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Hybrid Dung Beetle Optimization and BiFormer Framework for Energy Optimization and Network Lifetime Maximization in MANETs

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ABSTRACT: Due to dynamic topology, limited battery power and frequent link failures, Mobile Ad Hoc Networks (MANETs) is crucial to adopt efficient and dependable routing protocols. Efficient Cluster Head (CH) selection and proper routing lead to better network performance and prolonged network longevity. The proposed approach presents an energy-efficient routing method for MANETs which utilizes Dung Beetle Optimization (DBO) with BiFormer Framework. This approach begins with the collection of required parameters such as including residual energy, position of node, degree of node, mobility speed and quality of link. This collected information is delivered by optimizing the CH selection and cluster formation by applying DBO, which creates energy-efficient and enables secure communication. The BiFormer Framework is used for obtaining the most efficient route. This approach allows for more efficient packet forwarding to reduce energy consumption and ensures proper balance of network load and congestion removal, which prolongs the lifespan of network operation. To measure the performance of the system, NS-2 simulator is implemented and achieves an average throughput rate of 435 kbps, energy consumption 92.5 J, a network life of 153 seconds as well as minimizing End-to-End Delay (E2E) and routing overhead performance improvements in relation to existing techniques.

Keywords: MANET, Dung Beetle Optimization, BiFormer Framework.

1. Introduction

MANET refer to dynamic, wireless networks consisting of mobile nodes that organize and configure themselves without a central controller. Applications of MANETs include many fields such as environmental monitoring, emergency rescue, military applications and industry [1]. A typical MANET configuration is illustrated in Fig. 1. In MANETs, mobile nodes move randomly around, possess limited power, computational and storage capacity, therefore, it is crucial to ensure proper usage of resources when collecting and sending data [2]. The random mobility of nodes in MANETs presents specific challenges related to providing stable and efficient connections. As the nodes are able to transfer out of range, the topology of the network change often. Such a dynamic environment requires adaptive routing protocols and management schemes that react promptly to new conditions [3]. The structure of MANET is shown in figure 1.

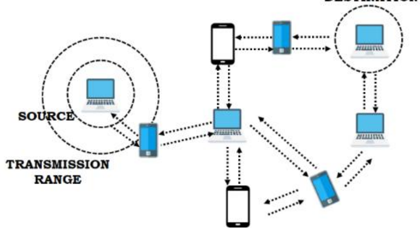

Figure 1: *MANET structure*

Classical algorithms for the shortest path, such as Dijkstra or Bellman-Ford, determine the most optimal routes for forwarding packets in MANETs. These algorithms are significant in providing efficient delivery of information in the decentralized and dynamic nature of MANETs. Routing protocols such as proactive, reactive define the routing techniques [4]. The proactive routing protocols include Destination Sequenced Distance Vector Routing (DSDV), which is table-oriented routing and establishes routes by keeping routing tables updated through the transmission of topological information [5]. Conversely, most reactive routing protocols such as the Ad-hoc On-Demand Distance Vector Routing (AODV) are used to establish routes. In MANETs, the clustering technique is termed as a mechanism instead of a routing protocol that aids in managing both the complex and dynamic traits of the MANET [6]. This technique divides mobile nodes into logical sets to improve the scalability of dynamic mobile networks. In each cluster, one of the nodes is selected to become the backbone of the network and to manage communication during clustering [7]. This hierarchical arrangement helps to reduce the burden of network management to optimize energy consumption. It assures sustainable and efficient growth of mobile networks [8].

The CH coordinates communication within its cluster by communicating with other cluster nodes for collecting, processing, and forwarding data. The cluster nodes send and receive the data from the CH node [9]. If a member node is located in the transmission range of at least two CHs, it is defined as Gateway (GW) node [10]. In this research, the development of stable cluster by selecting suitable CHs is focused to ensure energy efficiency and prolong the time span of networks existence in MANET. By effectively defining the roles of nodes, routing performance is improved. Traditional MANET routing techniques either focus on implementing the processes of selection of CH or performing routing as separate processes which results in greater energy consumption and less duration of network life cycles. Hence, the proposed DBO-BiFormer is used to bridge this gap by integrating the processes of energy-aware CH selection and intelligent routing, thus improving the efficiency of routing, decreasing routing overheads, and increasing the duration of the network life cycle. The main contributions of this research includes,

- This paper presents the DBO-BiFormer framework, which unifies the DBO algorithm for energy-efficient CH selection with the BiFormer framework for smart routing in MANETs.
- The DBO algorithm chooses the best CH based on the remaining energy of nodes, their node degree, mobility status, position and link quality allowing creating clusters that are stable and energy-efficient.
- The BiFormer approach detects the most reliable routes that do not suffer from congestion and thus enhance forwarding packets and lower routing costs.

2. Recent Works

Table 1: *The related works of existing methods for detecting network lifetime maximization in MANETs*

Author/Year	Methods	Merits	Demerits
Neenavath Veeraiah et al [2023]	BSWO [11]	BSWO creates efficient CH selection while achieving an efficient balance between exploitation and exploration.	The algorithm computes with utmost complexity and requires a longer time to process the data especially.
Nikitina Vlada et al [2025]	EPSO [12]	EPSO is quick in convergence and effectively performs routing optimization while conserving energy use.	EPSO is inclined to decreasing into the local optimal stage which leads to poor routing performance.
Chandrashekhar Goswami et al [2026]	GWO [13]	GWO shows steady convergence and good ability to perform a global search	GWO tends to reduce its convergence while operating in the final optimization

		while enabling reliable routing and increased network longevity.	period, resulting in poor adaptation to changing topologies.
Satveer Kour et al [2023]	ACO [14]	ACO easily find an optimal routing path and has good adaptability to change.	The algorithm converge slower in large size networks.
B.Somasekhar et al [2023]	ABC [15]	ABC provide an easy implementation and is great at searching for the optimal routing path.	In large scale MANETs, communication relatively takes longer time.

3. Proposed Methodology

The proposed structure introduces a routing framework for MANETs that is energy-efficient and secure. The framework of the proposed work is shown in figure 2. This is accomplished through the use of DBO in combination with BiFormer. Initially, important aspects such as residual energy, position of nodes, and quality of link of the nodes are collected for recognizing network conditions. Based on these constraints, the DBO algorithm is used to choose the correct CHs and forms clusters by identifying nodes with high residual energy and stable connections. Next, BiFormer is used to identify optimal routing path while accessing both local and global dependencies of the network to find reliable routes free of congestion.

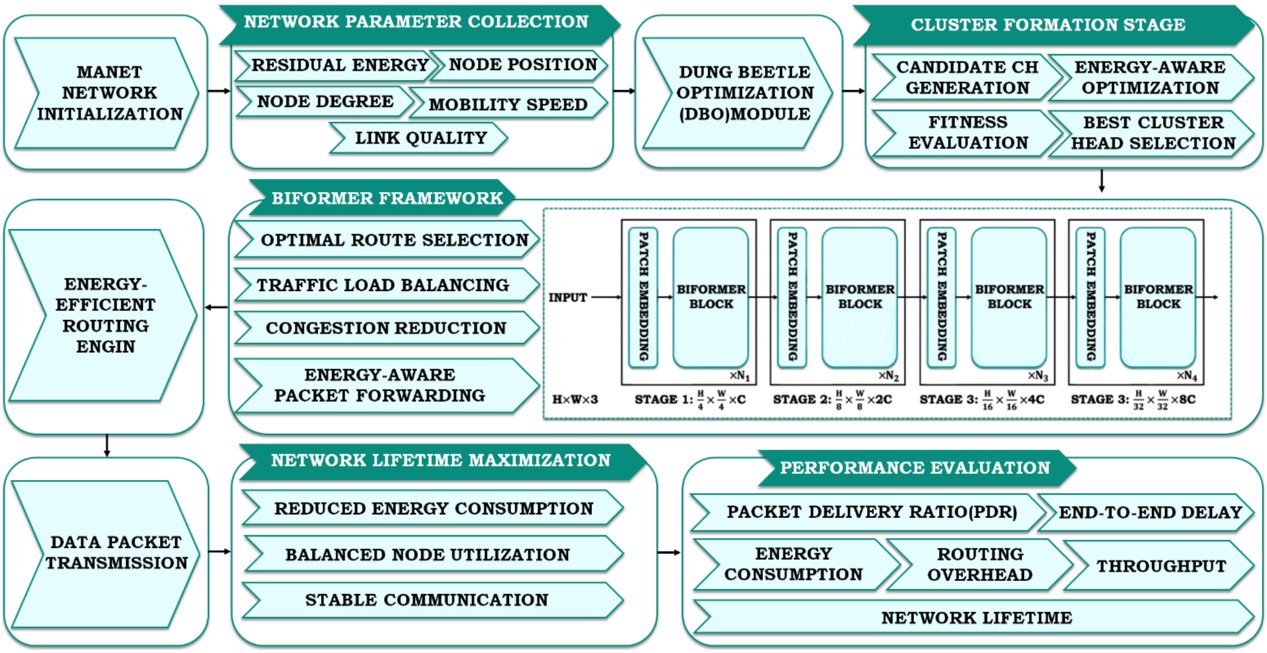

Figure 2: *Proposed framework*

This combined method allows for effective forwarding of packets while providing load balancing, decrease in routing costs, reduction of congestion and an increase in a general network lifetime. The efficiency of the proposed system is tested using specific performance indicators to prove the advanced routing performance of MANETs.

3.1 Dung Beetle Optimization

In the proposed framework of MANET routing, the usage of the DBO algorithm helps in determining the best possible CHs in addition to forming energy-efficient clusters. Each possible solution is a potential CH while the fitness is obtained using a fitness function that has residual energy, node degree, node location, speed of movement and link quality. The first step of the algorithm is the ball-rolling behavior where the positions of potential CHs are changed.

$$x_i(t+1) = x_i(t) + \alpha \times k \times x_i(t-1) + b \times \Delta x \quad (1)$$

$$\Delta x = |x_i(t) - X^w| \quad (2)$$

Where, $x_i(t)$ indicates the position of i^{th} potential CH in the t^{th} iteration. The process of updating the positions discover nodes with higher levels of residual energy, stable motion and better connectivity. In the case of search receiving to a local optimum, the dancing behavior modifies the straightforward direction as,

$$x_i(t+1) = x_i(t) + tan(\theta)|x_i(t) - x_i(t-1)| \quad (3)$$

Where, $tan(\theta)$ regulates the direction of the potential CHs, thus allowing for better exploration of search space. After effective CH candidates are obtained, the breeding behavior is responsible for performing local exploitation in the breeding region. The convergence factor is calculated as follows,

$$R = 1 - {}^{t}/_{T_{max}} \quad (4)$$

Here, T_{max} is defined as the supreme iteration numbers. The adaptive searching boundaries are calculated as follows,

$$Lb^* = max(X^* \times (1-R), Lb) \quad (5)$$

$$Ub^* = min(X^* \times (1+R), Ub) \quad (6)$$

Where, X^* is the local optimal solution of the CH. The new potential CHs are determined by,

$$B_i(t+1) = X^* + b_1 \times (B_i(t) - Lb^*) + b_2 \times (B_i(t) - Ub^*) \quad (7)$$

Here, $B_i(t)$ is the breeding solution. The flowchart of DBO is illustrated in figure 3.

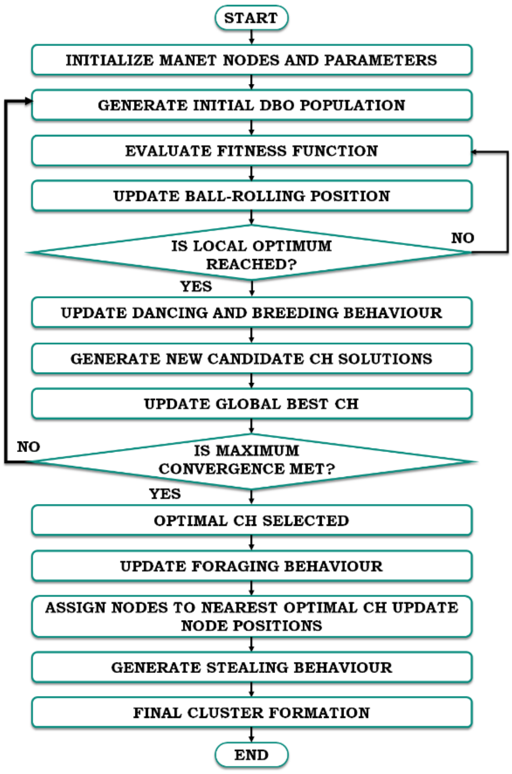

Figure 3: *Flowchart of DBO*

Once the potential CHs are defined, the foraging behavior carries out effective cluster formation by leading ordinary nodes towards the best CH.

$$Lb^b = max(X^b \times (1-R), Lb) \quad (8)$$

$$Ub^b = min(X^b \times (1+R), Ub) \quad (9)$$

In this context, X^b is used to represent the ideal CH solution. The method of associating nodes are then revised through the following function,

$$x_i(t+1) = x_i(t) + C_1 \times (x_i(t) - Lb^b) + C_2 \times (x_i(t) - Ub^b) \quad (10)$$

Where, C_1 and C_2 are random vectors based on the uniform distribution. This phase permits all nodes to connect effectively with the closest energy efficient CH. Hence the proper and equal clustering is performed. Further by applying the technique of stealing, the number of potential solutions is raised and the CHs are relocated according to

$$x_i(t+1) = X^b + S \times g \times (|x_i(t) - X^*| + |x_i(t) - X^b|) \quad (11)$$

Here, S stands for a fixed value. By using all the approaches, DBO helps to identify best CHs at the same time and create the clustering process effective.

3.2 BiFormer framework

BiFormer is used in the proposed MANET routing framework to attain optimal route selection by accurately learning connections between nodes. The input network information is presented as a feature map (X). The input to the BiFormer framework is processed using the Bi-Level Routing Attention (BRA) system, which helps in observing interactions among nodes. First, the query (Q), key (K), and value (V) feature are generated based on the input feature representation through the following formula,

$$Q = X^r W^Q, K = X^r W^K, K = X^r W^V \quad (12)$$

Where, W^Q, W^K and W^V are projection matrices that obtained initially.

$$A^r = Q^r (K^r)^T \quad (13)$$

Where, A^r is used to show the dependency between network areas. The architecture of BiFormer is presented in figure 4.

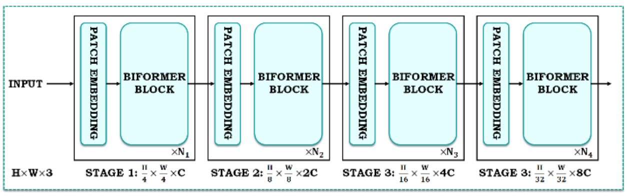

Figure 4: *BiFormer*

The first step involves selecting the best network areas through affinity. The most suitable areas are defined as follows,

$$I^r = topkIndex(A^r) \quad (14)$$

By this, the model continue through quality routing without unnecessary interactions of nodes. The final outcome of attention is measured as,

$$O = Attention\ (Q, K^g, V^g) + LCE(V) \quad (15)$$

Where, O indicates a better routing feature, while $LCE(V)$ indicates local context information. The BiFormer framework optimizes the route finding process as it captures local and global dependencies and selects efficient, stable, and congestion-free routings. Thus, BiFormer enhances packet transmission efficiency, routing overhead, and the lifetime of MANETs.

3.3 Network Lifetime Maximization

In MANET, it is used to prolong the lifespan through an efficient use of reliable communication. The mechanism ensures effective transferring of packets through best routing paths as per residual energy, link conditions, traffic, and mobility conditions. The system control energy consumption, balance load among all nodes in the network and ensures the stable communication of the nodes while minimizing the occurrence of node failures.

4. Results and Discussion

The evaluation of the proposed routing framework based on DBO-BiFormer is evaluated using most important metrics of MANET performance. The parameter specifications are illustrated in Table 2.

Table 2: *Parameter Specifications*

Parameters	Values
Simulator	NS-2
Simulation time	50 s
No. of nodes	50
Transmission power range	50mW
CH selection	DBO
Routing Protocol	BiFormer

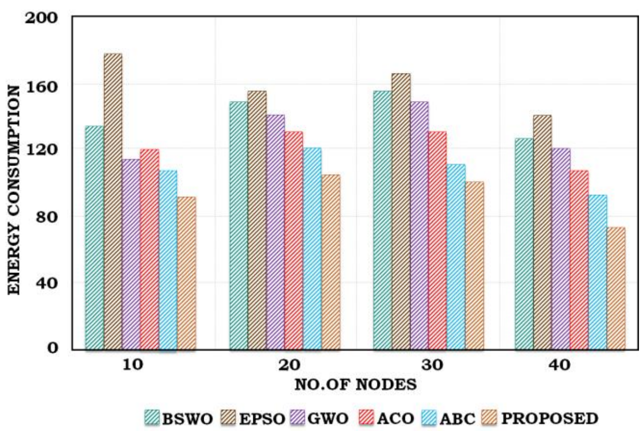

Figure 5: *Comparison of Energy Consumption*

Figure 5 indicates that the proposed method provides the minimum energy expenditure of 92.5J as compared to BSWO [11], EPSO [12], GWO [13], ACO [14], and ABC [15] for different nodes, which shows that the proposed technique is better at conserving energy due to better CH selection and routing process, which results in better use of resources.

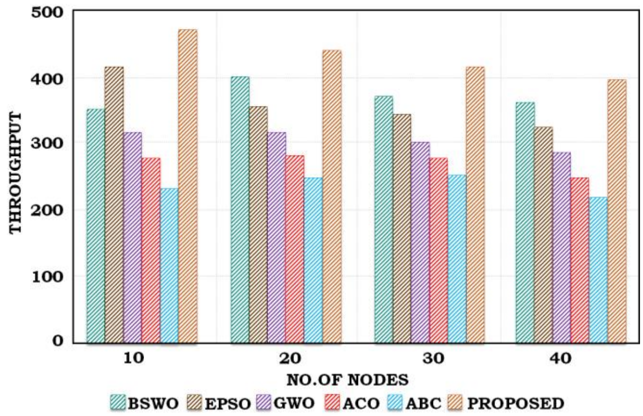

Figure 6: *Comparison of Throughput*

Figure 6 depicts that the proposed method leads to highest throughput of 435 kbps as compared to BSWO [11], EPSO [12], GWO [13], ACO [14], and ABC [15] for all numbers of nodes. This method provides the maximum level of efficacy and is stable over the progression of experiment.

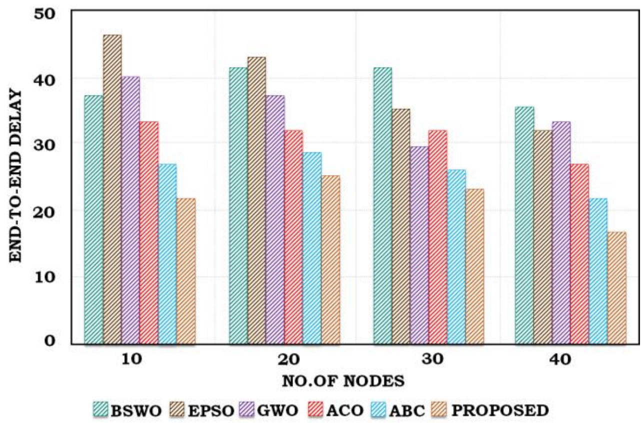

Figure 7: *Comparison of E2E*

In Figure 7, the proposed method leads to minimum E2E of 21.8 ms between all the attacking methods compared, including BSWO [11], EPSO [12], GWO [13], ACO [14], and ABC [15].

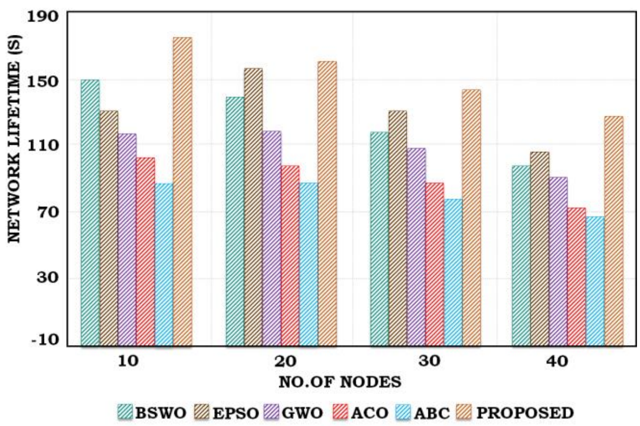

Figure 8: *Comparison of Lifetime of the network*

Based on the information illustrated in Figure 8, the proposed method has the ability to prolong the network's standards of 153 s and life expectancy, outperforming BSWO [11], EPSO [12], GWO [13], ACO [14], and ABC [15] across every possible node count. Even though network life expectancy tends to decline with growing numbers of nodes, the proposed method continues to show better energy-saving capabilities and network sustainment.

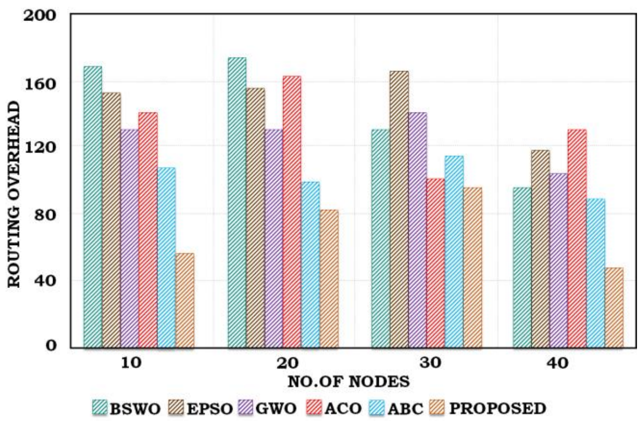

Figure 9: *Comparison of Routing Overhead*

Figure 9 highlights that routing overhead compares with six protocols BSWO [11], EPSO [12], GWO [13], ACO [14], ABC [15] and proposed method at various nodes. The proposed method demonstrates lower overhead of 71.3, which indicates high efficiency in contrast to the previously mentioned systems, as it achieves the highest values at each node scale.

5. Conclusion

This research combines DBO with BiFormer framework to implement energy-efficient and reliable routing strategies in MANETs. The information collected from the initial stage provide valuable information for determining the health of the network. The DBO optimization stage aids in the selection of the CH and cluster establishment through the detection of the nodes that perform better in terms of energy efficiency and connectivity, which provides maximized resource usage and stable communication. The BiFormer framework helps in the route selection process by evaluating the connections among the nodes and identifying the most significant routing characteristics. Energy-efficient routing is recognized to obtain the solutions of energy consumption problem through optimized packet forwarding. The results of the proposed method are evaluated in NS-2 platform and achieve high PDR, throughput, network lifetime with low E2E and energy consumption. Future work include implementation in real-time, experimentation under different network scenarios with the aim of improving the model for routing.

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