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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 (MANET) is described as the network of self-organizing mobile nodes with no fixed infrastructure. Because of the frequent changes in network topology, routing becomes a major challenge in MANET, which can reduce the overall network efficacy. As routing protocol has vital part in MANET, the energy-efficient routing model can enhance the network longevity with minimal rate of energy consumption. This paper uses Temporally Ordered Routing Algorithm (TORA) for attaining higher scalability rate and Elephant Herding Optimization (EHO) model for employing energy-efficient feature to the routing protocol. The computations of the proposed model include the length of the route (LR) in optimal route selection and energy level of routes (ER). It devises the routing problem as an optimization issue, further incorporates EHO for route selection that enhances the weighted rate of LR and ER. The experimentations are carried out using NS-3 simulation tool and the factors such as, delay, packet delivery ratio, throughput, reliability and rate of energy consumption. By comparing the results with the previous works, the efficiency of the proposed model is evidenced.

Keywords:
Temporally Ordered Routing Algorithm (TORA), Elephant Herding Optimization (EHO), MANET, Energy Efficiency, Routing Protocol.

1. Introduction:

An independent group of mobile nodes called a MANET provides an infrastructure-free architecture for communication across a common wireless channel [1, 2]. MANET nodes' communication, battery, storage, and computing power are constrained. Routing algorithms in MANETs are among their most difficult problems [3,4]. The self-organizing system MANET has a highly dynamic and unexpected layered structure. It is made up of decentralized mobile nodes linked by wireless technology [5]. MANETs are a kind of wireless ad hoc network with peer-to-peer, self-healing, and self-forming networks. It is not necessary to classify the MANET based on its centralized structure, diverse nodes, dynamic environment, constrained bandwidth, and energy constraints [6]. To improve network performance, a MANET has to give priority to data transmission consistency, best route selection, security, and effective security. One of the most important types of MANET research is routing, which involves figuring out a path between nodes to transfer packets from the source node to the destination node [7]. Stated differently, the sender node has to carry out certain 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, because of their dynamic nature, MANETs are susceptible to node failures and disruptions. Nodes are often powered by batteries, therefore conserving energy is crucial. As a result, it may be difficult for the conventional routing techniques to appropriately adapt to these changes.

The amount 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 Temporally Ordered Routing

Algorithm (TORA) [9] and the Dynamic Source Routing protocol (DSR) [10]. Recently, energy-aware routing in MANETs has garnered a lot of interest because of its limited battery capacity. In mobile ad hoc networks, energy-aware routing is a practical way to extend the lifespan of energy-constrained nodes [11, 12]. According to [13], there are two main types of energy-aware routing concepts: max-min routing, which chooses the route with the highest bottleneck residual node energy, and minimum energy (ME) routing, which chooses the route with the lowest overall energy consumption for packet transmission. To create TORA an energy-efficient routing protocol, this work concentrates on the algorithm, which is a distributed source-initiated on-demand routing algorithm that is extremely flexible, efficient, and scalable.

A Swarm Intelligence-based optimization method called Elephant Herding Optimization (EHO) was presented in [9]. Clan-updating and separating operators 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 certain 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 avoiding hostile nodes and weak paths. The operations in EHO are demonstrated in Figure 1. In this proposed model, the EHO algorithm is incorporated with TORA for designing the **Temporally Ordered Energy Efficient Routing Model (TO-EER).**

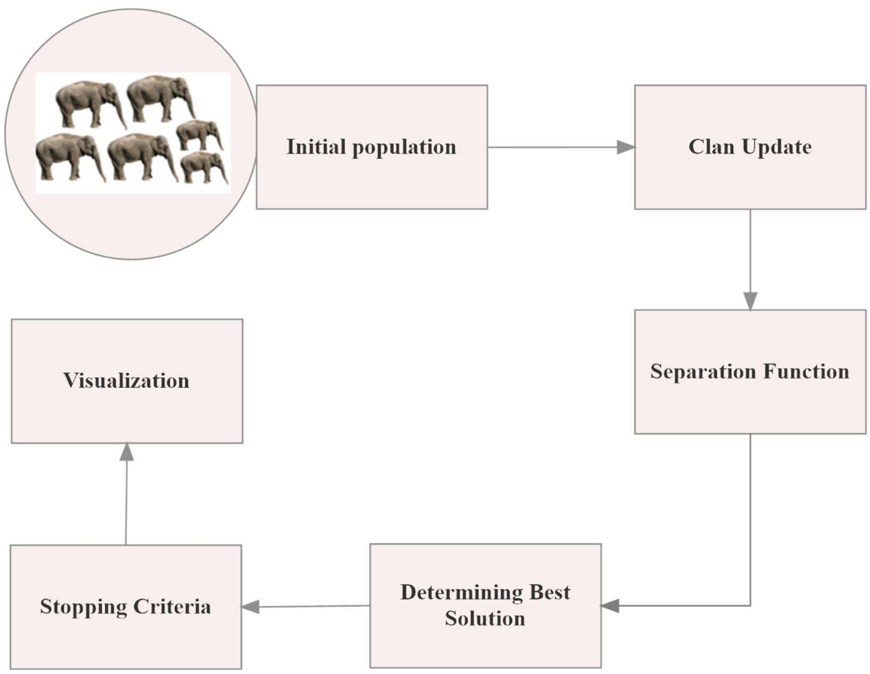

Figure 1: SI based EHO Model

The remainder of this work is organized as follows: Section 2 narrates the existing works on energy efficient routing models in MANET. The working principles and model explanations of the proposed model is presented in Section 3. The performance of proposed model is evaluated and the results are presented in Section 4. Finally, the paper 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. A genetic method that was adaptively constructed utilizing a tree topology was used to produce it. A genetic algorithm was used as a computation approach based on evolution to choose the optimal intermediate nodes with the lowest energy usage. Next, the remaining battery life and multicasting range 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 to EED was developed. The authors estimated an ideal load distribution-based routing mechanism using two factors, such as hop count and residual node energy. Expectations for this effort were maximum packet delivery ratio, maximum network longevity, and optimum energy consumption. But without taking the Internet of Things into account, this approach applied a load-balancing routing mechanism to the MANET.

Unlike AntHocNet, DSDV, and AODV, the authors [17] developed a novel routing scheme that makes use of the cuckoo search mechanism. The two metrics that are utilized to assess the quality of the routing system are PDP and E2ED. A novel routing system using the well-known AOMDV protocol with EHO was introduced in [18]. The process of classifying nodes into two groups increases their energy. Paths that are appropriate for reducing route failure and the number of dead nodes resulting from higher data loads are then discovered from the classes of those nodes. The recommended EHOAOMDV approach offers greater PDR with reduced routing cost, according to testing results.

A novel learning automata-based energy-efficient routing technique for MANETs was suggested by the authors in [19]. This work's main contributions were the definition of an efficient energy rate function and the proposal of a novel node stability measuring model based on learning automata theory. According to simulation findings, when compared to certain conventional routing protocols, the proposed algorithm improves network performance in terms of usage of energy, latency, and packet delivery ratio. A novel energy-conscious data distribution infrastructure for multimedia applications in the urban 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, in additional density and mobility urban-IoT situations, the proposed framework outperforms the current frameworks based on energy consumption, latency, and throughput.

A novel TDMA scheduling-based, energy-efficient routing method for tactical MANETs was developed in [23]. This paper focuses on scheduling energy efficiency strategies and suggests a TDMA slot at the commander node. According to simulation findings, under certain tactical MANET settings, the proposed algorithm improves system performance and energy efficiency. A brand-new, energy-efficient, MAC layer-based routing protocol for MANETs is proposed in [22]. The goal of this study is to create a multi-objective optimizer by using certain MAC layer routing parameters, such as transmit power, residual energy, and gain. According to simulation studies, under MANET situations, the proposed protocol outperforms some conventional routing protocols in terms of network performance and longer network lifespan.

3. Proposed Model:

The proposed model works on defining **Temporally Ordered Energy Efficient Routing Model (TO-EER),** comprises 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 model for energy efficient routing in MANET. The TORA algorithm is a distributed source-initiated on-demand routing algorithm that is highly flexible, efficient, and scalable and aims to create an energy-efficient routing protocol. The workflow of the proposed model is presented in Figure 2. To do this, the max-min principle is used to create a TORA-based energy-aware routing protocol using the EHO algorithm. In TORA, there are five types of data, mobile node, number of nodes, set of mobile nodes in 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}. The link state between the nodes are measured by the heights, M_i, $MN_{i,j}$. The links directed from higher node to lower node is called as UPSTREAM (UP) and the vice versa is termed as DOWNSTREAM (DN). If the height of the neighbour node is given as '0', it can be called as, UNDIRECTED (UD). The phases in the proposed model for efficient routing are explained below.

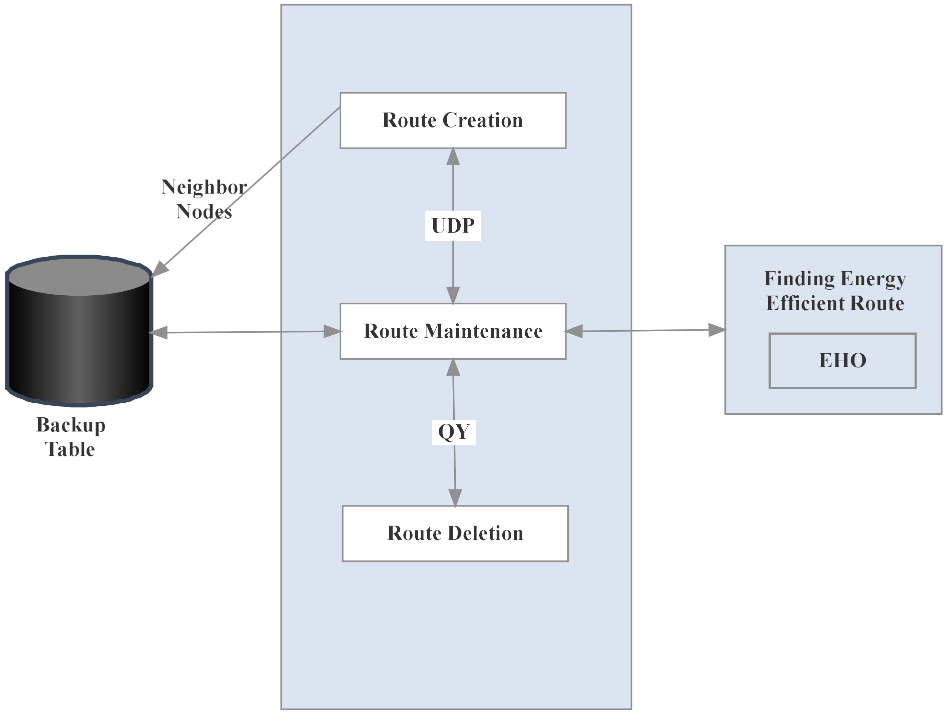

Figure 2: Workflow of TO-EER

3.1. Route Creation:

In this phase of route creation, the UPD and Query (QY) packets are required. The QY packet comprise of the ID of the destination node, whereas, the UDP consists of destination ID and height of M, involves in packet broadcast M_i. When the mobile node has UD links and its $RF_i = 0$, require a route to the destination, a QY packet is broadcasted, then it turns, $RF_i = 1$. When there is a node in the route gets the QY packet, the following operations are carried out.

a. if there is no DN links and its $RF_i = 0$, the QY packets are broadcasted again and fixes $RF_i = 1$.

b. if there is 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 compares the time the previous UPD packet was sent and the time the QY packet was received over an active connection. It rejects the QY packet if a UPD packet has been broadcast since the connection became active; if not, it broadcasts a UPD packet. A node broadcasts a QY packet upon the establishment of a new connection if it has $RF_i = 1$.

When the node M_i get an UPD packet from a neighbour node, $j \epsilon M_i$, mobile node 'i' updates the entry $MN_{i,j}$ with height encapsulated in the packet and then, the following function is processed,

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 $\neq NULL$ neighbour and height is $\min(neighbour\ nodes)$, then, the updates are given as, LS_i, then, UDP packet has new height is broadcasted.

ii. If $RF_i = 0$, updates the LS_i array.

3.2. Route Maintenance:

When the height of mobile nodes 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 neighbour M_i is NULL. A node M_i is assumed to have no DN links when $M_i < MN_{i,j} \forall\ non-NULL$ neighbours. 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,

$$(\gamma_j, oID, r_j) = (t, i, 0) \quad (1)$$

Where 't' denotes failure time.

Case 2:

The node M_i has no DN links because of the link reversal based on UPD packet, where the sets (γ_j, oID, r_j) are not equal for all neighbour nodes. The case can be denoted as,

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

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

Case 3:

The node M_i has no DN links because of the link reversal based on acquiring UPD packet, where the sets (γ_j, oID, r_j) are equal with $r_i = 0$ for all neighbour nodes. The case can be denoted as,

$$(\gamma_i, oID_i, r_i) = (\gamma_j, oID_j, 1) \quad (4)$$

$$(\beta_j, j) = (0, j) \quad (5)$$

Case 4:

The node M_i has no DN links because of the link reversal based on acquiring UPD packet, where the sets (γ_j, oID, r_j) are equal with $r_i = 1$ for all neighbour nodes and $oID_j = i$. The case can be denoted as,

$$(\gamma_i, oID_i, r_i) = (-, -, -) \quad (6)$$

$$(\beta_j, j) = (-, j) \quad (7)$$

Case 5:

The node M_i has no DN links because of the link reversal based on acquiring UPD packet, where the sets (γ_j, oID, r_j) are equal with $r_i = 1$ for all neighbour nodes and $oID_j \neq i$. The case can be denoted as,

$$(\gamma_i, oID_i, r_i) = (t, i, 0) \quad (8)$$

$$(\beta_j, j) = (0, j) \quad (9)$$

3.3. Route Deletion:

Based on case 4, the node M_i fixes its height for all neighbour node $|j\epsilon M_i$ to NULL, else, the destination node is the neighbour node, which has its $M_{ht} = 0$. All the entries are updated to LS_i array and broadcast a DEL packet. Here, the DEL packet comprises of M_{ht} and (γ_i, oID_i). When a M_i receives a DEL packet from its neighbour, it performs the following operations.

i. When the referral ID of DEL packet matches with the referral ID of M_i, it fixes $M_{ht} = NULL$, else, the destination node is the neighbour node, which has its $M_{ht} = 0$. Further, it is updated on to LS_i array and broadcasts a DEL packet.

ii. When the referral ID of DEL packet matches with the referral ID of M_i, it fixes $M_{ht} = NULL$, and updates the matching entries in LS_i array. Hence, M_{ht} in the network, which are sectioned to fix as NULL and all void routes are deleted.

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

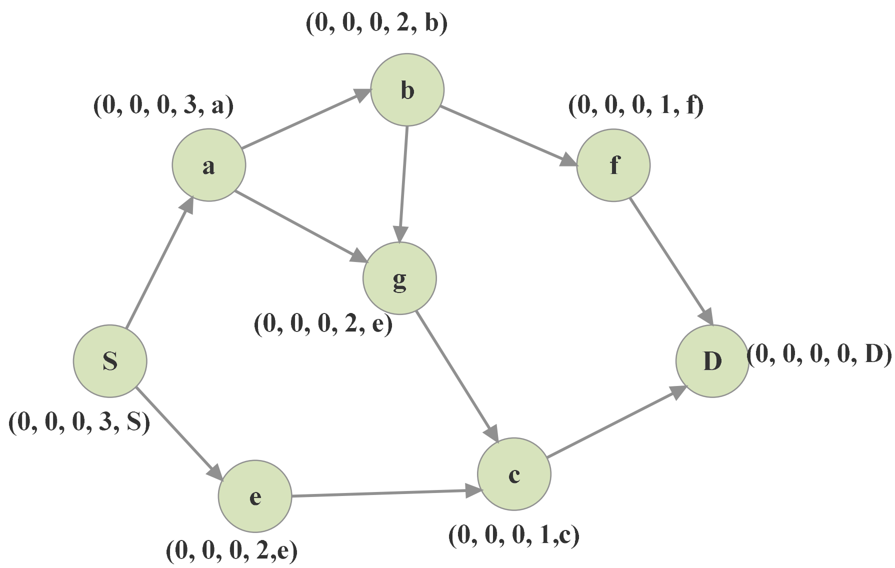

Figure 3: Process of Route Creation in TORA

3.4. SI based Optimization – EHO:

Though, TORA aids in creating routes between source and destination, the routes are chosen with minimal hops. This provides heavier load for smaller routes apparently, hence, there is an energy depletion of nodes than other mobile nodes in the network. This may reduce the network longevity and accordingly the overall throughput is also reduced. For solving this problem, the TORA protocol requires an 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 need not always be the shortest one since the shortest path might need less energy. It's true that this is one of the shorter routes with a higher energy level. Swarm intelligence-based optimization is utilized to locate such a path. Here, Elephant Herding Optimization (EHO) is incorporated in TORA, which helps in finding best particle position and defining objective function. With 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 matriarch. Male members often reside overseas, whilst female members are determined to remain with the family. They will gradually distance themselves from their family members until they do so entirely. Some male elephants with the lowest fitness values leave the herd to establish themselves elsewhere. Every generation, the herd changes based on where the location of matriarch. The elephants that are culled are replaced by random people from the search area. Two instances of these phenomena are Clan Update and separation function. The Figure 4 provides the workflow demonstration of EHO.

3.4.1. Clan Update:

A matriarch monitors the elephant behaviour in every clan based on their natural features. There are several clans S_i, may have 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 $A_{new,S_i,j}$ determines 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 $A_{center,S_i,n}$.

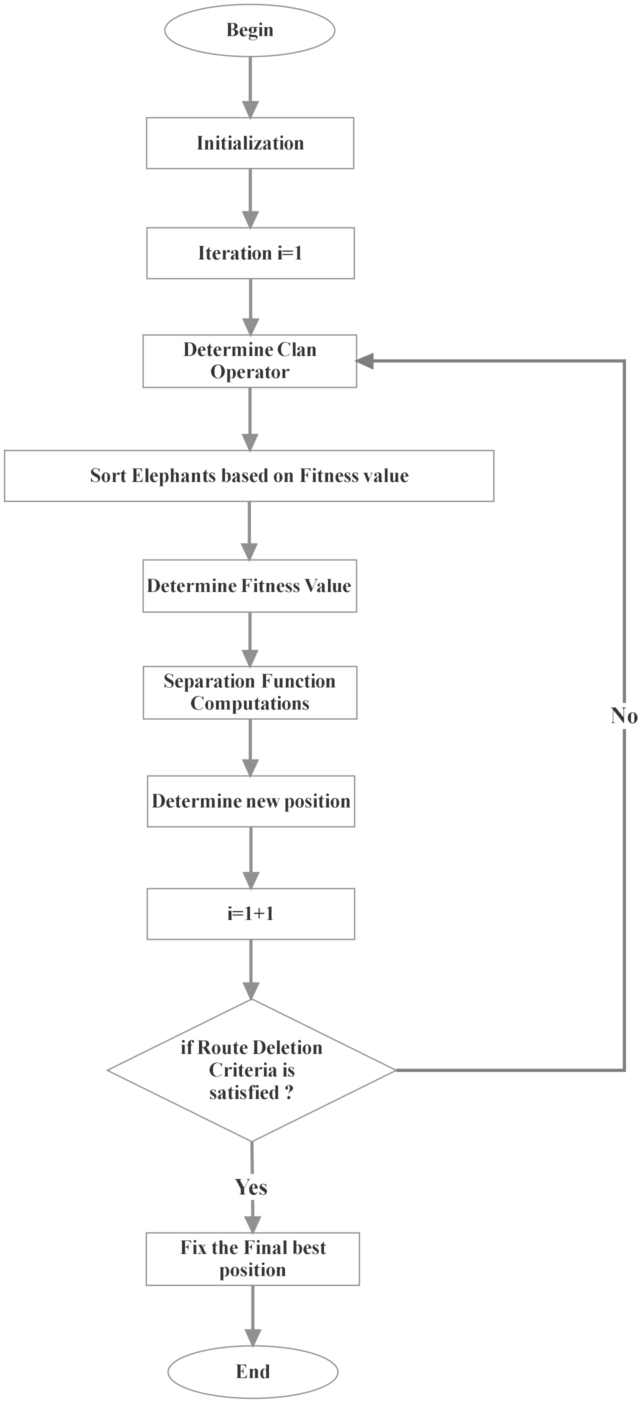

Figure 4: Flow of EHO to Determine Best Route

3.4.2. Separation Function:

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

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

Here, A_{max} and A_{min} are the upper and lower bound values of A_{low,s_i}, considered as the elephant has minimal fitness rate and will be separated. And, $rand$ is denoted as the Stochastic function, ranges between 0 and 1. The optimal path between the source and the designated is taken by the EHO. In the MANET setting, each elephant is seen as a node that selects the optimal route according to fitness. The EHO method is used in routing maintenance to find the optimal path between a source and a destination based on its fitness rating. In the EHO method, the routing paths have to be represented as distinct solutions or entities.

4. Results and Discussions:

For evaluating the performance of the proposed model in MANET, the experimentations are carried out in NS-3 simulation tool. The proposed model employs EHO model in TORA for defining energy efficient route between the source and destination in the MANET. The robustness of the proposed TO-EER is compared with 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 Parameters and Domain Values

Parameters	**Domain Values**
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
Initial energy of 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 a range of network conditions, providing valuable information about its effectiveness and efficiency. The proposed model is evaluated based on the five performance metrics—routing overhead, packet delivery rate (PDR), transmission delay, throughput, and average energy consumption—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 packet delivery ratio, or PDR, is the proportion of data packets that reach their destination successfully. Furthermore, the factor determines the protocol's efficiency. Figure 5 displays the PDR values that the proposed model produced in relation to the nodes' speed of mobility, and Table 2 displays the results of the observations. A standard pause 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 results of the research show that the proposed model provides a higher rate of packet delivery ratio in both cases. The PDR value decreases as node velocity increases when node mobility speed is used for PDR analysis. However, the PDR values of the proposed model are higher than those of the other models, indicating its efficacy. The following is the PDR formula:

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

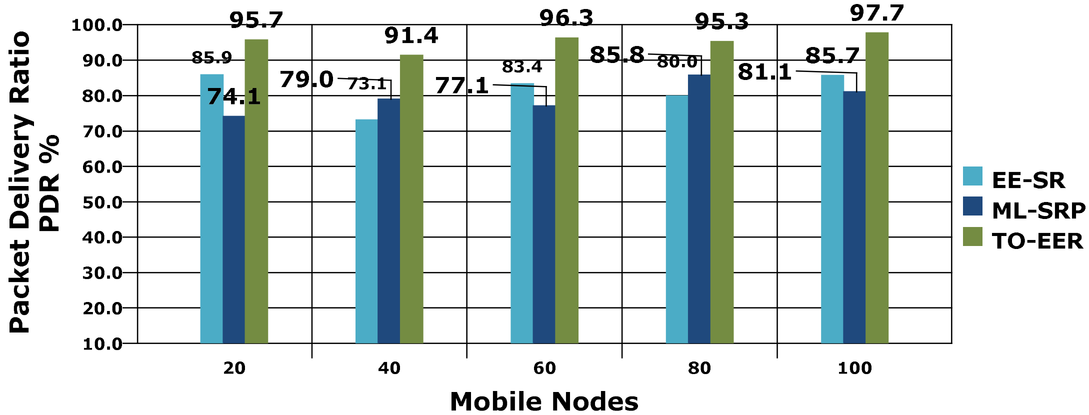

Figure 5: PDR Vs Mobile Nodes

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

The 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

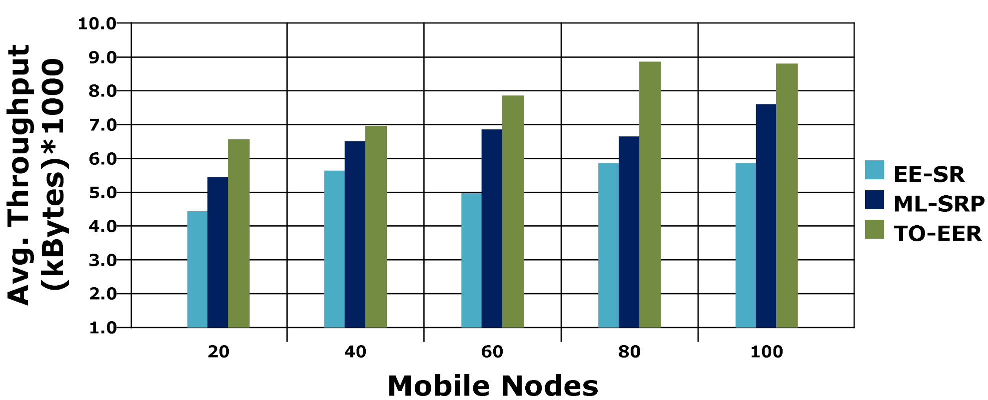

Figure 6: Throughput Results Comparison

The term Mean Transmission Delay (TD) refers to the average amount of time that a data packet takes to reach its destination. By subtracting the time the source sent the initial packet from the time it reached its destination, TD is calculated. This computation takes into consideration 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. The best network performance is indicated by a low TD rates. 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□

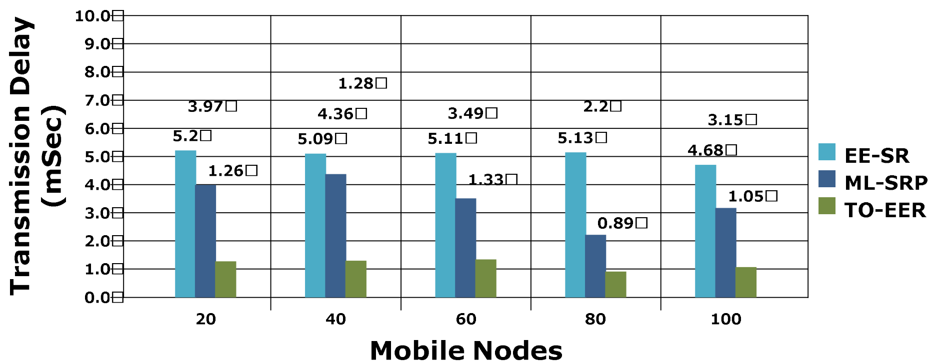

Figure 7: Transmission Delay Vs Mobile Nodes

The mean energy (in Joules) that nodes in a network use for routing-related tasks over a specific period or under a particular network condition is called the average energy utilization (EU) of routing in a MANET. This indicator shows how energy-efficient strategies for routing are and how they affect the total energy use of the network. The formula for EU is given in (16). The results are given in Table 5 and the comparisons are given in Figure 8, evidences that the proposed model performs better than the previous works in determining energy efficient route for MANET.

$$EU = \frac{\sum_{i=1}^{n}(initialEnergy_i - remainingEnergy_i)}{n} \qquad (16)$$

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

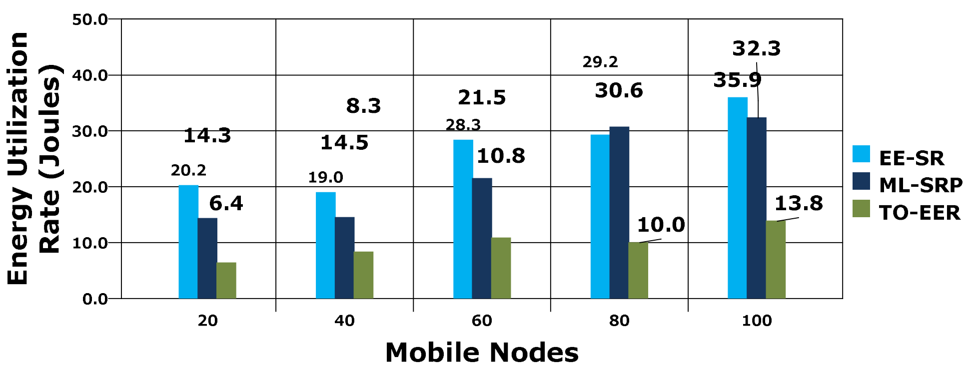

Figure 8: Energy Utilization Rate Comparisons among Models

5. Conclusions and Future Work:

Energy efficient MANET is a significant research area that has a tremendous growth in recent times with the amalgamation of optimization and SI techniques. This paper developed TO-EER for defining energy efficient routing in MANET. The model uses TORA for route discovery and EHO for solving optimization problems. The advantages of both techniques enhance the results by providing efficient routing with minimal rate of EU. The model evaluations are carried out using 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 compared previous work.

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

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

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