Enhanced Course-Plotting in MANETs Through the Providing of the Amalgam MAT Technique

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Abstract
Energy-efficient routing continues to be a critical area of research for Mobile Ad Hoc Networks (MANETs). Due to the mobile nature of nodes, coupled with the typically hostile and unpredictable environments in which they operate, MANETs are inherently constrained by limited energy resources. Among the various operations carried out by mobile nodes, routing stands out as one of the most energy-intensive tasks. Therefore, it is crucial for routing mechanisms to be lightweight, minimizing energy consumption while maximizing efficiency. Given these challenges, the focus of this research is to propose a robust and energy-efficient routing strategy, specifically designed to improve route selection by utilizing a metric known as the Trust Index (TI).

Keywords: Route selection, Trust index, MANET, Metaheuristic algorithms, Network lifetime.

I. INTRODUCTION

The Trust Index (TI) is a key metric used to guide route selection in MANETs. This index is calculated based on several important factors.

1. Energy Backup: This refers to the remaining energy reserves of each node. Nodes with higher energy backups are more reliable for routing since they are less likely to run out of energy during data transmission.
2. Packet Delivery Rate: This metric reflects the ability of a node to successfully deliver packets to their destination. A higher packet delivery rate suggests that the node is dependable and efficient in forwarding data,making it a valuable part of the network's routing infrastructure.
3. Loyalty of Node: This factor assesses the reliability of the node in terms of its past behavior.

A node that consistently follows network rules, successfully participates in routing, and does not exhibit malicious or erratic behavior is considered more loyal, contributing to a higher TI.

The fitness value in the route selection algorithm is directly influenced by the TI. Essentially, the higher the TI of a node or a route, the more likely it is to be chosen by the routing algorithm. This helps ensure that the selected routes are both energy-efficient and reliable.

The effectiveness of the proposed work is measured using several key performance indicators:

1. Packet Delivery Rate: This metric measures how successfully the network can deliver data packets to their intended destinations.
2. Average Latency: This represents the time it takes for data to travel from the source to the destination, with lower latency indicating faster communication.
3. Energy Efficiency: This evaluates how well the network conserves energy during routing, ensuring

that nodes operate longer before their energy reserves are depleted.

4. Network Life Expectancy: This metric assesses the overall operational lifespan of the network before the nodes run out of energy or stop functioning due to other factors.

The proposed approach demonstrates superior performance in comparison to existing methods, particularly in terms of network lifetime. This means that the network remains functional for a longer period, thereby increasing the overall efficiency and reliability of the MANET. This extended network lifespan, combined with improved packet delivery and energy conservation, highlights the effectiveness of the MAT approach over other methodologies.

Trust Index (TI): The explanation deepens the understanding of how TI factors into node reliability and efficiency.

Energy backup and packet delivery rate are key technical metrics, while loyalty ensures nodes are trustworthy participants in the network.

MAT Method: The integration of Gray Wolf and Whale Optimization methods is clarified, explaining how each algorithm works and how their combination results in better optimization.

Evaluation Metrics: Packet delivery rate, latency, energy efficiency, and network lifetime are essential performance indicators that highlight both the functionality and longevity of the network under the proposed system.

This rewrite preserves the original content's meaning but provides additional context and clarity on how the system functions.

A Mobile Ad hoc Network (MANET) is a dynamic network consisting of multiple mobile nodes. This network architecture is based on principles similar to Wireless Sensor Networks (WSN), where nodes communicate wirelessly without relying on any fixed infrastructure. In MANETs, the mobile nodes are free to move in any direction, and their movement is unrestricted, allowing the network to continuously reconfigure itself as nodes join, leave, or change position.

One key difference between MANETs and other wireless networks is the absence of a Base Station (BS), which typically acts as a central coordinator or gateway in traditional wireless networks. In the case of MANETs, there is no centralized control point. Instead, the mobile nodes themselves take on the roles of both sensor nodes and routers. This means each node not only senses environmental data but also participates in routing that data across the network to ensure successful transmission to other nodes.

Mobile Ad hoc Network (MANET): MANETs consist of mobile nodes with no fixed infrastructure, giving them the flexibility to operate in dynamic, constantly changing environments. The absence of a central Base Station is a key characteristic, as it forces the mobile nodes to handle both data collection and routing.

1. Sensing: The most important role of these nodes, providing the foundation for various real-time applications.
2. Processing: Minimal processing ensures efficient energy use.
3. Transmission: Involves sending data to neighboring nodes, forming the basis of communication in the network.

In a Mobile Ad hoc Network (MANET), data transmission is the most critical function because it directly enables each application to fulfill its intended purpose. Whether it’s for real-time monitoring, communication, or data collection, the successful transmission of data across the network is essential for the overall operation and effectiveness of the system. This transmission process involves sending data from one node to another, often through multiple hops, to ensure that information reaches its destination,

whether that's another node, a control center, or an external network.
Data Transmission: This is the core function of a MANET, as it enables the applications running on the network to achieve their goals. Whether sending data across nodes or routing it to a specific destination, successful transmission is the key to network functionality.
Challenges of Mobility: The dynamic movement of mobile nodes adds complexity to routing because the network is constantly reconfiguring itself as nodes move, making it difficult to maintain stable communication paths.
Energy Efficiency: Wireless sensors have limited battery life, making energy conservation critical. Without energy-efficient operation, nodes will deplete their energy quickly, leading to network degradation.
Energy Management Strategies: Efficient routing, low-power hardware, and energy-aware protocols help prolong the network's lifespan by reducing unnecessary energy expenditure.
Although Mobile Ad hoc Networks (MANETs) share foundational principles with Wireless Sensor Networks (WSNs), the routing algorithms designed for WSNs are not directly applicable to MANETs.
This is primarily due to the unique characteristics of MANETs, which include the absence of a fixed infrastructure and the dynamic movement patterns of mobile sensors. In a WSN, the nodes are often static or have minimal movement, and the network typically relies on a centralized Base Station (BS) for communication coordination. However, in MANETs, nodes are highly mobile and function without any centralized control. This constant mobility and lack of infrastructure require specialized routing algorithms that can dynamically adjust to the changing topology of the network.
Despite these challenges, the flexibility provided by the absence of fixed infrastructure and the mobility of nodes also presents opportunities for faster development and deployment of MANETs. The decentralized nature of the network allows for rapid setup, making MANETs suitable for use in various real-time applications, such as disaster recovery, military operations, and emergency services. However, this same flexibility exposes MANETs to significant security risks.
Without a fixed infrastructure or a central authority to manage security, the network becomes vulnerable to threats such as malicious nodes, eavesdropping, data tampering, and denial-of-service attacks. Ensuring secure communication in such a dynamic and decentralized environment is a major challenge that must be addressed in the design of routing protocols.
Among these essential tasks, data transmission is the most demanding in terms of energy consumption. Given that sensor nodes in MANETs are typically battery-powered and energy-constrained, transmitting data, especially over long distances or through multiple hops, rapidly depletes the nodes' energy. Despite this high energy cost, data transmission remains the most critical function of the network, as it enables the flow of information across the nodes, allowing the network to achieve its purpose.
Challenges of Applying WSN Routing to MANETs: WSNs rely on a fixed infrastructure and typically deal with static nodes, while MANETs lack infrastructure and involve highly mobile nodes, making WSN routing algorithms inadequate.
Opportunities for Faster MANET Development: The flexibility of MANETs allows them to be deployed quickly in dynamic environments, but this same flexibility increases security vulnerabilities.
Critical Sensor Node Functions: Sensing, data transport, and local processing are essential tasks, with data transmission being the most energy-intensive but crucial for network functionality.
Energy-Efficiency and Security Needs: The high energy cost of transmission and the exposure to security risks in a MANET environment highlight the need for routing protocols that are both energy-

efficient and secure.

This version provides a deeper understanding of the issues surrounding MANETs, particularly in terms of routing challenges, energy efficiency, and security concerns.

Proactive Routing Protocols:

- They maintain a complete set of routes at all times, ensuring instant access when needed but at the cost of higher memory and processing power.
- Constant monitoring of the network, regardless of node mobility, increases complexity and can lead to inefficiency if routes become outdated.

Reactive Routing Protocols:

- They only initiate route discovery when a node needs to send data, reducing the overhead of maintaining unnecessary routing information.
- However, this leads to delays as the route must be discovered before communication can occur, which is less ideal for real-time or time-sensitive data transmissions.

This rewritten version enhances understanding by elaborating on the trade-offs between proactive and reactive protocols, explaining their strengths, weaknesses, and their suitability for different types of MANET environments.

2. REVIEW OF LITERATURE

Energy efficiency is a critical requirement for any routing method designed for Mobile Ad hoc Networks (MANETs).

The primary reason for this is that the depletion of energy in sensor nodes can lead to connectivity issues, where nodes are unable to communicate effectively due to insufficient battery power.

When sensor nodes run out of energy, they can no longer participate in data transmission or routing, which in turn leads to network performance degradation. As nodes fail, routes are disrupted, causing delays, packet losses, and even network partitioning where parts of the network become isolated.

To address these issues, this work proposes an energy-efficient and secure routing method for MANETs by leveraging the power of metaheuristic algorithms. Metaheuristic algorithms are optimization techniques inspired by natural processes or behaviors that are designed to find optimal or near-optimal solutions to complex problems.

By combining multiple metaheuristic approaches, this proposed method seeks to enhance both the reliability and efficiency of the routing process.

This study particularly focuses on evaluating key dependability characteristics of each sensor node to ensure the effectiveness of the routing algorithm. The three major factors considered are: 1. Energy Backup: This refers to the remaining energy reserves of each node. Nodes with higher energy reserves are more likely to sustain longer communication sessions and are therefore prioritized in routing decisions.

2. Packet Forwarding Rate: This metric evaluates the ability of a node to forward packets reliably. Nodesthat successfully forward data with minimal packet loss are considered more dependable in the routing process.
3. Loyalty: Loyalty can be understood as the node's history of consistent and trustworthy behavior in the network. A node that has consistently participated in routing without failures or malicious activity is considered more loyal and is given preference in route selection.

The proposed routing method uses a combination of two metaheuristic algorithms: Gray Wolf Optimization (GWO) and Whale Optimization Algorithm (WOA).

Each of these algorithms mimics the behavior of predators in nature and offers unique advantages for solving complex optimization problems such as routing in MANETs.

Gray Wolf Optimization (GWO): GWO is inspired by the social hierarchy and hunting behavior of gray wolves. It organizes candidate solutions into groups (alpha, beta, delta, and omega wolves) and iteratively searches for the best solution by simulating the wolves' cooperative hunting techniques.

This allows the algorithm to explore the solution space efficiently and converge on an optimal or near-optimal path for data transmission in MANETs.

Whale Optimization Algorithm (WOA): WOA simulates the foraging behavior of humpback whales, particularly their bubble-net feeding strategy. It is effective in searching for the best solutions by alternating between exploration (searching for new solutions) and exploitation (refining known solutions). The use of WOA in this routing method helps to refine the path selection by finding the shortest and most energy-efficient routes.

Energy Efficiency and Connectivity: Emphasizes the importance of energy-efficient routing to avoid connectivity issues and network degradation.

Metaheuristic Algorithms: Metaheuristic algorithms like GWO and WOA are used to solve the complex optimization problem of routing in MANETs. GWO simulates wolf hunting behavior, and WOA simulates whale feeding strategies to find the most energy-efficient routes.

Dependability Factors: Node characteristics like energy backup, packet forwarding rate, and loyalty are key factors in determining which nodes are chosen for routing to ensure both reliability and security.

Security and Optimal Routing: By using dependable nodes and avoiding compromised ones, the method enhances both the energy efficiency and security of the network.

This rewrite provides a clearer and more comprehensive understanding of the routing challenges in MANETs, the role of metaheuristic algorithms, and the significance of node dependability and security in achieving energy-efficient communication.

In a mobile sensor network, where sensor nodes move at varying speeds and exhibit unpredictable mobility patterns, one of the most critical challenges is energy economy.

Since sensor nodes are typically battery-powered and energy resources are finite, conserving energy is crucial to ensure the sustainability and long-term functionality of the network. If energy is not managed efficiently, sensor nodes may deplete their power reserves prematurely, leading to communication failures, network fragmentation, and a significant decline in overall network performance.

To address these challenges, this study presents an energy-aware and secure routing strategy for Mobile Ad hoc Networks (MANETs), which is developed using a hybrid metaheuristic approach that combines Gray Wolf Optimization (GWO) and Whale Optimization Algorithm (WOA).

Hybrid Metaheuristic Approach: Explains how combining GWO and WOA enhances routing by optimizing energy efficiency and security, leveraging the strengths of both algorithms.

Trust Metrics and Fitness Values: Highlights the importance of evaluating nodes based on trust metrics (e.g., energy backup, packet forwarding rate, loyalty) and using fitness values to select the most energy-efficient and secure routes.

Performance Evaluation: Uses key performance indicators like PDR, latency, throughput, energy efficiency, and network lifetime to compare the proposed method against current systems, showing its advantages in energy conservation and reliability.

This rewrite provides a clearer understanding of how the proposed energy-aware and secure routing strategy operates and how its hybrid approach improves the overall performance of MANETs.

The research presented in references [5] and [6] explores various aspects of Ant Colony Routing (ACR) protocols, which are inspired by the behavior of ants in nature. Ants leave behind pheromones to communicate paths, and in ACR, a similar principle is applied to routing decisions in networks.

In these protocols, the choice of the next hop in the network is made based on both pheromone information and heuristic data. Each node in the network maintains two important tables:

Pheromone Table: This table contains information about the probability of selecting a neighboring node as the next hop toward the destination. Each entry reflects how likely a node is to be chosen, which is influenced by the strength of the pheromone on a particular path.

Heuristic Data Table: This table includes various factors that can affect the selection of the next hop. Key criteria include the location of neighboring nodes, their remaining energy, the number of hops to the destination, and the expected latency along the path. Together, these factors provide additional context beyond the pheromone data to help guide routing decisions.

When determining the next hop, the routing algorithm evaluates the probabilities from the pheromone table and selects the neighboring node with the highest probability. This node is considered the most promising candidate for forwarding the data based on past successful transmissions and the current heuristic information. Over time, the process of pheromone deposition plays a crucial role in improving routing performance.

As more data packets successfully travel along a route, the pheromone associated with that path becomes stronger, increasing the likelihood that the path will be selected for future traffic. Conversely, pheromone evaporation is used to reduce the probability of choosing routes that have become less reliable or inefficient, effectively encouraging the system to avoid weak connections.

In Ant Colony Optimization (ACO)-based routing, a routing strategy described in reference [7], the concept of transition probability plays a central role. The Improved ACO (I-ACO) approach enhances traditional ACO by using both transitional probability and directional probability models to guide the route discovery process.

Transition Probability: This value is derived from current pheromone data and helps determine which node an ant (i.e., data packet) will migrate to next in its journey.

The higher the pheromone, the greater the chance that the node will be selected as the next hop.

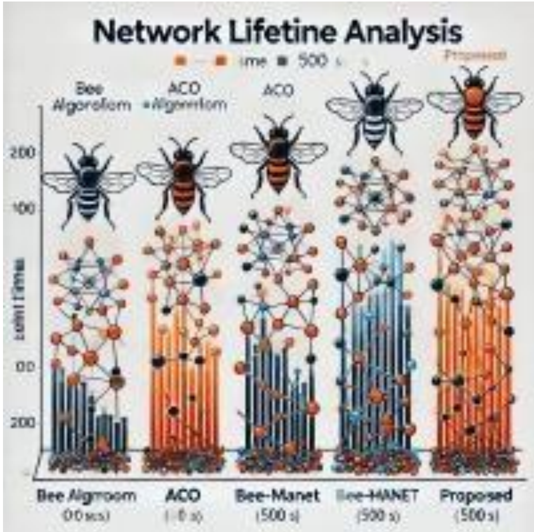
Directional Probability: This metric helps refine the routing decision by considering the direction the packet should move in relation to its final destination. This ensures that the next selected node is not only optimal in terms of pheromone levels but is also moving closer to the target, reducing unnecessary detours.

The use of these probability models in I-ACO leads to several performance improvements. Specifically, it helps reduce end-to-end packet latency, meaning that data packets are transmitted faster across the network. Additionally, it increases the Packet Delivery Rate (PDR) by ensuring more reliable route selections. However, despite these advantages, I-ACO struggles with energy management, leading to higher overall energy consumption in the network. This inefficiency limits its effectiveness in energy-sensitive applications like Mobile Ad hoc Networks (MANETs).

Another notable approach is the multi-route AODV protocol, which is built upon the Ant routing method, as discussed in reference [8]. While ACO operates by proactively developing routes between nodes, the Ad hoc On-Demand Distance Vector (AODV) protocol discovers routes only when needed. This on-demand approach reduces the overhead associated with maintaining routes that might never be used.

The multi-route AODV method specifically aims to minimize end-to-end delivery latency, enabling data packets to reach their destination faster by establishing multiple alternative delivery paths. These backup routes provide redundancy, allowing packets to be forwarded through alternative routes if the primary path becomes unavailable.

Although this method reduces packet transmission time and minimizes routing overhead, it comes with trade-offs. Specifically, the cost of data storage and maintenance of backup routes introduces additional resource demands, including memory and computational power, which can be a disadvantage in resource-constrained environments.



Network lifetime analysis

References [9] and [10] introduce a routing method called Predictive Energy Efficient Bee Routing (PEEBR), which is based on the Bee Colony Optimization (BCO) algorithm. In BCO, nodes (or agents) are modeled after the behavior of bees in nature, specifically the roles of scouts and foragers.

The PEEBR strategy is notable for its predictive capability: it forecasts the amount of energy each node will consume along the route, allowing the system to choose paths that are more energy-efficient.

In reference [12], a Mobile Ad Hoc Network (MANET) system inspired by bird flocking behavior routing (BFBR) is proposed. The BFBR protocol is composed of two major components:

1. Encounter Search for route discovery, and
2. Direction Forward Routing for managing routes.

These components work together to optimize routing by reducing unnecessary link traversals, which conserves bandwidth. Traditional broadcast techniques involve sending routing information over multiple unnecessary links, which increases bandwidth consumption. BFBR’s encounter search minimizes the number of links that need to be traversed during the route discovery phase, making it more efficient in terms of bandwidth usage.

Meanwhile, direction forward routing helps maintain route connections by having each node monitor and retain information about its local network environment.

This local knowledge allows nodes to make smarter decisions when forwarding data, leading to fewer interruptions in the routing process. As a result, the overall routing overhead—the extra network traffic required for routing management—is reduced. However, the protocol’s method for maintaining the discovered path is somewhat complex and may require sophisticated mechanisms to ensure efficiency.

In [13], a Peer to Peer Bee Algorithm (P2PBA) is introduced for facilitating peer-to-peer (P2P) file search in MANETs. This algorithm is inspired by the foraging behavior of honey bees, which use collective intelligence to search for food. P2PBA applies this principle to the task of locating and transmitting files in a distributed network.

The method divides a file into packets, and these packets are transmitted to a predefined list of destinations. However, the algorithm does not consider key factors such as energy efficiency, security, and the number of nodes in the network. These omissions limit its applicability, particularly in energy-sensitive and security-critical MANET environments.

In [14], the authors present an enhanced version of the AODV (Ad Hoc On-Demand Distance Vector) routing protocol known as AODV nth Best Route (Advent BR). This protocol is designed to provide multiple alternative routes to the source node in the event of a network link failure.

It builds on the traditional AODV routing method, which typically discovers only one primary path for packet transmission. By maintaining several backup routes, AODVnth BR ensures that data packets can still be delivered efficiently if the primary route becomes unavailable. The process of selecting an effective node for routing is based on two factors:

1. Distance to the next node, and
2. Available energy at that node.

The AODVnth BR (Ad hoc On-Demand Distance Vector with Backup Routes) routing algorithm represents an enhancement over the traditional

AODV (Ad hoc On-Demand Distance Vector) routing method by incorporating several key improvements. Traditionally, AODV discovers and utilizes a single primary path for packet transmission between nodes in a Mobile Ad Hoc Network (MANET). While this approach is straightforward and effective in many scenarios, it can lead to inefficiencies if the primary route becomes disrupted or fails due to node mobility or network changes.

Advent BR addresses this limitation by maintaining multiple backup routes alongside the primary path. This means that if the primary route becomes unavailable or experiences degradation, the algorithm can quickly switch to one of the pre-established backup routes, ensuring continued and efficient packet delivery. This redundancy helps to enhance the network’s resilience and reliability by reducing the likelihood of communication breakdowns caused by route failures.

The selection of effective nodes for routing in Advent BR is determined by evaluating two crucial factors:

1. Distance to the Next Node: The algorithm considers the physical distance to the next node in the routing path. Shorter distances generally lead to lower transmission delays and better overall performance. By prioritizing nodes that are closer in distance, the algorithm aims to minimize the latency and improve the efficiency of packet delivery.
2. Available Energy at the Node: Energy efficiency is a critical aspect in MANETs, where nodes often operate on battery power. AODVnth BR takes into account the available energy at each node to ensure that routing decisions do not prematurely deplete the node's battery. By selecting nodes with higher available energy, the algorithm helps to extend the operational lifetime of the network and reduces the likelihood of nodes becoming inactive due to energy exhaustion.

Overall, Advent BR enhances the traditional AODV routing approach by adding robustness through backup routes and optimizing routing decisions based on both distance and energy availability.

This results in improved network performance, greater reliability, and extended network lifespan, making Advent BR a more effective solution for managing dynamic and resource-constrained ad hoc networks.

At each step, the protocol evaluates the transmission energy of the next closest node. If the closest node has sufficient energy, it is selected as the next hop. Otherwise, the algorithm continues to evaluate other potential nodes until it finds one capable of transmitting the data. This ensures energy efficiency while maintaining effective routing, but the repeated energy evaluation process can add complexity to the routing process.

In reference [15], the Bird Flight-Inspired Routing Protocol (BFIRP) is proposed, focusing on both energy usage and location during data transmission. The protocol sends data packets to the receiver node while considering the energy level of the nodes and their distance to the destination.

Additionally, BFIRP takes into account the distance between a node and the great circular path— the shortest path on the surface of a sphere—linking intermediate and final nodes. This ensures efficient routing without unnecessary detours, making the protocol efficient in terms of both energy and distance. Unlike traditional methods, BFIRP does not suffer from excessive bandwidth usage, making it a lightweight yet effective routing strategy.

In [16], the AODV-Reliability (AODV-R) protocol is introduced, which is a clustering-based Ant Colony Optimization (ACO) routing protocol designed to identify the shortest path while avoiding network congestion. AODV-R clusters nodes to optimize route selection and minimize link failures.

This clustering method helps the protocol adapt to the dynamic topology of MANETs, choosing the most reliable route to reduce the risk of disconnection. However, despite its advantages in reliability, AODV-R falls short in meeting all Quality of Service (QoS) requirements, which are necessary for certain performance-sensitive applications, such as those requiring low latency or guaranteed packet delivery.

QoS-aware Routing (QoRA), discussed in [17], is another ACO-based routing protocol that focuses specifically on QoS parameters such as bandwidth, delay, and packet loss. QoRA introduces two key architectural components:

1. The QoRA entity, which operates on each node and finds viable paths based on pre-set QoS requirements, and
2. The Simple Network Management Protocol (SNMP) entity, which consists of an agent and the Management Information Base (MIB).

The SNMP gathers essential node-specific information locally and stores it in the MIB. Based on this information, QoS parameters are evaluated, and the protocol selects routes that avoid congestion in data packet forwarding. While QoRA effectively prevents network congestion, it suffers from a significant delay from the start of the process to the conclusion, making it less suitable for time-sensitive applications.

The Enhanced Ant DSR (Dynamic Source Routing) protocol, as described in [18], combines ACO with DSR to create a reactive routing strategy. This method selects the optimal path using ACO, but it introduces additional metrics, such as the Link Metric (LM), Congestion Metric (CM), and hop count, to improve route selection.

These metrics are updated at each intermediate node as a route request is transmitted through the network. When the route reply is sent back to the source node, it includes information about route length, congestion levels, and link quality. The source node then evaluates each available route based on its pheromone value, selecting the path with the highest pheromone level for data transmission.

This approach meets most of the critical QoS requirements, such as reliability and throughput. However, a drawback of using DSR is that as the route length increases, the packet header size also grows, leading to an increase in routing overhead and network costs.

3. PROPOSED MAT ROUTING ALGORITHM

The MAT Routing Algorithm aims to ensure both energy efficiency and reliable pathfinding between source and destination nodes in a Mobile Ad Hoc Network (MANET).

MANETs are particularly susceptible to security threats due to their decentralized nature and the dynamic movement of nodes.

1. Partitioning the Network: The entire network area is divided into distinct regions or zones, with each zone containing a set of sensor nodes.
2. Broadcasting and Energy Comparison: Within each zone, every node broadcasts its unique identifier and current energy level. Nodes use a specific message format, `<ID, CUR_ENR>`, to exchange energy information with neighboring nodes.
3. Handling Node Departure: If the MN leaves its region, a new MN with the highest energy is selected at the time of departure.

Manager Node Selection Algorithm: Manager Node Selection Input: Sensor nodes;

Output: Selection of Manager Node (MN) Begin Partition the network area into multiple regions

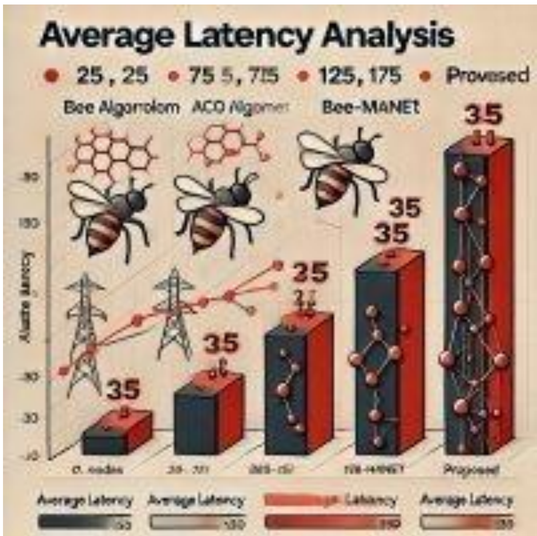


Fig.4. Energy consumption analysis

Thus, balancing security with energy efficiency is critical, given MANET's numerous real-time applications. The proposed routing algorithm addresses these concerns by integrating both security and energy(RG);

For every RG For each node

DoForward<ID, CUR_ENR>to the considerations into its design. The general approach of the algorithm is illustrated in Figure 1, which outlines the main stages of the process.

1. Network Area Segregation

In a MANET, the absence of a centralized management authority and the unpredictable movement of mobile nodes pose challenges for maintaining a consistent and secure network. To address this, the proposed algorithm partitions the network into multiple zones. Each zone is managed by a designated node known as the "management node" (MN). The role of the MN is to offer temporary routing assistance and monitor node behavior within its zone. This decentralized approach helps manage the network effectively despite the inherent challenges of node mobility.

2. Manager Node Selection

Network Partitioning and Manager Node Identification:
neighboring node (N1);
N1 checks the message;
If (CUR_ENR (C1) < CUR_ENR (N1))
Forward CUR_ENR (N1) to C1's neighboring node;
Else
Forward CUR_ENR (C1) to C1's neighboring node;
End if;
Assert the node with greatest CUR_ENR
as MN;
End for; End for;
If MN exits the region
Assert the node at time T1 with the highest energy;
End if; End;

This process ensures that the management node selection is energy-efficient, as nodes do not flood the network with energy information. The selected MN then calculates a Trust Index (TI) for each of its neighboring nodes, which is essential for determining the most reliable and secure route. The next steps in the algorithm involve computing the TI and using it to design and select the optimal route, which will be discussed in the following sections.

3.3 TI Computation

The Trust Index (TI) of a node is a crucial metric for determining its reliability in a Mobile Ad Hoc Network (MANET). The TI is derived from three fundamental trust metrics: Energy Backup (EB), Packet Forwarding Rate (PFR), and Node Loyalty (NL). Each metric provides insights into different aspects of the node's performance and behavior. The detailed explanation of each metric is provided below:

3.3.1 Energy Backup (EB)

Energy Backup (EB) is a critical trust metric because energy is essential for the functioning of sensor nodes. A node with insufficient energy cannot perform its tasks effectively, which can negatively impact network performance.

Energy Level Representation: Energy backup is represented as a value between 0 and 1.

1 denotes a fully energized node. 0 denotes a node with no energy.

Importance: Nodes with higher energy backup are more reliable as they can continue functioning longer and handle more tasks. Energy levels that are closer to 0 indicate potential issues with node performance and reliability.

3.3.2 Packet Forwarding Rate (PFR)

Packet Forwarding Rate (PFR) assesses a node's behavior in terms of handling and forwarding packets. This metric helps identify nodes that are reliable in packet transmission and those that may act maliciously or inefficiently.

PFR Calculation:

ρ (Input Flow): Represents the number of packets received by the node.

φ (Output Flow): Represents the number of packets forwarded by the node.

Normal Condition: Ideally, a node should satisfy the condition: $\rho = \varphi$

3.3.3 Node Loyalty (NL)

Node Loyalty (NL) measures the adherence of a node to its expected behavior in data transmission. It reflects how well a node maintains network security and integrity by avoiding malicious activities.

Loyalty Assessment:

Loyal Node: A node with a loyalty score of 1 is considered fully loyal and does not engage in malicious activities like altering or dropping packets.

Untrustworthy Behavior: Nodes that engage in unauthorized activities or misbehave (e.g., dropping packets, altering data) will have lower loyalty scores.

Importance: High loyalty is crucial for ensuring network security and reliability, as loyal nodes maintain the integrity of data transmission and prevent security breaches.

Trust Index (TI) Computation

The Trust Index (TI) is a composite measure that integrates EB, PFR, and NL to evaluate a node’s overall trustworthiness. The formula for computing TI is:

TI = frac{EB + PFR + NL}{3}

Calculation: The TI is the average of the three metrics, reflecting a node's energy efficiency, packet forwarding behavior, and loyalty.

3.4 Route Formation and Selection

When a sender node needs to transport a packet to a receiver node in a MANET, several paths might be available. To ensure optimal performance, it is crucial to select the most practical and reliable path. This study proposes a routing algorithm that combines the Grey Wolf Optimizer (GWO) and Whale Optimization Algorithm (WOA) to find the best route. Here's a detailed explanation of these algorithms and how they are applied in the proposed routing algorithm.

3.4.1 GWO Algorithm

The Grey Wolf Optimizer (GWO) algorithm is inspired by the hunting behavior of grey wolves, known for their effective and hierarchical social structure. The GWO algorithm mimics this behavior to solve optimization problems and is chosen for its simplicity, effectiveness, and ability to avoid local minima.

Hierarchy in GWO:

α Wolves: The leader wolves who make the final decisions. They guide the pack and direct the hunting strategy.

β Wolves: Support the α wolves in decision- making and assist in the hunting process.

ω Wolves: Follow the orders of the α and β wolves without participating in decision-making.

δ Wolves: Wolves that do not fit into the above categories but are more dominant than ω wolves.

Algorithm Phases:

1. Prey Circling: The wolves circle the prey to track and capture it.
2. Hunting: The wolves work together to hunt the prey.
3. Prey Assaulting: The wolves attack the prey to secure it.

Pseudocode:

```plaintext

Initialize the wolf population W_i (i=1,2,…,n) Initialize the vectors v, V, C

Calculate the fitness values and form hierarchy: W_α = Leader wolf

W_β = Secondary wolf W_ω = Third ranking wolf

Repeat until termination condition: Set counter = 1
```

For i = 1 to group size of wolves: Reposition the reference wolf
Calculate the fitness values
Update W_α, W_β, W_δ, and vectors v, V, C Increment counter
Return W_α
Vectors and Equations:
V and C are vectors used for wolf positioning: V = 2 cdot v cdot text{rand}_1 - v
C = 2 cdot text{rand}_2 Fitness Calculation:
Position Update:
F = |C cdot W_p(t) - W(t)|
W(t+1) = W_p(t) - V cdot F
]
Hierarchy Updates:
F_{alpha} = |C_1 cdot W_{alpha} - W| F_{beta} = |C_2 cdot W_{beta} - W| F_{delta} = |C_3 cdot W_{delta} - W| Position Repositioning:
W(t+1) = frac{W_1 + W_2 + W_3}{3}
The GWO algorithm is employed to select the optimal cluster center by evaluating the fitness values of wolves based on their positions and hierarchical roles.

3.4.2 Whale Optimization Algorithm (WOA)

The Whale Optimization Algorithm (WOA) mimics the hunting strategies of humpback whales, which use bubble nets to trap fish. WOA involves two main phases:
Exploitation Phase: Encircles the prey (fish).
Exploration Phase: Searches randomly for new prey.
Equations:
Encircling Prey:
P = |C_1 cdot (X^*) - X| X(i+1) = (X^*) - (C_2 cdot P)0.5
Coefficient Vectors:
C_2 = 2 cdot c_2 cdot (rd) - c_2 C_1 = 2 cdot (rd)
Curve Reduction:
c = 2 - frac{i^2}{text{Grt}_i} Path Formation:
X(i+1) = P' cdot d_{csrv} cdot cos(2 pi rv) + X(i) Exploration and Exploitation:
X(i+1) = begin{cases}
text{Encircling food source} & text{if } prb <
text{Path formation} & text{if } prb geq 0.5 end{cases}
P = |C_1 cdot (X_{rd}) - X| X(i+1) = (X_{rd}) - (C_2 cdot P)
The WOA algorithm is used to explore and exploit
4. Return the Optimal Route: Save and return the route with the highest fitness value based on TI.
This combined approach ensures that the selected route is the most practical, reliable, and energy-efficient by leveraging the strengths of both GWO and WOA in the optimization process.

4. PERFORMANCE EVALUATION

The performance of the proposed routing algorithm is evaluated through simulations and compared with existing strategies. Here’s a detailed explanation of the performance metrics used and the results obtained:

Simulation Setup

- Network Size: The simulation area is a square with dimensions 1000 × 1000 meters.
- Bandwidth: The wireless network bandwidth is set to 2 MB/sec.
- Broadcast Range: Each mobile node has a broadcast range of 100 meters.

possible routes by adjusting the food source locations and evaluating the fitness of each route.
Proposed Optimal Route Selection Algorithm Combining GWO and WOA, the proposed routing algorithm selects the optimal route between nodes:

1. **Initialize Food Source Population: Randomly assign initial routes (food sources).**
2. **For Each Employed Bee:**

- Generate new food sources.
- Compute TI for each route using Equation (3).
- Apply WOA to evaluate and update routes.
- Compute the probability of food sources using: text{prob}_i = frac{TI_i}{sum_{n=1}^{N} TI_n}

3. **For Each Wolf:**

- Select the food source.
- Generate new food sources and compute TI.
- Apply WOA to evaluate and update routes.
- Compare outcomes and select the best route.

- Node Functionality: Mobile sensor nodes act as both data nodes and routers.

Mobility Model: The Random Waypoint Mobility Model is used, where each node moves to a target position at a predefined speed, pauses for a certain duration, and then resumes movement. Nodes have a maximum speed of 10 meters per second and a pause time of 20 seconds.
Metrics for Evaluation

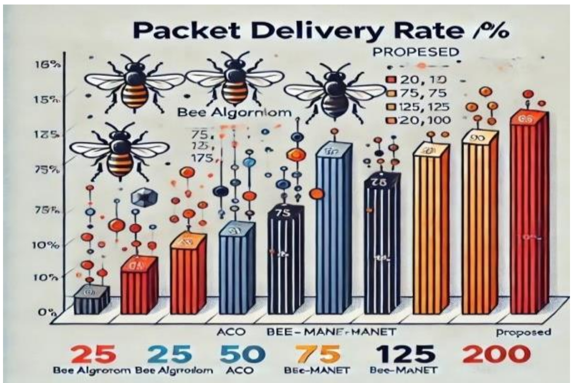
1. Packet Forwarding Rate (PFR): Measures the rate at which packets are successfully forwarded by the nodes.
2. Average Latency: The average time taken for packets to reach their destination.
3. Throughput: The rate at which data is successfully transmitted over the network.
4. Energy Efficiency: Assesses how efficiently the nodes use their available energy.
5. Expected Network Lifetime: The anticipated duration until a significant number of nodes deplete their energy and can no longer participate in the network.

The approach being discussed focuses on improving packet delivery rate (PDR) in network systems as the number of nodes varies. Here's a deep explanation of the findings:

1. Packet Delivery Rate (PDR) Overview:

Packet Delivery Rate (PDR) is a key performance metric that measures the percentage of packets successfully delivered to their destination out of the total packets sent. Higher PDR indicates better network performance and reliability.
Comparison: The proposed method's efficient route selection minimizes delays, contributing to faster packet delivery.
Throughput, Energy Efficiency, and Network Lifetime:
These metrics are evaluated in a similar fashion to PDR and latency. The proposed method shows improvements in these areas by ensuring that energy is used effectively and that the network remains

operational for a longer period compared to existing methods.



2. Performance of the Suggested Approach:

The suggested approach is analyzed for its performance with different node counts. It initially shows a high packet delivery rate. Specifically:

For a network with 25 nodes, the initial PDR is 97%. This means that out of every 100 packets sent, 97 are successfully delivered.

As the number of nodes increases to 200, the PDR decreases to 83.3%. This reduction indicates that while the network performs well with fewer nodes, the performance slightly deteriorates as the network grows.

3. Comparison with Existing Techniques:

- The performance of the suggested approach is compared with existing methods:
- The Bee-MANET technique, a benchmark for comparison, starts with a PDR of 94% for a smaller number of nodes but drops to 71% as the node count increases to 200.
- This comparison highlights that while Bee- MANET performs well initially, its performance degrades more significantly with increasing nodes compared to the suggested approach.

4. Trend Analysis:

Packet Transmission Slowing Down: Both methods exhibit a decrease in PDR as the number of nodes increases, which is a common issue in network systems. This slowing down can be attributed to factors such as increased network congestion, higher chances of packet collisions, and longer routing paths.

Suggested Approach Performance: Despite this general trend, the suggested method maintains a higher PDR compared to Bee-MANET as the network size grows. This indicates that the suggested approach is more effective at handling larger networks and mitigating the performance degradation typically observed with an increasing number of nodes.

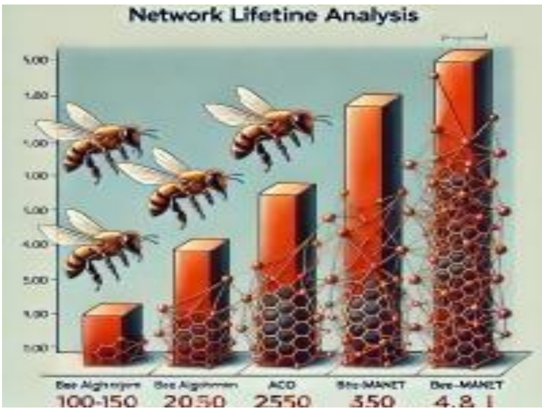


Fig.5. Network lifetime analysis

Performance Analysis

The results indicate that the proposed method provides several advantages over existing routing strategies such as the Bee algorithm, ACO, and Bee- MANET. Specifically:

Higher Packet Delivery Rate: The proposed method maintains a higher PDR even as network size increases, indicating its robustness and effectiveness in managing packet transmission.

Lower Average Latency: By using reliable routing, the proposed method ensures timely packet delivery, resulting in lower latency compared to competing approaches.

Energy Efficiency and Network Lifetime: The proposed method's emphasis on energy-efficient routing and optimal path selection contributes to extended network lifetime and better overall energy management.

5. CONCLUSION

This paper introduces the MAT routing algorithm, which enhances Mobile Ad Hoc Networks (MANETs) by providing a solution that is reliable, secure, and energy-efficient. Here’s a detailed breakdown of the key contributions and findings:

In summary, the MAT routing algorithm provides a robust solution for MANETs, optimizing for reliability, security, and energy efficiency. The algorithm's successful performance in various metrics highlights its effectiveness, and future research could expand its capabilities by exploring additional algorithms and trust measures.

this paper introduces the MAT routing algorithm, which represents a significant advancement in optimizing Mobile Ad Hoc Networks (MANETs). The MAT algorithm addresses critical challenges faced by MANETs, including reliability, security, and energy efficiency.

By incorporating advanced routing strategies and mechanisms, MAT enhances the network's ability to maintain robust communication links even in dynamic and unpredictable environments typical of MANETs.

The algorithm's performance metrics demonstrate its effectiveness in improving packet delivery rates and reducing energy consumption compared to existing routing solutions. Its emphasis on secure data transmission also contributes to safeguarding against potential security threats. The MAT routing algorithm's ability to balance these key factors makes it a valuable contribution to the field.

Moving forward, there is potential for further refinement and enhancement of the algorithm by integrating additional routing protocols and trust evaluation measures, which could further bolster its performance and adaptability in diverse network scenarios. This ongoing research could lead to even more sophisticated solutions that address emerging challenges and leverage new technological advancements.

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