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RESEARCH ARTICLE

# Enhanced AOMDV-based multipath routing approach for mobile ad-hoc network using ETX and ant colony optimization

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## Abstract

Mobile ad-hoc network (MANET) are self-organizing and flexible networks where communication takes place with no fixed infrastructure. The network has a dynamic nature because the devices constantly change position. Due to this, establishing reliable and scalable connections, particularly in routing and route discovery, is a challenging task here. This mobility and topological changes is taken into consideration by the ad-hoc on-demand multipath distance vector (AOMDV) protocol by creating numerous paths to a destination, hence improving network resilience. This research proposes to combine the ant colony optimisation (ACO) and expected transmission count (ETX) to optimise the performance of the AOMDV protocol. The ETX metric determines the number of retransmissions needed and determines the probability that a packet will be delivered successfully in order to determine the quality of the network. The ACO is a nature-inspired method that is used to enhance the efficiency of route discovery. By combining ETX and ACO with AOMDV, vital improvements in route discovery and computational efficiency are achieved. The proposed algorithm enhances network performance and energy efficiency in dynamic MANET environments by simulating it in a network simulator and assesses the results of route discovery time, throughput, end-to-end delay, packet delivery ratio, and energy usage.

**Keywords:** MANET, Multipath routing, AOMDV, Expected transmission count, Ant colony optimisation

## Introduction

A mobile ad hoc network is a self-organising network that uses wireless links to connect nodes. The network architecture changes always and the nodes are free to move around. Routing is a difficult task, particularly when it comes to guaranteeing scalability, efficiency, and dependability due to the mobility of nodes and lack of central control. MANETs are utilised in a variety of applications where communication can be facilitated without depending on a fixed infrastructure, including wireless sensor networks, vehicle networks, emergency communication systems, and military networks (Khudayer *et al.*, 2023). In a MANET, routing is the process of determining the best routes for data to be transferred between devices.Nodes have to find and modify routes on demand because of the infrastructure-less nature of networks.This implies that data can be transferred regularly regardless of the changes in the network (Sinwar *et al.*, 2020). Figure 1 shows the communication of nodes in MANET.

Routing protocols are utilised frequently to provide communication paths between source and destination nodes. These protocols frequently suffer from excessive overhead and unstable routes, especially in dynamic situations. Multipath routing has been recommended as a practical approach to overcome these problems and improve fault tolerance and dependability in these kinds of networks (Mathur & Jain, 2018). In the AOMDV protocol, the source node broadcasts a Route REQuest (RREQ) message in the network to start the route discovery process. If the intermediary nodes have a valid route, they reply with a Route REPly (RREP) message; otherwise, they convey this RREQ. The RREQ allows the source to choose paths and start data transmission by sending back

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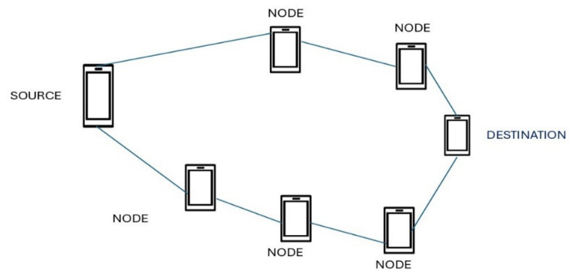


**Figure 1:** Nodes in MANET

RREP messages with available routes as soon as it has arrived at the destination. If there is a link failure during communication, a Route ERRor (RERR) message alerts the source to either take a different route or begin a fresh route discovery. The protocol changes the routing table on a regular basis to ensure route validity. Especially in congested networks with high mobility, the protocol's reliance on hop count measurements ignores important critical link quality parameters.In addition, maintaining several pathways results in higher energy and control overhead. Furthermore, AOMDV lacks tools to maximise the effectiveness of path selection, which affects network performance as a whole (Aouiz *s*., 2018; Setijadi *et al*., 2018).

ETX was developed to improve current path selection in mobile ad-hoc networks, hence enhancing routing protocols such as AOMDV, in order to address the problems with AOMDV (Periyasamy & Karthikeyan, 2017). By analysing network quality measurements and packet retransmission probability, ETX-based routing systems optimise path selection. This method chooses high-quality links with fewer transmissions, reducing energy consumption and packet losses while increasing transmission reliability (Pitchaipillai & Eswaramoorthy, 2017).

The ACO is an optimisation method inspired by nature that imitates ants' foraging habits. It has been applied successfully to several optimisation challenges, such as network routing. In ACO, the artificial ants constantly search for paths within the network and deposit pheromones to indicate successful routes (Rathore & Khan, 2016). Through iterative pheromone deposition, ants converge on paths with lower ETX values, indicating superior link reliability. This bio-inspired optimization mechanism enables dynamic route selection, enhancing network efficiency and path reliability (Wang *et al*., 2008).

The integrated ETX-ACO approach enhances path selection by identifying routes with optimal link quality and minimal transmission costs. This methodology reduces routing overhead and energy consumption while improving network throughput through intelligent path selection based on minimum ETX values. The structure of the research is as follows, section 2 reviews relevant MANET routing protocols, focusing on AOMDV and multipath routing, section 3 presents the proposed ETX-ACO integration with AOMDV, section 4 outlines the simulation methodology and performance metrics, section 5 evaluates the route discovery phase, section 6 analyses results, while further research options are discussed in section 7.

## Related Works

Saxena *et al*. (2023) proposed a multi-objective AOMDV (MO-AOMDV) algorithm to improve routing efficiency for MANET. The MO-AOMDV protocol extends the traditional AODV and AOMDV protocols by integrating energy-aware and congestion-sensitive path selection mechanisms that contribute to more reliable data transmission and improved network lifespan.

Bhardwaj *et al*. (2020) introduced an enhanced AOMDV protocol incorporating genetic algorithm (GA) based route optimization and a novel fitness function (FFn) for MANET. Two variants were developed: AOMDV-FFn using only fitness function-based selection, and AOMDV-GA implementing complete GA operations. While effective, the GA implementation's computational overhead impacts scalability in larger networks.

Selvaraj & Ramasamy (2024) developed an opportunistic routing algorithm integrating age-based particle classification with AOMDV to address network performance challenges. The aging multi population optimization (AMPO) component optimizes discovered routes based on energy and congestion parameters through fitness functions evaluating packet collisions, queue length, and link stability. However, the age-group mechanism introduced computational overhead and potential delays, limiting real-time applications.

Kumar & Singla (2022) proposed AOMDV-ant colony optimization and particle swarm optimization (ACOPSO), combining AOMDV with hybrid ACO-PSO optimization for path selection based on energy, distance, and congestion metrics. While simulation results demonstrate superior performance over AODV, AOMDV, and ACO-AOMDV, the path preservation mechanism introduces computational overhead that may impact scalability and energy efficiency.

Sharma *et al*. (2020) proposed a stable and bandwidth-aware dynamic routing (SBADR) protocol, utilizing received signal strength to compute path stability and bandwidth estimation models incorporating node energy metrics. While the protocol demonstrates improved throughput, PDR, and reduced control overhead, its dependence on precise signal strength measurements and complex parameter management limits effectiveness in dynamic networks.

Marydasan & Nadarajan (2022) developed an algorithm to improve stability and reliability of MANET. This algorithm utilises a hop-by-hop data transfer scheme, thereby choosing the most stable paths based on metrics like destination region selection, connectivity and weighted closeness. Overhead is reduced by using a forwarding node self-selection technique.

Kumar *et al*., (2022) introduced AOMDV-sleep scheduling particle swarm optimisation (SSPSO), which integrates AOMDV routing with PSO and sleep scheduling in MANET to improve energy efficiency and longevity of the network. The state transitions between active, idle, and sleep states in nodes cause the protocol to have higher end-to-end delay, even while throughput and energy consumption are balanced.

Aouiz *et al*., (2019) developed a congestion-aware routing protocol for MANETs that uses the channel busyness ratio as a centrality metric to find saturated nodes and direct traffic via routes that are less congested. Even though load balancing improves packet delivery ratio and delay, this protocol faces difficulty in estimating centrality values and route discovery delays in networks that are congested.

Alleema & Kumar (2019) introduced the Volunteer Node ACO protocol for P2P MANETs. Route optimisation is carried out by choosing capable nodes based on connectivity, processing time, energy, and bandwidth metrics. The protocol faces issues with volunteer node mobility and selection overhead, which in turn affect network speed and stability, even though delay and packet loss have improved.

Periyasamy & Pitchaipillai (2021) proposed the link reliable on-demand multipath distance vector routing (LROMDV) protocol to improve video streaming dependability in MANET by enhancing AOMDV with an enhanced cumulative ETX metric for multiple route selection. This protocol uses numerous routes, which reduces route breaks and link failures, but it also introduces overhead that could affect real-time performance in time-sensitive applications.

The quality of service (QoS)-AOMDV protocol was proposed by Sharma *et al*. to improve packet delivery and lower overhead in MANETs by bolstering AOMDV with dynamic queue congestion control and rate-based data transmission (Sharma & Vashistha, 2014). To maintain precise QoS metrics, the protocol encounters overhead problems and challenges while handling extremely dynamic topology constraints.

A hybrid trust assessment method that integrates the exponential cauchy kernelized adaptive neuro-fuzzy inference system for trust evaluation, improved K-harmonic mean for cluster head selection, and range emperor penguin optimisation REPO was proposed by Dupak *et al*. for optimal routing and to improve MANET security and performance (Dupak & Banerjee, 2022). In this technique, AOMDV-REPO integration improves security in routing; however, the computational complexity is complicated due to weight assessment dependencies and trust evaluation procedures.

Sarhan *et al*. (2021) created the elephant herding optimisation (EHO)-AOMDV protocol by integrating AOMDV and EHO, which optimises energy efficiency in MANET by classifying nodes and choosing the best paths. Due to energy calculations and frequent path re-evaluations, this protocol experiences significant end-to-end delays, whereas energy usage and network lifetime are improved.

Alotaibi *et al*. (2021) presented the balanced and energy efficient multipath routing protocol, through multipath routing and load balancing, which combines FF-AOMDV with genetic algorithms to increase packet delivery, energy efficiency, and network stability in MANETs. Despite improving fault tolerance, complex path management in this protocol causes delay and computational complexity.

In order to increase MANET performance and network lifespan, Sharma *et al*. (2014) suggested an energy-efficient improvement to AOMDV that combines load balancing, shortest path selection, and energy conservation.The protocol has difficulties in preserving precise energy statistics and possible delays during network reconnection, despite efficiently allocating energy use.

Le Duc Huy *et al*. (2021) introduced AOMDV-OAM one time password (OTP) authentication mechanism, enhancing AOMDV routing protocol security in MANETs through OTP authentication to prevent flooding attacks. While simulations demonstrate improved packet delivery and reduced routing load, the protocol faces increased computational overhead from OTP verification, potentially impacting route discovery timing and network performance.

Choudhury *et al*. (2023) developed a C-QoS-AOMDV protocol for MANETs, integrating modified bird mating optimization for clustering, mine blast optimization for trust computation, and a hierarchical decision tree-based deep neural network for optimal node selection to enhance QoS and energy efficiency. While effective, the protocol's use of hybrid soft computing techniques increases computational complexity, potentially affecting real-time performance.

The above literature studies in MANET primarily focused on energy and cost optimization without considering multiple parameters. ETX evaluates link quality and path costs to identify reliable, energy-efficient routes, while ACO enables dynamic path discovery with reduced computational overhead, resulting in improved load balancing, lower latency, and enhanced packet delivery ratios in highly mobile environments.

## Proposed Methodology

In dynamic MANET environments, the ETX measure and ACO are included in the proposed approach to improve the performance of the AOMDV protocol. This combination aims to augment route discovery, energy efficiency, packet delivery ratio, and route maintenance to achieve more dependable and scalable network performance. To identify an effective communication path in the network, the proposed methodology aims to combine ETX measures with the ACO's pheromone-based path selection. It enhances the discovery process of network paths by integrating the ETX and ACO. This technique seeks to increase the efficiency of the network by utilising ACO to determine the optimal routes and ETX to assess link quality. Reducing energy consumption, delays, and computing load is intended to improve overall reliability and performance in dynamic conditions.

### *Route discovery algorithm with AOMDV using ETX and ACO*

*Step 1*

Initialize pheromone trails on all links

*Step 2*

For each source node:

a. Broadcast RREQ to neighbours
b. Upon receiving RREQ, each intermediate node:
   i. Calculate ETX for the link to the next hop
   ii. Apply ACO to select a path based on ETX and pheromone values
   iii. Forward the RREQ to the next node
c. RREQ is received by Destination node and sends back RREP
d. RREPis received by Source node and selects paths with minimum ETX

*Step 3*

Update pheromone trails:

a. On each selected path, increment pheromone based on ETX
b. Evaporate pheromones on unused paths

*Step 4*

Maintain paths for future data communication

*Step 5*

Periodically update ETX and pheromone values to adapt to network changes

Initially, all network paths are assigned a baseline pheromone level. When a node requires data transmission, it broadcasts an RREQ packet. Upon receiving the RREQ, each node evaluates the link quality to its neighbours using the ETX metric. Nodes utilize a combination of ETX values and existing pheromone levels to select the next hop and forward the request. Upon reaching the destination, a RREP packet is sent back, enabling the source node to select the optimal path based on ETX values. The pheromone update mechanism dynamically adapts by reinforcing successful paths with increased pheromones while causing unused paths to lose pheromones through evaporation. Regular updates of both ETX and pheromone levels allow the network to adapt effectively to varying conditions. This creates a self-optimizing system where the network naturally finds and maintains efficient communication paths while adapting to changes in network conditions.

A RREQ packet is sent to the destination node by the source node. During the RREQ process, nodes calculate the ETX value for each link. As the RREQ packet propagates through the network, ACO is applied. Ants are dispatched to find multiple candidate paths. The ants will deposit pheromones proportional to the ETX of the path they explore. Paths with lower ETX will have stronger pheromone trails, increasing the probability that ants will select those paths. A RREP packet with the pathways chosen based on the pheromone values is sent back to the source node by the RREQ after it has reached the destination node. The source node receives the RREP and chooses the paths with the least ETX values. The source will prefer paths with lower ETX for communication, balancing the load across multiple paths.

The ETX for a link between two nodes u and v is calculated as,

$$ETX(u,v) = \frac{1}{\left(1 - Link\ Sucess\ Rate(u,v)\right)} \quad Eq.(1)$$

where, link success rate (*u,v*) is the probability that a packet transmitted from the node *u*over the link is successfully received by the destination node *v*.

Once paths are selected, the ETX values are updated periodically, and the pheromone trails are adjusted based on network changes such as node mobility, link failures, and congestion. When the path quality degrades, the ACO algorithm updates the pheromone values, directing ants toward better paths. From the calculated multiple paths, the probability $P_k$ of selecting the k[th] path is influenced by its pheromone level $T_k$ and the inverse of its ETX value $ETX_k$

$$P_k = \frac{\mathrm{T}_k^{a}\ .\ ETX_k^{-\beta}}{\sum i \mathrm{T}_i^{a}\ .ETX_i^{-\beta}} \quad Eq.\ (2)$$

where,

$T_k$ is the pheromone level on the k[th] path

$ETX_k$ is the ETX value for the k[th] path

$\alpha$ *and* $\beta$ are parameters that control the influence of pheromones and ETX on path selection.

After each iteration, the pheromone level for each path is updated as follows.

$$\mathrm{T}_k(t+1) = (1-\rho)\cdot \mathrm{T}_k(t) + \Delta \mathrm{T}_k \quad Eq.\ (3)$$

where,

$\rho$ is the evaporation rate (the rate at which pheromones dissipate).

$\Delta\mathrm{T}$ represents pheromone increment based on the quality of the path (lower the ETX values higher the increments).

## Experimental Simulation System

NS-3 simulator is a popular discrete-event simulation tool in networking research. It supports a broad variety of network types, including wired, wireless, and mobile networks, in addition to supporting TCP, UDP, IP, and a number of routing algorithms. NS-3 makes it possible to measure significant performance indicators like energy consumption, packet loss, delay, and throughput. It provides the perfect environment for testing and verifying new protocols because of its open-source nature, which allows for substantial specialisation and expansion. NS-3 is a vital tool for research and protocol development since it also replicates actual networking conditions.

*Simulation Parameters for NS-3*

The following Table 1 tabulates the parameters needed for simulation to run the previously proposed method in the NS-3 simulator, utilising ETX and the ACO-based AOMDV protocol.

## Route Discovery Phase Evaluation

A, B, C, D, and E are nodes.

*i) Source Node A Sends RREQ*

Node A broadcasts an RREQ to its neighbours (B and C)

*ii) Actions by Intermediate Nodes*

ETX values are computed by Node B for linkages to C and D.

- ETX(A → B) = 1.2 (delivery probability = 0.833).
- ETX(B → D) = 1.1

Node B combines ETX with pheromone levels to calculate probabilities:

- *P(B → D) = [pheromone × (1 / ETX)] = 0.5 × (1 / 1.1)*
- Node B forwards the RREQ to D.

Similarly, Node C processes the RREQ and forwards it to D.

## Destination Node Actions

Node D receives RREQ from multiple paths (A → B → D and A → C → D).

These paths are used by Node D to transmit an RREP back to A.

**Table 1:** Parameters used for simulation

| *Parameter* | *Value* |
|---|---|
| Number of sensor nodes | 20 – 100 |
| Time taken for simulation | 300 secs |
| Node mobility model | Random Waypoint Model |
| Traffic type | TCP (or UDP, depending on requirements) |
| Packet size | 1024 bytes |
| Traffic source | On-Off Application (UDP) |
| Traffic rate | 500 kbps |
| Routing protocol | AOMDV (with ETX and ACO enhancements) |
| Routing metric | ETX |
| Pheromone update rate | 0.1 (can be adjusted for faster/ slower convergence) |
| Pheromone evaporation rate | 0.05 (controls pheromone decay) |
| Routing table size | 50 (configurable based on node network size) |

**Table 2:** Route Discovery Phase Evaluation

| *Step* | *Node* | *Link* | *ETX Value* | *Initial pheromone* | *Updated pheromone* | *Action* |
|---|---|---|---|---|---|---|
| 1 | A | A → B | NA | 0.5 | NA | Broadcast RREQ to B and C |
| 2 | B | A → B | 1.2 | 0.5 | NA | Calculate ETX, forward RREQ to D |
| | B | B → D | 1.1 | 0.5 | 0.4545 | Calculate Pheromone for B → D, forward RREQ |
| 3 | C | A → C | 1.3 | 0.5 | N/A | Calculate ETX, forward RREQ to D |
| | C | C → D | 1.1 | 0.5 | 0.4545 | Calculate Pheromone for C → D, forward RREQ |
| 4 | D | A → B → D | NA | NA | NA | Receive RREQ from A → B → D and A → C → D |
| 5 | A | A → B → D | 2.3 | NA | NA | Receive RREP, select Path 1 (A → B → D) |
| | A | A → C → D | 2.4 | NA | NA | Compare with Path 2, select Path 1 |
| 6 | B | A → B | NA | 0.5 | Updated pheromone | Reinforce pheromone on Path 1 (A → B → D) |
| | D | B → D | NA | 0.5 | Updated pheromone | Reinforce pheromone on Path 1 (B → D) |
| | A | A → C | NA | 0.5 | Reduced pheromone | Evaporate pheromone on unused Path 2 (A → C → D) |
| | C | C → D | NA | 0.5 | Reduced pheromone | Evaporate pheromone on unused Path 2 (C → D) |

*Source Node Actions*

Node A receives RREP and calculates path ETX values:

- Path 1 (A → B → D): ETX = 1.2 + 1.1 = 2.3.
- Path 2 (A → C → D): ETX = 1.3 + 1.1 = 2.4.

Node A selects path 1 for data transmission due to lower ETX.

*Pheromone Trail Updates*

Reinforce pheromones on Path 1 (A → B → D):

- New pheromone(A → B) = Old + Δ (Δ depends on ETX).
- New pheromone(B → D) = Old + Δ.

Evaporate pheromones on unused Path 2 (A → C → D):

- New pheromone(A → C) = Old × (1 - evaporation rate).
- New pheromone(C → D) = Old × (1 - evaporation rate).

*Periodic Updates*

Periodically recalculate ETX and adjust pheromone levels to adapt to changes in link quality or network topology.

*AOMDV-ETXACO Routing Map*

A neighbour receives an RREQ from a source node with its identifier and routing details. Intermediate nodes calculate ETX values for outgoing links using link quality data and update them as the RREQ passes through. Each node forwards the updated RREQ to its neighbors until it reaches the destination. The ETX value is added to the RREQ by each intermediate node based on the link from the source node to itself. An RREP is sent back to the source by the destination node, including ETX values for the entire path. The source node evaluates ETX values from multiple paths in the RREP to choose the most reliable route. The source node chooses the route with the lowest ETX value from RREP messages, ensuring higher reliability and fewer retransmissions. Figure 2 shows the route discovery phase using ETX values. ETX values are updated dynamically to reflect changing link conditions, adapting to network topology changes. Increased ETX for unreliable links signals the need to avoid them or reduce their pheromone value in ACO-based protocols.

### *Route optimization and stability phase*

calculate the probabilities for each route

For route 1 ($k_1$) the value for $T_1$ = 0.5 and $ETX_1$ = 1.2

For route 2 ($k_2$) the value for $T_2$ = 0.5 and $ETX_2$ = 1.3

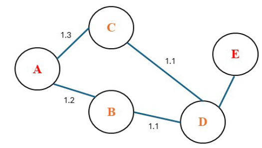


**Figure 2:** Route Discovery Phase

For route 3 ($k_3$) the value for $T_3$ = 0.5 and $ETX_3$ = 1.1

α = 1 and β = 1

*For Path 1 (k1)*

$P_1$ = 0.4167/1.2558 = 0.3317

*For Path 2 (k2)*

$P_2$ = 0.3846/1.2558 = 0.3067

*For Path 3 (k3)*

$P_3$ = 0.4545/1.2558 = 0.3623

Pheromone update process for Path 1 (A → B → D) and Path 2 (A → C → D)

Path 1 (A → B → D) receives a higher pheromone value due to its lower ETX value.

## Result and Discussions

The proposed algorithm, AOMDV integrated with ETX and ACO, significant improvements over existing algorithms are anticipated with regard to route discovery time, route maintenance time, PDR, E2Edelay, and energy consumption. By utilizing ETX for more accurate path selection and ACO for dynamic path optimization, it is expected that the performance metrics will demonstrate enhanced efficiency. These improvements are anticipated to be reflected in better route stability, lower latency, higher packet delivery, and reduced energy consumption, providing a more reliable and efficient routing solution for MANET.

### *Performance Metrics*

Simulations in a MANET environment are used to assess the proposed method's performance.

*The key metrics considered are.*

- The time taken for a node to identify a valid route to the destination is the route

Table 3: Updated Pheromone

| *Step* | *Path* | *Initial pheromone ($T_k(t)$)* | *ETX Value (for Path)* | *Evaporation rate (ρ)* | *$\Delta T_k$ (Change in pheromone)* | *Updated pheromone ($T_k(t+1)$)* |
|---|---|---|---|---|---|---|
| 1. Path 1 update | A → B → D | 0.5 | 1.2 | 0.1 | 1/1.2=0.8333 | (1−0.1)×0.5+0.8333= 1.2833 |
| 2. Path 2 update | A → C → D | 0.5 | 1.3 | 0.1 | 1/1.3=0.7692 | (1−0.1)×0.5+0.7692= 1.2192 |

discovery time. The time for route discovery is estimated as,

$$T_{discovery} = \frac{N_{nodes} \times D_{avg}}{R_{discovery}} \quad Eq. (4)$$

where,

$T_{discovery}$ is the time for route discovery

$N_{nodes}$ is the network's total number of nodes.

$D_{avg}$ is the average distance between the source and destination nodes

$R_{discovery}$ is the rate at which route discovery messages propagate across the network.

- Throughput is the quantity of data that is successfully received at the destination in a certain unit of time.The throughput value in terms of kilobits per second is evaluated as,

$$Throughput = \frac{Total\ data\ received(bytes) \times 8}{Total\ simulation\ time(\sec) \times 1000} \quad Eq. (5)$$

where,

$Total\ data\ received\ (bytes)$ is the amount of data (in bytes or bits) successfully

received by the destination node(s) during the simulation. This excludes dropped or lost packets.

$Total\ simulation\ time$ is the total duration of the simulation in seconds (sec).

- The ratio of packet deliveries that were successful out of all packets sent.
- The greater value specifies better network performance and reliability.

$$PDR = \frac{N_{Received}}{N_{Sent}} \times 100 \quad Eq. (6)$$

where,

$N_{Received}$ is the total number of packets that have reached the destination node successfully, $N_{Sent}$ is the total number of packets sent from the source node.

*End to End Delay*

The average amount of time it takes for a packet to go across a network from its source to its destination.

$$E2E\ Delay = \frac{1}{N_{Received}} \sum_{i=1}^{N_{Received}} \left(T_{Arrival}(i) - T_{Departure}(i)\right) Eq.(7)$$

where,

$N_{Received}$ represents the total quantity of packets that were successfully received at the destination.

$T_{Arrival}(i)$ represents the arrival time of i$^{th}$ packet at the destination and

$T_{Departure}(i)$ indicates thei$^{th}$ packet sent time by the source.

- The total amount of energy used by the nodes to send and receive packets.

$$E_{total} = \sum_{i=1}^{N_{Transmitted}} E_{Transmit}(i) + \sum_{j=1}^{N_{Received}} E_{Receive}(j) \quad Eq. (8)$$

where,

$E_{total}$ is a total energy consumption of a node.

$N_{Transmitted}$ represents the quantity of packets sent totally.

$E_{Transmit}$ (i)represents the i$^{th}$ packet amount of energy consumed for transmission

$N_{Received}$ indicates the number of packets that were received totally.

$E_{Receive}$ (j)represents energy consumption for receiving the j$^{th}$packet

The performance of the proposed methodology was evaluated by comparing four different approaches using five significant metrics such as energy consumption, Packet Delivery Ratio (PDR), End-to-End (E2E) delay, time for route maintenance, and time for route discovery.AOMDV-GA, AMPO-AOMDV, AOMDV-ACOPSO, and MO-AOMDV are some of these methods, which each offer distinct strategies to route optimisation in mobile ad-hoc networks. A thorough comparison of these metrics is provided in the next section to evaluate the proposed approach's reliability, efficiency and overall network performance. Equation 5 is used to determine the route discovery time. The route discovery time is measured in seconds (sec). Table 4 depicts the comparative analysis of the route discovery time between existing and proposed approaches.

Figure 3 demonstrates that AOMDV-ETXACO offers the most efficient route discovery across increasing node densities, particularly for larger networks. This proposed method, combining ETX and ACO, minimizes time compared to algorithms like AOMDV-GA and MO-AOMDV. The significant reduction in route discovery time for AOMDV-ETXACO reflects its ability to optimize both energy efficiency and link reliability. The throughput value is calculated using equation 6. The throughput is measured by using the unit kilobytes per second (kbps). The throughput value for the proposed method with existing methods is compared in Table 5.

**Table 4:** Route Discovery Time (sec)

| *No. of Nodes* | *AOMDV-GA* | *AMPO-AOMDV* | *AOMDV-ACOPSO* | *MO-AOMDV* | *AOMDV-ETXACO* |
|---|---|---|---|---|---|
| 20 | 1.5 | 1.2 | 1.2 | 1.3 | 1.2 |
| 40 | 3.2 | 2.9 | 2.7 | 3.0 | 2.1 |
| 60 | 4.5 | 4.0 | 3.8 | 4.2 | 2.8 |
| 80 | 6.0 | 5.3 | 5.1 | 5.5 | 3.4 |
| 100 | 7.5 | 6.8 | 6.5 | 7.0 | 4.0 |

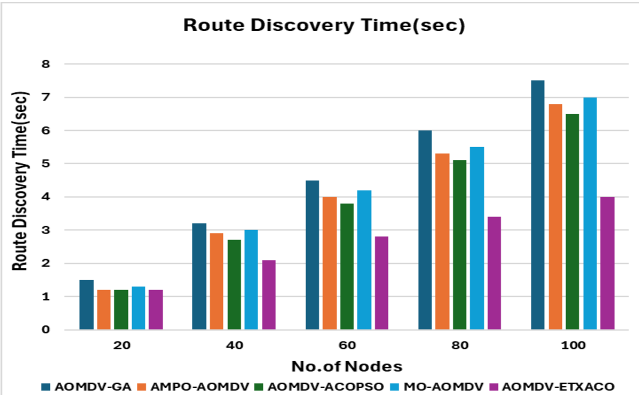


**Figure 3:** Route discovery time (sec)

**Table 5:** Throughput (kbps)

| *No. of Nodes* | *AOMDV-GA* | *AMPO-AOMDV* | *AOMDV-ACOPSO* | *MO-AOMDV* | *AOMDV-ETXACO* |
|---|---|---|---|---|---|
| 20 | 320 | 350 | 370 | 390 | 410 |
| 40 | 540 | 580 | 600 | 630 | 660 |
| 60 | 710 | 740 | 760 | 800 | 830 |
| 80 | 850 | 880 | 900 | 940 | 980 |
| 100 | 970 | 1000 | 1020 | 1060 | 1100 |

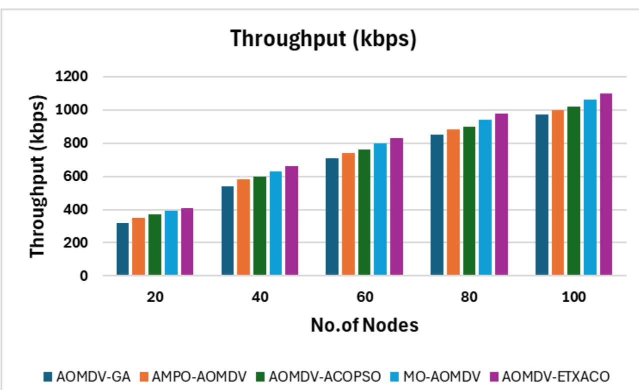


**Figure 4:** Throughput (kbps)

Figure 4 shows that the proposed AOMDV-ETXACO outperforms existing AOMDV-based enhancements in terms of throughput across varying node densities. Its superior performance demonstrates its potential for use in high-mobility and high-density MANET environments, where efficient, reliable communication is critical. This improvement makes AOMDV-ETXACO a promising candidate for multimedia and real-time applications in ad hoc mobile networks. Equation 7 is used to calculate the packet delivery ratio. The PDR computation for the existing approach and the proposed approach is compared in Table 6.

**Table 6:** Packet Delivery Ratio (%)

| *No. of Nodes* | *AOMDV-GA* | *AMPO-AOMDV* | *AOMDV-ACOPSO* | *MO-AOMDV* | *AOMDV-ETXACO* |
|---|---|---|---|---|---|
| 20 | 85 | 87 | 89 | 90 | 98 |
| 40 | 82 | 85 | 88 | 90 | 97 |
| 60 | 79 | 83 | 86 | 89 | 96 |
| 80 | 76 | 80 | 84 | 88 | 95 |
| 100 | 74 | 78 | 82 | 86 | 94 |

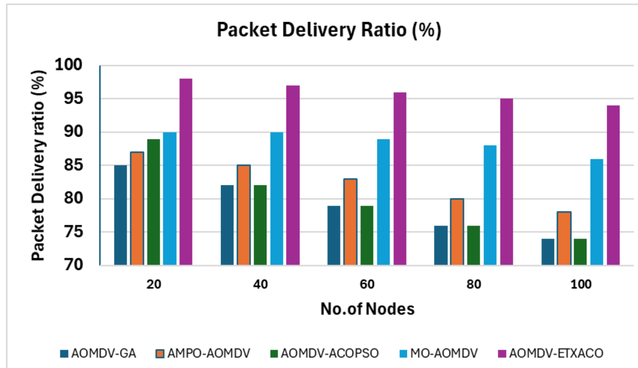


**Figure 5:** Packet Delivery Ratio (%)

**Table 7:** End-to-End Delay (mS)

| *No. of Nodes* | *AOMDV-GA* | *AMPO-AOMDV* | *AOMDV-ACOPSO* | *MO-AOMDV* | *AOMDV-ETXACO* |
|---|---|---|---|---|---|
| 20 | 50 | 55 | 55 | 50 | 50 |
| 40 | 60 | 65 | 65 | 60 | 55 |
| 60 | 75 | 80 | 70 | 72 | 60 |
| 80 | 85 | 90 | 80 | 82 | 65 |
| 100 | 95 | 100 | 90 | 92 | 70 |

Figure 5 shows that the proposed AOMDV-ETXACO protocol significantly improves the PDR compared to existing AOMDV variants across different node densities. By integrating the ETX metric for reliable link selection and ACO for adaptive multipath discovery, the protocol maintains a PDR above 92% even with 100 nodes. This demonstrates AOMDV-ETXACO's robustness and scalability in dynamic MANET environments. Its performance makes it highly suitable for critical applications such as disaster response and military communication, where reliable and efficient data delivery is essential. Equation 8 is used to compute the End-to-End (E2E) delay. The delay time is measured in milliseconds (mS). Table 7 presents a comparison between the proposed methodology and the existing methods.

Across all studied routing algorithms, Figure 6 shows that the E2E delay grows as the number of nodes increases.

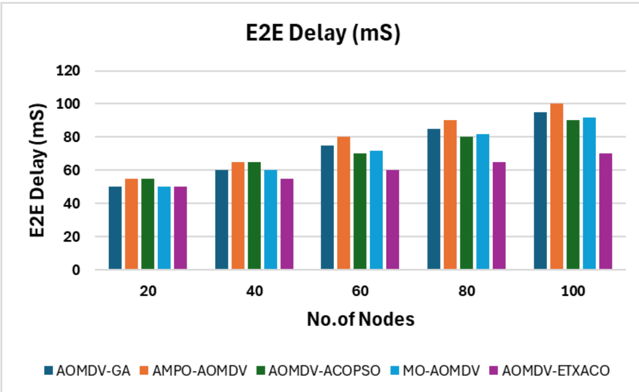


**Figure 6:** E2E delay (mS)

**Table 8:** Energy Consumption (J)

| *No. of Nodes* | *AOMDV-GA* | *AMPO-AOMDV* | *AOMDV-ACOPSO* | *MO-AOMDV* | *AOMDV-ETXACO* |
|---|---|---|---|---|---|
| 20 | 0.15 | 0.18 | 0.12 | 0.14 | 0.11 |
| 40 | 0.30 | 0.35 | 0.25 | 0.28 | 0.22 |
| 60 | 0.45 | 0.50 | 0.40 | 0.42 | 0.32 |
| 80 | 0.60 | 0.65 | 0.55 | 0.58 | 0.39 |
| 100 | 0.75 | 0.80 | 0.70 | 0.72 | 0.45 |

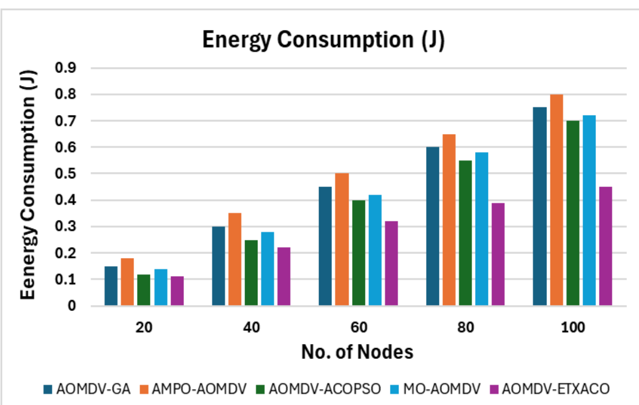


**Figure 7:** Energy Consumption (J)

The AOMDV-ETXACO is effective at reducing transmission latency, as evidenced by its consistent achievement of the lowest E2E delay. This performance is ascribed to the suggested method, which prioritises increasing computing efficiency and optimising route finding. As a result, AOMDV-ETXACO works well in large-scale MANET setups for low-latency applications. Equation 9, which uses Joules (J) as the unit of measurement, is used to determine the energy consumption. Table 8 shows the energy consumption comparison of the proposed and existing methods.

Figure 7 shows that for every routing technique that was assessed, energy usage rises as the number of nodes grows. It is noteworthy that AOMDV-ETXACO constantly exhibits the lowest energy consumption. This pattern implies that by making it easier to choose dependable and energy-aware routes, the integration of the ETX measure with ACO improves energy efficiency. On the other hand, algorithms like MO-AOMDV and AOMDV-GA use a lot more energy. These outcomes support the suggested methodology and demonstrate how well AOMDV-ETXACO enhances route discovery and energy efficiency, making it an excellent choice for MANET situations with limited energy resources.

## Conclusion

Mobile ad hoc networks are self-organising, infrastructure-free wireless networks that function in dynamic settings where it can be difficult to maintain trustworthy and efficient communication. In MANETs, routing systems have to adjust to limited energy resources, link failures, and frequent topology changes. Fault tolerance is provided by the Ad hoc On-Demand Multipath Distance Vector protocol, which keeps several pathways that are not connected between the source and destination nodes. However, its efficacy in dense or highly dynamic networks is limited by its dependence on hop count and absence of link quality monitoring.

This research suggests an enhanced AOMDV method called AOMDV-ETXACO, which integrates the ETX measure with ACO to overcome these restrictions. ETX quantifies link reliability based on transmission success probabilities, while ACO optimises multipath selection through a pheromone-based learning mechanism modelled after ant foraging behaviour. In combination, a robust framework is offered for routing that is intelligent, flexible, and energy-efficient.

Simulations carried out in the NS-3 environment show that AOMDV-ETXACO improves performance metrics to a great extent compared to existing AOMDV-based variants. Energy usage, throughput, end-to-end delay, and packet delivery ratio are all improved, particularly when the node density increases from 20 to 100. These results certify the suggested method's scalability and reliability, which makes it appropriate for mission-critical, energy-constrained MANET applications like military communications and disaster response. Future developments might include security features, machine learning-based adaptability, and QoS measurements to strengthen its applicability in complex and heterogeneous network contexts.

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