International Journal of Advanced Trends in Engineering and Management
(ISSN 2583-7052)

Vol. IV, No. 03, pp. 22-28, March

Energy-Efficient Routing in MANET using Mountain Gazelle Optimizer and LEACH-Based Clustering

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ABSTRACT: The rise of Internet of Things (IoT) applications and the widespread use of mobile devices have made Mobile Ad Hoc Networks (MANETs) more important in modern day. Enabling effective data transport in decentralized wireless networks is largely dependent on the routing mechanism. In the present research, Mountain Gazelle Optimizer (MGO) is integrated with Low Energy Adaptive Clustering Hierarchy (LEACH) protocol to offer an effective routing and clustering framework for MANETs. Intelligent approaches are necessary for dependable data transmission and energy conservation in MANETs due to their inherent mobility and dynamic topology changes. To overcome these obstacles, the LEACH protocol is used for energy-efficient and adaptive clustering, in which cluster heads are chosen at random to distribute energy usage among nodes. The Mountain Gazelle Optimizer, an evolutionary algorithm modelled after the adaptive movement behavior of gazelles, is used to optimize routing between cluster heads and destination nodes. By reducing parameters like energy usage, transmission latency, and route instability, MGO optimizes the routing paths. When compared to conventional methods, the proposed MGO-LEACH model improves Packet Delivery Ratio (PRD) and network lifetime and lowers routing costs. The proposed design greatly enhances MANET's performance, as shown by extensive simulation findings, which makes it ideal for dynamic and energy-constrained wireless network situations.

Keywords: Internet of Things, Mobile Ad Hoc Networks, Mountain Gazelle Optimizer, Low Energy Adaptive Clustering Hierarchy, Routing Paths.

1. Introduction

In the technical world of this day and age, being network connected is essential. MANET represents a revolutionary shift in wireless communication, enabling devices to connect and communicate without relying on fixed infrastructure or centralized administration. MANET offers a powerful and flexible solution for wireless communication in environments where traditional infrastructure is unavailable or impractical [1-2]. In contrast to conventional wireless networks, which depend on a permanent backbone like routers and access points, MANETs operate in a decentralized manner. It allows the network to be self-configuring and highly adaptable to changes in topology [3-4]. Communication in a MANET typically occurs over multiple hops, as data is relayed through intermediate devices to reach its destination. Because there is no central authority or infrastructure, MANETs are especially useful in situations where conventional networks are impractical, such as in military operations, disaster recovery, and temporary events [5-6]. However, MANETs also face significant challenges, including dynamic routing, limited bandwidth, energy constraints, and security risks due to the open and decentralized nature of the network. Despite these challenges, MANETs remain a promising solution for enabling communication in dynamic and unpredictable environments [7-9]. In MANETs, energy efficiency is a critical concern due to the limited battery power of mobile nodes. One effective strategy for conserving energy is to organize the network into clusters and employ energy-aware routing protocols. Energy-efficient routing in MANETs is essential to prolong network lifetime and ensure stable communication among mobile nodes with limited battery power. In order to achieve efficient data packet, many optimization techniques are applied [10-12]. The optimization approaches including Bacteria for Aging Optimization Algorithm (BFOA), Ant Colony Optimization (ACO), Adaptive Neuro-Fuzzy Inference System (ANFIS)-based Grey Wolf Optimization (ANFIS-GWO) [13-14]. These methods have some downsides that result from this method's time delay, time consumption, and low throughput [15]. So, to overcome all of the downsides, advanced effective optimization is required. Hence, this paper employs MGO- and LEACH-based clustering techniques. The following objectives are examined in this work:

- To analyze the data packet transmission from the source node to the destination node by using a base station.
- To minimize energy consumption and reduce the amount of data transmitted directly to the base station, LEACH is employed.
- To reduce packet drop and increase data delivery ratio with high throughput using the MGO algorithm.
- To maintain and enhance the security of routing, the LEACH - MGO technique is utilized.

The following list shows the order in which the paper is presented: Section II discusses the recent work. In Section III, the proposed work is described. Section IV presents the results. It contains a conclusion in Section V.

2. Recent Works

Jalal Ghadermazi *et al* (2025) [11] have presented a BitTorrent-like algorithm for video-on-demand streaming over mobile ad hoc networks: the BT-MANET algorithm. It ensures fair distribution of tasks among nodes, avoiding overburdening any single node. It reduces routing overhead, frequent re-clustering in highly mobile environments introduces latency during transitions.

Kudret Yilmaz *et al* (2025) [12] have developed a two-stage Hybrid Adaptive Clustering Algorithm for Dynamics MANETs (HACADM) to improve the network performance in MANETs. It combines Gravity Search Algorithm (GSA) and dynamic clustering strategies to minimize energy consumption, extending the network's overall lifetime. However, it requires more processing power at each node to evaluate multiple parameters like mobility, energy, and connectivity.

Uppalapati Srilakshmi *et al* (2022) [13] have presented the BFOA in advancing the energy-efficient navigation in MANETs. However, it lacks an effective local search mechanism to fine-tune the solutions, which limits its ability to find precise solutions in highly specialized areas of optimization like aging.

Sarra Benzerogue *et al* (2024) [14] have proposed a design of Multi-Path Transmission Protocol for Video Streaming (MPTP-VS) over vehicular fog computing environments. It ensures seamless video streaming without prior knowledge of the network topology. Moreover, it suffers from slow convergence when compared to other optimization techniques.

Fatemeh Safari *et al* (2023) [15] have developed a Cross-layer Adaptive Fuzzy-based Ad hoc On-

Demand Distance Vector routing protocol (CLAF-AODV) to reduce the routing broadcast traffic. It highly effective in finding optimal or near-optimal solutions in complex, multi-dimensional search spaces. Nevertheless, it is computationally expensive due to the large number of ants and iterations required.

3. Proposed Work Explanation

The paper proposes a LEACH based MGO algorithm developed for the highest efficiency and throughput. The block diagram illustrated in Figure 1.

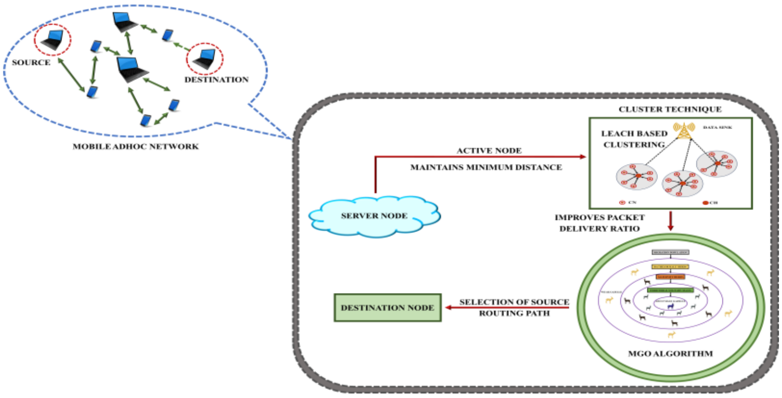

Figure 1: *Block Diagram for Proposed System*

Initially, the source node checks the path that survives between itself and the terminus. Active nodes are also employed to collect the data and then forward it to the next stage. Further, it maintains the minimum distance. Following the stage, data packets are entered, and the clustering technique is handled by LEACH. LEACH is used for energy efficiency, in which cluster heads are chosen at random to distribute energy usage among nodes. Next, the selective data packets are analyzed by using the MGO algorithm to select the source routing path. Additionally, the MGO algorithm reduces packet drops and increases the data delivery ratio with high throughput. Lastly, an effective data packet is received at the destination point.

3.1 Source Node

A source node is the device that initiates communication by generating and sending data packets to another node (the destination node) in the network. Unlike traditional networks with fixed infrastructure, MANETs are decentralized and composed of dynamically changing topologies, where each node moves freely and independently. When a source node wants to send data, it must first determine a valid route to the destination, often by initiating a route discovery process through protocols. Since nodes in a MANET also serve as routers, the source node relies on neighboring nodes to forward packets across multiple hops until the data reaches its destination. The mobility and limited resources of nodes in MANETs add complexity to this process, requiring the source node to be adaptive and resource-efficient in managing communication.

3.2 Clustering – LEACH

The LEACH is designed for WSNs, and it adapts to MANETs to improve energy efficiency. In LEACH-based clustering, nodes are grouped into clusters, each managed by a Cluster Head (CH) that aggregates and forwards data to the destination or to other CHs. The selection of cluster heads is typically based on residual energy levels and is rotated periodically to balance energy consumption among nodes. By reducing the number of direct transmissions and enabling data aggregation, LEACH significantly lowers communication overhead and energy usage. When applied to MANETs, this approach helps extend network lifetime, improve scalability, and maintain more stable routes despite node mobility. However, adaptations are required to handle the high mobility and dynamic topology of MANETs, such as mobility-aware CH selection and dynamic reclustering mechanisms. The Cluster Process of LEACH is presented in Figure 2.

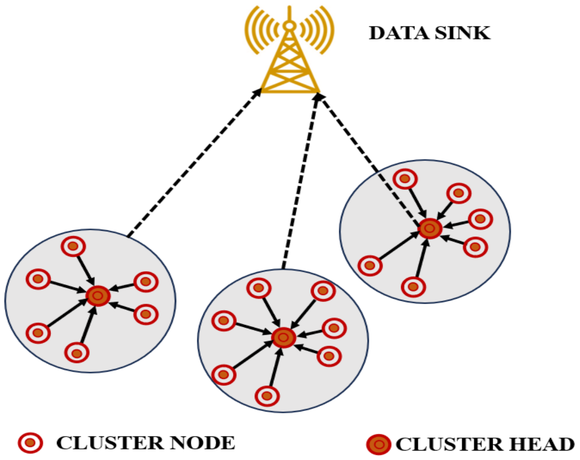

Figure 2: *The Cluster Process of LEACH*

In this approach, a few nodes are selected as CHs based on a probability model and their residual energy levels. These CHs manage communication within their clusters and are responsible for collecting, aggregating, and forwarding data to other CHs or directly to the destination. The remaining nodes join the cluster with the strongest signal from a nearby CH and send their data to it using a scheduled transmission pattern to avoid collisions and save energy. CHs are rotated periodically to distribute the energy load evenly across the network and prevent early battery depletion of any single node. In MANETs, where node mobility frequently alters the network topology, LEACH must be adapted to handle dynamic cluster formation and mobility-aware CH selection. This involves continuously monitoring node movement and adjusting cluster membership and CH roles accordingly. By reducing redundant transmissions, aggregating data, and ensuring balanced energy usage, LEACH-based clustering enhances routing efficiency, prolongs network lifetime, and supports more stable communication in energy-constrained MANET environments.

3.3 Optimization– MGO

The MGO is a nature-inspired metaheuristic algorithm modelled after the evasive and adaptive behaviors of mountain gazelles when escaping predators. When applied to MANET routing, MGO helps in identifying optimal or near-optimal routes between source and destination nodes while minimizing energy consumption. The algorithm works by simulating a population of candidate routes, which evolve over iterations through behaviors such as sudden directional changes and energy-aware movement toward better routes. Based on the four main facets of mountain gazelle life Territory Solitary males (TSM), Maternity Herds (MH), Bachelor Male Herds (BMH), and Migration in search of food (MSF) the MGO algorithm performs optimization operations. MGO operations have been represented in Figure 3.

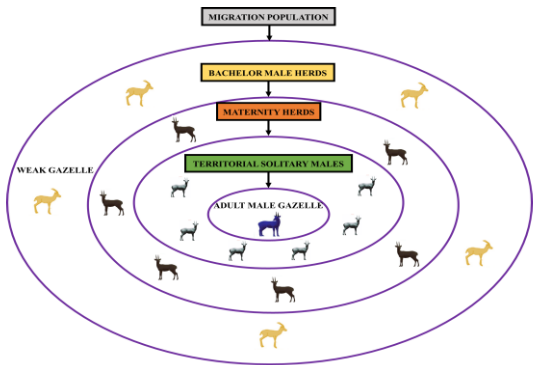

Figure 3: *The MGO Operation*

3.3.1 TSM

In the algorithm, TSMs play a strategic role in maintaining diversity in the population and enhancing the exploration capabilities of the optimizer. In nature, solitary male gazelles establish individual territories to attract females and avoid conflict with dominant males. TSMs generate new, potentially diverse solutions by exploring areas where the main population has not focused. Further, it is evaluated with a fitness function.

3.3.2 MH

MH is inspired by the social behavior of female gazelles, these form herds during the breeding season to provide safety and support for their young. It encourages collaboration among solutions to reinforce strong candidates, gradually improving the overall quality of solutions. It improves the quality of the final solution by utilizing group knowledge, which is particularly beneficial for optimizing energy-efficient routing in dynamic networks like MANETs.

3.3.3 BMH

It is inspired by the behavior of bachelor male gazelles that form groups for socializing, protection, and shared exploration. It provides a mechanism for collective exploration and search for new territories, often working together to enhance their chances of survival or reproductive success.

3.3.4 MSF

The concept of Migration in Search of Food (MSF) is inspired by the natural behavior of gazelles migrating to new areas in search of food and better living conditions. This behavior is crucial for survival, as gazelles must constantly adapt to changing environments and resources. In the MGO algorithm, MSF represents the search for better solutions by migrating through different regions of the solution space to find optimal or near-optimal results.

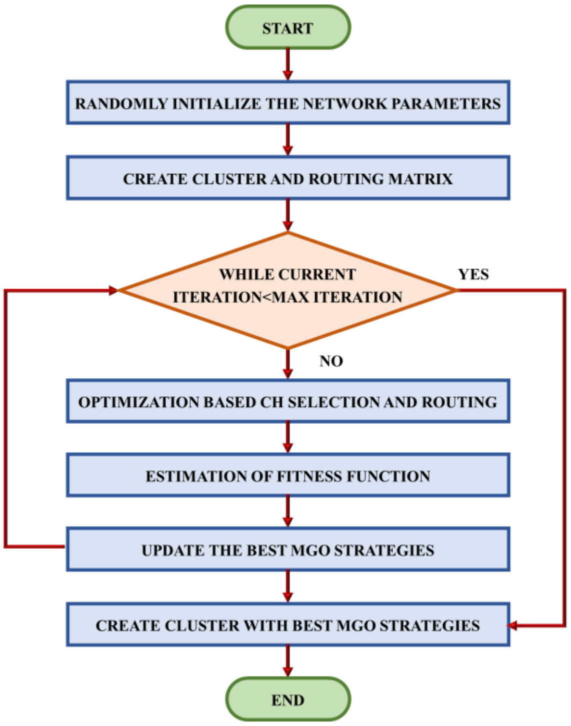

Figure 4: *Flowchart of the MGO*

Figure 4 displays the flowchart of the MG optimization. In routing, each solution represents a possible path, and its fitness is evaluated based on factors like residual energy of nodes, hop count, and link stability. MGO dynamically updates paths to adapt to node mobility and changing network conditions, thereby avoiding energy-draining routes and balancing the energy load across the network. This results in reduced packet loss, extended node lifetime, and improved overall network performance. The adaptability and lightweight nature of the MGO make it particularly suitable for the decentralized and resource-constrained environment of MANETs.

Table 1: *Performance of Comparative Analysis*

Parameters	**Optimizations**		
	HACADM – GSA [12]	**BFOA [13]**	**Proposed LEACH-MGO**
Energy Consumption	8.33	7.43	4.05
Latency	2.80	3.5	1.25
Throughput	40	70	92
PDR	91	92	95

The Table 1. Displays the parameter and its specifications. The proposed LEACH – MGO provides the highest parameter results compared with different types of optimizations.

The comparison of latency is demonstrated in Figure 6. In this graph, latency is 1.25 attained and it demonstrates that is a low latency when compared to other approaches.

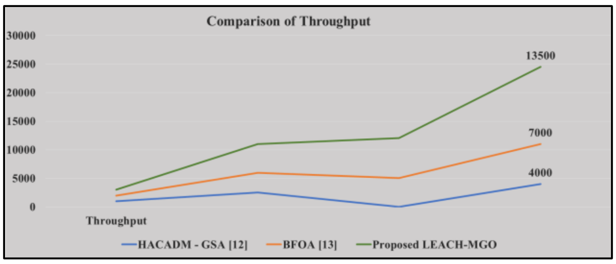

Figure 7: *Comparison of Throughput*

Figure 7 displays the throughput value, which determines the throughput and it attain high throughput value of 13500 kbps.

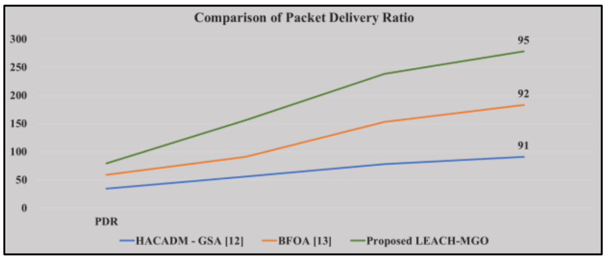

Figure 8: *Comparison of PDR*

The precise PDR comparison is displayed in Figure 8. This method demonstrates that it consistently gives a greater packet delivery ratio than other methods. When the packet delivery ratio is high, the performance is improved.

5. Conclusion

Energy-efficient routing is crucial in MANETs, where nodes rely on limited battery power to maintain communication. To address this challenge, combining the MGO and LEACH-based clustering offers a promising solution. LEACH-based clustering organizes the network into clusters, reducing energy consumption by minimizing the number of direct transmissions and aggregating data. MGO provides adaptive and resilient solutions for identifying energy-efficient paths despite the unpredictable nature of node mobility. Further, this hierarchical structure helps manage energy more efficiently, especially in networks with mobile nodes were topology changes frequently. As a result, the proposed algorithm of LEACH-MGO, the highest throughput and PDR value of 92%, and 13500 kbps and the minimum latency of 1.25 are achieved. Overall, this work ensures that energy resources are utilized optimally, offering a more reliable and scalable solution for MANETs in a variety of applications, from military to environmental monitoring.

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