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On Developing a Temporally Ordered Energy Efficient Routing Model (TO-EER) using Bio-Inspired Optimization for MANET

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Abstract

Mobile Ad-hoc Network is a structure of dynamic cellular network devices with no fixed architecture. Due to the network's constantly changing environment, characterized by frequent changes in its topology routing becomes a major challenge in MANET, which can reduce the overall network efficacy. As routing protocol plays a vital role in MANET, the energy-efficient routing model can enhance network longevity with a minimal rate of energy consumption. This paper uses a Temporally Ordered Routing Algorithm (TORA) to attain a higher scalability rate and an Elephant Herding Optimization (EHO) model to employ energy-efficient routing protocol features. The computations of the proposed model include the length of the route (LR) in optimal route selection and the energy level of routes (ER). It devises the routing problem as an optimization issue and further incorporates EHO for route selection, enhancing the weighted rate of LR and ER. The experimentations are carried out using the NS-3 simulation tool and factors such as latency, packet success rate, throughput, reliability, and energy depletion rate. Through a comparative analysis of the results with the previous works, the effectiveness of the proposed model is demonstrated.

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1. Introduction

An independent group of mobile nodes called a MANET provides an infrastructure-less communication framework across a common wireless medium channel [1, 2]. MANET terminals' communication, battery, storage, and computing power are constrained. Routing algorithms in MANETs are among their most challenging problems [3,4]. The self-organizing system MANET has a highly dynamic and unexpected layered structure. It comprises decentralized mobile nodes linked by wireless technology [5]. MANETs are a wireless ad hoc network with decentralized, resilient, and autonomous networks. Classifying the MANET is unnecessary based on its hierarchical architecture, diverse terminals, ever-changing ecosystem, constrained network throughput, and energy efficiency constraints [6]. To improve network performance, a MANET has to optimize data transmission stability, best route selection, confidentiality, and robust protection. One of the most essential types of MANET research is routing, which involves figuring out a path between nodes to transfer packets among originating source node and destination node [7]. Stated differently, the sender node has to carry out specific tasks to ascertain the precise position of the destination node before transmitting data packets to it [8]. Because of the unpredictable and dynamic network topologies caused by node mobility, MANETs provide several issues when using traditional routing techniques. Moreover, MANETs are vulnerable to node crashes and disruptions because of their constantly changing environment. Given that nodes typically rely on battery power, conserving power is crucial. As a result, it may be difficult for the conventional routing techniques to appropriately adapt to these changes.

The number of tables about routing and how topological information is dispersed across the network varies throughout these routing methods. Other on-demand routing protocols include the TORA [9] and the DSR [10]. In wireless ad hoc networks, power consumption-productive path selection in a practical way to prolong the lifespan of power-constrained terminals [11, 12]. According to [13], there are two main types of power-aware routing strategies: max-min flow path selection technique, that chooses the path having the highest optimal remaining energy of the bottleneck node, and energy-minimized (EM) routing strategy, which identifies the route having the lowest overall power expenditure for communication purposes. To create TORA, a routing protocol optimized for energy efficiency, which work concentrates on the proposed method, a decentralized source-initiated reactive routing protocol that is highly flexible, efficient, and scalable.

A Swarm Intelligence-based optimization method called The Elephant Herding Optimization (EHO) algorithm was formulated in [9]. Clan updating and separation mechanisms are the two distinct operators found in EHO. Each clan's elephant places and the condition of the matriarch are updated. Engineers and academics have taken note of EHO's commendable achievement. EHO can help find paths that save mobile device energy consumption and increase network longevity. EHO may modify routing routes to meet specific QoS objectives, such as low latency or high throughput. EHO can distribute traffic loads along many paths to avoid congestion. A novel routing system based on the EHO technique may be provided by using EHO to optimize routes that enhance network security by preventing hostile nodes and weak paths [14]. The operations in EHO are demonstrated in Figure 1. The EHO algorithm is incorporated with TORA to design the (TO-EER) in this proposed model.

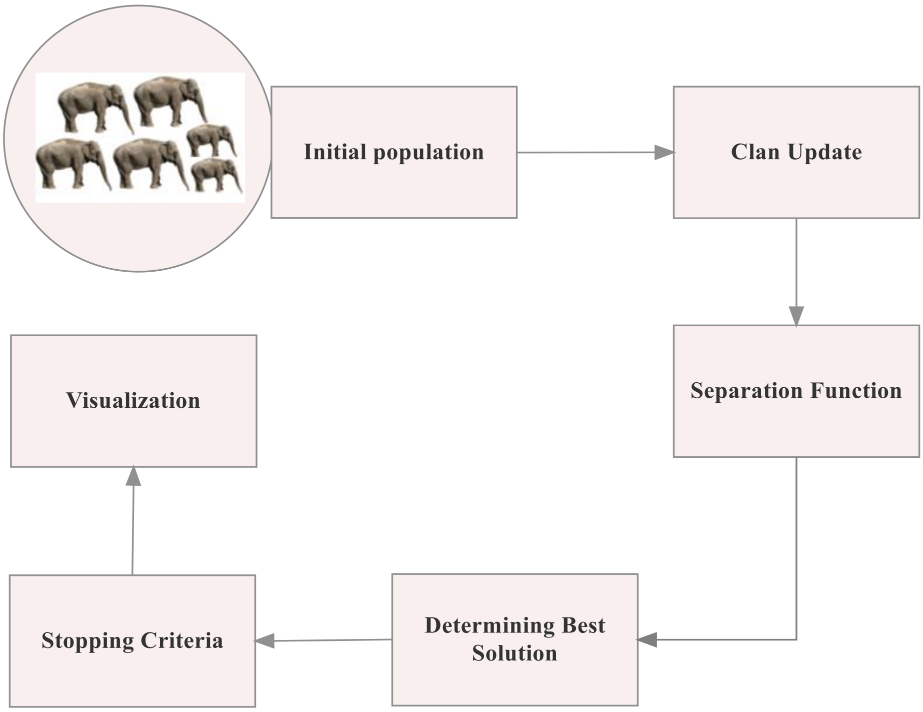

Figure 1. SI based EHO Model

Section 2 narrates the prevailing operates on energy. The working principles and model explanations of the formulated pattern are presented in Section 3. The effectiveness of the suggested model is assessed, and the findings are given in Section 4. To summarize, the article concludes in section 5, highlighting the proposed model efficacy and future works.

2. Related Works

Optimal routing hinders the MANET environment because of constrained energy and resource utilization. Many strategies and techniques are now being explored to improve MANET performance via effective routing. The authors discussed a lifetime-aware and energy-efficient multicast route selection method. An adaptively constructed genetic method utilizing a tree topology was used to produce it. A genetic algorithm was used as a computation approach based on evolution to select the ideal relay nodes equipped with the lowest Power consumption. Next, the remaining battery endurance and multicasting distance were increased by using the fitness feature. When it comes to reducing barriers to improved route identification, EELAM excels. However, there are still problems with load balancing throughout network nodes [15]. In [16], a unique algorithmic method for EED was developed. The authors estimated an ideal load distribution-based routing mechanism using two factors including factors like hop count and remaining node energy.

Expectations for this effort were optimal packet success rate and extended network lifespan, and optimum power consumption. However, without considering the Internet of Things, this approach applied an adaptive load-balancing routing protocol for MANETs. Unlike AntHocNet, DSDV, and AODV, the authors [17] developed a novel routing scheme that makes use of the cuckoo search mechanism. The two metrics used to assess the routing system's quality are PDP and E2ED. A novel routing system utilizing the well-established AOMDV protocol with EHO extensions was introduced in [18]. The process of classifying nodes into two groups increases their energy. Paths that are appropriate for reducing route node failures and the count of inactive nodes resulting from increased data traffic are then discovered from the classes of those nodes. According to testing results, the recommended EHOAOMDV approach offers greater PDR with reduced routing cost.

The authors suggested a novel learning automata-based energy-efficient routing technique for MANETs [19]. This work's main contributions were defining an efficient energy rate function and proposing a novel node stability-measuring model based on learning automata theory. According to simulation findings, when relative to specific conventional routing protocols, the suggested algorithm offers improved network performance metrics including usage of power consumption, delay, and packet delivery ratio. A novel energy-conscious data distribution infrastructure optimized for multimedia services in urban areas Internet of Things was suggested in the study [20]. This method demonstrates that QoS-guaranteed routes should be used for packet transmission. According to simulation findings, the proposed framework outperforms the current frameworks based on energy consumption, latency, and throughput in additional density and mobility urban IoT situations. A novel energy-aware routing with TDMA scheduling method for tactical communications networks MANETs was developed in [21]. This paper focuses on scheduling energy efficiency strategies and suggests a reserved TDMA slot at the command centre node. According to simulation findings, the newly developed algorithm improves network performance along with power efficiency under specific tactical mobile ad hoc network settings. A brand-new, energy-efficient, MAC layer-based routing protocol for MANETs is proposed in [22]. This study aims to create a multi-objective optimizer using specific MAC layer routing factors including sending power level, leftover energy capacity, and antenna gain. According to simulation studies, the proposed protocol outperforms some conventional routing protocols in terms of network performance and longer network lifespan under MANET situations.

3. Proposed Model

The proposed pattern works on defining the (TO-EER), comprised of the following phases:

i. Route Creation

ii. Route Maintenance

iii. Route Deletion

iv. SI-based Optimization - EHO

Moreover, the model incorporates TORA and SI models for energy-efficient routing in MANET. The TORA algorithm offers exceptional flexibility, an efficient and scalable distributed routing algorithm that initiates on-demand routing from the source that aims to create an energy-conserving routing protocol. The workflow of the suggested model is presented in Figure 2. The max-min principle is used to create an energy-aware routing protocol rooted in the TORA using EHO framework. In TORA, there are five types of data: mobile node, number of nodes, set of mobile devices on the network, required route, and link state. M_i, N_i, $MN_{i,j}$, RF_i, LS_i. Initially, the height of MN in the network is given as NULL, and the destination node's height is considered as ht, given as M_{ht}. Node heights are used to measure the link state between neighbouring nodes, M_i, $MN_{i,and\ j}$. The links flowing from the above-elevation node to the bottom-elevation node are called UPSTREAM (UP), and vice versa; they are termed DOWNSTREAM (DN). Altitude of the neighbour node is given as '0', it can be called UNDIRECTED (UD). The phases in the proposed model for efficient routing are explained underneath.

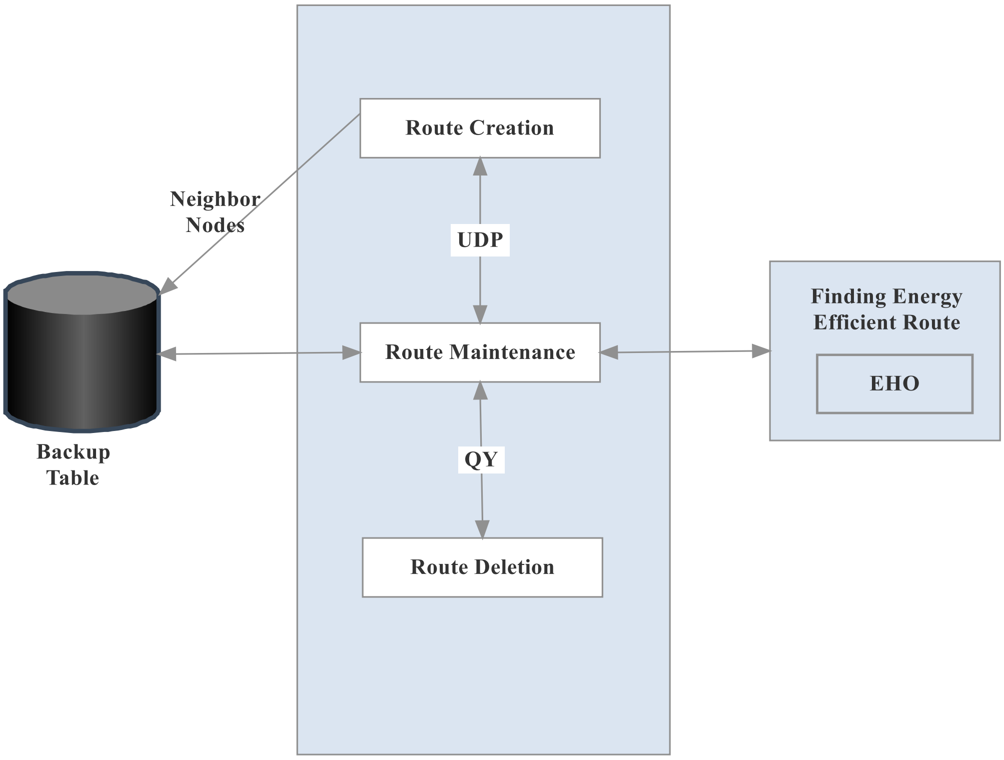

Figure 2. Workflow of TO-EER

3.1. Route Creation

In this phase of route creation, the UPD and Query (QY) packets are required. The QY packet comprises the identifier of the target node, whereas the UDP consists of the recipient ID and height of M, involved in the packet broadcast M_i. When the mobile node has UD links and its $RF_i = 0$ requires a destination-bound path, paired with a QY packet is broadcasted, and then it turns $RF_i = 1$. When a node in the route gets the QY packet, the following operations are carried out.

a. If there are no DN links and it's $RF_i = 0$, the QY packets are broadcasted again and fixed $RF_i = 1$.
b. If there are no DN links, when the $RF_i = 1$, then the QY packet is rejected.
c. Where there is one DN link, when the $M_{ht} = NULL$, the height of the M_i is set as,
d. $M_i = (\gamma_j, oID, r_j, \beta_j + 1, j)$ and $MN_{i,j} = (\gamma_j, oID, r_j, \beta_j, j)$
e. If there is one DN link and the $M_{ht} \neq NULL$, First, it evaluates the packet's arrival time transmitted with the time it was received in the previous UPD packet and the time the QY packet was received over an active connection. It rejects the QY packet if a UPD packet has been disseminated since the connection became operational; if not, it transmits a UPD frame. A terminal broadcasts a QY frame upon establishing a new connection if it has $RF_i = 1$.

When the node M_i gets a UPD packet from a nearby node, $j \epsilon M_i$, mobile terminal 'i' modifies the entry $MN_{i,j}$ with elevation encapsulated in the frame, and then sends it to the next hop,

i. If the $RF_i = 1$, mobile node 'i' fixes its height to $M_i = (\gamma_j, oID, r_j, \beta_j + 1, j)$, that 'j' is its $\neq NULL$ neighbor nodes are evaluated based on their height to optimize routing is $\min(neighbor\ nodes)$, then the updates are given as, LS_i, then, UDP packet has a new height is broadcasted.
ii. If $RF_i = 0$, update the LS_i array.

3.2. Route Maintenance

When the elevation of mobile terminals is not Null, i.e.,$MN_{i,j} \neq NULL$, the route maintenance operations are processed. It is also to be considered that the computations are not carried out when the height of the neighbor M_i is NULL. A terminal M_i is assumed to have no downward (DN) links, indicating a leaf node when $M_i < MN_{i,j} \forall\ non - NULL$ neighbors. This may result in processing any function based on the node state and previous actions. Each M_i that has no DN links changes height based on the following cases,

Case 1:

Because of link failure, the node M_i has no DN links. And the case can be stated as

$$\left(\gamma_j, oID, r_j\right) = (t, i, 0) \tag{1}$$

Where 't' denotes failure time.

Case 2:

The node M_i has no DN links because of the link reversal based on the UPD packet, where the sets $\left(\gamma_j, oID, and\ r_j\right)$ are not equal for all neighbor nodes. The case can be denoted as

$$\left(\gamma_j, oID, r_j\right) = \max\{\left(\gamma_j, oID, r_j\right) | j \epsilon M_i\} \tag{2}$$

$$\beta_j, j = (\min\left\{\beta_j \left| \begin{matrix} | j \epsilon M_{i\ with(\gamma_j, oID, r_j)} \\ \max\left(\gamma_j, oID, r_j\right) \end{matrix} \right.\right\} - 1, i) \tag{3}$$

Case 3:

The terminal M_i lacks downward connections because of the link reversal based on acquiring the UPD packet, where the sets $\left(\gamma_j, oID, r_j\right)$ are equal to $r_i = 0$ for all neighbor nodes. The case can be denoted as

$$(\gamma_i, oID_i, r_i) = \left(\gamma_j, oID_j, 1\right) \tag{4}$$

$$\left(\beta_j, j\right) = (0, j) \tag{5}$$

Case 4:

The terminal M_i lacks downward connections because of the link reversal based on acquiring UPD packet, where the sets $\left(\gamma_j, oID, r_j\right)$ are identical to $r_i = 1$ in all cases neighbor nodes and $oID_j = i$. The scenario can be denoted as,

$$(\gamma_i, oID_i, r_i) = (-, -, -) \tag{6}$$

$$\left(\beta_j, j\right) = (-, j) \tag{7}$$

Case 5:

The node M_i has no DN links because of the link reversal based on acquiring UPD packet, where the sets $\left(\gamma_j, oID, r_j\right)$ are identical to $r_i = 1$ in all cases neighbor nodes and $oID_j \neq i$. The scenario can be denoted as

$$(\gamma_i, oID_i, r_i) = (t, i, 0) \tag{8}$$

$$\left(\beta_j, j\right) = (0, j) \tag{9}$$

3.3. Route Deletion

Based on case 4, the node M_i fixes its height for all neighbor nodes $| j \epsilon M_i$ to an empty value; else, the Target node is the adjacent node, which has its $M_{ht} = 0$. All the entries are updated to $the\ LS_i$ Delete the neighbour entry and transmit a removal notification. Here, the DEL frame comprises M_{ht} and (γ_i, oID_i). When a M_i gets a DEL frame from its adjacent node, it performs the following operations.

i. When the referral ID of the DEL packet matches Mi's referral ID , it fixes $M_{ht} = NULL$; otherwise, the destination node is the neighbor node, which has its $M_{ht} = 0$. Further, it is updated on an LS_i array and broadcasts a DEL packet.

ii. When the referral ID of the DEL packet matches Mi's referral ID , it fixes $M_{ht} = NULL$ and updates the matching entries in the LS_i array. Hence, M_{ht} in the network, which is sectioned to fix as to nothing

iii. , and all invalid routes are removed.

When (ii) Triggers M_i to forfeit its final DN Connection, it performs the operations of case 1 for route maintenance. After performing the above three phases, the routes between sender and receiver nodes are defined. The following Figure 3 displays the routing process using TORA. Every node has a height structure when the routes are formed. Every node also contains an array that stores neighbour information. Thus, a node and neighbour scenario can be defined for each M_i.

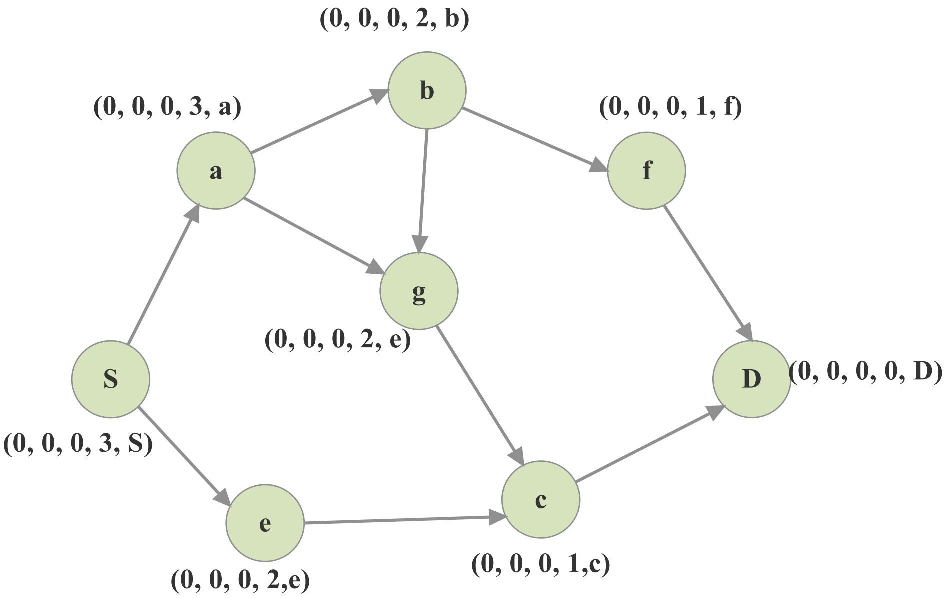

Figure 3. Process of Route Creation in TORA

3.4. SI based Optimization – EHO

Though TORA aids in creating routes between source and destination, the routes chosen have minimal hops. This provides a heavier load for more minor routes. Hence, there is an energy depletion of nodes than nearby mobile entities. Surrounding mobile terminals network longevity and overall throughput are reduced. To solve this problem, the TORA protocol requires optimization, in which the node's energy levels are considered in computations along with the node energy rates. The objective is to choose a route with a high energy level and a short length. This path may not always be the shortest one since the shortest path might require less energy. This, indeed, is a more direct route with an increased energy state. Swarm intelligence-based optimization is utilized to locate such a path. Here, Elephant Herding Optimization (EHO) is incorporated in TORA, which helps find the best particle position and define the objective function. This energy-efficient route can be framed between the source and destination.

Elephants are sociable animals that live in groups with other elephants and their young. An elephant clan is made up of many elephants under the leadership of a female leader. Males commonly reside overseas, whilst female individuals are determined to live with relatives. They are going to gradually distance themselves from their family members until they do so entirely. Some less fit male elephants' values leave the herd to migrate to a new location. For every generation, the herd changes based on the location of the matriarch. Random people from the search area replace the culled elephants. Two instances of these phenomena are Clan Update and separation function. Figure 4 provides the workflow demonstration of EHO.

3.4.1. Clan Update

A maternal figure monitors the elephant conduct within every family based on their natural features. Several clans,S_i, may have a limited number of elephants. It can be mathematically given as,

$$A_{new,S_i,j} = A_{S_i,j} + x \times (A_{best,S_i} - A_{S_i,j}) \times m \quad (10)$$

Where, $A_{S_i,j}$ and $A_{new,S_i,j}$ determine the new and old positions of A_{best,S_i}, where, the matriarch, $m\epsilon[0,1]$. Further, in each clan, the best elephant can be determined as follows,

$$A_{new,S_i,j} = \alpha \times A_{center,S_i} \quad (11)$$

Here, $\alpha\epsilon[0,1], A_{new,S_i,j}$, denotes the new individual, and A_{center,S_i} is the clan's center, which can be computed as,

$$A_{center,S_i,n} = \frac{1}{k_{S_i}} \times \sum_{j=1}^{k_{S_i}} A_{S_i,j}, n \quad (12)$$

Here, $1 \leq n \leq N, n_{S_i,j}$ denotes the elephant, $A_{S_i,j}, n$ is n^{th} dimensional $A_{center,S_i,n}$.

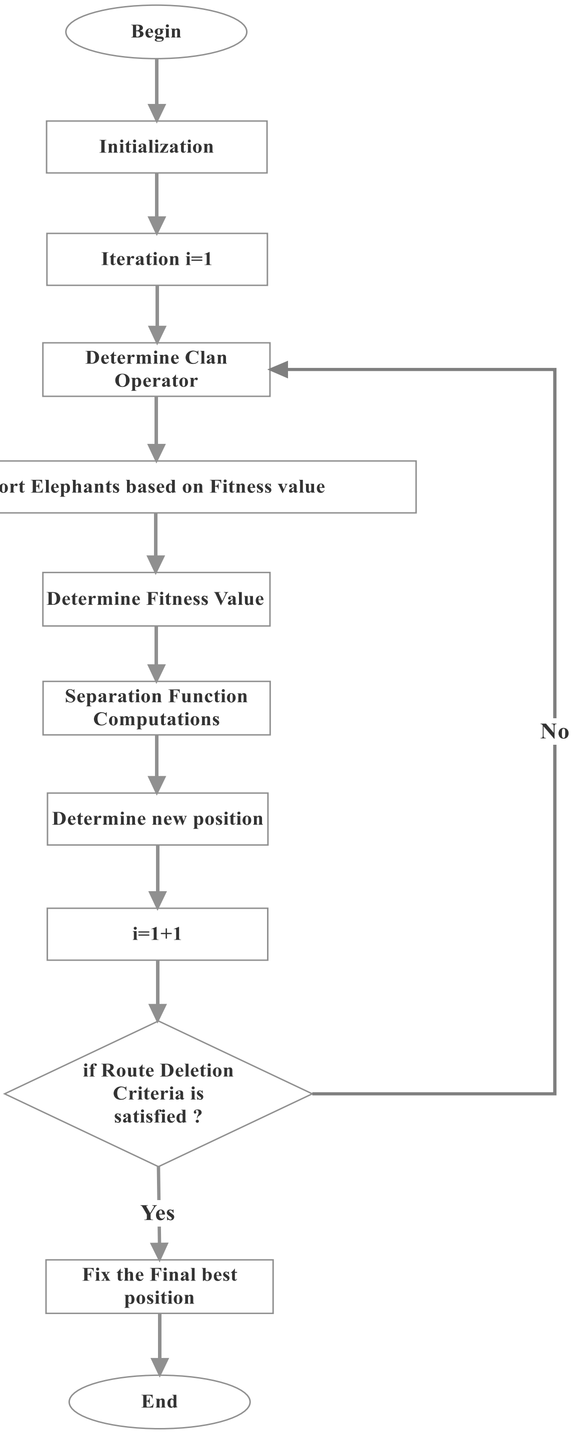

Figure 4. Flow of EHO to Determine Best Route

3.4.2. Separation Function

For processing the challenges in optimization, the separation function is defined as how the males get separated from their group. The individuals with a minimal fitness rate will use the separation function mentioned below.

$$A_{low,S_i} = A_{min} + (A_{max} - A_{min} + 1) \times rand \quad (13)$$

A_{max} *and* A_{min} are the ceiling and floor values of A_{low,S_i}, as the tusker has a minimal fitness rate and will be separated. In addition, denoted as the stochastic function, ranges between 0 and 1. The EHO takes the optimal route between the origin and goal. In the MANET setting, each elephant is seen as a node that selects the optimal route according to fitness. EHO is utilized for pathfinding maintenance to find the shortest path connecting a starting point to a target based on its evaluation results. In the EHO method, the routing paths have to be represented as distinct solutions or entities.

4. Results and Discussions

The experimentation was carried out using the NS-3 simulation tool to evaluate the proposed model's performance in MANET. The proposed model employs the EHO model in TORA to define a power-saving route across the network in the MANET. The reliability of the suggested TO-EER is relative to the previous works such as Energy Efficient- Secure Routing (EE- SR) and Secure Routing Protocol (ML- SRP). The simulation parameters for the model experimentation and analysis are presented in Table 1.

Table 1: Simulation Variables and Domain Metrics

Variables	**Domain Metrics**
Simulation Tool	NS-3
Protocols	AODV, TORA
Simulation Area	1000*1000
Mobility Type	Random Way Point
Radio Propagation	TwoRay Ground
Antenna Type	Omni Directional
Packet Length	512
Time	300s
Number of M_i	100
Protocol	UDP
Minimal Speed M_i	5 m/s
Maximal Speed M_i	20 m/s
The initial energy of the mobile node	50j

4.1 Comparative Evaluations

In MANETs, performance measurements are crucial for evaluating and enhancing routing protocols. These metrics assess a routing protocol's performance under various network conditions, providing valuable information about its effectiveness and efficiency. The suggested model is assessed based on the five evaluation criteria—routing overhead, Packet Delivery Rate (PDR), transmission delay, throughput, and average energy consumption—, which made it simpler to evaluate the effectiveness of our routing system.

The findings for the packet delivery ratio in relation to node mobility are shown in the graph that follows, which is shown in Figure 5. The PDR, is the percentage of data packets delivered successfully. Additionally, the factor determines the protocol's performance. Figure 5 displays the PDR values that the proposed model produced about the nodes' mobility speed, and Table 2 presents the findings of the study. A norm pauses duration, variable mobility speed (from 5 to 20 m/s), and a variety of mobile nodes (20 to 100) were used in the study. The research results demonstrate that the proposed model offers a improved packet delivery ratio in both scenarios. The PDR value drops as node velocity rises when node movement speed is utilized for PDR analysis. However, the PDR results of the proposed model are greater than those of the other models, indicating its efficacy. The following is the PDR formula:

$$PDR = \frac{No.of\ successfully\ delivered\ packets}{Total\ no.of\ packets\ transmitted} \times 100 \qquad (14)$$

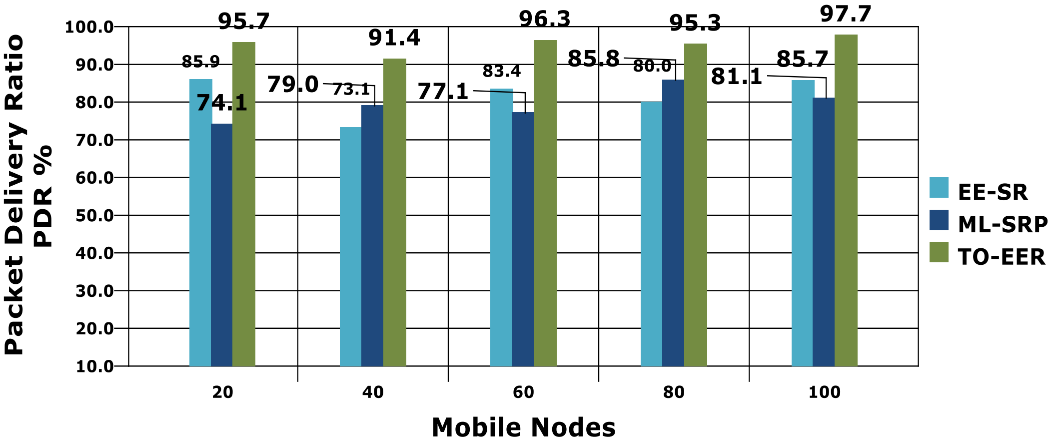

Figure 5. PDR vs. Mobile Nodes

Table 2: Observations for PDR

Node Mobility (m/Sec)	20	40	60	80	100
EE-SR	85.9	73.1	83.4	80.0	85.7
ML-SRP	74.1	79.0	77.1	85.8	81.1
TO-EER	95.7	91.4	96.3	95.3	97.7

Table 3 offers the data, while Figure 6 compares the proposed and compared models' throughput (measured in packets/second). From the results of PDR, it is evidenced that the proposed model attains maximal network throughput. It is discovered that the recommended protocol's throughput performance much outperforms that of the existing models. In contrast, the proposed approach produces greater average throughputs.

Table 3: Observations for Throughput

Mobile Nodes	20	40	60	80	100
EE-SR	4.42	5.62	4.95	5.85	5.85
ML-SRP	5.44	6.49	6.84	6.63	7.58
TO-EER	6.55	6.95	7.84	8.84	8.79

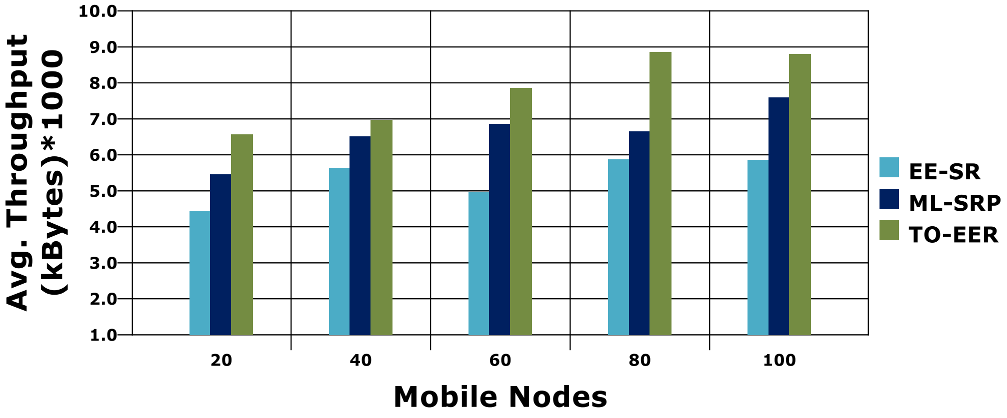

Figure 6. Throughput Results Comparison

Mean Transmission Delay (TD) describes the average latency of data packet transmission its target. TD is calculated by removing the source delay sent the initial data packet sent by when it reached its destination. This computation considers all possible delays caused by buffering during propagation time, transfer, interface queuing, MAC layer retransmission delays, and route-finding latency. This process is essential for figuring out how long route discovery takes. Low TD rates indicate the best network performance. The comparison graph is presented in Figure 7, based on the observations in Table 4. The formula for computing TD is given below.

$$TD = \sum_{i=1}^{m}(packets.receivingTime_i - packets.transmittingTime_i\ ) \qquad (15)$$

Table 4: Results for Transmission Delay

Time (mSec)	**20**	**40**	**60**	**80**	**100**
EE-SR	**5.2□**	**5.09□**	**5.11□**	**5.13□**	**4.68□**
ML-SRP	**3.97□**	**4.36□**	**3.49□**	**2.2□**	**3.15□**
TO-EER	**1.26□**	**1.28□**	**1.33□**	**0.89□**	**1.05□**

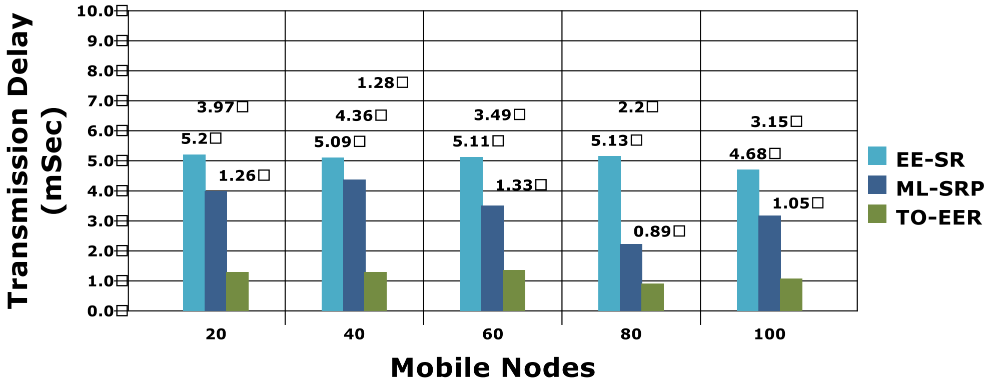

Figure 7. Transmission Delay Vs Mobile Nodes

The mean energy (in Joules) that nodes in a network utilize for path determination over a specific interval or under a specific network condition is called the mean energy utilization (EU) For packet forwarding in a MANET. This metric shows how power-efficient routing strategies are present and how they influence total energy expenditure of the network. The formula for the EU is given in (16). The results are given in Table 5, and the comparisons are given in Figure 8, evidence that the suggested framework performs superior to the previous works in determining an efficient route for MANET.

$$EU = \frac{\sum_{i=1}^{n}(initial\ energy\ \ -remaining\ energy\ \ )}{n} \qquad (16)$$

Table 5: Results for EU computations

Vehicle Mobility (m/Sec)	20	40	60	80	100
EE-SR	**20.2**	**19.0**	**28.3**	**29.2**	**35.9**
ML-SRP	**14.3**	**14.5**	**21.5**	**30.6**	**32.3**
TO-EER	**6.4**	**8.3**	**10.8**	**10.0**	**13.8**

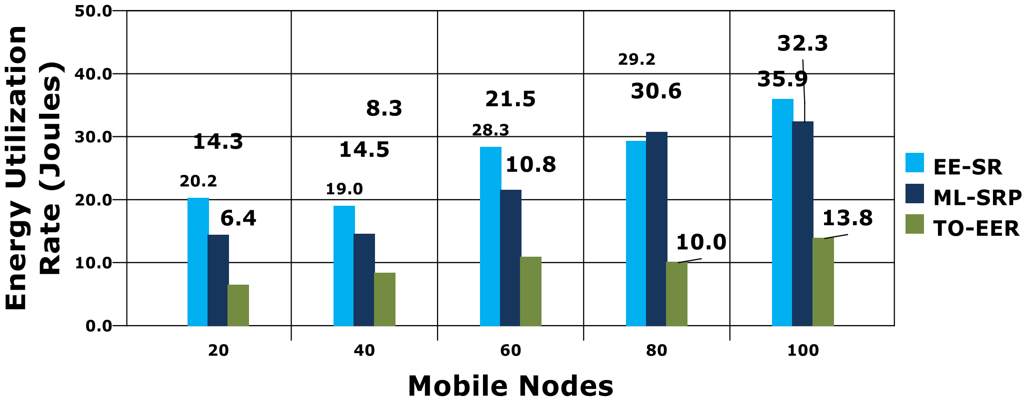

Figure 8. Energy Utilization Rate Comparisons among Models

5. Conclusion and Future Work

Energy-efficient MANET is a significant research area that has recently experienced tremendous growth due to the amalgamation of optimization and SI techniques. This paper developed TO-EER to define energy-efficient routing in MANET. The model uses TORA for route discovery and EHO to solve optimization problems. The advantages of both techniques enhance the results by providing efficient routing with a minimal rate of EU. The model evaluations are carried out using the NS-3 tool, and outcomes are measured in terms of PDR, throughput, TD, and EU rate. The comparison graphs stated that the proposed model outperforms the previous work.

In the future, the work can be enhanced in the following ways,

i. The model can be combined with machine learning to provide better outcomes
ii. The model can be focused on designing an efficient routing model for IoT networks
iii. Security-based research can also be incorporated when defining routes between nodes.

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