# Multipath Routing Protocol for MANET Using Hybrid Optimization Approach to Support QoS

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## ABSTRACT

MANETs are infrastructure-less networks consisting of mobile nodes that form temporary networks. Ensuring Quality of Service (QoS) in MANETs is challenging due to mobility and limited resources. This research proposes a multipath routing protocol prioritizing QoS support to address dynamic network conditions and limited bandwidth. The protocol aims to enhance QoS provisioning in MANETs for efficient and reliable real-time data delivery. In this paper, an Optimization-Based Energy-Efficient Demand Multipath Routing Protocol (OEDMRP) is proposed for Mobile Ad hoc Networks (MANETs). The protocol combines optimal cluster formation and routing protocol optimization using hybrid optimization techniques. By forming clusters of unequal sizes and dynamically adjusting routing parameters, the protocol aims to optimize energy consumption and ensure reliable communication in MANETs. The result was evaluated in terms of end-to-end delay, packet delivery ratio, throughput, and energy consumption. The result was also compared with existing state-of-art and outperforms better.

Keywords: Multipath Routing, MANET, Optimization, QoS.

## 1. Introduction

Mobile Ad hoc Networks (MANETs) are decentralized networks of mobile devices that establish communication among themselves without relying on a fixed infrastructure or centralized control. The flexibility, easy deployment, and adaptability to dynamic and demanding environments have garnered significant interest in MANETs [1][2]. These networks have diverse applications, including disaster response, military operations, and sensor networks. However, the absence of a fixed infrastructure in MANETs presents numerous challenges when it comes to ensuring Quality of Service (QoS). QoS refers to a network's ability to deliver different levels of service for various types of traffic, ensuring efficient and reliable data transmission. Providing QoS support in MANETs is crucial to meet the varied requirements of applications and guarantee a satisfactory user experience. The necessity for quality of service (QoS) assistance in mobile ad hoc networks (MANETs) arises from the distinctive characteristics of these networks. MANETs are known for their limited bandwidth, variable link quality, dynamic network topology, and nodes with limited resources. These factors pose challenges in guaranteeing QoS parameters like delay, packet loss, and throughput. QoS support becomes crucial to fulfill the requirements of real-time applications such as video streaming, voice over IP (VoIP), online gaming, and teleconferencing. These applications rely on low latency, high throughput, and minimal packet loss rates to ensure a seamless user experience. Therefore, it is of utmost importance to develop efficient QoS mechanisms and routing protocols specifically tailored for MANETs to enable the successful deployment of such applications [3][4]. Multipath routing protocols present a promising solution for enhancing QoS support in MANETs. Unlike traditional single-path routing protocols, multipath routing protocols establish multiple routes between source and destination nodes [5]. The basic steps involved in this process are illustrated in Fig 1. The Multipath Routing Protocol for MANET for QoS support operates as follows:

- Initialization: Each node in the network establishes its identity and initializes routing tables.
- Path discovery: The source node broadcasts a request for available paths to the destination, and intermediate nodes forward this request to their neighbors [5].
- Path establishment: Intermediate nodes select suitable paths based on received responses and send route replies to the source node.
- Path selection and load balancing: The source node performs path selection and load balancing, choosing multiple paths that meet QoS requirements.

- Data transmission: The source node distributes packets across the selected paths, ensuring efficient data transmission.
- Dynamic path monitoring and adaptation: Throughout the process, the protocol continuously monitors the paths and adapts accordingly. It can switch to alternative paths if degradation or unavailability is detected.

These steps collectively enable efficient and reliable data delivery while prioritizing QoS support in MANETs. Multipath routing protocols distribute traffic across multiple paths, resulting in load balancing and improved network performance [6]. The use of multiple paths in MANETs offers several advantages. Firstly, it enhances reliability by providing alternative routes in the event of link failures or node mobility. If a path becomes unavailable or experiences degraded performance, the multipath protocol can dynamically switch to an alternate path while maintaining QoS requirements. Secondly, multipath routing helps alleviate congestion by effectively utilizing network resources and balancing traffic load across available paths. This leads to improved throughput and reduced packet loss.

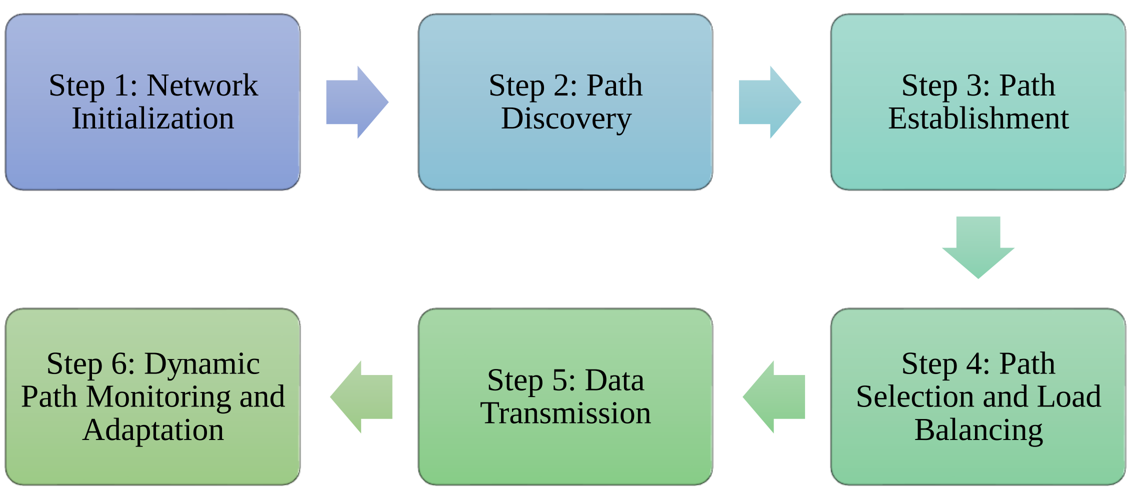


**Fig. 1.** The Basic Working of Multipath Routing for MANET

This research paper proposes a cluster based multipath routing protocol for MANETs to prioritize Quality of Service (QoS) support. The protocol aims to overcome challenges related to dynamic network conditions, limited bandwidth, and resource constraints. The paper focuses on designing an adaptive multipath routing algorithm, establishing dynamic paths, evaluating performance through simulations, and assessing the impact on QoS parameters. The goal is to contribute to the advancement of QoS support in MANETs by introducing an efficient multipath routing protocol.

## 2. Overview of MANET

MANETs (Mobile Ad hoc Networks) rely on wireless communication between nodes, leading to a dynamic topology as nodes can join or leave the network. Neighboring nodes can communicate directly, but data transmission to non-neighboring nodes requires multiple hops through intermediate nodes acting as routers. Deploying MANETs presents several challenges:

- Unpredictable Environment: Ad hoc networks may be deployed in unknown, hazardous, or hostile terrains, where node failures due to tampering or destruction are common.
- Unreliable Wireless Medium: Communication through the wireless medium is error-prone, influenced by environmental factors like electromagnetic interference and adverse weather. This may lead to fluctuating link quality.
- Resource-Constrained Nodes: Nodes in a MANET are typically battery-powered and have limited storage and processing capabilities. Energy-efficient algorithms are essential to cope with these limitations and the limited available bandwidth.
- Dynamic Topology: The network's topology constantly changes due to node mobility, resulting in links breaking and new links forming as nodes move in and out of range.

In summary, MANETs face challenges related to unpredictable environments, unreliable wireless communication, resource limitations, and the dynamic nature of their topology. Addressing these issues is crucial for successful deployment and operation of such networks.

MANETs are susceptible to various types of faults, including:

- Transmission Errors: The wireless medium's unreliability and environmental unpredictability can lead to packets being corrupted during transmission, resulting in errors upon reception.
- Node Failures: Nodes can fail due to hazardous conditions or energy depletion, causing them to drop out of the network.

- Link Failures: Node failures and changing environmental conditions can cause links between nodes to break.
- Route Breakages: Changes in the network's topology due to node or link failures can render existing routes incorrect, leading to delayed or dropped packets.
- Congested Nodes or Links: Certain nodes or links may become overutilized, causing congestion, which results in delays or packet loss.

To address these issues effectively, routing protocols for MANETs need to be designed carefully.

**Literature Review**

Jabbar et al. [7] conducted a comparative analysis of two routing schemes, MBMA-OLSRv2 and MBQA-OLSRv2, using mobility-based simulations in the EXata Network Simulator. They considered various Quality of Service (QoS) and energy-related metrics and found that the MBMA-OLSRv2 scheme performed better than the MBQA-OLSRv2 scheme in terms of throughput, end-to-end delay, packets dropped, energy consumption, and energy efficiency. Karuppasamy et al. [8] proposed a mobile ad hoc network (MANET) dynamic multipath routeing technique. When the bandwidth of the present link goes below a certain level or a node's load delay falls below a certain threshold, this mechanism finds alternate channels for data transfer. In terms of average end-to-end delay and delivery ratio, their simulation findings indicated that this suggested approach beat the single path protocol Optimised Link State Routeing (OLSR). Chen et al. [9] created Topological Change Adaptive Ad hoc On-demand Multipath Distance Vector (TA-AOMDV) to improve Quality of Service (QoS) in high-speed node mobility scenarios. This protocol features a stable path selection technique that takes into account node resources such as residual energy, available bandwidth, and queue length, as well as the likelihood of node connection stability. The protocol also includes a link interrupt prediction system that adjusts the routeing strategy based on periodic probabilistic predictions of link stability to adapt to quick topology changes. On the NS2 platform, the researchers ran simulations with varied node speeds, data rates, and node numbers. Srilakshmi et al. [10] presented the Genetic Algorithm with Hill Climbing (GAHC) routing protocol, which utilizes a hybrid GA-Hill Climbing algorithm to select the optimal route in a multipath scenario. The protocol incorporates the Improved Fuzzy C-means algorithm to determine cluster heads (CHs) based on recent, indirect, and direct trust, using density peak as a foundation. Trust thresholds are used to identify worthy nodes for computation. The optimal route is chosen by considering all the paths from the CHs, taking into account the predicted hybrid protocol and aggregate features such as throughput, latency, and connection. The proposed technique achieves a minimum energy consumption of 0.10 mJoules, a low delay time of 0.004 ms, a maximum throughput of 0.85 bits per second, a detection rate of 91%, and a packet delivery ratio of 89%. The protocol is also evaluated against selective packet dropping attacks. Venkatasubramanian [11] introduced multi-path routing to balance data transmission by establishing multiple efficient paths. To address high energy consumption, the Fruit Fly Algorithm (FFA) is employed to find optimal values/fitness functions for the objective parameter (energy). Each available path's fitness value is evaluated and sorted based on the foraging behavior of fruit flies in the FFA-DSR protocol. Compared to existing routing protocols, FFA-based DSR achieves better performance, as demonstrated through simulations using the NS-2 simulator. The proposed DSR-FFA protocol reduces energy consumption by approximately 20% compared to existing Ant Colony Optimization (ACO), as validated by experimental results. Hamdi et al. [12] presented two theoretical models for analyzing and predicting the Quality of Service (QoS) performance of star and grid network topologies. The star topology exhibits a 15% better throughput performance compared to the grid topology. The average end-to-end delay is recorded as 17.25 ms for star networks and 76.25 ms for grid networks. Jitter decreases with an increasing data rate (1 to 11 Mbps) in both grid and star topologies, with the average jitter in the star topology being lower than that in the grid topology across all tests. In terms of energy usage, the average energy consumption is 0.065 mWh in the star network, while the grid network records an average of 0.045 mWh. These two network architectures, cluster-based and grid-based, are evaluated using the Qual-Net simulator. Karanje and Eklarker [13] proposed fractional hybrid optimization for finding the optimal path in existing multipath scenarios within Mobile Ad hoc Networks (MANETs). Quality of Service (QoS) optimization is the goal, and a routing table is established to assess the performance of nodes for communication based on factors such as trust, response time, request messages, and packets sent and received between the source and destination. The multi-objective function considers energy, jitter, delay, throughput, distance, and latency using the shortest path algorithm. The fractional optimization achieves an average residual energy of 0.077 J, a delay of 0.512 s, and identifies 27 alive nodes out of 200 nodes. Based on the Multiple Criteria Decision Making (MCDM) measure, Tilwari et al. [14] suggested a mobility and Queue Length (QL) aware multipath (MQAM) routeing strategy. When compared to the standard Multipath-Optimized Link State Routeing (MP-OLSR) routeing technique, the findings show that the proposed MQAM routeing approach successfully improves performance metrics such as throughput, PDR, end-to-end latency, and packet losses. Gayatri and Kumaran [15] proposed a genetic particle swarm optimization algorithm (GPSO) that combines particle swarm optimization (PSO) and genetic algorithms (GA). The Genetic Particle Swarm Optimization Algorithm is used to cluster sensor nodes and create a QoS-aware multipath routing protocol. Energy efficiency is achieved through clustering, which extends network lifetime. The proposed protocol utilizes Cluster Heads to establish reliable multi-hop communication pathways. Alghamdi et al. [16] presented a meta-heuristic technique called cuckoo search to optimize load-balancing and energy efficiency in routing. It assigns optimal routing paths based on individual nodes' residual energy, ensuring balanced routing overhead across participating nodes. Sharma et al. [17] introduced an energy-efficient reactive routing protocol that utilizes received signal strength (RSS) and power status (PS) of mobile nodes. Their link failure prediction (LFP) algorithm updates active routes using link-layer feedback, resulting in improved energy consumption, reduced link failure probability, and fewer packet retransmissions compared to existing algorithms. Nasehi et al. [18] employed omnidirectional antennas to transfer information simultaneously over various channels to find different paths between source and destination nodes. In terms of energy efficiency and end-to-end latency reduction, their suggested method, based on the AODV routeing protocol, outperformed existing multipath routeing protocols (AOMDV, AODVM, and IZM-DSR). To extend the lifetime of MANETs, Hiremath and Joshi [19] proposed an energy-efficient routeing protocol based on an adaptive fuzzy threshold energy (AFTE). AFTE outperformed the load-aware energy efficient protocol (LAEE), greatly increasing network lifespan under various failure situations. To fulfil Quality of Service (QoS) limitations and minimise route discovery methods, De-Rango et al. [20] addressed journey time and energy awareness. They proposed the link-stability and energy-aware routeing (LAER) protocol, which balances link stability with low energy usage. In terms of packet delivery ratio, control overhead, connection duration, node lifespan, and average energy consumption, the suggested protocol beat previous protocols (PERRA, GPSR, and E-GPSR). Chen et al. [21] focused on two factors affecting transmission bandwidth: signal strength of received packets and contentions in the contention-based MAC layer. These factors can lead to higher power consumption during data transmission. To address this, they introduced the minimum transmission power consumption routing protocol (MTPCR), which aims to discover routing paths with reduced power consumption during data transmissions. MTPCR considers mobility-related issues in MANETs and analyzes power consumption using neighboring nodes and a path maintenance mechanism to maintain optimal path bandwidth and reduce power consumption and path breakages. Rajaram and Sugesh [22] addressed energy consumption and path distance in MANETs and proposed the power-aware ad-hoc on-demand multipath distance vector (PAAOMDV) routing protocol, based on the AOMDV protocol.

PAAOMDV updates the routing table with the energy levels of mobile nodes and provides multipath routing without additional overhead, delay, or packet loss. Simulation results showed that PAAOMDV outperforms AOMDV after incorporating energy-related fields. Sun et al. [23] proposed the Energy-Entropy Multipath Routeing Optimisation Algorithm (EMRGA) for MANETs. During the path selection process, the protocol seeks pathways with the least amount of node residual energy, balancing individual node battery power utilisation and extending the network's lifetime. In dynamic mobile networks, EMRGA shown potential performance gains for multipath traffic engineering and route stability evaluation.

## 3. Proposed Methodology

Mobile Ad hoc Networks (MANETs) are self-configuring networks composed of mobile nodes without any fixed infrastructure. Due to the limited energy resources of nodes, energy efficiency is a crucial factor for the proper functioning and sustainability of MANETs. In this paper, we propose an Optimization-Based Energy-Efficient Demand Multipath Routing Protocol (OEDMRP) that intelligently balances traffic across multiple paths to optimize energy consumption while ensuring reliable communication. In this paper, an unequal dynamic cluster formation using hybrid optimization-based dynamic routing protocol for Mobile Ad hoc Networks (MANETs) is a concept that combines two key components: optimal cluster formation and routing protocol optimization. The proposed approach combines the concepts of unequal dynamic cluster formation and hybrid optimization to improve the performance of the routing protocol in MANETs. By forming clusters of unequal sizes, the network can adapt to the heterogeneous characteristics of nodes and optimize resource utilization. The hybrid optimization techniques are employed to enhance the cluster formation process and dynamically adjust the routing protocol parameters based on network conditions. Therefore, this approach aims to create a more efficient and adaptable MANET by leveraging unequal dynamic cluster formation and hybrid optimization-based dynamic routing protocols. It seeks to address the challenges posed by the dynamic nature of MANETs, such as node mobility, limited resources, and varying link qualities, to enhance network performance and reliability. The working steps is presented in below fig 2.

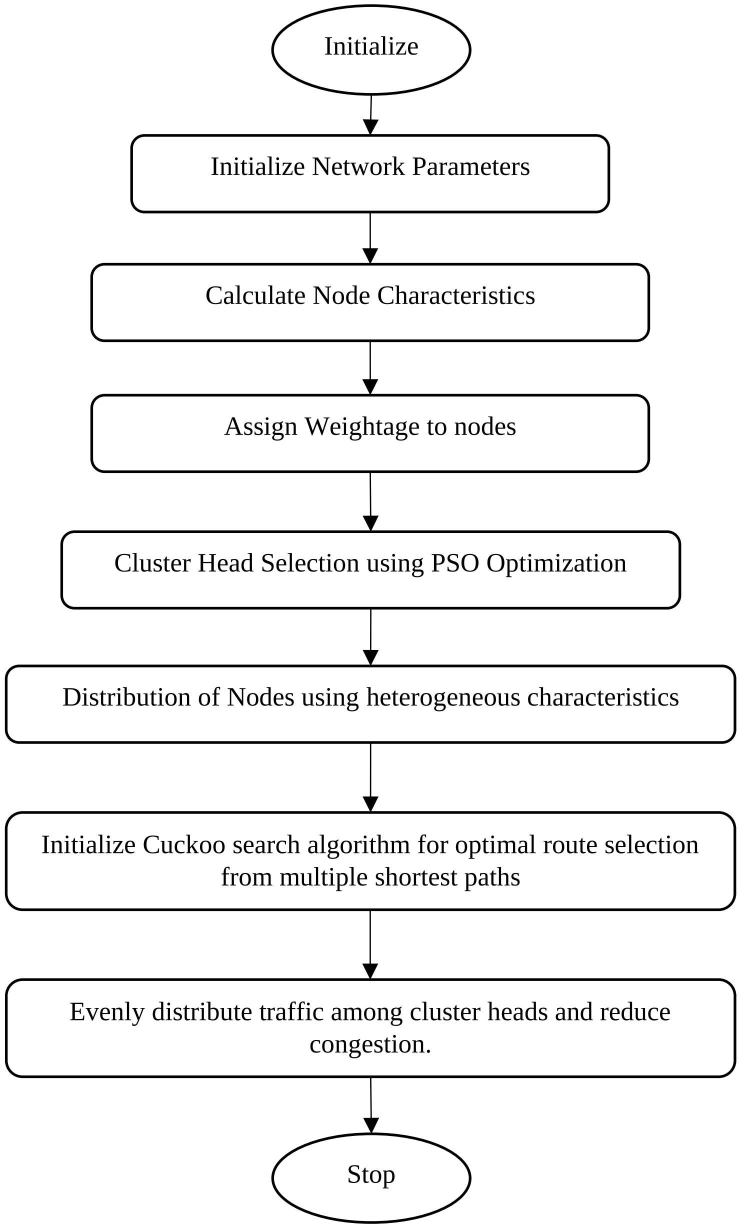


**Fig. 2.** Working Step of Proposed Methodology

### 3.1 Network Assumptions

The following is the model-based presumption employed in this study:

- N sensor nodes are placed at random throughout the sensing region, which is A= N*N in size. Both the sensor nodes and the base stations are situated random.

- Every node in the network has a unique ID identifier and the similar beginning energies. The nodes have a definite amount of energy, but the Base Station has an endless amount.
- The connection is symmetric. Depending on the acquired signal strength, the node can estimate the span between the transmitter and itself.
- Every node only requires one primetime to connect with its parent node, and in that timeframe, every node can only accept or transmit one data packet and accompanying control packet.
- The transmit power of the node can be adjusted based on the interaction distance.

### 3.2 Energy Consumption Model

This research focuses on the energy consumption of data exchange among sensor nodes. Specifically, it examines the energy used for transmitting and receiving data and merging information. The study does not take into account other energy costs:

$$E_{tx}(m,s) = \begin{cases} mE_{selects} + m\varepsilon_{fs}s^2, & s < s_0 \\ mE_{selects} + m\varepsilon_{amp}s^4 & s \geq s_0 \end{cases} \tag{1}$$

$$E_{rx}(m) = mE_{selects} \tag{2}$$

Where, m = data length, s = data transmission distance or span, Eselects = energy usage during transmitting and receiving of unit length data, $\varepsilon_{fs}$ *and* $\varepsilon_{amp}$ = amplifier energy usage of free space model and multiple path attenuation model. In this context, the researchers use the free space model when the distance (s) between the transmission and receiving nodes is smaller than the energy usage model cutoff. The free space model assumes that the transmission range is attenuated by $s^2$. On the other hand, when the distance exceeds the energy usage model cutoff, the multi-path attenuation framework is applied, and the transmitted power is attenuated by $s^4$. This distinction in power attenuation models allows for a more accurate representation of energy usage in different transmission scenarios.

### 3.3 Unequal and Optimal Cluster Formation and Head Selection

Cluster optimization is one of the very useful techniques in wireless sensor network that was introduced to optimize the cluster size and selection of optimal candidate of cluster head. The bio-inspired algorithms are used to evaluate the optimal parameters for cluster head selection that is based on intelligence and capabilities. The main challenges in wireless sensor networks include sensor node deployment, coverage, and routing plans. As the scale of the network grows, the complexity of optimization strategies increases. Therefore, an efficient optimization algorithm that requires minimal memory and processing but provides excellent results is preferable. The approach presented in the text involves using particle swarm optimization (PSO) to achieve unequal and optimal cluster formation and cluster head selection in a distributed system. The methodology aims to create non-uniform clusters and identify the most suitable cluster head based on specific optimization criteria:

1. Define the problem and optimization objectives.
2. Represent particles to capture potential cluster configurations.
3. Create a fitness function to evaluate the quality of a particle's solution.
4. Initialize a population of particles.
5. Implement the PSO algorithm to update particle positions and velocities.
6. Define rules for cluster formation based on factors like distance or node density.
7. Select the optimal cluster head within each cluster based on defined criteria.
8. Evaluate the fitness of each particle's solution.
9. Repeat the PSO algorithm for a certain number of iterations.
10. Identify the best particles as the final cluster configurations.
11. Analyze the results to understand the achieved trade-offs.

### 3.4 Optimal Path Selection

The methodology for optimal route selection from multiple shortest paths in a Wireless Sensor Network (WSN) using the Cuckoo search algorithm. The Cuckoo search algorithm offers advantages such as global optimization capabilities, flexibility, balance between exploration and exploitation, ability to explore multiple solutions simultaneously, fast convergence speed, robustness to noise and uncertainty, and potential for parallelization. These advantages make it a suitable choice for optimal path selection in Wireless Sensor Networks (WSNs). Algorithm for optimal path selection is presented below:

1. Formulate the problem by defining the objective and constraints of the route selection.
2. Discover multiple shortest paths in the WSN.
3. Develop a fitness function that evaluates the quality of a route based on criteria such as energy consumption, reliability, and latency.

4. Adapt the Cuckoo search algorithm for route optimization, considering parameters like population size and maximum iterations.
5. Apply the fitness function to evaluate each discovered route and assign fitness values accordingly.
6. Select the optimal routes based on the fitness values, considering trade-offs between different criteria if necessary.
7. Monitor and update routes periodically based on network dynamics such as node failures or changes in link quality.

## 4. Results and Discussions

The result analysis on the proposed algorithm is presented in this section. The experimental simulation is presented on MATLAB. Below in table 1, parameters for simulating the environment are presented:

**Table 1.** Parameters for Simulation

| Parameters | Values |
|---|---|
| Area | 1000*1000 |
| Sensor Nodes | 500 |
| Transmission Range | 500m |
| Mobility Model | Random waypoint |
| Packet size | 512 bytes |

The following performance parameters are used to evaluate the result:

Remaining Energy: It refers to the difference between total energy and consumed energy. It is evaluated as:

$$Remaining_{energy} = (Total\ Energy - Energy\ consumed\ during\ transmission\ n - bit\ data\ packets) \quad (1)$$

Packet Delivery Ratio (PDR): Packet Delivery Ratio (PDR) is a metric that indicates the percentage of data packets generated by the source node that successfully reach the destination node in a routing protocol. It measures the effectiveness and efficiency of the routing protocol in delivering data packets. A higher PDR value indicates better performance, as it signifies a higher proportion of successfully delivered packets. PDR is calculated by dividing the number of delivered packets by the total number of packets generated by the source node.

$$PDR = \frac{No.\,of\ packets\ received}{Total\ packets\ transmitted} * 100 \tag{2}$$

Delay: Delay refers to the time taken to deliver data to base station. Mathematically it is represented as:

$$Delay = Time\ taken\ to\ transmit\ nbit\ packet * Total\ Packets \tag{3}$$

Throughput: Throughput is the term used to describe the number of bits that are successfully received at the destination. It is measured in kilobits per second (Kbps). Throughput is a metric used to evaluate the efficiency of a routing mechanism in receiving data packets and delivering them to their intended destination. The calculation for throughput is as follows:

$$Throughput = Received\frac{Packets}{Simulation\ time} * 1000kbps \tag{4}$$

Below figures presents the result analysis. The fig 3 presents the end-to-end delay with variation of number of nodes. Fig 4 presents the packet delivery ratio with variation of number of nodes. Fig 5 presents the throughput with variation of number of nodes. Fig 6 presents the energy consumption with variation of number of nodes. Based on the analysis of the presented figures, several observations can be made regarding the results:

- End-to-End Delay: As the number of nodes increases, the end-to-end delay also increases. This indicates that with a larger network size, there is more congestion and possibly longer paths between nodes, leading to increased delays. The average end-to-end delay observed in the analysis was approximately 3.3484 seconds.
- Packet Delivery Ratio (PDR): With an increasing number of nodes, the PDR decreases. This suggests that as the network becomes more crowded or larger, there may be more packet losses or failures in delivering packets to their intended destinations. The average PDR observed in the analysis was approximately 99%.
- Throughput: The throughput demonstrates an increasing trend with the increasing number of nodes. This indicates that as the network size expands, the overall data transfer capacity improves. The average throughput observed in the analysis was approximately 1700 kbps.
- Energy Consumption: The energy consumption increases with an increasing number of nodes. This implies that as the network size grows, more energy is required to sustain the operations of a larger number of nodes. It suggests that network scalability may have an impact on energy efficiency.

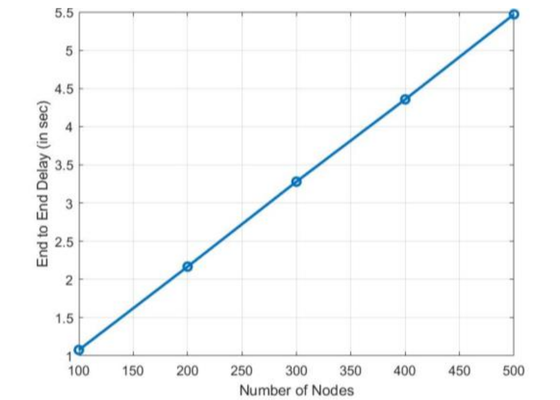


**Fig. 3.** End to End Delay with Variation of Nodes

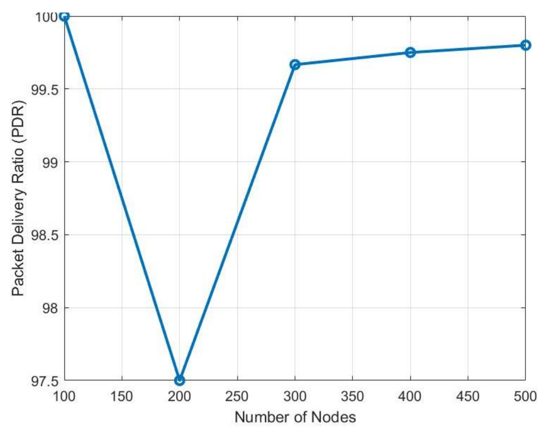


**Fig. 4.** PDR with Variation of Nodes

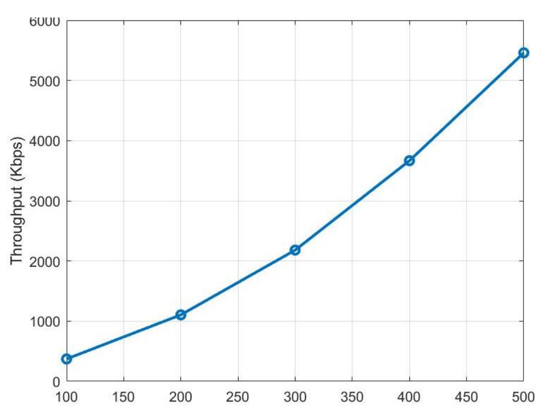


**Fig. 5.** Throughput with Variation of Nodes

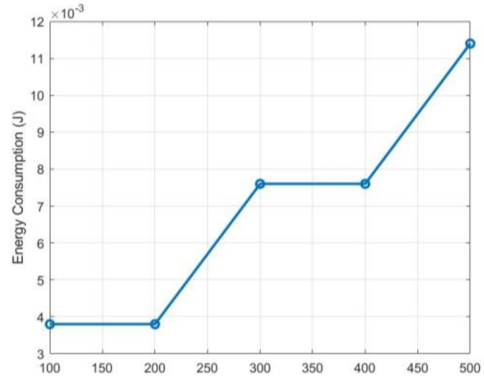


**Fig. 6.** Energy Consumption with Variation of Nodes

Table 2 presents a comparative analysis of three different routing protocols: GAPSO, CS, and the proposed protocol. The table includes three performance metrics: End-to-End Delay, Packet Delivery Ratio (PDR), and Energy Consumption.

- End-to-End Delay: The GAPSO protocol achieves an end-to-end delay of approximately 600 seconds, while the CS protocol achieves 1.8 seconds. The proposed protocol has an end-to-end delay of 3.3 seconds.
- Packet Delivery Ratio (PDR): The GAPSO protocol achieves a PDR of 85%, while the CS protocol achieves 98%. The proposed protocol achieves a higher PDR of 99%.
- Energy Consumption: The GAPSO protocol has an energy consumption of 0.16 Joule, while the CS protocol has 0.15 Joule. The proposed protocol achieves significantly lower energy consumption of 0.008 Joule.

The table provides a comparison of these metrics for the three protocols, highlighting the performance differences between them. The CS protocol outperforms the GAPSO protocol in terms of end-to-end delay and PDR, while the proposed protocol demonstrates comparable performance to the CS protocol in terms of end-to-end delay and PDR but significantly outperforms both protocols in terms of energy consumption.

**Table 2.** Comparative State of Art

| Metrices | GAPSO [15] | CS [16] | Proposed |
|---|---|---|---|
| End-to-End Delay | ~600sec | 1.8 sec | 3.3 sec |
| PDR | 85% | 98% | 99% |
| Energy Consumption | 0.16 Joule | 0.15 Joule | 0.008 Joule |

## 5. Conclusion

In conclusion, the proposed Optimization-Based Energy-Efficient Demand Multipath Routing Protocol (OEDMRP) for Mobile Ad hoc Networks (MANETs) addresses the challenges of limited energy resources and ensures reliable communication. By combining optimal cluster formation and routing protocol optimization using hybrid optimization techniques, the protocol optimizes energy consumption and enhances network performance. The approach adapts to the heterogeneous characteristics of nodes, dynamically adjusts routing parameters, and effectively handles node mobility and varying link qualities. The result findings highlighted the impact of network size on performance metrics, such as delay, reliability, capacity, and energy efficiency. The result findings show that as the number of nodes increases in the network, the end-to-end delay increases, the packet delivery ratio (PDR) decreases, the throughput improves and the energy consumption increases. Therefore, it can be stated that OEDMRP protocol offers a promising solution for energy-efficient and reliable communication in MANETs.

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