Journal of Intelligent Systems and Internet of Things
Vol. 17, No. 02, PP. 228-237, 2025
DOI: https://doi.org/10.54216/JISIoT.170214

Hybrid Routing and Efficient Mobility Model with Ant Optimization in Mobile Ad-Hoc Networks

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Abstract

Mobile Ad hoc Networks (MANETs) are emerging technologies used to transfer data across locations within both infrastructure-less and infrastructure-based network models. To ensure quality communication among mobile devices in various applications, an efficient routing model and an optimal data transfer path are essential, helping to reduce delay and power consumption during transmission. This article focuses on 'A hybrid routing and efficient mobility model with ant optimization' (HEMAOM). HEMAOM introduces a novel hybrid routing approach combined with an energy-efficient optimization model to lower power consumption and improve data transmission. Using an energy model, power usage during data transfer is minimized, boosting overall efficiency. Additionally, an optimization model is developed to identify the best path for data transfer between areas. These processes collectively decrease delay and power consumption, enhancing the communication performance of mobile devices. Compared to state-of-the-art methods like EOMFM, OLSRM, and MPOUA, HEMAOM shows superior performance in energy efficiency and data delivery. The model is implemented using NS3 software, considering parameters such as packet delivery ratio, network throughput, average delay, energy efficiency, and routing overhead.

Received: January 16, 2025 Revised: March 13, 2025 Accepted: May 30, 2025

Keywords: Mobile Ad hoc Networks; Efficient Mobility Model; Hybrid Routing Protocol; Ant Optimization Algorithm

1. Introduction

Mobile ad hoc networks (MANETs) technologies consist of mobile devices connected via a wireless medium [1] and are typically used to establish a routable networking system over a connected layer related to the ad-hoc network [2]. This network enables communication without an infrastructure model [3] or with one [4]. The devices in this technology are arranged dynamically, with nodes capable of moving in any direction, whether horizontal or vertical [5]. Recently, the number of devices used in mobile communication has significantly increased across various applications [6], leading to improvements in routing protocols to enhance performance among devices [7].

Ad hoc networking will support this white-space technology by providing high-quality communication for portable devices with advancements in wireless communication [8].

Additionally, recent developments have brought several advantages to mobile communication, improving the quality of military applications [9]. In general, the development of Ad hoc networks has certain limitations and is also driven by the intervention of the external environment and the speed of the devices [10]. To manage the large number of devices in the network, an improved routing model is necessary, as well as data transfer along optimal paths, and optimization-based algorithms are needed to enhance the quality of mobile devices. To address these issues, this article presents a hybrid routing approach with an efficient mobility model and an ant optimization in the mobile Ad hoc network.

Mainly to achieve efficient data usage among the vehicles in mobile communication, this proposed model is developed. The core modules of this model are a hybrid routing protocol, an efficient mobility model, and an optimization algorithm. With the presence of these processes, the data communication efficiency among the devices is improved, and that leads to achieving overall better performance among the mobile devices. The organization of the article includes a detailed study of the earlier methodologies and their drawbacks, the improvements that are carried out in the proposed model, the implementation and performance analysis of the proposed model, and the conclusion of the article.

2. Related Works

In [11], Asif Nawaz Robotics involves mobile stations with decentralized control in MANETs, functioning as both hosts and routers, and this mechanism for detecting and mitigating Black hole attacks in the AODV routing protocol has, drawback is a high delay. In [12]. D.H. Manjaiah explained that a Simple Ant Routing Protocol in MANETs establishes optimal paths between nodes but lacks consideration for congestion and node residual energy during path selection, with the drawback of high overhead.

In [13], author Asmae Bengag aims to enhance traffic safety through reliable communication; however, challenges such as dynamic topology and frequent link breakages exist, resulting in high packet loss. In [14], author Anuj Jain developed MANETs for self-configuring and self-organizing multi-hop wireless networks affected by node mobility and posing challenges for routing due to dynamic node movement. Here, the drawback is the high delay.

In [15], author Sampad Banik expressed that in WSNs and MANETs, research evaluates the performance of various routing protocols with the disadvantage of high packet loss.

In [16], author Mohammad Ayyad introduces an authentication technique using MD5 hashing for the DYMO protocol based on reinforcement learning to enhance security, but it has the disadvantage of high delay. In [17], author Tajul Islam addresses black hole attacks in AODV and AOMDV routing protocols for MANETs by employing a combined SHA-3 and Diffie-Hellman algorithm approach.

In [18], author Khalid A. Farhan describes MANET as an emerging wireless technology that connects mobile nodes in a decentralized manner without the need for a base station or centralized administration, with the drawback of high delay. In [19], author Lucinda Dupak examines the role of bio-inspired algorithms in designing routing protocols for MANETs by reviewing existing protocols to identify gaps and ongoing issues in the MANET environment.

In [20], author S. Vijayalakshmi proposes a Multi-Route AODV Ant algorithm that aims to bypass routing bottlenecks, reduce congestion, and dynamically reconfigure routes to improve performance, though it also suffers from high delays. In [21], author Shuhei Harada introduces the Extended Orthogonal Matched Filter in MANET, which addresses the near-far problem and unknown spreading sequences through a Code Division Multiple Access scheme, proposing optimal parameters for the EOMF with high delay.

Table 1: Earlier Research Drawbacks Details

Ref.	Model	Advantages	Disadvantages
[11]	Robotics mechanism in the AODV routing protocol	Enhances security	High delay
[12]	Ant Routing Protocol	Establishes optimal paths	High overhead
[13]	Greedy Perimeter Stateless Routing	Improving communication reliability	High packet loss
[14]	Self-configuring and organizing multi-hop	Challenges posed by node mobility	High delay
[15]	Various routing protocols	Provides various protocols	Nil
[16]	MD5 hashing for DYMO protocol	Improves security	High delay
[17]	Diffie-Hellman algorithm	Enhanced performance	High power
[18]	Exploration of MANET technology	Highlights the benefits of MANETs	High delay
[19]	Bio-inspired algorithms	Reviews existing routing protocols	Risk of data leakage
[20]	Multi-Route AODV Ant algorithm	Minimize congestion	High delay
[21]	Extended Orthogonal Matched	Addresses the near-far problem and unknown spreading sequences	High delay

3. Proposed HEMAOM Approach

To enable effective routing among devices in mobile communication and to transfer data efficiently from one location to another, this proposed methodology has been developed. The main features of this model include the development of a hybrid routing protocol with a suitable mobility model for the devices, as well as a path selection process based on colony optimization. The workflow of the proposed model is shown in Figure 1.

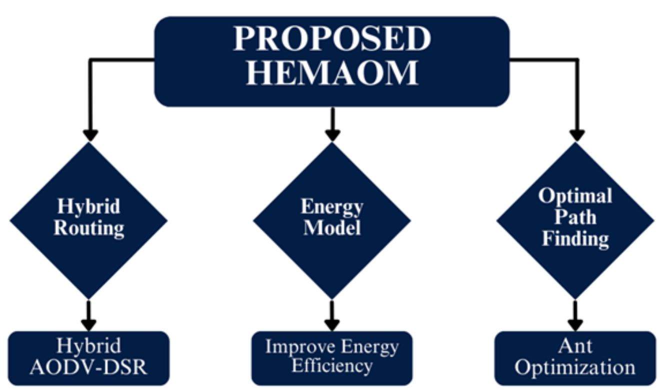

Figure 1. Proposed HEMAOM Workflow

The proposed hybrid reactive routing protocol modifies AODV so that all route set nodes maintain reverse and forward connections, like in AODV. However, all alternative intermediate nodes behave like DSR and include their identities in the RREQ message header. The node list, which contains all alternative or designated intermediate nodes along a route, is collected by the source node when it receives the RREP. This node list is then used to construct a data packet, which is successfully transmitted to the destination through forward connections and the node list.

The four phases in the hybrid procedure are as follows:

- Step 1: Numerous mobile devices with wireless capabilities independently establish a networked MANET and implement the AODV routing protocol via the local broadcasting of RREQ messages.
- Step 2: As RREQ progresses on MANET, each alternative node along the path contributes its identity to the RREQ header, just like in DSR, and establishes reverse connections, just like in AODV. Once the nodes in RREQ have reached their destination, they may be referred to as a node list.
- Step 3: While the forward links are set up as in AODV, the destination uses reverse links and the node-list to deliver the RREP message, which includes the node-list, to the source node. If the routing table is updated properly, an intermediate node may also utilize the node list that is formed using the nodes from the RREQ received, the node itself, and nodes from its routing table for the remaining path to the destination.
- Step 4: during data transmission to the destination, the source node using both forward links and the node list, which it includes in the packet header, forwards the packet.

A comparison is made between the proposed hybrid protocol, AODV, and DSR routing techniques. The reverse and forward connections used for data transfer are indicated by double arrows. Frequent and unpredictable connection failures caused by erratic node mobility led to data and time loss. Some intermediary nodes can act as secondary source nodes if they follow the DSR protocol. This helps reduce issues caused by node mobility. Additionally, there is significantly less extra cost associated with sending route or path information with each data packet. In some cases, an ad-hoc network can operate using either DSR or AODV protocols since our protocol combines elements of both.

The proposed mobility model accurately captures and provides detailed information about individual mobile users in an actual MANET. The goal of the GBM model is to represent node mobility within a real MANET environment. A graph model consists of vertices and edges [6]. Edges represent the links connecting nodes in the network, while vertices indicate the locations within the network. Each mobile node is wirelessly connected to others, and data packets are sent from the source to the destination via the shortest possible route. After reaching its target, a node stops for a random amount of time before selecting a new destination at random from among the remaining vertices for its next move. In the GBM model, mobile nodes always move along the edges of the graph rather than moving randomly. An example of the suggested GBM model is shown in Figure 1, illustrating a city center. The radio transmission range of a node in the GBM does not cover the entire region. If each node has the same transmission range R, the maximum radio coverage of the graph model can be expressed as

$$G_{max,g} = \sum_{e \in E} l(e) \times 2R \tag{1}$$

E represents the set of conventional boundaries in the graph shown in Equation (1). For short radio ranges, the equation performs well. The maximum radio coverage range is not reliant on the radio range of any one node. The random walk model's maximum radio coverage range of the random walk model is specified and may be represented as.

$$G_{max,r} = A_r = l \times W \tag{2}$$

where A_r stands for the total area of the graph, l for the total length, and W for the total width of the area. In this model, we assume that a mobile node's radio coverage does not extend across the entire network. Then, the node moves randomly, and the total area covered equals the maximum radio range. coverage range.

The ant-based algorithm has two phases: finding the route and maintaining it. In this protocol, the network is modelled as a weighted graph with edges and nodes. Each edge is given a specific weight. This function identifies the neighboring nodes for a given node. The source node broadcasts FANT to its neighbouring nodes to find a new route, and only one node can rebroadcast the FANT. This process is called controlled neighbor broadcasting. The next node is chosen based on how many times the connection to that node was previously used. This information is shown in equation (3).

$$P(n, M, d) = \frac{1}{1+n} \tag{3}$$

Pheromone concentration across a connection is increased during control or data packet traversal by α and decreases by γ After a period of τ. The probability of selecting the next hop in equation (4).

$$P(n, j_k, d) = \frac{\Phi_{(n,j_k,d)}}{\sum_{i=0}^{M} \Phi_{(n,j_k,d)}} \tag{4}$$

The node n in this equation has a set of M Neighbouring linkages. Among them, the link j_k, goes to the location d. It is possible to equate the cost function. $\Phi_{(n,j_k,d)}$. In equation (5), the convergence factor k Aids in the separation of pathways with minimal variations in pheromone concentration.

$$\Phi = \frac{(ph+1)^k}{e^h} \tag{5}$$

The number of hops between the designated node and the destination is indicated by the letter "h" because energy is needed for both transmitting and receiving packets. The network's stability is determined by the nodes' remaining energy along the path. This is because nodes with lower battery power run out of power sooner and result in connection failure, which in turn leads to route failure. The difference between the initial energy (E_0) and the energy used up to this point (E_c) is the residual energy at any given point in time t. This can be equated to equation (6).

$$E_r = E_0 + E_c \tag{6}$$

Here, the initial energy and the energy used up to time t are denoted by E_0 and E_c, respectively. The packets that are sent (E_{tx}), received (E_{rx}), and overheard (E_{0x}All use energy. The total energy used is equivalent to equation (7).

$$E_c = E_{tx} + E_{rx} + E_{0x} \tag{7}$$

The amount of buffer on a connection may be used to estimate congestion. Assuming that the queue length is the same for every node in the network. A node with a larger buffer size value is probably more congested. Each node trades its neighbouring nodes the value of its occupied buffer size and residual energy. Each node uses the occupied buffer size (B_{size_i}) and the residual energy (E_r) value to compute the Energy Congestion ($E_c$measure for each of its surrounding nodes.

$$E_{c_i} = 0.4 \times E_{ri} + 0.6 \times (\frac{1}{B_{size_i}}) \tag{8}$$

As seen in (8), the connection cost function of SARA may therefore be changed to include energy and congestion limitations.

$$\Phi = \frac{(ph + E_c + 1)^h}{e^h} \tag{9}$$

Here, h Is the number of hops from the destination to this node, and k It is the convergence factor. The energy congestion statistic is provided by E_c. The protocol operates in this manner. For each node that it is close to, it computes the energy congestion constraint metric. The cost function considers this value. The complete optimization process is described in the pseudocode below. The pseudo-code of the proposed optimization process:

***Input**: Node movements,*

***Step 1:** Initialize parameters*

- Set initial pheromone values Φ for all paths, residual energy E_r for all nodes and cost function parameters k, h

***Step 2:** For each data transmission cycle or time step:*

- Calculate pheromone probability: P(n, j_k, d) = Φ(n, j_k, d) / Σ (over all i) Φ(n, i, d)

Select the previous node based on maximum pheromone probability using Eq (3)

- Calculate cost function Φ for selected nodes:

For each selected path:

Calculate cost function: Φ = ((ph + 1)^k) / e^h

Where ph = pheromone level, k and h are parameters

- Calculate residual energy for each node: E_r = E_0 + E_c

***Step 3:** Optimal Path Selection*

- Use pheromone values and residual energy to select the optimal path

- Select a path that minimizes the cost function (Φ) and maximizes residual energy

***Step 4:** Update pheromone levels on the selected paths*

- Increase pheromone to encourage their future selection

- Evaporate pheromone to reduce their influence

***Output:** Optimal routing paths that balance energy efficiency and transmission cost*

4. Experimental Results

The simulation scenarios were designed using the NS3 simulator, incorporating realistic mobility patterns such as the Random Waypoint model [1] and [6] to emulate node movement. Performance metrics, including packet delivery ratio, average end-to-end delay, throughput, energy consumption, and routing overhead, were used to evaluate the proposed HEMAOM model in comparison with existing routing protocols. The performance of the proposed HEMAOM method is evaluated by the parameters, Packet delivery Ratio (%), Throughput (kbps), Delay (ms), Energy efficiency (joules), and Routing overhead (packets), and the parameters that are used to construct the HEMAOM model are given in Table 2. In [1], [6], and [24], the authors discuss random waypoint, group mobility.

Table 2: Input Parameter

DISCRIPTION	VALUES
SOFTWARE	NS2/SUMO
RUNNING TIME	500 ms
COVERAGE AREA	2000m*2000m
NO OF NODES	200 Vehicles
NODE RADIUS	100m
INITIAL ENERGY	100 Joules
TRANSMISSION POWER	0.05 Joules
RECEIVING POWER	0.05 Joules

The ratio of successfully transmitted data packets to the destination from the source to the data packets used in the network. Figure 2 shows the packet delivery ratio calculation.

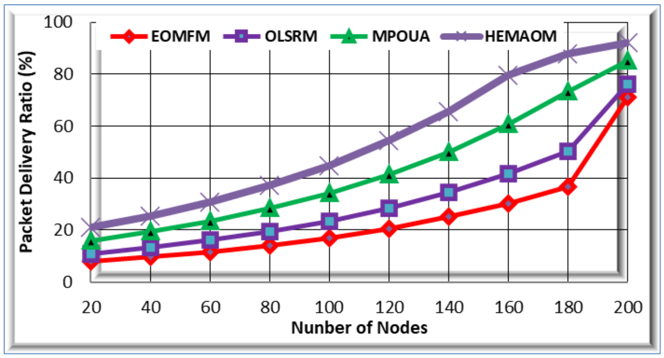

Figure 2. Performance of packet delivery ratio

The proposed HEMAOM method has the highest delivery ratio of 92%, surpassing the existing methods of EOMFM, OLSRM, and MPOUA. Hence, this proposed protocol transmits the data packets faster and efficiently. The packets' speed is transferred to the destination from the source. Figure 3 shows the graphical representation of throughput.

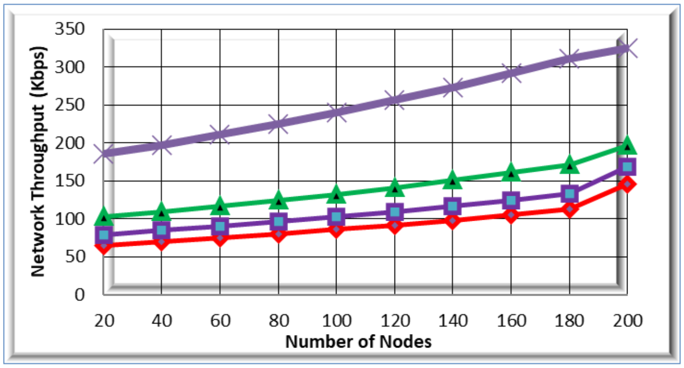

Figure 3. Performance of the Throughput calculation

The proposed HEMAOM protocol demonstrates the highest throughput at 325 kbps, surpassing the throughput achieved by EOMFM, OLSRM, and MPOUA. This indicates that the proposed protocol can transfer data at a faster rate and provides efficient data transmission in the network. The average delay is the time used for a data packet to transmit from its source to its destination. Figure 4 shows the performance of the average delay.

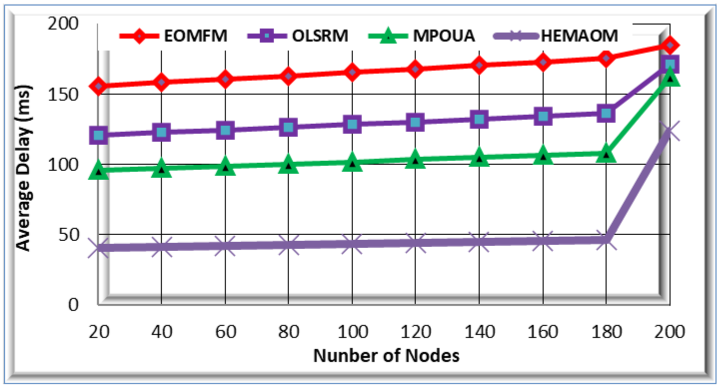

Figure 4. Performance of Average delay

The proposed HEMAOM method achieved the lowest delay of 124 ms, which shows that data packets have less delay when transferring from source to destination compared to the other methods. This minimum delay enhances network responses and reduces waiting times for data transmission. Energy efficiency is the amount of energy consumed per unit of data transmitted through the network. Figure 5 shows the performance of the energy efficiency calculation.

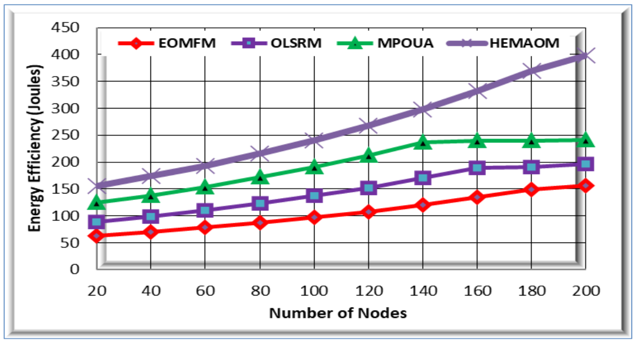

Figure 5. Performance of energy efficiency calculation

The proposed HEMAOM method shows the highest energy efficiency of 398 joules. This indicates that the proposed protocol uses energy more efficiently compared to EOMFM, OLSRM, and MPOUA, which results in lower energy consumption in the network. Routing overhead refers to the extra data packets generated from routing and control information exchanged between network nodes. Figure 6 illustrates the routing overhead calculation.

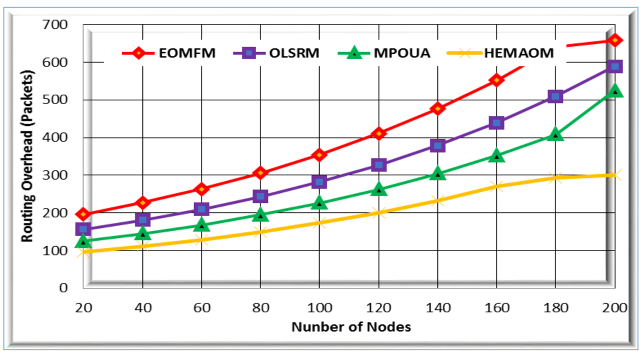

Figure 6. Performance of routing overhead

The proposed HEMAOM method results in the lowest routing overhead at 301 packets, demonstrating that it produces fewer additional packets for routing compared to other existing methods. This indicates that the proposed protocol incurs less unnecessary overhead in managing operations. The overall performance of the participating methods is shown in Table 3.

Table 3: Performance of the existing method and the proposed method

PARAMETER	EOMFM	OLSRM	MPOUA	HEMAOM
PACKET DELIVERY RATIO (%)	71	76	85	92
THROUGHPUT (KBPS)	145	168	196	325
DELAY (MS)	185	171	162	124
ENERGY EFFICIENCY (JOULES)	156	196	241	398
ROUTING OVERHEAD (PACKETS)	658	589	525	301

5. Conclusion

We proposed a hybrid routing model to simplify control packet transmission among mobile devices, which reduces the frequency of link failures during data transmission. Additionally, to optimize data packet delivery, the ant colony optimization algorithm is used, helping to lower power consumption and delay among devices. A key novelty of this work lies in the integration of the ant optimization algorithm within a hybrid routing and mobility framework, enabling dynamic and energy-aware path selection that adapts to changing network conditions, an aspect not sufficiently addressed in prior approaches. The results of the experiments show that this model effectively decreases routing overhead and delays, thereby maximizing device lifespan in the network. For future work, to address errors in real-world scenarios, a more advanced network model should be designed for the devices.

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