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Energy Efficient Intelligent Hunter–Prey Optimization-Based Routing Protocol for MANET

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ABSTRACT: Mobile Ad Hoc Networks (MANETs) are characterized by dynamic topology, limited battery, and intermittent connections through wireless access, significantly affecting routing performance and lifespan of the network. Traditional routing protocols are not able to adjust changes in node mobility and energy imbalance because they are based on shortest path or hop count decision mechanisms. This paper proposes an intelligent routing system using the Hunter–Prey Optimization (HPO) algorithm for optimal path selection in MANETs to address these limitations. The proposed predator-prey behavioural model generates energy-efficient, low-latency, and consistent data movement. The Hunter–Prey Optimization method defines the globally optimal routing solution with a hunter representing the globally optimal route, while the prey agents dynamically explore other candidate routes to avoid premature convergence. Using the combination of residual node energy, end to end delay, number of hops, packet delivery ratio and link stability, complete fitness function is created. The HPO routing protocol selects the most reliable route based on adapting the exploit and explore principles throughout the duration of operation in mobile environments, with repeated rounds of exploration and exploitation. This method demonstrated superior performance over traditional routing protocols and current routing protocols based on metaheuristics with regards to packet delivery ratio, average delay, energy consumption and overall network lifetime through extensive simulation testing with a range of node densities and mobility patterns.

Keywords: MANET, Hunter-Prey Optimization, Routing protocols, Energy efficiency, exploration and exploitation.

1. Introduction

A MANET is a development of mobile nodes and mobile users that allows for communications over a shared wireless medium without any required infrastructure. MANET is an automatically created network of mobile nodes that communicate via wireless interfaces and have a random topology, as nodes move without any restrictions, the topology of the wireless network also be random and change very quickly [1]. The nodes participate in the MANET are self-directing and do not physically connect to another node through a larger network providing access to the broader internet. An Ad-Hoc network created by a network of sensors consists of sensors, data, and communication components. When the network infrastructure is incomplete, each node becomes relay for sending data packets from one of the other nodes transmitting wirelessly over both remote and local distances [2]. By using battery power and having limited processing and routing capabilities, MANET's nodes are slower, less capable of performing complex analysis of information, and only store a limited amount of data [3].

Routing algorithms for MANETs face many difficulties due to the limitations of the node's processing power, battery life, storage capacity, and communication capabilities. Recently, routing protocols for MANETs have received much interest due to their limited battery capacity. Energy-aware routing is a good approach for extending the life of energy-constrained nodes in MANET [4]. There are two types of energy-aware routing protocols, Minimum Energy (ME) routing selects the pathway that consumes the least total energy for transmitting packets, and Max-Min routing selects the link whose bottlenecked residual node has maximum remaining energy [5]. The structure of MANET is shown in figure 1.

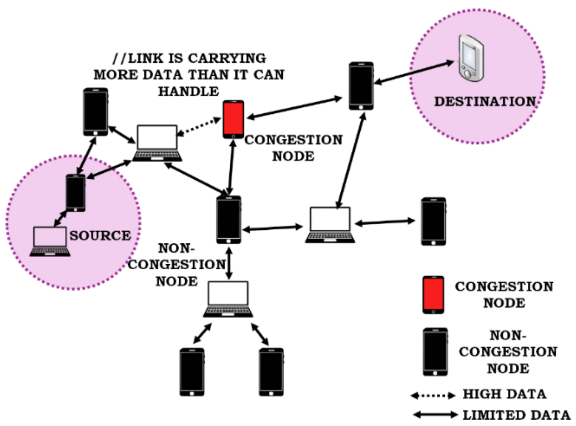

Figure 1: *Structure of MANET*

Two types of routing protocols exist in MANET based on the discovery of routes such as proactive (table-driven) and reactive (on-demand). Each mobile host in a table-driven routing protocol maintains up-to-date and consistent routing tables with the directing data for each other mobile host in the network. When the network topology changes, each mobile host transmits reorganized communications to all other mobile hosts in the network to keep routing information consistent for the entire network [6]. The main difference between the two types is that the table-driven routing protocols keep current routes in entire portable clouds and distribute the routing information between them, while reactive routing protocols create a path to the destination host only when a datagram needs to be routed to that host [7].

Destination-Sequenced Distance-Vector Routing Algorithm (DSDV) is a table-driven routing protocol and Ad hoc On-Demand Distance Vector Routing (AODV) uses the DSDV routing algorithm as a basis, but allows routing paths to be created when a datagram needs to be sent to a specific host [8]. AODV does reduce the total number of route broadcasts by generating routes on a needed basis whereas DSDV has a complete paths. Both Dynamic Source Routing Protocol (DSR) and Temporally Ordered Routing Algorithm) (TORA) are reactive directing procedures that use the same on-demand method for routing as AODV. However, Due to the essential for maintaining a fully populated routing table via periodic updates DSDV has excessive routing overhead and doesn't scale properly. AODV has to deal with routing overhead since routes are created on demand, though, AODV suffers route discovery delays from having to continue to create routes despite previous links failing, which increases the amount of control packets for the same reason that AODV organizes [9]. DSR has to continuously create packets with new source routes, and this further increases packet overhead, due to the dynamic nature of these networks DSR has stale route caches that contribute to further increase overall packet overhead. TORA is complex to implement and has excessive control message generation during its route maintenance processes, causing TORA to produce very poor performance in highly mobile, dense, and large-scale ad hoc networks [10]. In order to overcome these shortcomings, the proposed system implements a Hunter-Prey Optimization algorithm.

Table 1: *Related works of existing optimization methods for energy efficient routing protocols in MANET*

SI.NO	AUTHOR/YEAR	METHODS	MERITS	DEMERITS
1.	Ohood Almutairi et al [2024] [11]	Particle Swarm Optimization [PSO]	Fast convergence and an efficient global search capability are provided therefore, routes are optimally selected.	In high dynamic MANETs, PSO experience premature convergence, which results in routing decisions that are not optimal.
2.	Shaik Shafi et al [2023] [12]	Ant Colony Optimization [ACO]	ACO provides greater reliability in travelled routes and facilitates load balancing and fault tolerance.	It suffers from both scalability problems and increased latency when discovering routes during dynamic conditions.
3.	Vasantha Kumara Mahadevachar et al [2023] [13]	Battle Royale Optimization [BRO]	BRO optimize route selection by encouraging the survival of high-fitness nodes.	It creates more computation complexity with increased control overhead which ultimately makes it less effective in large-scale MANETs.
4.	Minal Patil et al [2025] [14]	Grey Wolf Optimization [GWO]	By offering an excellent balance of exploration and exploitation, GWO lengthen the network's life span.	If the level of node mobility is high, GWO prone to premature convergence and create suboptimal routing decisions.
5.	G. Rohini et al [2023] [15]	Firefly Optimization Algorithm [FOA]	It possesses the highest residual energy and lower quality of links based on the use of nodes.	It is slow to converge in highly dynamic and larger scale MANET networks.

The objectives of this research include,

- ❖ To reduce mobile nodes total energy consumption, best routing options based on hop distance, transmission cost and residual energy is determined.
- ❖ To dynamically adjust node mobility, frequent topology changes, increase routing stability and dependability, Hunter–Prey Optimization algorithm is implemented.
- ❖ To improve MANET routing's scalability and resilience in large-scale, dense networks.

2. Proposed System Description

The energy-efficient intelligent HPO based routing protocol is a proposed solution for the design of a MANET routing protocol based on the use of a predator-prey mechanism, allowing for route selection based on dynamic topologies and energy constraints. The diagram of energy efficient routing protocol for MANET using HPO is shown in figure 2.

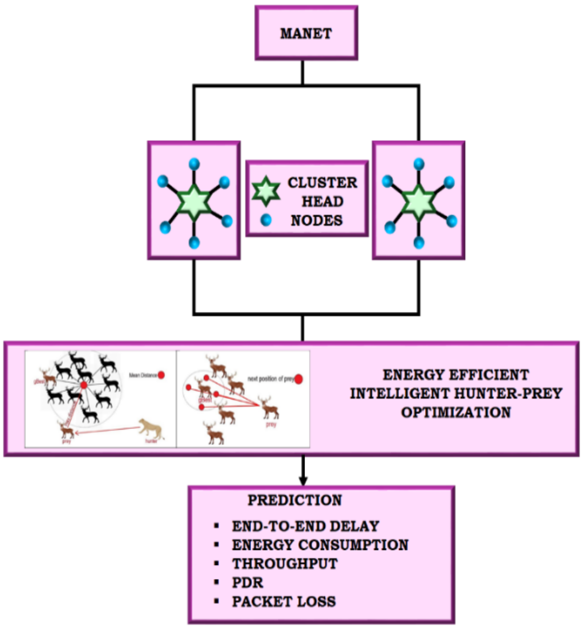

Figure 2: *Diagram for the proposed system*

This methodology models the routing process as a predator-prey relationship with the hunter representing the best global route, while the prey has the ability to search for additional alternative routes to find the best route to achieve a balance of exploration and exploitation, while avoiding premature convergence. Routing paths are evaluated based on a composite fitness function that consists of a combination of the available residual node energy, end to end delay, hops, packet delivery ratio, and link stability during the route discovery and route maintenance phases. The HPO algorithm provides dynamic adaptability to node mobility and network changes presented during the routing process through the use of multiple iterations of route optimization to select reliable, low latency, energy-efficient routing paths. This intelligence based, energy-efficient, and improved routing protocol reduce energy consumption, increase the packet delivery ratio, decrease delays, and increase the lifetime of the network by outperforming conventional MANET routing protocols and existing metaheuristic-based MANET routing protocols.

3. PROPOSED SYSTEM MODELLING

3.1 MANET:

In MANET, a secure path for data transmission is selected from a user node to a sender node and receiver node. In order to preserve the communication between each of the different user nodes and sender nodes, more optimized power is provided. For any two nodes, there should be a total of m user nodes, then all user nodes should be considered as part of tools and a total of all links must equal to r link creates within the set of all other user nodes as shown below,

1. The set of all possible user nodes for $i = 1$ and $i = m$ is U (i = user node 1, user node 2, ..., user node m) $(1 \leq j \leq r \leq 2)$ and $j = 1, \ldots, m$.
2. The total number of possible links that connect two user nodes is given by the set $V\,(j = i = 1, j = i = r)$.
3. Each user node needs excess power in order to transmit data through the user nodes.
4. The length of the link user transmits data to the receiver node is considered as the primary element of the distance between the source node and the destination node.

3.2 Energy Efficient Routing in MANET:

The Energy Efficient Routing Algorithm (EERA) for MANETs, is designed to minimize energy expenditure by selecting routes based on both high residual energy and short distance. When a source node transmits a route request, several potential paths to the destination are discovered and stored along with information pertaining to the energy of the node and distance of the route. To derive the optimal energy efficient route EERA employs the energy-based metric defined by,

$$IR_a = \frac{\sum \boldsymbol{\delta(n) \in I_R \times Energy\delta_{(n)}}}{\sum \boldsymbol{\delta \in_v \times Energy\ (\delta)}} \tag{1}$$

Where, δ represents the vertices of the graph, IR_a is the ideal route, v is the usual nodes in the linkage, and this equation provide the route that exhibits the greatest total cumulative energy. EERA utilizes the distance-based metric to evaluate the efficiency of a route with respect to the distance of the route, as demonstrated by the following equation,

$$IR_b = \frac{\sum \boldsymbol{\delta(n) \in I_R \times Distance\ \varepsilon(n)}}{\sum \boldsymbol{\varepsilon \in L}} \tag{2}$$

Where, ε represents the edges of the graph and L is the set of all links that exist in the MANET. The energy efficient diagram for routing in MANET is displayed in figure 3.

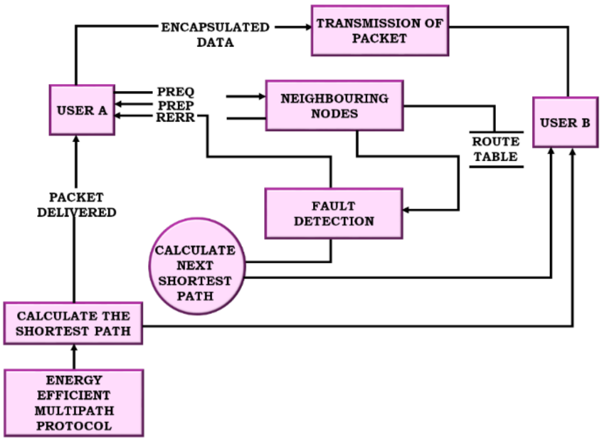

Figure 3: *Energy efficient routing in MANET*

By using both of these metrics together, EERA is able to choose a routing path that has the maximal amount of energy available while also minimizing the distance to be travelled. When the selected routing path fails, EERA either perform a new route discovery or switch to an alternate route from the routing table that requires the least amount of energy to negotiate. The resulting goals of this approach are to balance the utilization of energy, decrease route failure rates, and extend the lifetime of the network, therefore making EERA an effective energy efficient routing solution for dynamic MANETs.

3.3 Hunter–Prey Optimization algorithm:

The HPO-based routing protocol, is based on the natural relationship between a hunter and prey, where the detection and preservation of optimal paths is analogous to the act of hunting. The optimal routing path is represented by the hunter, and the different node sequences between the source and destination create the possible optimal routing paths, which are represented as the prey. In addition, based upon the hunt, the routing process is also improved by the use of energy-efficient routing.

Therefore, if the route chosen by the hunter has fewer weak nodes or congested nodes than a route chosen by the prey, then the hunter pursues the prey according to the route with the least number and greatest distance from the average network environment and thus require the greatest amount of energy to travel fewer hops, with a lower probability of yielding a successful delivery of packets and link stability. Additionally, as the prey agents attempt to escape from the hunter, they attempt to move toward a more stable area of the network in their pursuit of the hunter, which has an optimal fitness function containing residual energy, delay, hop count, packet delivery ratio, and link stability. To create the initial population of possible routes, the HPO protocol randomly creates a group of routing solutions,

$$x_i = rand(1, d) * (u - l) + 1 \tag{3}$$

To define the routing problem, the variables x_i defined as a potential route, u is the upper bound of routing metrics, l is the lower bound of routing metrics and d is the dimension of the problem. The fitness of all routes is calculated using $OF = (x)$, then the iterative optimization is performed. During both exploration and exploitation of routes, an update to the hunter occurs as described below,

$$x_{i,j}(t+1) = x_{ij}(t) + 0.5\left[\left(2CZP_{pos} - x_{ij}(t)\right) + \left(2(1-C)Z_{\mu i} - x_{i,j}(t)\right)\right] \tag{4}$$

Where, P_{pos} denotes the prey route, C is a balance constant used during the route's exploration and exploitation phases, Z is an adaptive universal parameter, and μ is the average position of all routes. The prey route is determined by choosing the maximum Euclidean distance from the average position. This operation helps to ensure that explorations of the search space continue and continue to happen until the value of k_{best} reduces to zero. Prey movement direct the optimal route towards T_{pos} to avoid a slow convergence rate and unnecessary energy consumption.

$$x_{i,j}(t+1) = T_{pos(j)} + CZcos(2\pi R_4) \times \left(T_{pos(j)} - x_{i.j}(t)\right) \tag{5}$$

The objective is to have a low power consumption and stable routing paths through convergence. A parameter, β distinguishes between hunter and prey updating helping adaptively refine the routing paths to reach a final state.

$$C = 1 - itr\left(\frac{0.98}{itr_{max}}\right) \quad (6)$$

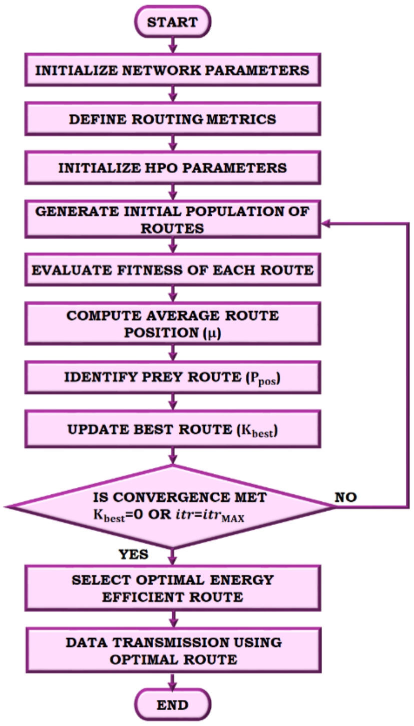

Figure 4: *Flowchart for HPO*

The flowchart for HPO is illustrated in figure 4. The decreasing balance parameter helps to maintain high levels of exploration in early phases while focusing more on exploitation later. Utilizing this HPO framework in combination with MANET routing allows for adaptive route discovery, balanced power usage, reduced route overhead, and extended network lifetime. Due to the small number of control parameters, non-gradient nature, and the use of intelligent exploration and exploitation balance, HPO is very beneficial for dynamic MANET environments that are energy-aware and out perform traditional routing protocols and current routing protocols based on metaheuristic-based routing approaches.

4. Result and Discussion

Through the use of extensive simulations under different node density levels and mobility conditions, the performance of the proposed energy efficient intelligent HPO-based routing protocol was compared to the existing meta-heuristic routing protocols. The results of this study showed that the performance of the newly developed HPO optimisation protocol is superior to existing meta-heuristic routing protocols across all evaluation metrics employed.

Table 2: *Simulation Parameters*

Parameters	Values
No. of Nodes	50
Packet size	512 *bytes*
Simulation time	500 *sec*
Area size	1000 × 1000
Range of transmission	50m
Tool for simulation	NS 2
Initial energy	1000J
Mobility model	Random waypoint movement

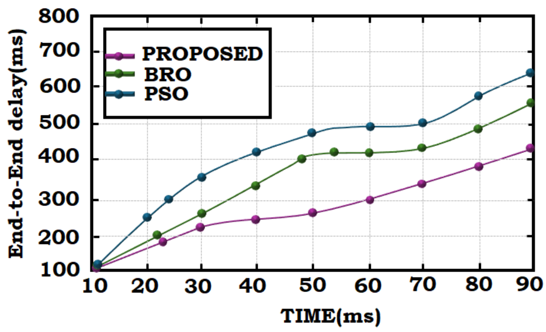

Figure 5: *Comparison of End-to-End delay*

Figure 5 shows that the proposed system has consistently been the most effective with respect to end-to-end delay time, therefore the proposed system is superior at all densities of nodes with regards to efficiency and scalability over BRO and PSO.

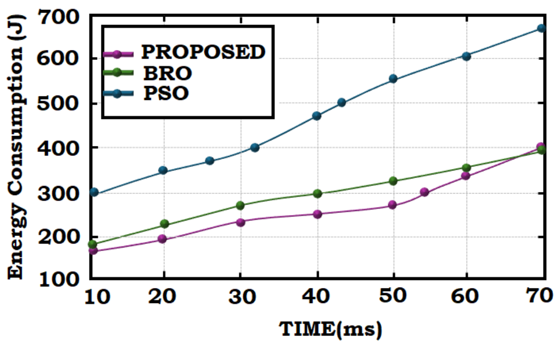

Figure 6: *Comparison of energy consumption*

In figure 6, the proposed system is the lowest energy consumer when compare with the conventional methods. The BRO consumes a moderate amount of energy and PSO consumes the most. Based on this information, the proposed system is the most energy-efficient selection available.

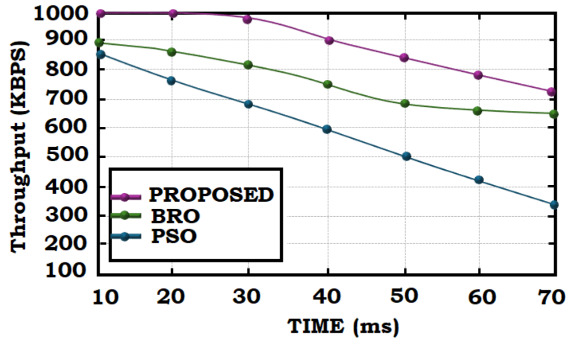

Figure 7: *Comparison of throughput*

Figure 7 demonstrates that the proposed method has the highest and most stable throughput. BRO exhibits moderate variability in performance and PSO demonstrates the poorest throughput. Therefore, the proposed approach consistently outperforms all other methods.

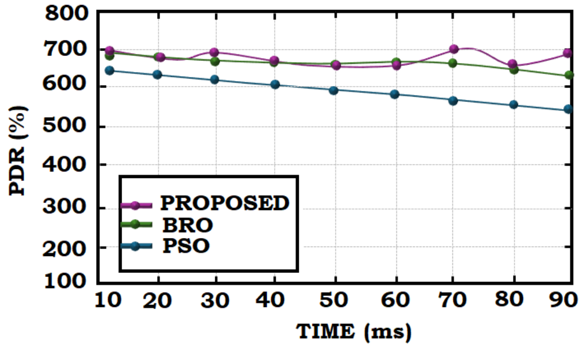

Figure 8: *Comparison of PDR*

In figure 8 the suggested algorithm consistently achieves the greatest PDR, while achieving both improved and stable PDR in less time than BRO and PSO. BRO outperforms moderately in terms of PDR, while PSO displays the lowest performance in terms of PDR, thus demonstrating that the proposed algorithm is superior to both the techniques.

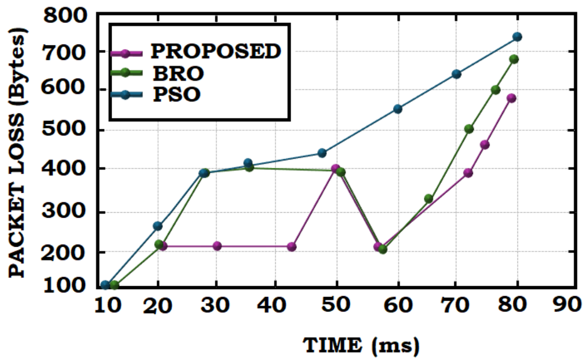

Figure 9: *Comparison of packet loss*

Packet Loss for the proposed, GA, and PSO methods are indicated in figure. In general, all the methods experienced increased packet loss as time increased, in particular, PSO had the greatest amount of packet loss, GA had a moderate amount of packet loss, and the proposed method had the least amount of packet loss at all times, demonstrating that has greater reliability, efficiency and robustness than any of the other methods.

5. Conclusion

An energy efficient smart HPO-based routing protocol for MANET is capable of dealing with dynamic topology, energy limitations and unstable wireless links by using adaptable methods to discover and maintain routes. All stages of the routing processes are performed using a multi-objective fitness function that contains residual energy, delay, hop count, packet delivery ratio and link stability to achieve the balance between exploration and exploitation without the premature convergence of routing. The intelligent coordination between the hunter and prey agents allows the use of stable and energy aware routes resulting in a reduction of control overhead, energy consumption, delays, and improved packet delivery performance. The simulation results demonstrate that the proposed routing protocol consistently outperforms other traditional mobile ad hoc routing protocols and all previously proposed metaheuristic-based methodologies. The proposed routing protocol increase the network's lifetime and provide reliable data transmission regardless of node density or node mobility, therefore demonstrating that it is suitable for dynamic and resource constrained mobile ad hoc networks.

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