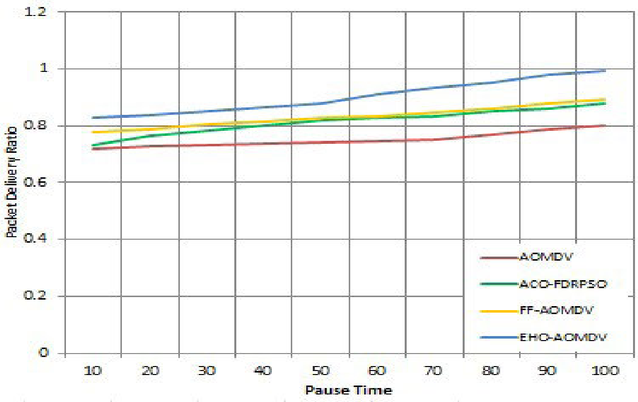
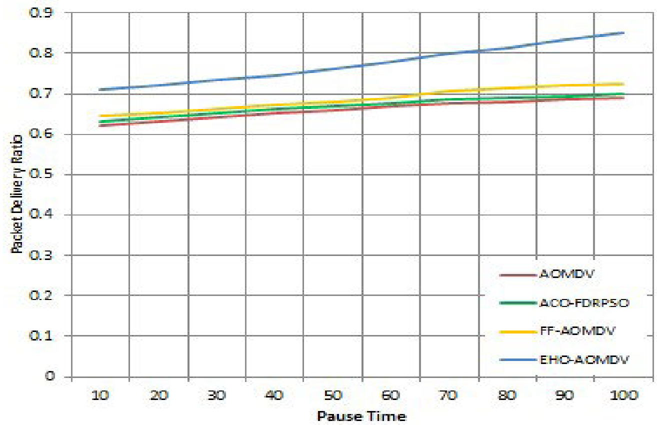


FIGURE 6. Routing overhead versus no of nodes.



a. 512 bytes packet size



b. 1024 bytes packet size

FIGURE 7. Packet delivery ratio versus pause time.

overhead increases at a lower rate than ACO-FDRPSO and AOMDV protocols while in case of 50 and 100 nodes it is nearly comparable to FF-AOMDV. For example at 150 nodes the EHO-AOMDV, ACO-FDRPSO, FF-AOMDV and AOMDV overheads are 0.24, 0.3, 0.24 and 0.35 respectively.

- Packet delivery ratio: was evaluated versus the network pause time with respect to two packet sizes 512 byte and 1024 byte. Figures 7a and 7b demonstrated that the proposed EHO-AOMDV attained higher packet delivery ratio increasing rate than the rest three protocols while the AOMDV attained the least packet delivery ratio increasing rate with respect to all different pause time values through the experiment and with respect to the two different packet sizes. We can also observe that the higher the packet size the less the packet delivery ratio. For example at 10 seconds pause time and 512 bytes packet size, EHO-AOMDV, ACO-FDRPSO, FF-AOMDV and AOMDV packet delivery ratios are 0.829, 0.732, 0.779 and 0.72 respectively; while at 10 seconds pause time and 1024 bytes packet size, EHO-AOMDV, ACO-FDRPSO, FF-AOMDV and AOMDV packet delivery ratios are 0.711, 0.631, 0.645 and 0.622 respectively.
- Average energy consumption: as we mentioned before that our main concern through this study is to propose and energy efficient routing protocol to reduce the consumed node energy and preserve the network life time as much as possible so the average energy consumption is the most important metric we need; to evaluate our proposed protocol through. Figure 8 demonstrates that the proposed EHO-AOMDV average energy consumption increasing rate is less than the rest implemented protocols. Also we can observe that the proposed EHO-AOMDV consumed less energy 0.19, 0.33, 0.43 and 0.51 joule when compared to the others, while the AOMDV attain the most consumed energy 0.24, 0.41, 0.62 and 0.89 joule at 50, 100, 150 and 200 nodes. The two BIAs protocols attained nearly comparable results with unpretentious superiority for FF-AOMDV.
- End-to-end delay: most of the energy efficient routing protocols suffer from high end to end delay due to the energy calculations performed at every round, where higher number of packets and packets size means

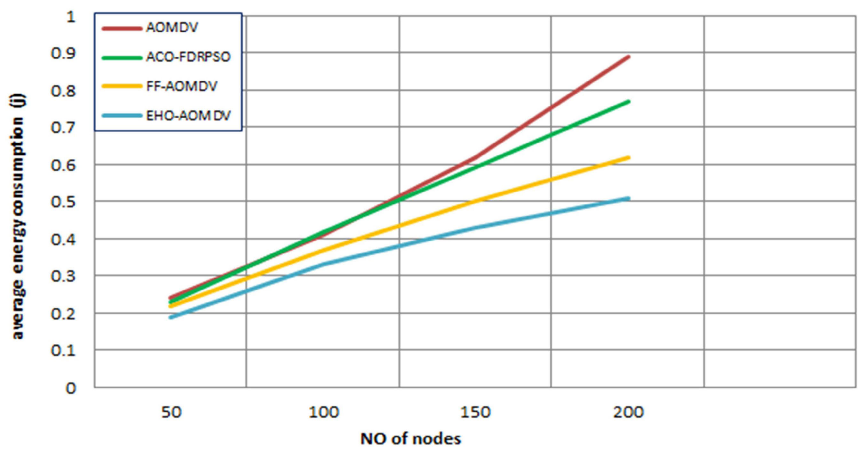
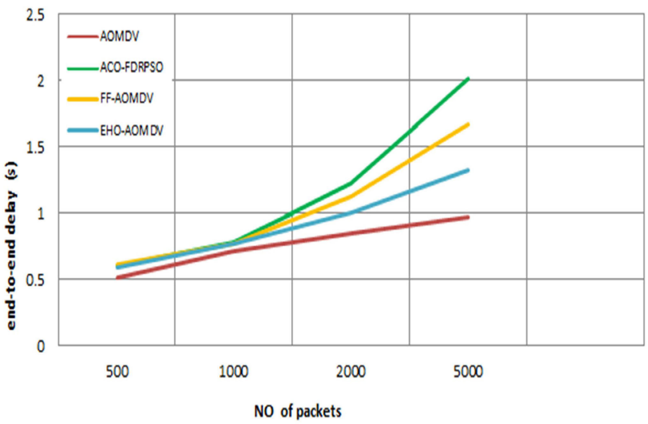
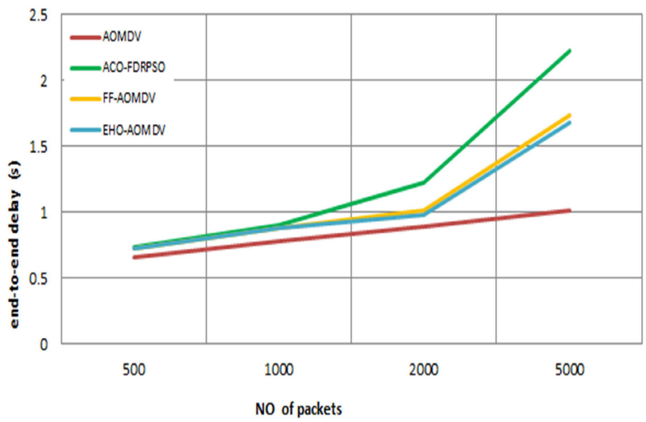


FIGURE 8. Average energy consumption versus number of nodes.



a. **512 bytes packet size**



b **1024 bytes packet size**

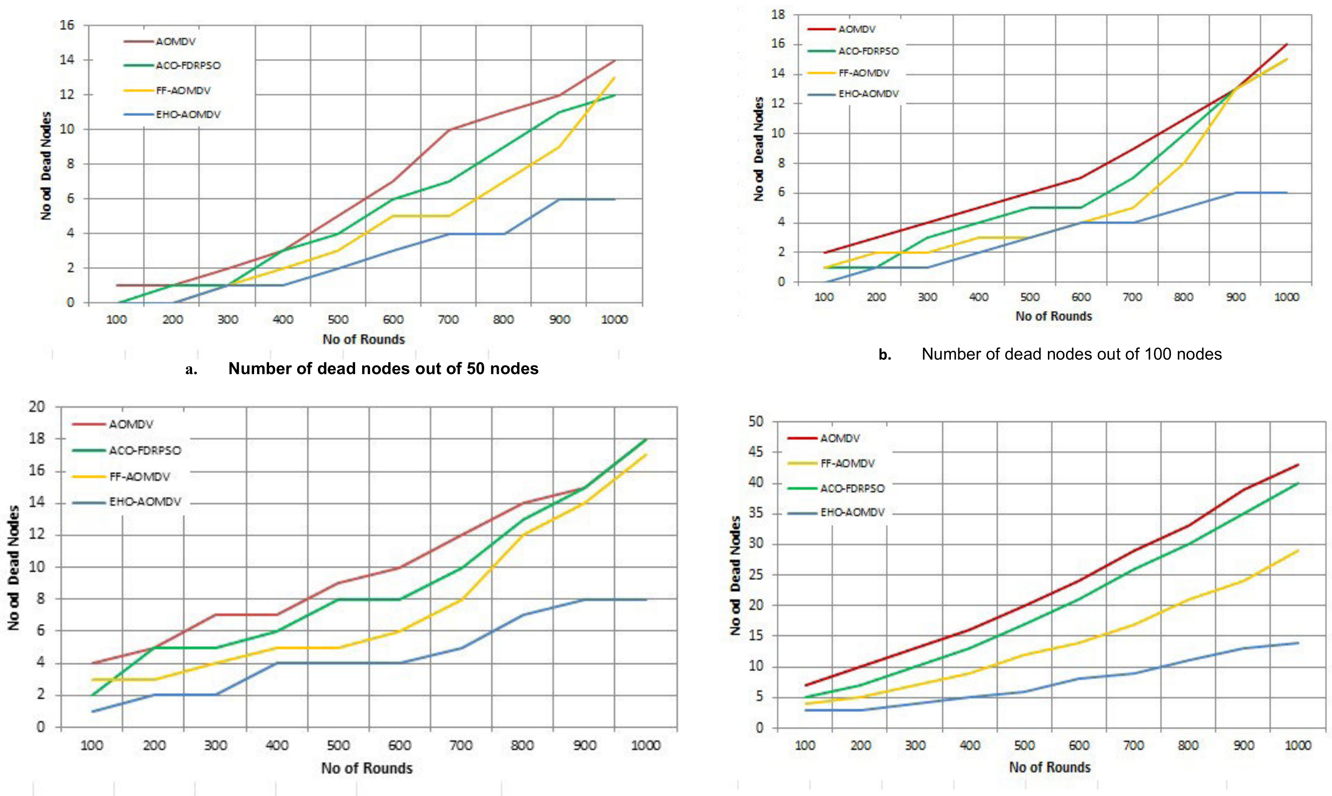
FIGURE 9. End-to-end delay versus no of packets.

higher delay which is obvious from Figures 9a and 9b. We can notice from Figure 9 that the three BIAs protocols EHO-AOMDV, ACO-FDRPSO and FF-AOMDV attain higher delay than the AOMDV for example at 2000 packets of 1024 byte size the delays of EHO-AOMDV, ACO-FDRPSO, FF-AOMDV and AOMDV are 0.986, 1.23, 1.011 and 0.887 respectively. It is also noticed that the delay increasing rate of the AOMDV is much less than the three BIAs protocols.

- Number of dead nodes: the number of dead nodes is a reflection of the protocol energy consumption rate as the higher the consumed energy the higher the number of dead nodes. Figures 10a, 10b, 10c and 10d demonstrate the number of dead nodes out of 50, 100, 150 and 200 nodes with respect to the number of rounds. From these figures we can observe that the proposed EHO-AOMDV attain more stable number of dead nodes increasing rate at the 50, 100 and 150 nodes and a decreasing number of dead nodes increasing rate at the 200 nodes unlike the oscillatory increasing rate of the other protocols. For example EHO-AOMDV, ACO-FDRPSO, FF-AOMDV and AOMDV at 1000 rounds attain 6, 12, 13 and 14 nodes respectively out of 50 nodes.

From the previous metrics, we can indicate that the proposed EHO-AOMDV has attained superiority over the ACO-FDRPSO, FF-AOMDV and AOMDV in routing overhead, packet delivery ratio, average energy consumption and number of dead nodes while in the end-to-end delay AOMDV has gained superiority. The authors due this to the less calculations and processing needed for the AOMDV to discover paths and the packets routing over these paths while the rest three protocols consider the energy of the nodes before paths discovery and packets routing.

Through this study the authors have believed that the EHO separating and clan updating operators can enhance the AOMDV protocol performance, when considering to deliver the maximum number of packets with the minimum number of dead nodes and therefore the less energy consumption. Finally the authors recommend that EHO-AOMDV could



a. Number of dead nodes out of 50 nodes

b. Number of dead nodes out of 100 nodes

c. Number of dead nodes out of 150 nodes

d. Number of dead nodes out of 200 nodes

FIGURE 10. Number of dead nodes versus number of rounds.

be effective in systems demanding higher delivery rate with less energy consumption and tolerable delay as banking, marketing and management.

V. CONCLUSION

Optimizing energy consumption in mobile ad hoc networks is a major research field that has developed recently with highly concentration of benefiting from bio inspired algorithms and their optimization abilities. From here the researchers in this study propose an energy efficient routing protocol based AOMDV protocol and elephant herding algorithm. Experiments were conducted using Ns-3, implementing four protocols the proposed EHO-AOMDV in addition to the AOMDV protocol and two bio-inspired protocols ACO-FDRPSO, FF-AOMDV. The results indicated that the proposed protocol surpasses the others in four metrics out of five; routing overhead, packet delivery ratio, average energy consumption and number of dead nodes, while in the end-to-end delay the EHO-AOMDV have attained tolerable delay compared to the AOMDV. Results also clarified that the proposed protocol attained better performance than the other implemented protocols in terms of load balancing which was obvious in its superiority in the packet delivery ratio. The authors recommend that the EHO-AOMDV could be effectively applied in systems preferring higher packet delivery ratio over delay as marketing and management.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

[1] M. K. Marina and S. R. Das, ‘‘Performance of route caching strategies in dynamic source routing,’’ in *Proc. 21st Int. Conf. Distrib. Comput. Syst. Workshops*, 2001, pp. 425–432.

[2] J. B. Cain, ‘‘Multiple path reactive routing in a mobile ad hoc network,’’ U.S. Patent 6 961 310 B2, 2005. Accessed: Mar. 4, 2020.

[3] M. Bouhorma, H. Bentaouit, and A. Boudhir, ‘‘Performance comparison of ad-hoc routing protocols AODV and DSR,’’ in *Proc. Int. Conf. Multimedia Comput. Syst.*, Apr. 2009, pp. 511–514.

[4] Y. Cheng, E. Çetinkaya, and J. Sterbenz, ‘‘Dynamic source routing (DSR) protocol implementation in ns-3,’’ in *Proc. 5th Int. Conf. Simulation Tools Techn.*, 2012, pp. 367–374.

[5] E. M. Royer and C. E. Perkins, ‘‘Multicast operation of the ad-hoc on-demand distance vector routing protocol,’’ in *Proc. 5th Annu. ACM/IEEE Int. Conf. Mobile Comput. Netw. (MobiCom)*, Aug. 1999, pp. 207–218.

[6] M. K. Marina and S. R. Das, ‘‘Ad hoc on-demand multipath distance vector routing,’’ *ACM SIGMOBILE Mobile Comput. Commun. Rev.*, vol. 6, no. 3, pp. 92–93, 2002.

[7] M. G. Zapata, ‘‘Secure ad hoc on-demand distance vector routing,’’ *ACM SIGMOBILE Mobile Comput. Commun. Rev.*, vol. 6, no. 3, pp. 106–107, Jun. 2002.

[8] C. Perkins, E. Belding-Royer, and S. Das, *Ad Hoc On-Demand Distance Vector (AODV) Routing*, document RFC 3561, 2003.

[9] Y. Zhang and T. A. Gulliver, ‘‘Quality of service for ad hoc on-demand distance vector routing,’’ in *Proc. IEEE Int. Conf. Wireless Mobile Comput., Netw. Commun. (WiMob)*, Aug. 2005, pp. 192–196.

[10] T.-W. Chen and M. Gerla, ‘‘Global state routing: A new routing scheme for ad-hoc wireless networks,’’ in *Proc. IEEE Int. Conf. Commun. Conf. Rec. Affiliated With SUPERCOMM (ICC)*, vol. 1, Jun. 1998, pp. 171–175.

[11] C. Jing, C. G. Hua, and H. Liang, "A secure global state routing for mobile ad hoc networks," in *Proc. IFIP Int. Conf. Pers. Wireless Commun.* Berlin, Germany: Springer, 2006, pp. 228–238.

[12] C. K. Toh, "Associativity-based routing for ad hoc mobile networks," *Wireless Pers. Commun.*, vol. 4, no. 2, pp. 103–139, 1997.

[13] M. Kummakasikit, S. Thipchaksurat, and R. Varakulsiripunth, "Performance improvement of associativity-based routing protocol for mobile ad hoc networks," in *Proc. 5th Int. Conf. Inf. Commun. Signal Process.*, 2005, pp. 16–20.

[14] S. Buruhanudeen, M. Othman, B. M. Ali, and M. Othman, "Performance comparison of MANET associativity based routing (ABR) and the improvisation done for a more reliable and efficient routing," in *Proc. 3rd Inf. Commun. Technol. Seminar*, 2011.

[15] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in *Proc. 2nd IEEE Workshop Mobile Comput. Syst. Appl. (WMCSA)*, Feb. 1999, pp. 90–100.

[16] M. K. Marina and S. R. Das, "On-demand multipath distance vector routing in ad hoc networks," in *Proc. 9th Int. Conf. Netw. Protocols. (ICNP)*, 2001, pp. 14–23.

[17] W. Wang, Y. Lu, and B. Bhargava, "On security study of two distance vector routing protocols for mobile ad hoc networks," in *Proc. 1st IEEE Int. Conf. Pervas. Comput. Commun. (PerCom)*, Mar. 2003, pp. 179–186.

[18] H. Mohamed, M. H. Lee, M. Sarahintu, S. Salleh, and B. Sanugi, "Application of Taguchi's design of experiment in performance analysis of destination sequence distance vector (DSDV) routing protocol," *Sains Malaysiana*, vol. 38, no. 3, pp. 423–428, 2009.

[19] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum, and L. Viennot, "Optimized link state routing protocol for ad hoc networks," in *Proc. IEEE Int. Multi Topic Conf. Technol. 21st Century (IEEE INMIC)*, Dec. 2001, pp. 62–68.

[20] T. Clausen, P. Jacquet, C. Adjih, A. Laouiti, P. Minet, P. Muhlethaler, and L. Viennot, "Optimized link state routing protocol (OLSR)," Tech. Rep. inria-00471712, 2003. [Online]. Available: https://hal.inria.fr/inria-00471712/document

[21] A. Tønnesen, "Implementing and extending the optimized link state routing protocol," M.S. thesis, UniK Univ. Graduate Center, Univ. Oslo, Oslo, Norway, 2004. [Online]. Available: https://www.duo.uio.no/bitstream/handle/10852/9150/1/report.pdf

[22] S. Murthy and J. J. Garcia-Luna-Aceves, "An efficient routing protocol for wireless networks," *Mobile Netw. Appl.*, vol. 1, no. 2, pp. 183–197, 1996.

[23] P. Sholander, T. Oakes, and P. Coccoli, "Wireless routing protocol for ad-hoc networks," U.S. Patent 7 177 295, B1, 2007. Accessed: Mar. 4, 2020.

[24] Z. J. Haas and M. R. Pearlman, "The performance of query control schemes for the zone routing protocol," *IEEE/ACM Trans. Netw.*, vol. 9, no. 4, pp. 427–438, Aug. 2001.

[25] N. Beijar, "Zone routing protocol (ZRP)," Netw. Lab., Helsinki Univ. Technol., Espoo, Finland, Tech. Rep., 2002, vol. 9, pp. 1–2. [Online]. Available: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.19.5568&rep=rep1&type=pdf

[26] X. Zhang and L. Jacob, "Multicast zone routing protocol in mobile ad hoc wireless networks," in *Proc. 28th Annu. IEEE Int. Conf. Local Comput. Netw. (LCN)*, Oct. 2003, pp. 150–159.

[27] M. Joa-Ng and I.-T. Lu, "A peer-to-peer zone-based two-level link state routing for mobile ad hoc networks," *IEEE J. Sel. Areas Commun.*, vol. 17, no. 8, pp. 1415–1425, Aug. 1999.

[28] M. Takahashi, M. Bandai, and I. Sasase, "Multilevel zone-based hierarchical link state routing with location search technique applying hierarchical request for mobile ad hoc networks," *Electron. Commun. Jpn., I, Commun.*, vol. 88, no. 1, pp. 44–52, Jan. 2005.

[29] Y. Yuan, H. Chen, and M. Jia, "An optimized ad-hoc on-demand multipath distance vector (AOMDV) routing protocol," in *Proc. Asia–Pacific Conf. Commun.*, 2005, pp. 569–573.

[30] Y. Chen, Z. Xiang, W. Jian, and W. Jiang, "An improved AOMDV routing protocol for V2V communication," in *Proc. IEEE Intell. Vehicles Symp.*, Jun. 2009, pp. 1115–1120.

[31] M. S. Chadha and R. Joon, "Simulation and comparison of AODV, DSR AOMDV routing protocols in MANETs," *Int. J. Soft Comput. Eng.*, vol. 2, no. 3, Jul. 2012.

[32] B. Sharma, S. Chugh, and V. Jain, "Energy efficient load balancing approach to improve AOMDV routing in MANET," in *Proc. 4th Int. Conf. Commun. Syst. Netw. Technol.*, Apr. 2014, pp. 187–192.

[33] A. Taha, R. Alsaqour, M. Uddin, M. Abdelhaq, and T. Saba, "Energy efficient multipath routing protocol for mobile ad-hoc network using the fitness function," *IEEE Access*, vol. 5, pp. 10369–10381, 2017.

[34] R. Leung, J. Liu, E. Poon, A.-L.-C. Chan, and B. Li, "MP-DSR: A QoS-aware multi-path dynamic source routing protocol for wireless ad-hoc networks," in *Proc. 26th Annu. IEEE Conf. Local Comput. Netw. (LCN)*, Nov. 2001, pp. 132–141.

[35] E. K. Asl, M. Damanafshan, M. Abbaspour, M. Noorhosseini, and K. Shekoufandeh, "EMP-DSR: An enhanced multi-path dynamic source routing algorithm for MANETs based on ant colony optimization," in *Proc. 3rd Asia Int. Conf. Modelling Simulation*, 2009, pp. 692–697.

[36] J. J. Garcia-Luna-Aceves and J. Raju, "On-demand loop-free multipath routing (ROAM)," U.S. Patent 7 035 227 B2, 2006. Accessed: Mar. 7, 2020.

[37] N. Jaisankar and R. Saravanan, "An extended AODV protocol for multipath routing in MANETs," *Int. J. Eng. Technol.*, vol. 2, no. 4, pp. 394–400, 2010.

[38] M. Gunes, U. Sorges, and I. Bouazizi, "ARA-the ant-colony based routing algorithm for MANETs," in *Proc. Int. Conf. Parallel Process. Workshop*, 2002, pp. 79–85.

[39] S. Rajagopalan and C. C. Shen, "ANSI: A unicast routing protocol for mobile ad hoc networks using swarm intelligence," in *Proc. IC-AI*, 2005, pp. 104–110.

[40] S. Sethi and S. K. Udgata, "The efficient ant routing protocol for MANET," *Int. J. Comput. Sci. Eng.*, vol. 2, no. 7, pp. 2414–2420, 2010.

[41] A. K. Gupta, H. Sadawarti, and A. K. Verma, "MANET routing protocols based on ant colony optimization," *Int. J. Model. Optim.*, vol. 2, no. 1, pp. 42–49, 2012.

[42] M. Sheikhan and E. Hemmati, "PSO-optimized hopfield neural network-based multipath routing for mobile ad-hoc networks," *Int. J. Comput. Intell. Syst.*, vol. 5, no. 3, pp. 568–581, Jun. 2012.

[43] F. Sarkohaki, R. Fotohi, and V. Ashrafian, "An efficient routing protocol in mobile ad-hoc networks by using artificial immune system," 2020, *arXiv:2003.00869*. [Online]. Available: http://arxiv.org/abs/2003.00869

[44] I. Woungang, M. S. Obaidat, S. K. Dhurandher, A. Ferworn, and W. Shah, "An ant-swarm inspired energy-efficient ad hoc on-demand routing protocol for mobile ad hoc networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2013, pp. 3645–3649.

[45] S. Harishankar, I. Woungang, S. K. Dhurandher, I. Traore, and S. B. Kaleel, "E-MAnt net: An ACO-based energy efficient routing protocol for mobile ad hoc networks," in *Proc. IEEE 29th Int. Conf. Adv. Inf. Netw. Appl.*, Mar. 2015, pp. 29–36.

[46] K. Narayanan and S. G. D. Christhudas, "ACO-EEOLSR: Enhanced energy model based link stability routing protocol in mobile ad hoc networks," *J. Chin. Inst. Eng.*, vol. 39, no. 2, pp. 192–200, Feb. 2016.

[47] P. Vijayalakshmi, S. A. J. Francis, and J. A. Dinakaran, "A robust energy efficient ant colony optimization routing algorithm for multi-hop ad hoc networks in MANETs," *Wireless Netw.*, vol. 22, no. 6, pp. 2081–2100, 2016.

[48] H. Ali, W. Shahzad, and F. A. Khan, "Energy-efficient clustering in mobile ad-hoc networks using multi-objective particle swarm optimization," *Appl. Soft Comput.*, vol. 12, no. 7, pp. 1913–1928, Jul. 2012.

[49] S. Jamali, L. Rezaei, and S. J. Gudakahriz, "An energy-efficient routing protocol for MANETs: A particle swarm optimization approach," *J. Appl. Res. Technol.*, vol. 11, no. 6, pp. 803–812, Dec. 2013.

[50] Y. H. Robinson and M. Rajaram, "Energy-aware multipath routing scheme based on particle swarm optimization in mobile ad hoc networks," *Sci. World J.*, vol. 2015, pp. 1–9, Dec. 2015.

[51] N. R. V. D. Nair and R. Niji, "A hybrid PSO-GA algorithm for energy efficient routing in AMMNET," *Int. J. Innov. Res. Sci. Technol.*, vol. 3, no. 3, pp. 2349–6010, 2016.

[52] R. Jayavenkatesan and A. Mariappan, "Energy effective routing optimisation using ACO-FDR PSO for improving MANET performance," *Int. J. Environ. Sustain. Develop.*, vol. 18, no. 1, pp. 1–12, 2019.

[53] H. F. Wedde, M. Farooq, T. Pannenbaecker, B. Vogel, C. Mueller, J. Meth, and R. Jeruschkat, "BeeAdHoc: An energy efficient routing algorithm for mobile ad hoc networks inspired by bee behavior," in *Proc. Conf. Genet. Evol. Comput. (GECCO)*, 2005, pp. 153–160.

[54] B. C. Mohan and R. Baskaran, "Energy aware and energy efficient routing protocol for adhoc network using restructured artificial bee colony system," in *Proc. Int. Conf. High Perform. Archit. Grid Comput.* Berlin, Germany: Springer, 2011, pp. 473–484.

[55] I. M. Fahmy, H. A. Hefny, and L. Nasse, "PEEBR: Predictive energy efficient bee routing algorithm for ad-hoc wireless mobile networks," in *Proc. 8th Int. Conf. Inform. Syst. (INFOS)*, 2012, p. 18.

[56] S. Mohapatra and M. Siddappa, "Improvised routing using border cluster node for Bee-AdHoc-C: An energy-efficient and systematic routing protocol for MANETs," in *Proc. IEEE Int. Conf. Adv. Comput. Appl. (ICACA)*, Oct. 2016, pp. 175–180.

[57] M. Tareq, S. A. Abed, and E. A. Sundararajan, "Artificial bee colony for minimizing the energy consumption in mobile ad hoc network," in *Advances on Computational Intelligence in Energy*. Cham, Switzerland: Springer, 2019, pp. 21–38.

[58] N. Mazhar, "Energy efficient security in MANETs: A comparison of cryptographic and artificial immune systems," *Pakistan J. Eng. Appl. Sci.*, vol. 7, pp. 71–94, Jul. 2010.

[59] D. Gupta, A. Khanna, L. Sk, K. Shankar, V. Furtado, and J. J. P. C. Rodrigues, "Efficient artificial fish swarm based clustering approach on mobility aware energy-efficient for MANET," *Trans. Emerg. Telecommun. Technol.*, vol. 30, no. 9, p. e3524, Sep. 2019.

[60] M. A. Jubair, S. A. Mostafa, R. C. Muniyandi, H. Mahdin, A. Mustapha, M. H. Hassan, M. A. Mahmoud, Y. A. Al-Jawhar, A. S. Al-Khaleefa, and A. J. Mahmood, "Bat optimized link state routing protocol for energy-aware mobile ad-hoc networks," *Symmetry*, vol. 11, no. 11, p. 1409, Nov. 2019.

[61] S. Almufti, R. Asaad, and B. Salim, "Review on elephant herding optimization algorithm performance in solving optimization problems," *Int. J. Eng. Technol.*, vol. 7, no. 4, pp. 6109–6114, 2018.

[62] S. D. Correia, M. Beko, L. A. da Silva Cruz, and S. Tomic, "Elephant herding optimization for energy-based localization," *Sensors*, vol. 18, no. 9, p. 2849, 2018.

[63] E. Tuba, A. Alihodzic, and M. Tuba, "Multilevel image thresholding using elephant herding optimization algorithm," in *Proc. 14th Int. Conf. Eng. Mod. Electr. Syst. (EMES)*, Jun. 2017, pp. 240–243.

[64] S. Gupta, V. P. Singh, S. P. Singh, T. Prakash, and N. S. Rathore, "Elephant herding optimization based PID controller tuning," *Int. J. Adv. Technol. Eng. Explor.*, vol. 3, no. 24, pp. 194–198, Nov. 2016.

[65] S. M. Mohsin, N. Javaid, S. A. Madani, S. M. A. Akber, S. Manzoor, and J. Ahmad, "Implementing elephant herding optimization algorithm with different operation time intervals for appliance scheduling in smart grid," in *Proc. 32nd Int. Conf. Adv. Inf. Netw. Appl. Workshops (WAINA)*, May 2018, pp. 240–249.

[66] J. Sathiamoorthy and B. Ramakrishnan, "Energy and delay efficient dynamic cluster formation using improved ant colony optimization algorithm in EAACK MANETs," *Wireless Pers. Commun.*, vol. 95, no. 2, pp. 1531–1552, Jul. 2017.

[67] N. Alleema and D. Kumar, "Volunteer nodes of ant colony optimization routing for minimizing delay in peer to peer MANETs," *Peer-Peer Netw. Appl.*, vol. 13, no. 2, pp. 590–600, 2020.

[68] A. Karmel, V. Vijayakumar, and R. Kapilan, "Ant-based efficient energy and balanced load routing approach for optimal path convergence in MANET," *Wireless Netw.*, vol. 25, no. 5, pp. 1–13, Jul. 2019, doi: 10.1007/s11276-019-02080-w.

[69] A. C. J. Malar, M. Kowsigan, N. Krishnamoorthy, S. Karthick, E. Prabhu, and K. Venkatachalam, "Multi constraints applied energy efficient routing technique based on ant colony optimization used for disaster resilient location detection in mobile ad-hoc network," *J. Ambient Intell. Humanized Comput.*, vol. 11, no. 2, pp. 1–11, Feb. 2020, doi: 10.1007/s12652-020-01767-9.

[70] R. Chaudhry, S. Tapaswi, and N. Kumar, "Forwarding zone enabled PSO routing with network lifetime maximization in MANET," *Int. J. Speech Technol.*, vol. 48, no. 9, pp. 3053–3080, Sep. 2018.

[71] A. E. P. Mariadas and R. Madhanmohan, "Hybrid PSO-DE algorithm-based trust and congestion aware cluster routing algorithm for MANET," *Int. J. Cloud Comput.*, vol. 9, nos. 2–3, pp. 330–354, 2020.

[72] M. V. Anand and S. Hariharan, "Bee-mimetic DSR based secure routing in MANET using artificial bee colony optimization," *Int. J. Pure Appl. Math.*, vol. 119, no. 17, pp. 1337–1350, 2018.

[73] R. L. Babu and P. Balasubramanie, "Fuzzy rule selection using hybrid artificial bee colony with 2-opt algorithm for MANET," *Mobile Netw. Appl.*, vol. 25, pp. 1–11, Aug. 2019.

[74] C. Chen, L. Liu, T. Qiu, K. Yang, F. Gong, and H. Song, "ASGR: An artificial spider-Web-based geographic routing in heterogeneous vehicular networks," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 5, pp. 1604–1620, May 2019.

[75] S. Labed, A. Kout, and S. Chikhi, "A new approach based bee colony for the resolution of routing problem in mobile ad-hoc networks," *Int. J. Appl. Metaheuristic Comput.*, vol. 10, no. 2, pp. 131–151, Apr. 2019.

[76] A. V. Zade, R. M. Tugnayat, and G. B. Regulwar, "A novel optimization AHBeeP algorithm for routing in MANET," in *Innovations in Computer Science and Engineering*. Singapore: Springer, 2020, pp. 485–496.

[77] F. Sarkohaki, R. Fotohi, and V. Ashrafian, "An efficient routing protocol in mobile ad-hoc networks by using artificial immune system," 2020, *arXiv:2003.00869*. [Online]. Available: http://arxiv.org/abs/2003.00869

[78] S. Murugan, S. Jeyalaksshmi, B. Mahalakshmi, G. Suseendran, T. N. Jabeen, and R. Manikandan, "Comparison of ACO and PSO algorithm using energy consumption and load balancing in emerging MANET and VANET infrastructure," *J. Crit. Rev.*, vol. 7, no. 9, pp. 1–8, 2020.

[79] A. W. Y. Khang, S. J. Elias, N. Zulkifli, W. A. Indra, J. A. J. Alsayaydeh, Z. Manap, and J. A. M. Gani, "Qualitative-based QoS performance study using hybrid ACO and PSO algorithm routing in MANET," *J. Phys., Conf. Ser.*, vol. 1502, Mar. 2020, Art. no. 012004.

[80] G. G. Wang, S. Deb, and L. D. S. Coelho, "Elephant herding optimization," in *Proc. 3rd Int. Symp. Comput. Bus. Intell. (ISCBI)*, Dec. 2015, pp. 1–5.

[81] *Network Simulator3*. Accessed: Sep. 23, 2019. [Online]. Available: https://www.nsnam.org/

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